Welcome to the SECARB Offshore/GoMCarb Joint Partnership Meeting on March 26-27, 2020

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Presentation files can be found at:
https://app.box.com/s/x1ckb8yz544ikh8ndas7qc55frlw1o4s

Having trouble during the presentations?
Email or call Emily Moskal,
emily.moskal@beg.utexas.edu
281-796-9834

SECARB Offshore

GoMCarb

March 26-27: sseb.org/news-and-events | After March 27: sseb.org/news-and-events/past-events | gulfcoastcarbon.org/news/2020

March 26, 2020

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SECARB Offshore

Partnership for carbon capture & offshore geologic storage
GoMCarb

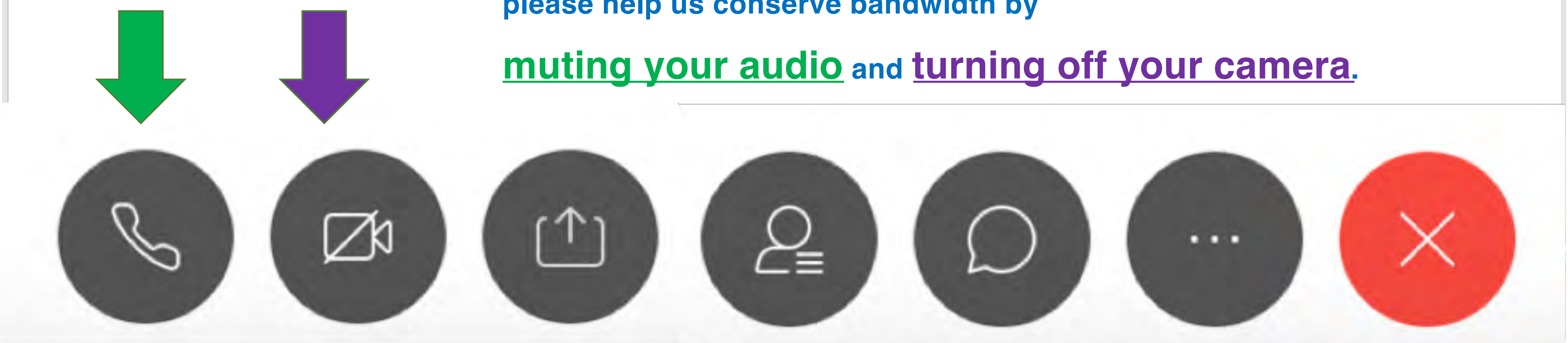
Experiencing Technical Difficulties?

Emily Moskal
Emily.Moskal@beg.utexas.edu
(281) 796-9834

WebEx Icons

Of course we would prefer to see you all in person, but please help us conserve bandwidth by

<u>muting your audio</u> and <u>turning off your camera</u>.



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Leave Meeting

March 26, 2020

GoMCarb Project Updates and Discussion

9:45 AM – 10:00 AM
Log In and Trouble Shooting

10:00 AM – 10:05 AM
Overview of GoMCarb Program and Key Accomplishments this Year – Susan Hovorka

10:05 AM – 11:05 AM
Task 2 – Offshore Storage Resource Assessment
Offshore Capacity Mapping Approach, Status of Mapping, Results of Seismic Interpretation – Dallas Dunlap, BEG
Net Sandstone, Reservoir Architecture Depositional Facies, and Phi-h: Goals and Progress – Iulia Olariu, BEG-GCCC
Progress on Characterization of the Chandeleur Area – Marcie Purkey-Phillips, UTIG
Buoyant CO_2 Storage Assessment: Methodology and Estimating Input Distributions – Sean Brennan, USGS
Discussion, questions, and next steps

11:05 AM – 11:10 AM | BREAK

11:10 PM –12:10 PM
Task 3 – Risk Assessment, Simulation, and Modeling
Well Blowout Simulations – Curt Oldenburg, LBNL
Reservoir Modeling – Sahar Bakhshian, BEG-GCCC
Analytical Model – Larry Lake, UT PGE
Fault-Conforming Model for Geomechanical Simulations – Antoine Mazuyer and Josh White, LLNL and Total
Discussion, questions and next steps

12:10 PM – 12:15 PM | BREAK

Agenda continued on next slide…

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Emily.Moskal@beg.utexas.edu
(281) 796-9834

March 26, 2020

GoMCarb Project Updates and Discussion

Agenda continued…

12:15 PM – 12:45 PM
Task 4 – Monitoring, Verification, and Assessment (MVA)
Distributed Acoustic Sensors – Jonathan Ajo-Franklin, Rice University
P-Cable Update – Tip Meckel, BEG-GCCC
Discussion, questions, and next steps

12:45 PM – 1:30 PM | LUNCH BREAK

1:30 PM – 2:00 PM
Task 5 – Infrastructure, Operations, and Permitting
CO_2 Transport and Delivery – Trimeric
Tracy Benson, Lamar University
Discussion, questions, and next steps

2:00 PM – 3:00 PM
Task 6 – Knowledge Dissemination
Stakeholder Outreach – Rachel Lim, UT Stan Richards School/UT PGE/GCCC
Technical Outreach – Emily Moskal, BEG-GCCC
Offshore Workshop 2020 – Alex Bump, BEG-GCCC
Discussion, questions and next steps

3:00 PM – 3:15 PM
Wrap-up and comments

PRIVATE: 3:30 PM – 5:00 PM GoMCARB Advisors Session
Wrap up and Comments

SECARB Offshore

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Overview of GoMCarb Program and Key Accomplishments This Year

Susan Hovorka

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Discussion via chat

Put Q- and your question in chat on WebEx.

Offshore Texas/Louisiana Seismic Structural Framework and Capacity Mapping

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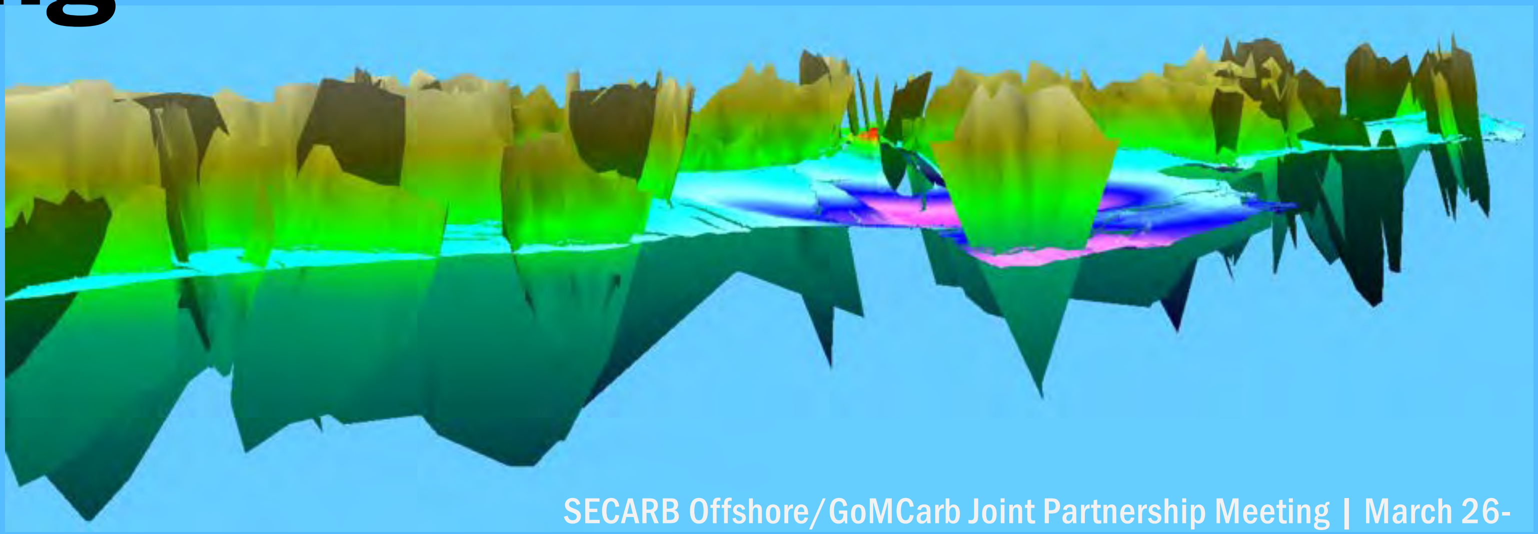
Bureau of Economic Geology

HALLIBURTON

SEI Seismic Exchange



Micheal DeAngelo

Dallas B. Dunlap

Reynaldy Fifariz

Tip A. Meckel

Ramon Trévino

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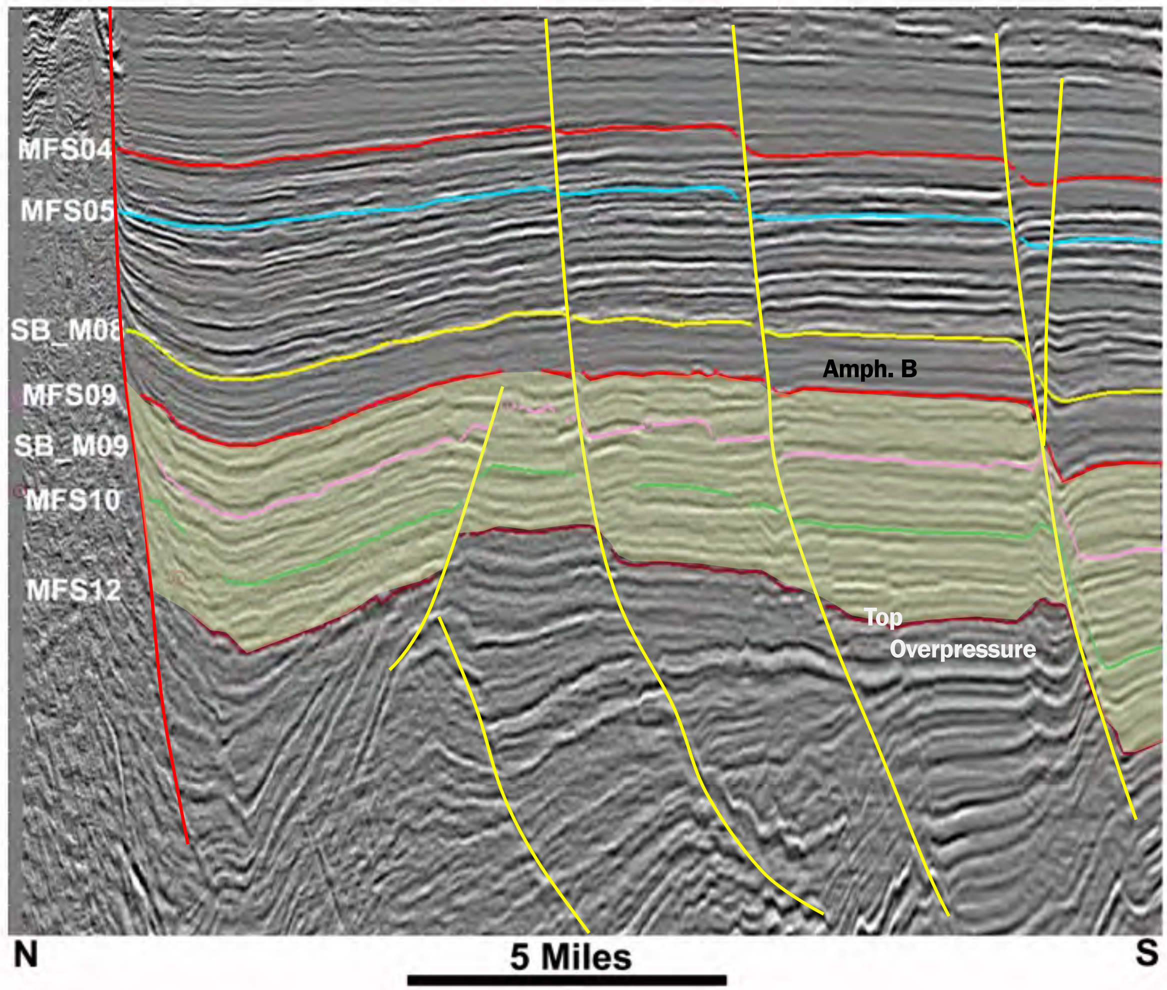
Seismic Stratigraphic Framework

Northern Texas Coast Amplitude Dip Line (TWT)

Amphistegina B - Lower Miocene (LM2) Maximum Flooding Surface 9 (MFS09)



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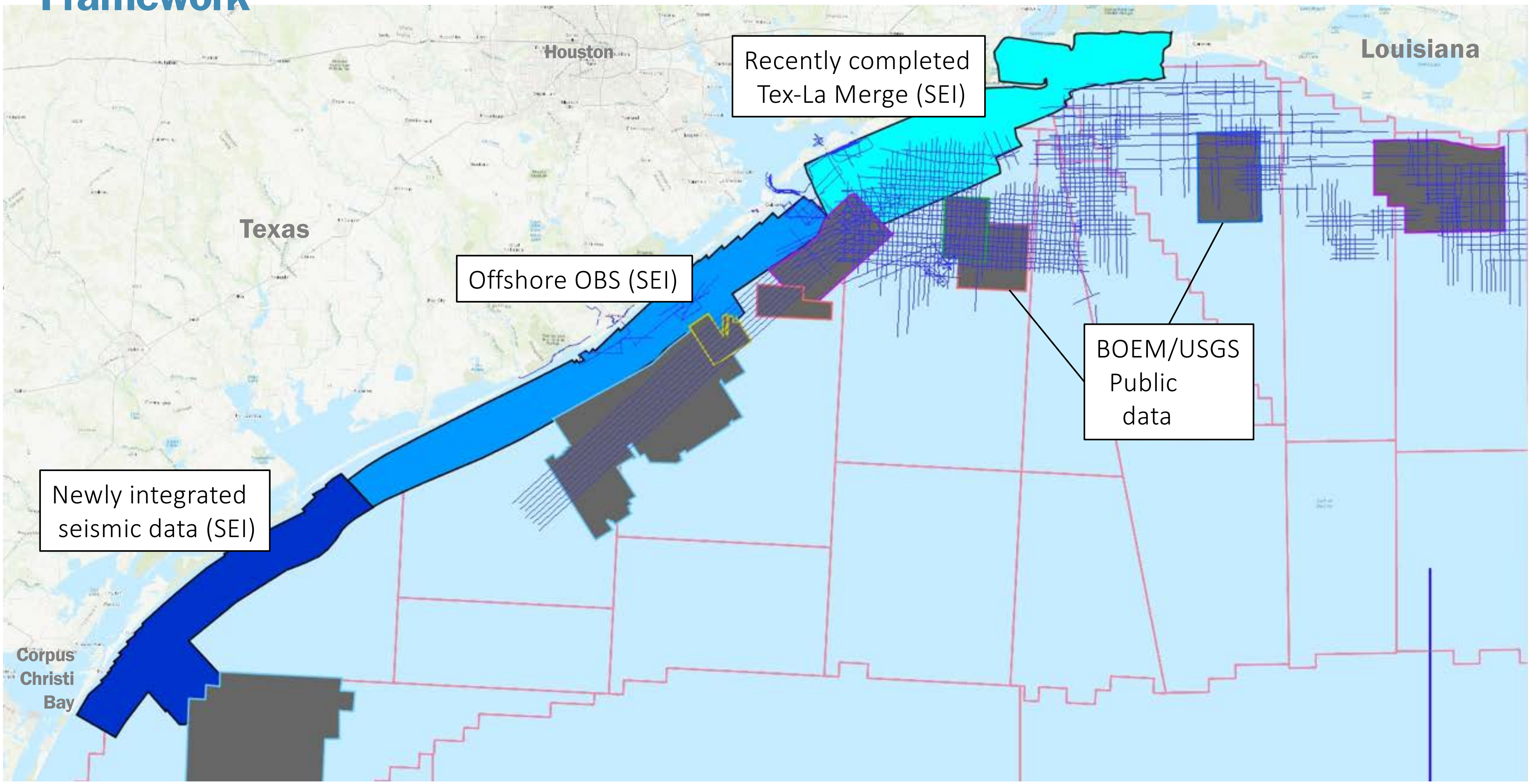
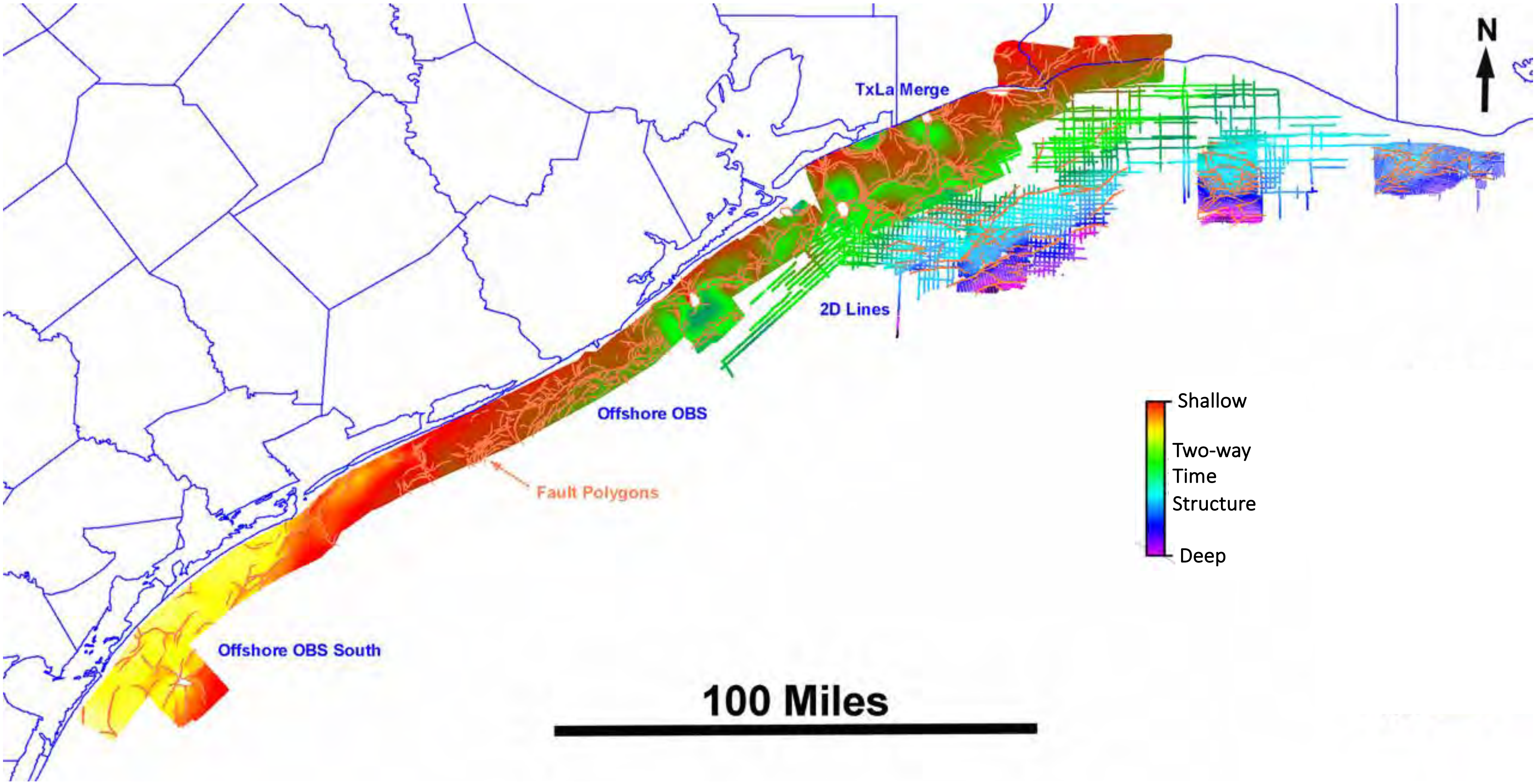
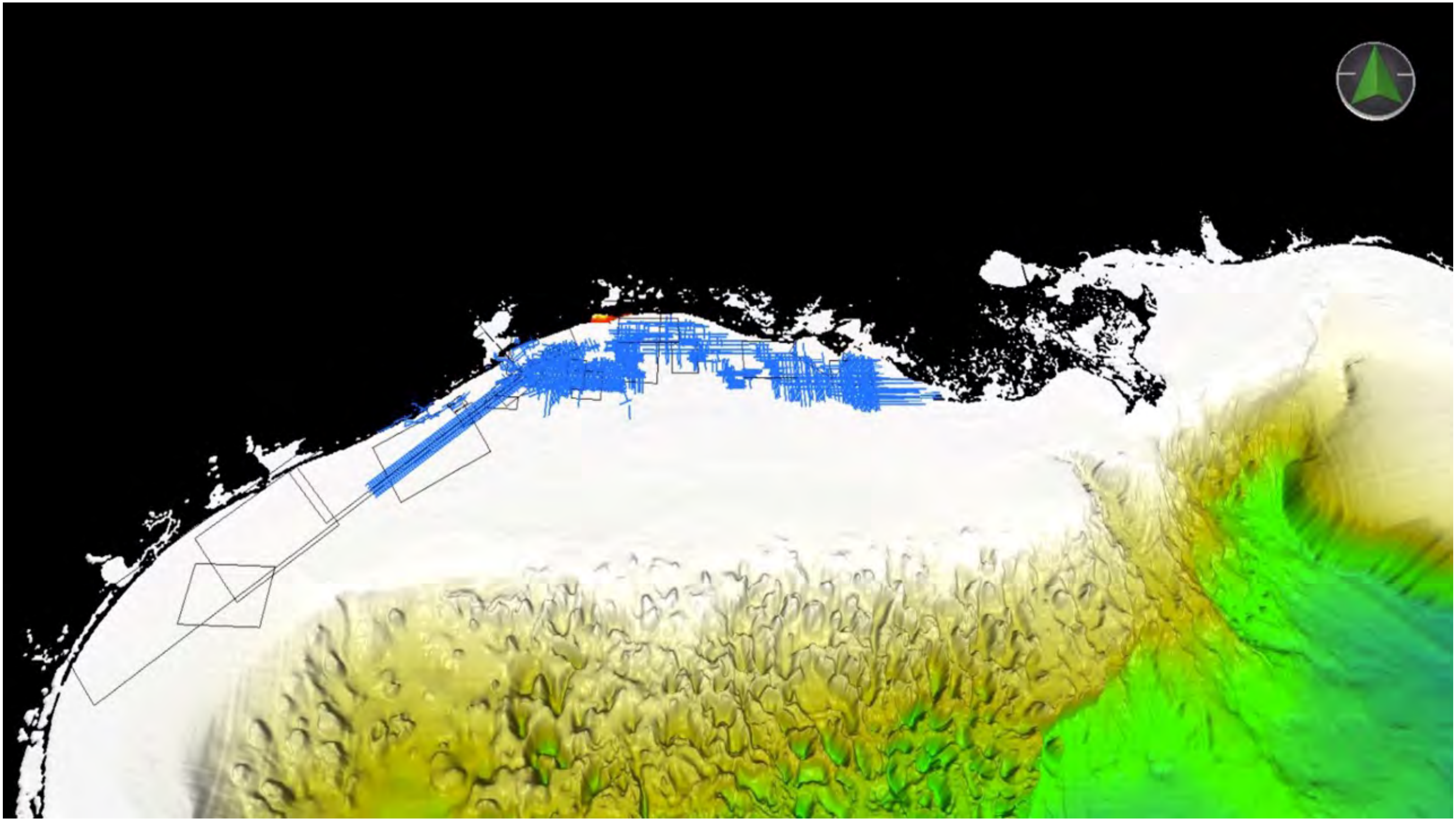
Seismic Stratigraphic Framework



MFS09 Structure map





Objectives for the Seismic Interpretation

1) Expanding existing interpretations into new areas of state waters
2) Expand the existing time/depth model into these emerging study areas
3) Develop workflows and initial inventory of offshore storage opportunities

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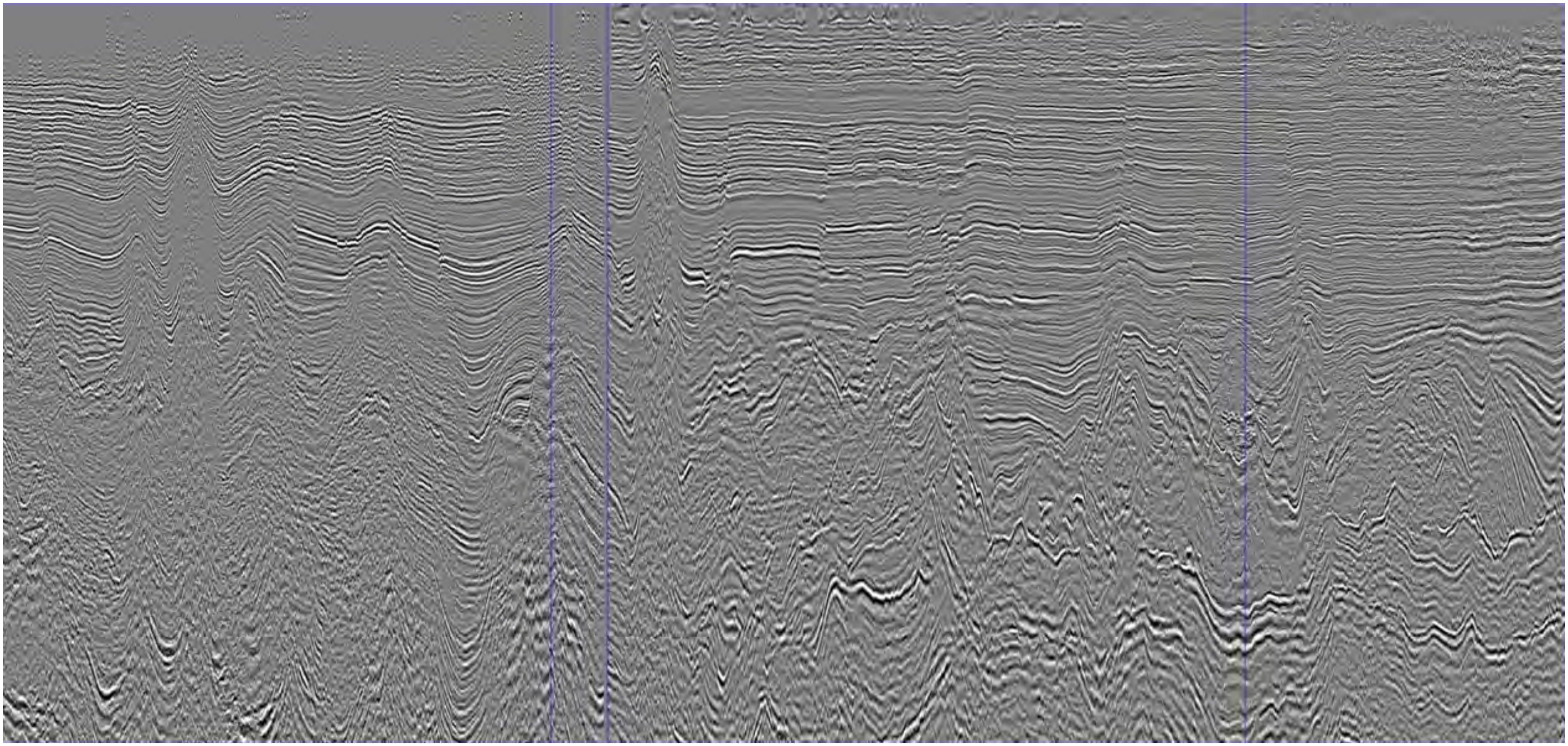
Composite Seismic Image Louisiana to Middle Texas Coast



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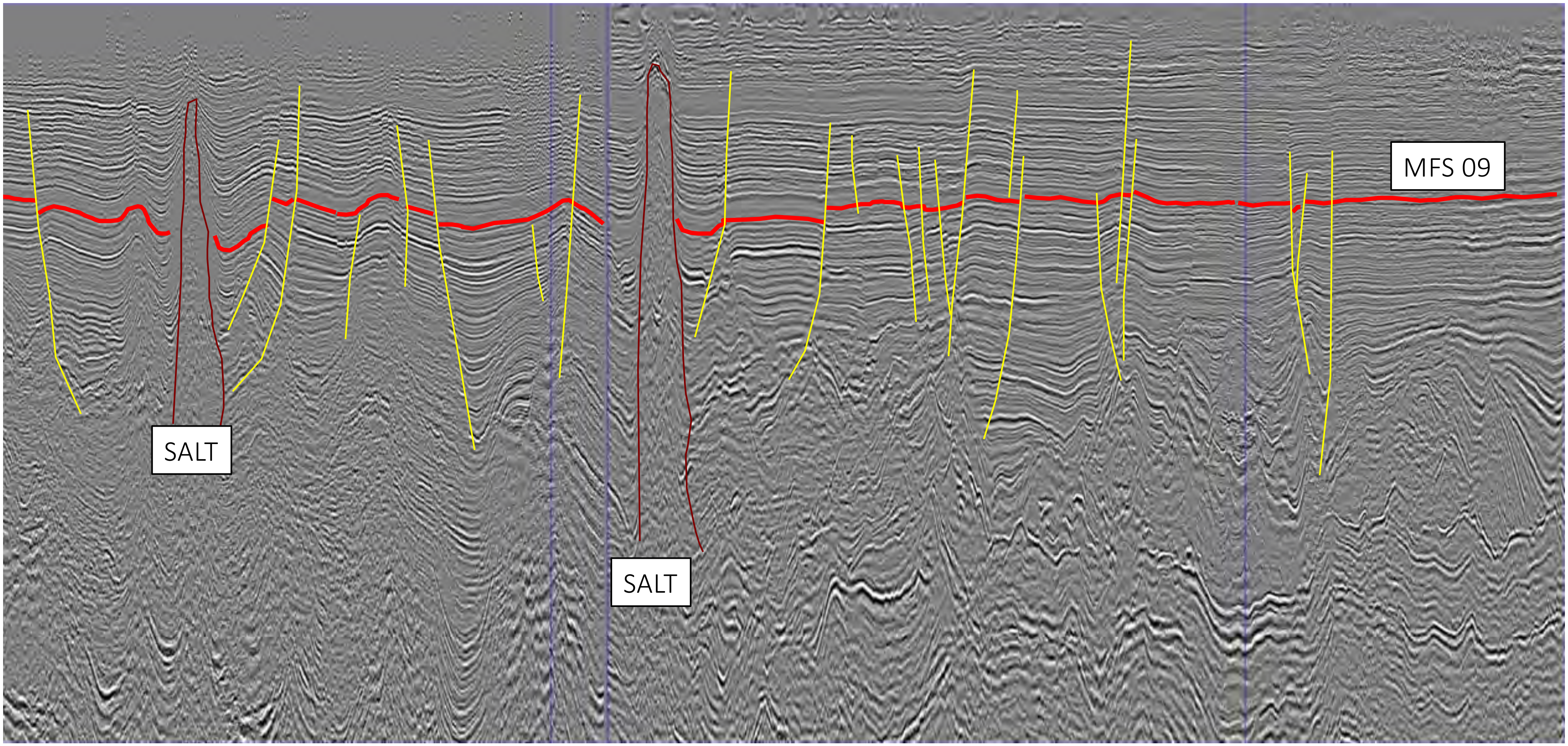
Composite Seismic Image
Louisiana to Middle Texas Coast



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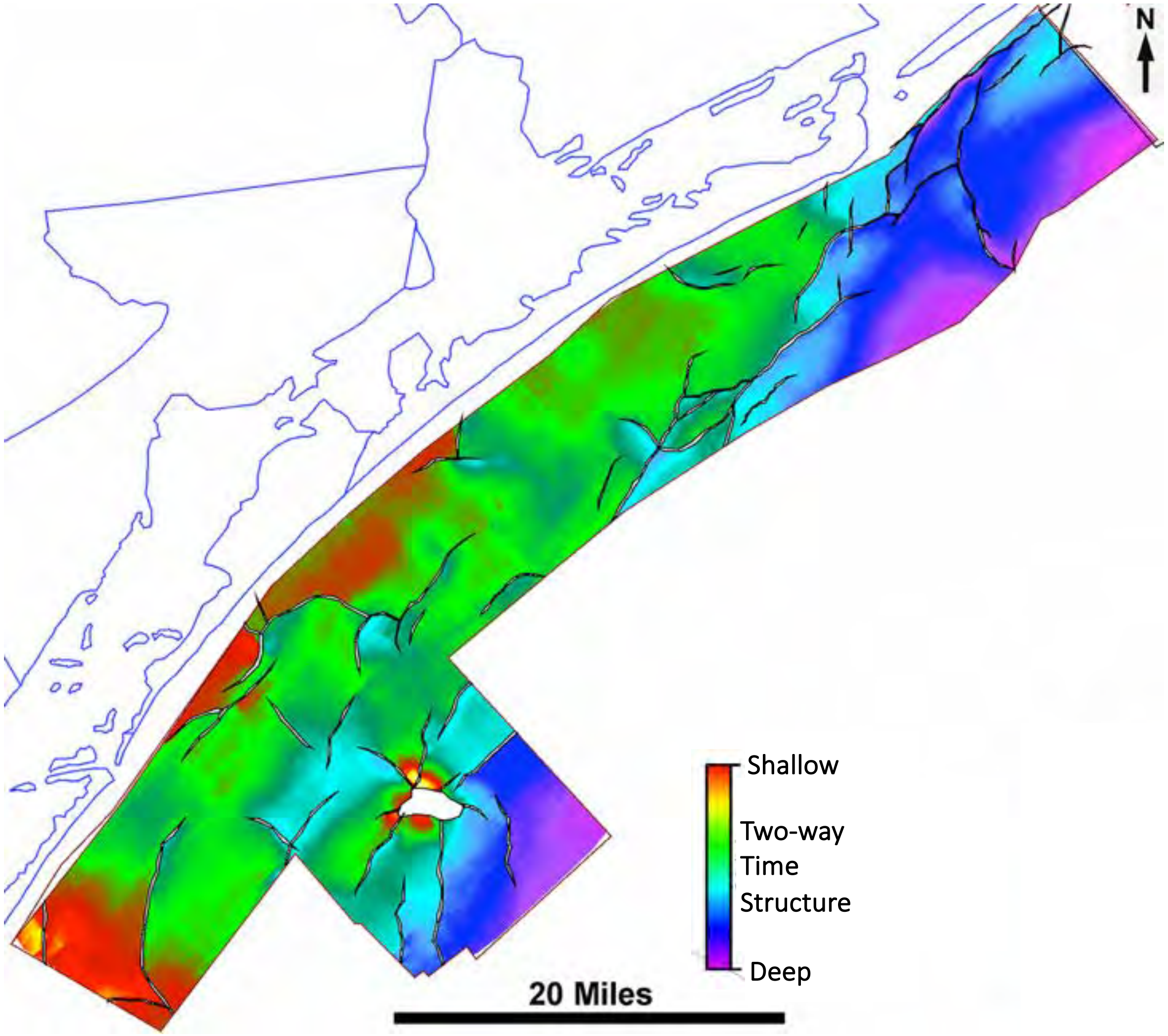
MFS09 Structure map
Offshore OBS South



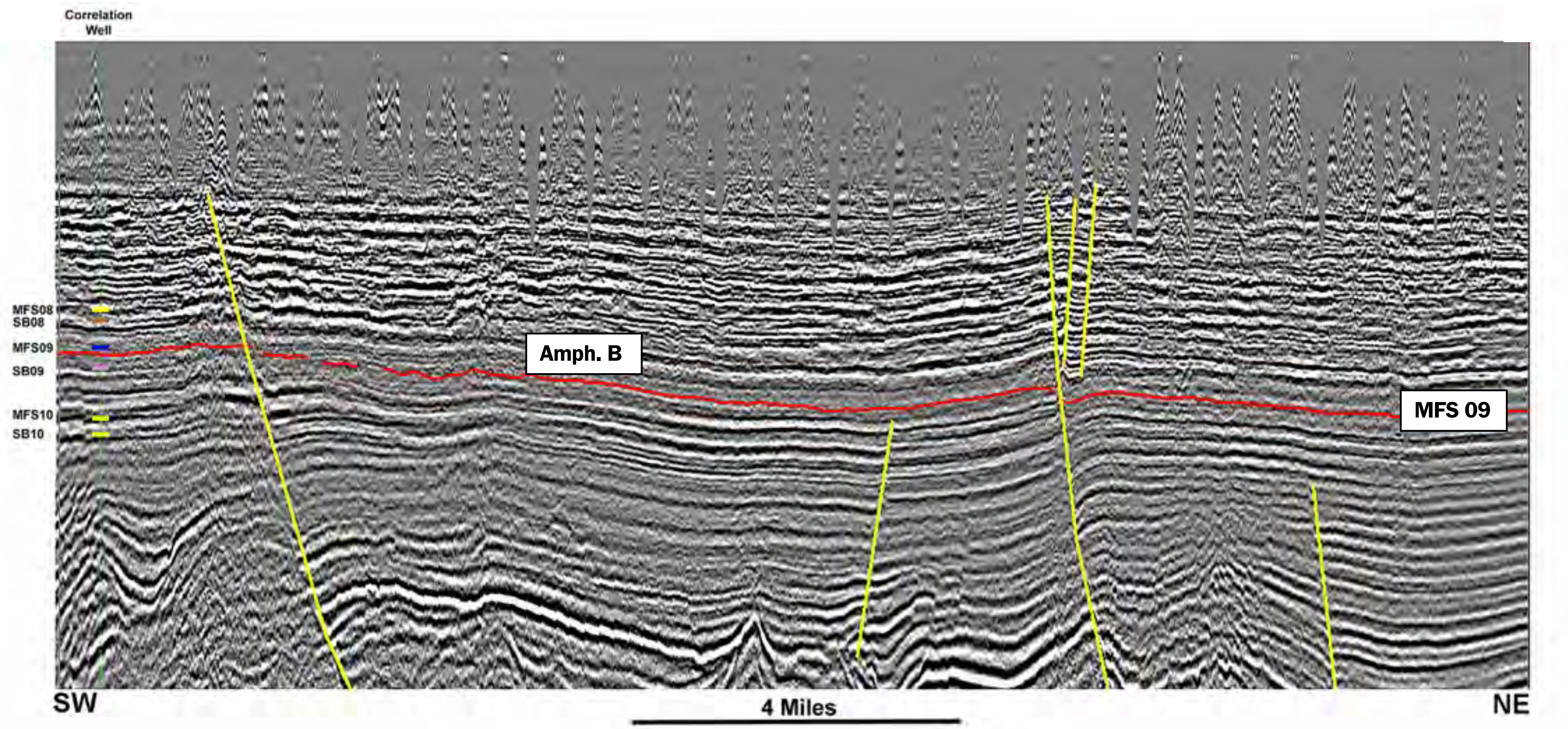
Amphistegina B - Lower Miocene (LM2)
Maximum Flooding Surface 9 (MFS09)

Fully interpreted in New Volume

Interpreted or documented:
- **Numerous faults sets,**
- **Incised valleys,**
- **salt domes,**
- **and areas of mass-wasting.**

In process of expanding interpretation stratigraphically down to Top-Overpressure (~MFS12)

Seismic Section
Middle Texas Shelf



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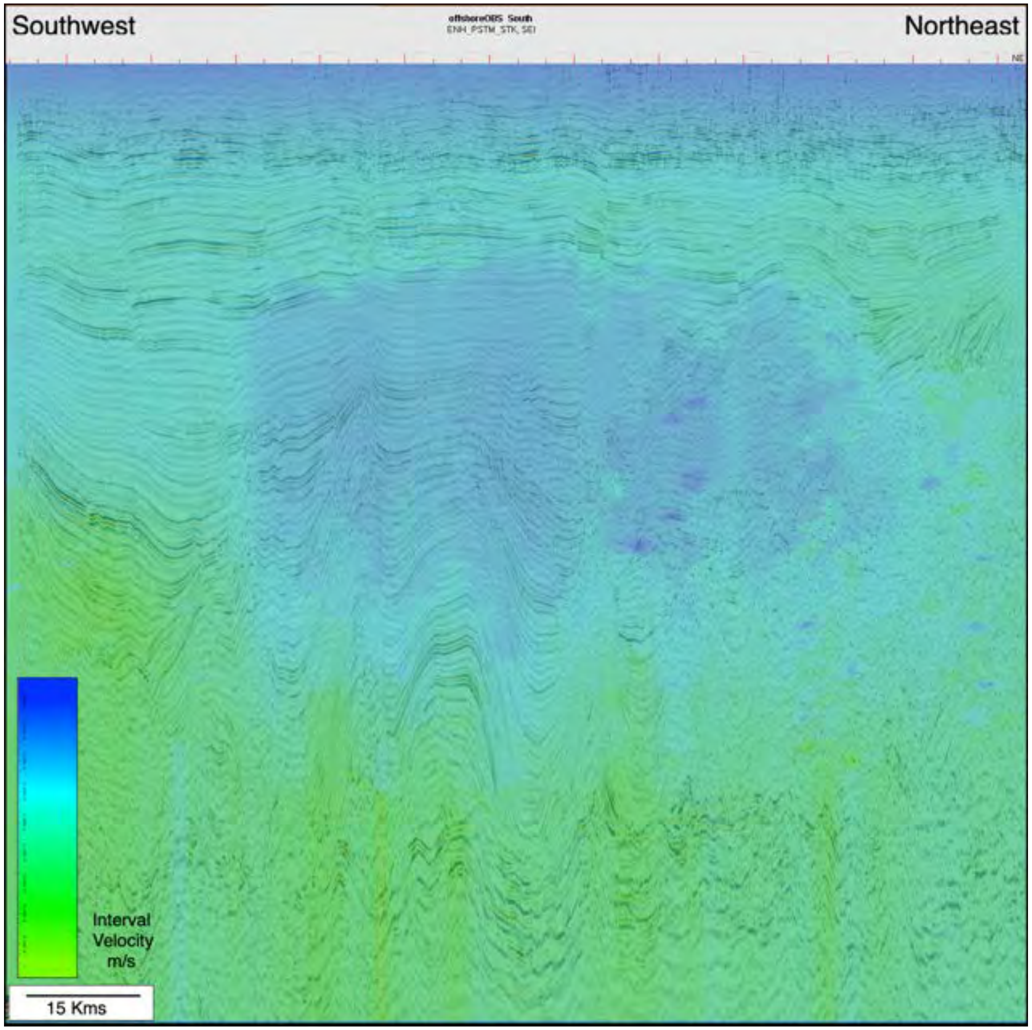
Time/Depth Velocity Model

Generated and merged velocity models in Offshore OBS South and Offshore OBS

Produced from PSTM stacking velocities to generate a first-pass velocity model

Dynamic velocity model now spans Western Louisiana to Corpus Christi Bay used in Seismic Interpretation and storage assessment



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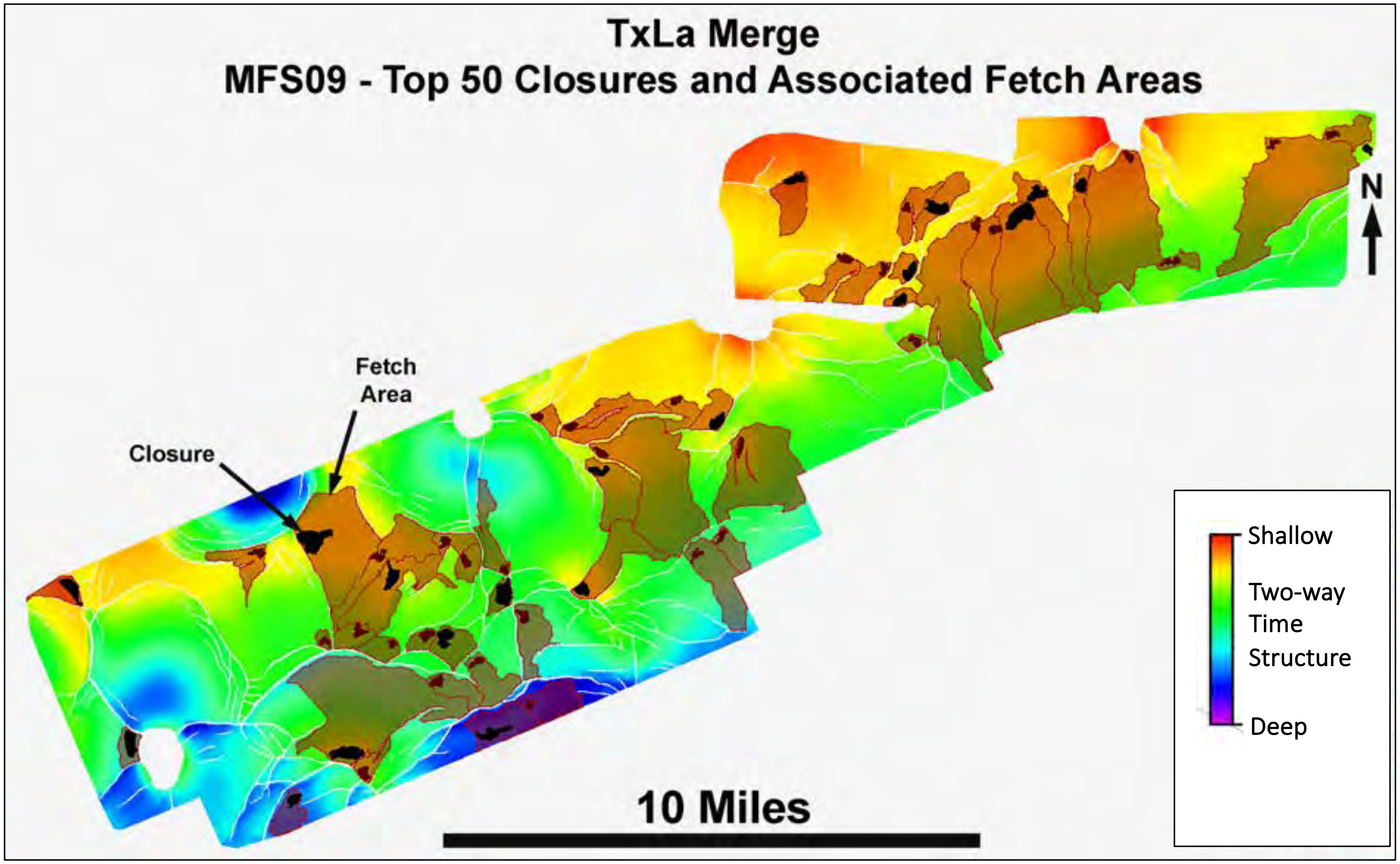
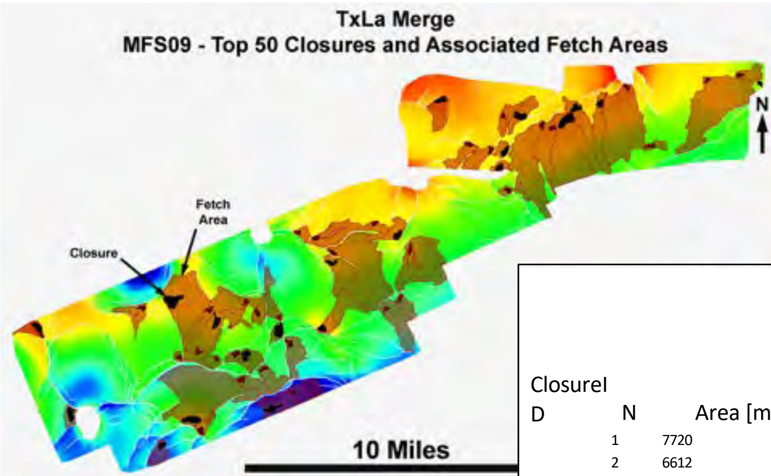
Closure and Fetch Areas

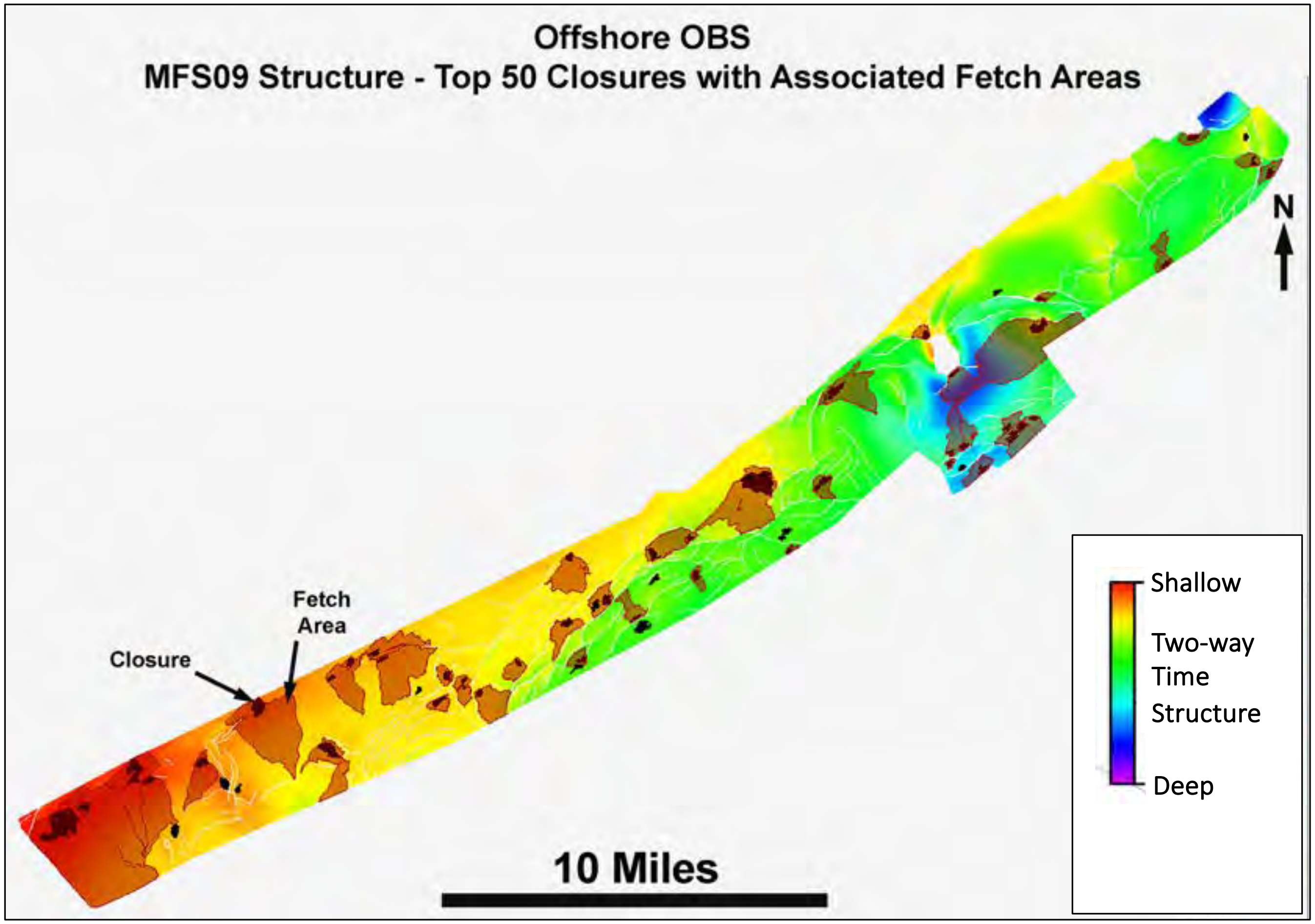


Closure and Fetch Results for TxLa Merge



ClosureID	N	Area [m2]	Area [km2]	Apex Depth [m]	Spill Depth [m]	Max Closure Height [m]	Fluid Depth [m]	Actual Column Height [m]	Bulk Rock Volume[m3]
1	7720	8680780	8.68078	2093.16	2149.61	56.4512	2149.61	56.4512	191385000
2	6612	7.43E+06	7.43488	2215.04	2249.88	34.8457	2249.88	34.8457	1.12E+08
3	6331	7.12E+06	7.11891	2505.44	2545.85	40.4067	2545.85	40.4067	1.09E+08
4	6277	7058190	7.05819	2060.37	2091.45	31.0833	2091.45	31.0833	74628800
5	6253	7.03E+06	7.03121	2310.69	2361.69	51.0005	2361.69	51.0005	9.10E+07
6	5367	6.03E+06	6.03494	2044.53	2097.13	52.5996	2097.13	52.5996	1.12E+08
7	4889	5.50E+06	5.49745	2022.39	2068.62	46.2325	2068.62	46.2325	1.13E+08
8	4787	5.38E+06	5.38276	2441.85	2491.12	49.261	2491.12	49.261	9.03E+07
9	4496	5.06E+06	5.05554	2213.1	2266.2	53.0925	2266.2	53.0925	1.32E+08
10	4468	5.02E+06	5.02406	2238.12	2290.88	52.7593	2290.88	52.7593	8.49E+07
11	4020	4.52E+06	4.5203	2157.73	2205.96	48.2361	2205.96	48.2361	8.20E+07
12	3995	4.49E+06	4.49219	2162.74	2216.68	53.9392	2216.68	53.9392	1.19E+08
13	3775	4.24E+06	4.24481	2393.28	2433.18	39.8977	2433.18	39.8977	5.84E+07
14	3368	3.79E+06	3.78716	2465.76	2504.77	39.0054	2504.77	39.0054	4.38E+07
15	3267	3.67E+06	3.67359	2083.85	2107.31	23.4622	2107.31	23.4622	3.15E+07
16	3254	3.66E+06	3.65897	2283.97	2340.14	56.176	2340.14	56.176	1.02E+08
17	2957	3.33E+06	3.32501	2432.68	2484.97	52.2917	2484.97	52.2917	5.83E+07
18	2824	3.18E+06	3.17546	2124.53	2162.67	38.1392	2162.67	38.1392	4.32E+07
19	2696	3031530	3.03153	2040.35	2091.39	51.0385	2091.39	51.0385	50487500
20	2674	3.01E+06	3.00679	2171.51	2211.7	40.1873	2211.7	40.1873	4.30E+07
21	2618	2.94E+06	2.94382	2303.92	4000	1696.08	4000	1696.08	4.91E+09
22	2548	2.87E+06	2.86511	2189.78	2240.83	51.052	2240.83	51.052	7.48E+07
23	2528	2.84E+06	2.84262	2203.13	2254.16	51.0293	2254.16	51.0293	5.51E+07
24	2485	2.79E+06	2.79427	2469.56	2522.19	52.6321	2522.19	52.6321	3.21E+07
25	2454	2.76E+06	2.75941	2075.48	2127.73	52.251	2127.73	52.251	4.37E+07
26	2337	2.63E+06	2.62785	2244.4	2295.42	51.0166	2295.42	51.0166	6.36E+07
27	2072	2.33E+06	2.32987	2392.32	2443.33	51.0117	2443.33	51.0117	5.72E+07
28	2061	2.32E+06	2.3175	2270.99	2322	51.0066	2322	51.0066	5.09E+07
29	1922	2.16E+06	2.1612	2168.46	2219.46	51.0015	2219.46	51.0015	3.71E+07
30	1871	2.10E+06	2.10385	2258.74	2296.13	37.3887	2296.13	37.3887	2.86E+07

Closure and Fetch Areas



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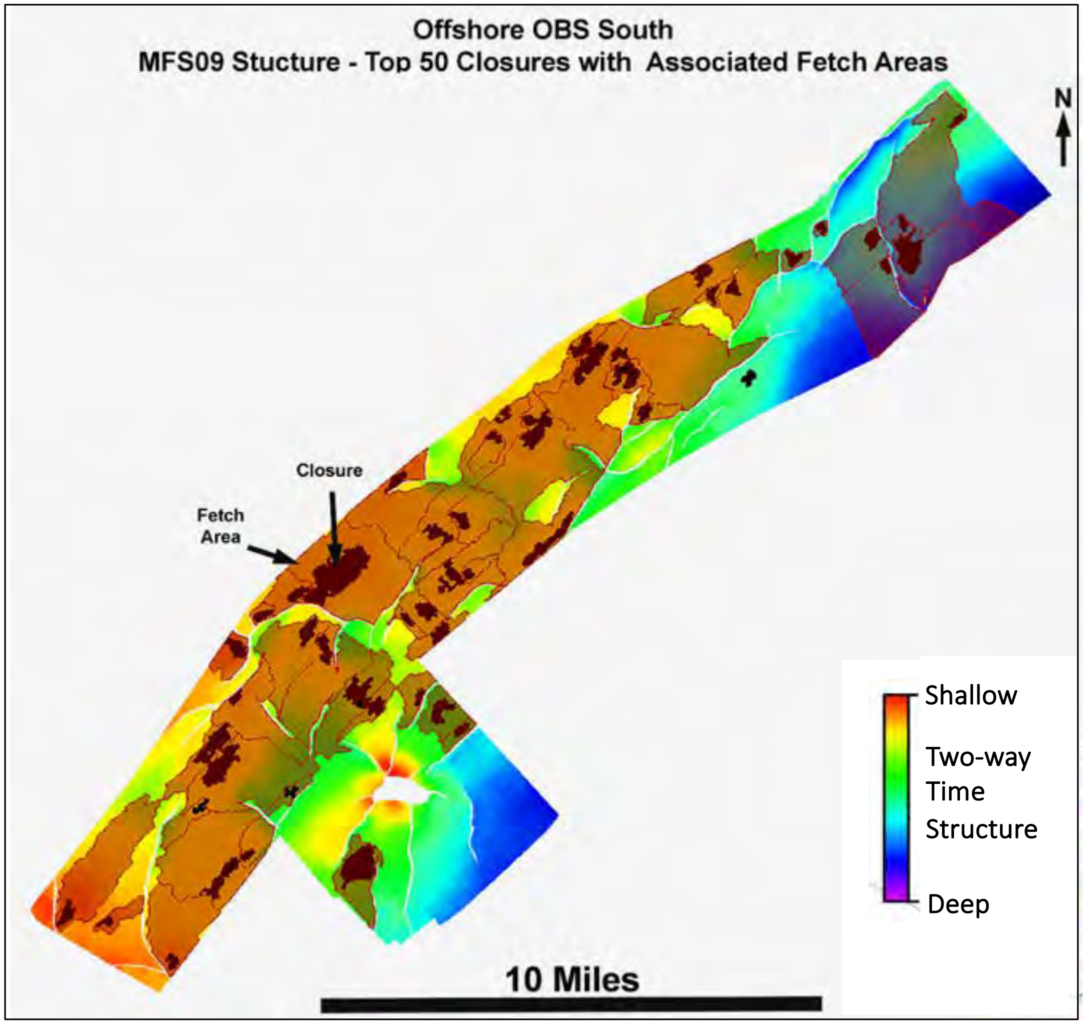

Large number of closures in the OBS South volume

These have greater closure areas and associated fetch areas than in the northern volumes

In the process of integrating well penetrations, production histories, and outlines of producing/non-producing fields

Next Steps

1) Build out the stratigraphy from MFS09 down to the top of overpressure in the middle Texas Shelf
2) Refine the southern extent of the depth model to more accurately constrain the volumetrics of offshore storage opportunities
3) Correlate offshore field locations and well production results with locations of predicated geologic closure and fetch

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Questions?

Acknowledgements:

Landmark Graphics for the use of the Landmark Software Interpretation Suite and Permedia

SEI for granting the display of SEI Seismic reflection data.

Undergraduate and graduate students for their efforts in this interpretation

BEG/UT Institute of Geophysics IT for software and hardware support

Task #2

Offshore Storage Resource Assessment

Iulia Olariu, Tucker Hentz
BEG UT

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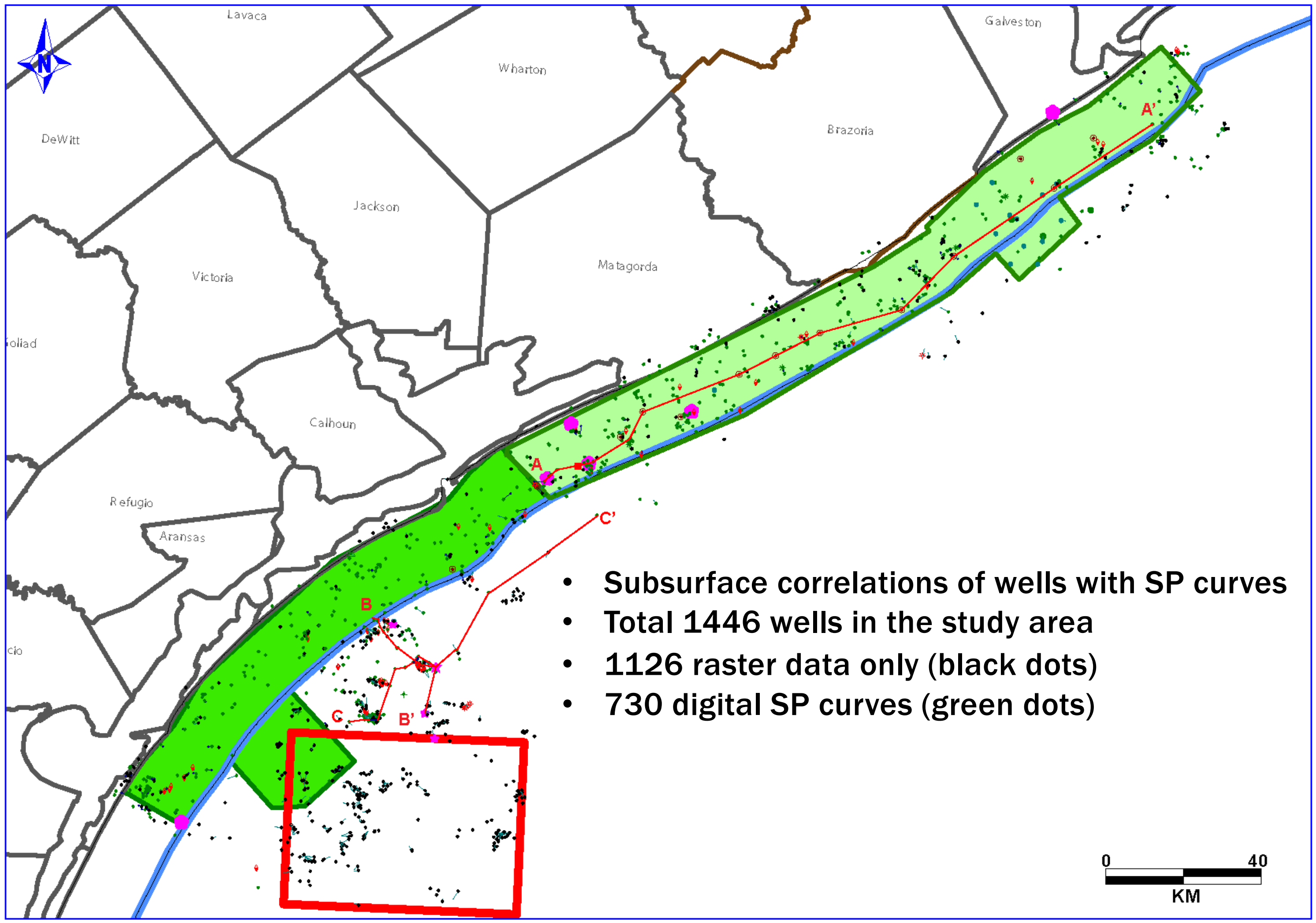
Problem

- Identify potential CO_2 storage intervals (between the supercritical depth and the top of the overpressure)
- Well-log database development offshore mid Texas coast from Galveston to Corpus Christi Bay
- Net sandstone maps - calculation of the sandstone thickness for the prospective interval of interest
- Estimate static regional capacity

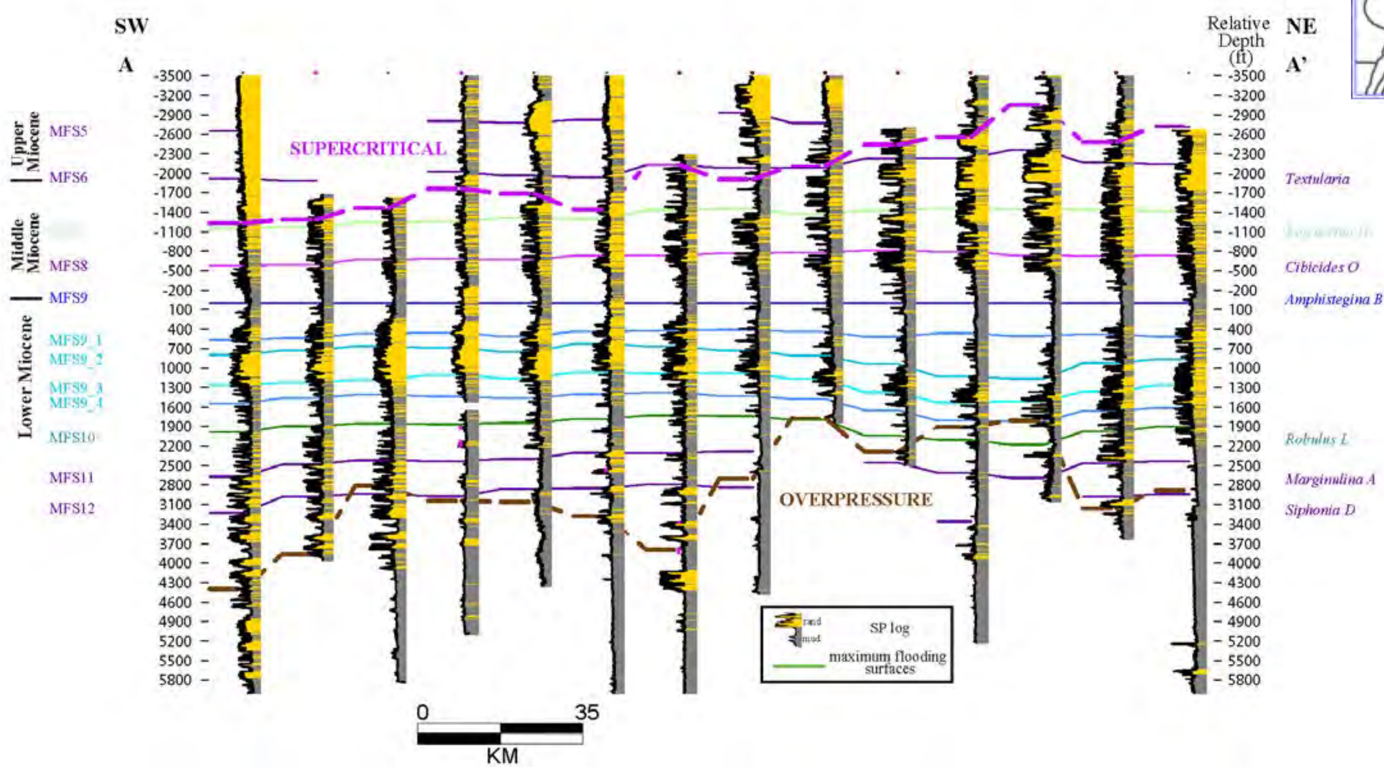
Approach



- Subsurface correlations of wells with SP curves
- Total 1446 wells in the study area
- 1126 raster data only (black dots)
- 730 digital SP curves (green dots)

Status and Results

The interval for CO_2 sequestration is the sandy section above the top of the overpressure between MFS 9 and MFS 10.



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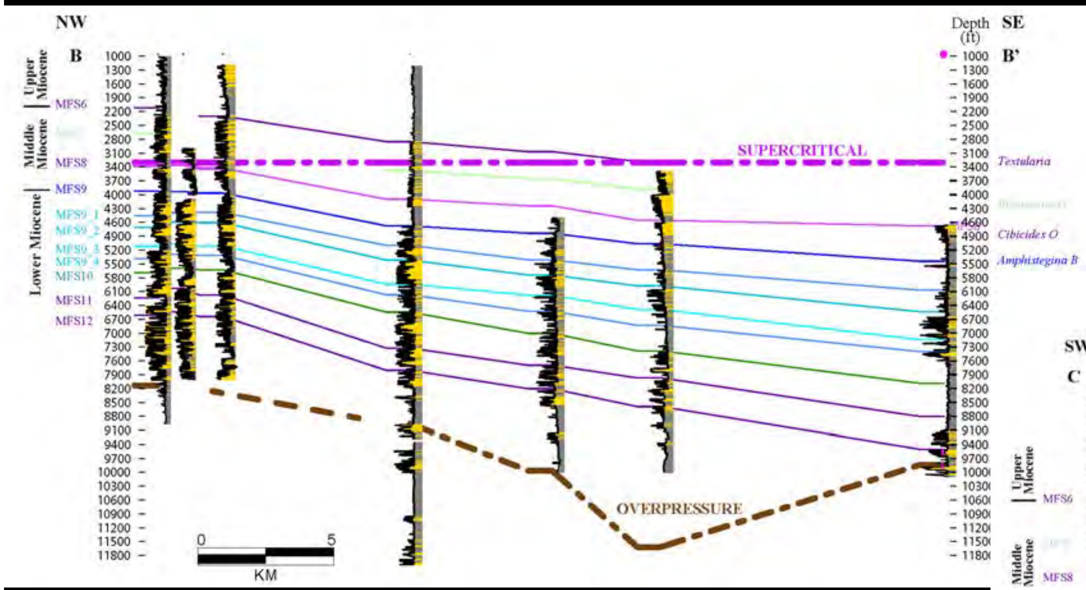

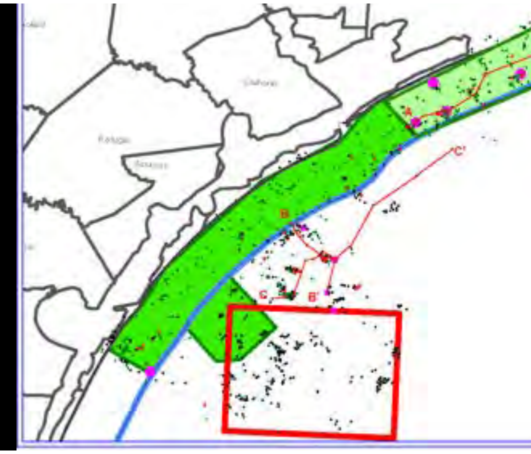

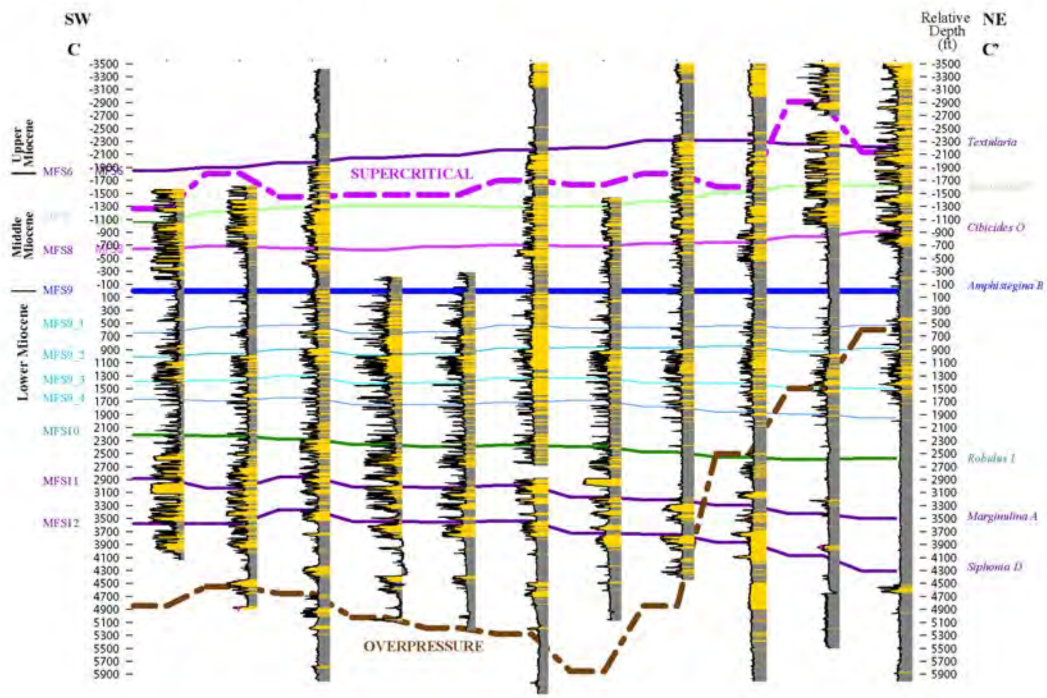

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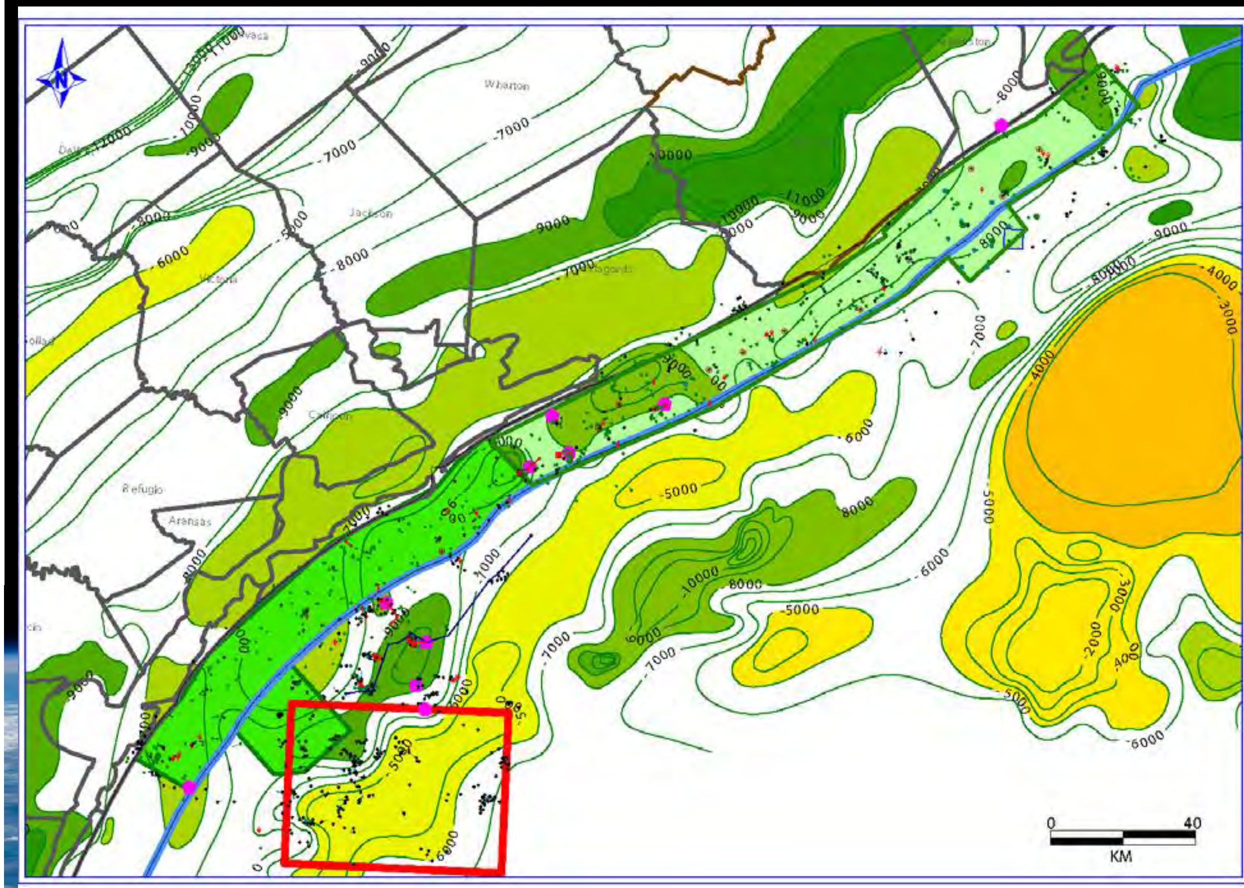
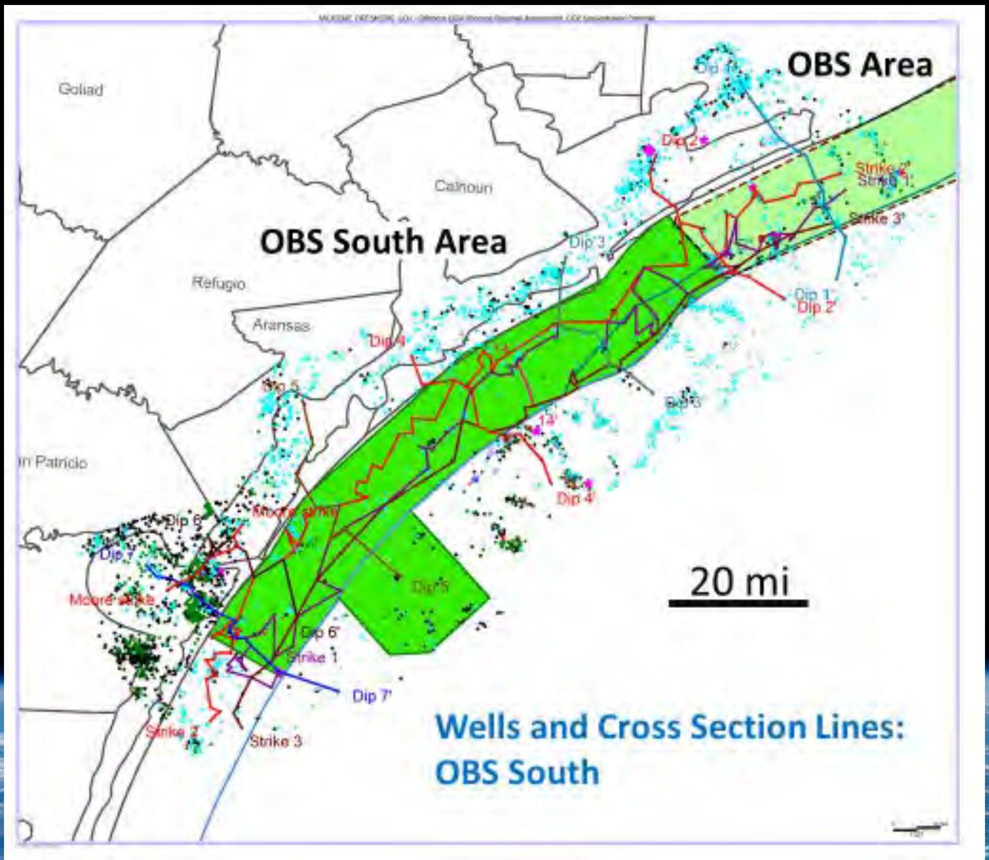
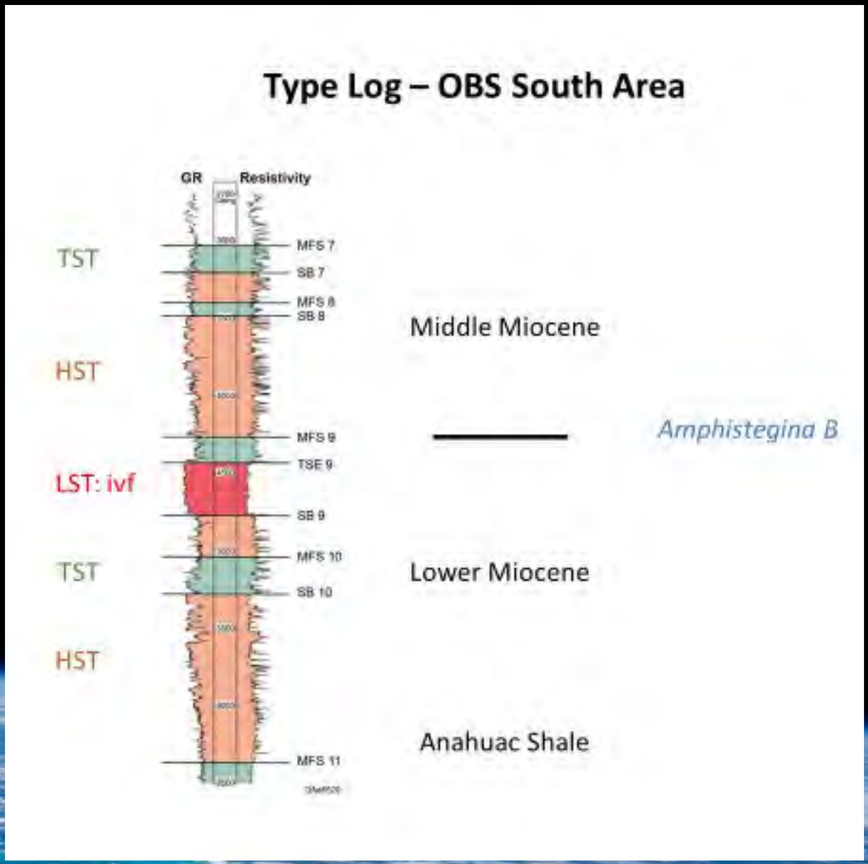


(from Pitman, 2011)

Top of the overpressure very shallow (4000-5000 ft) in the federal waters just south of the state waters offshore Matagorda and Corpus Christi Bay.

Status and Results





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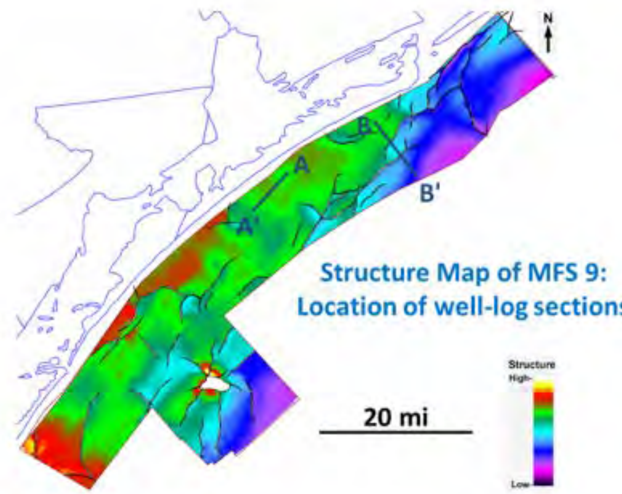
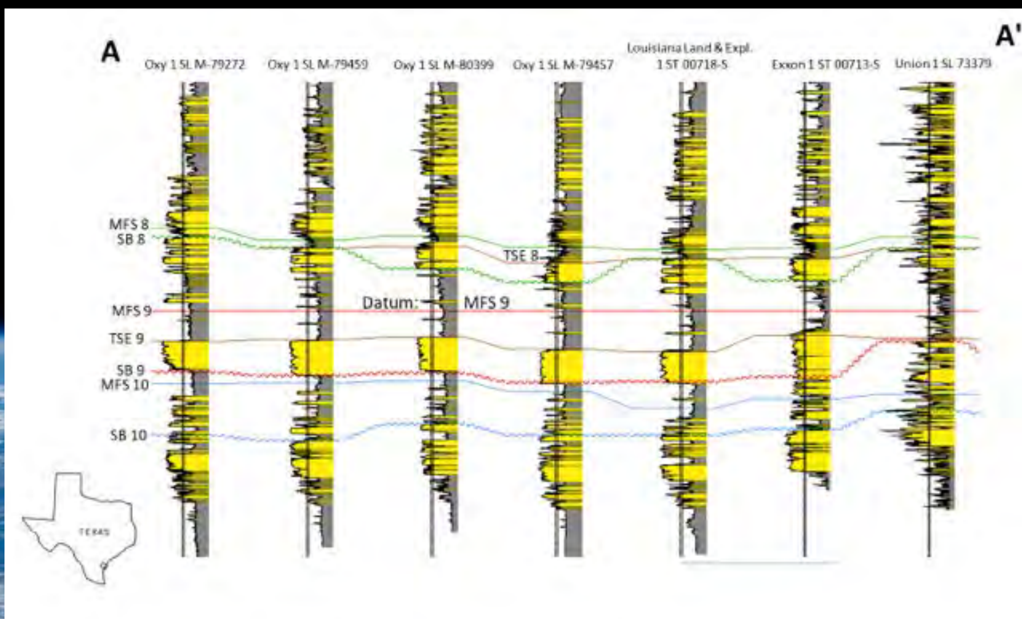
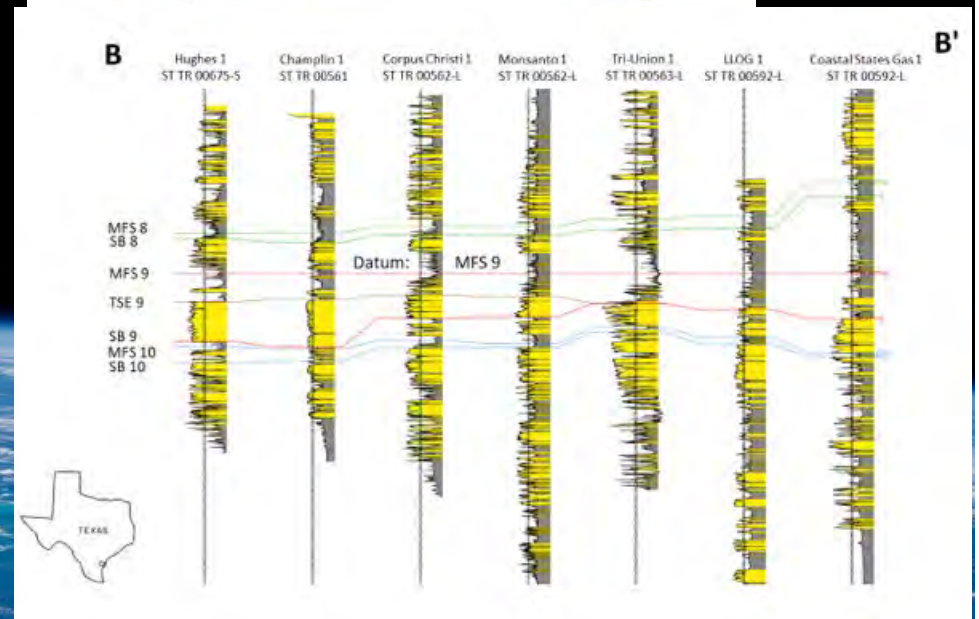
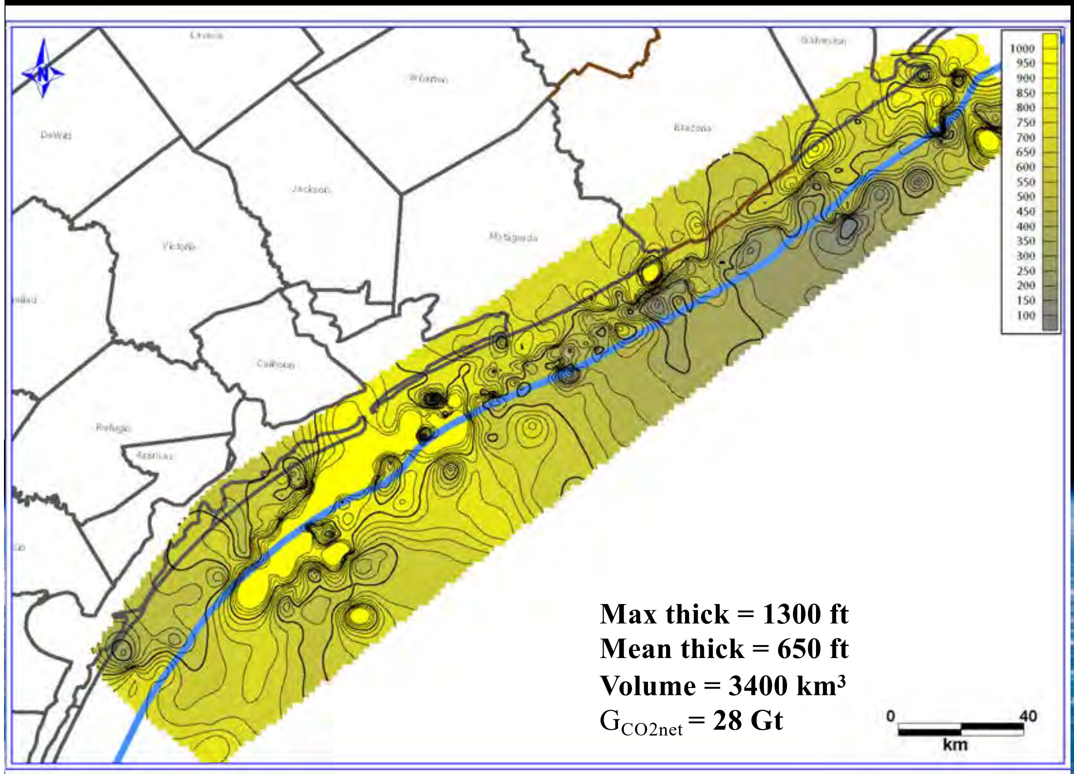


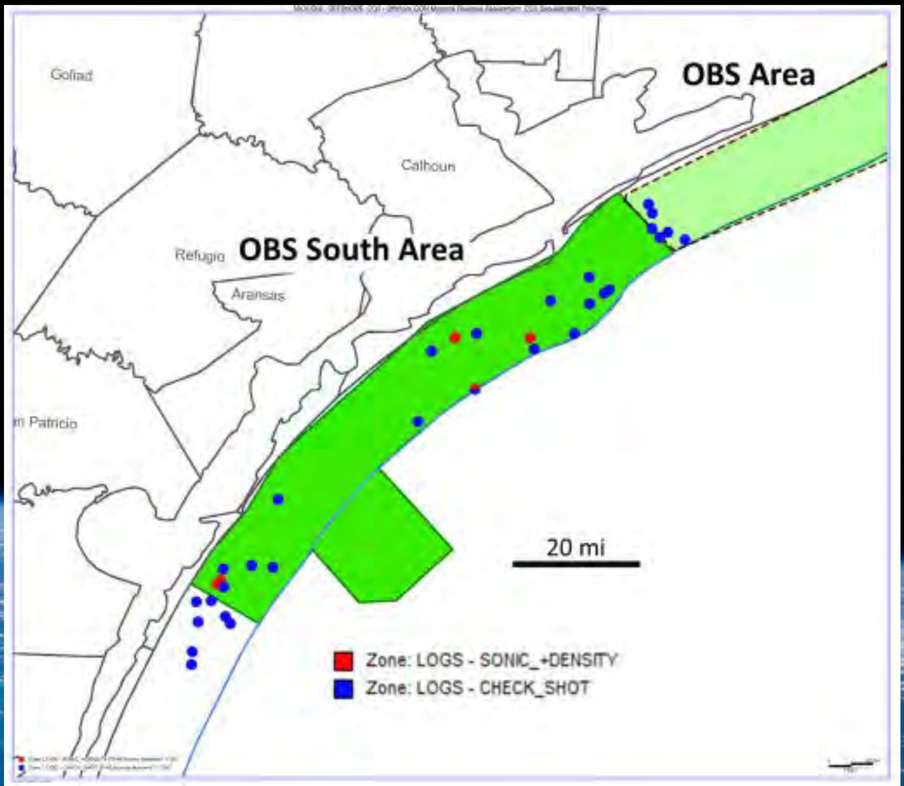




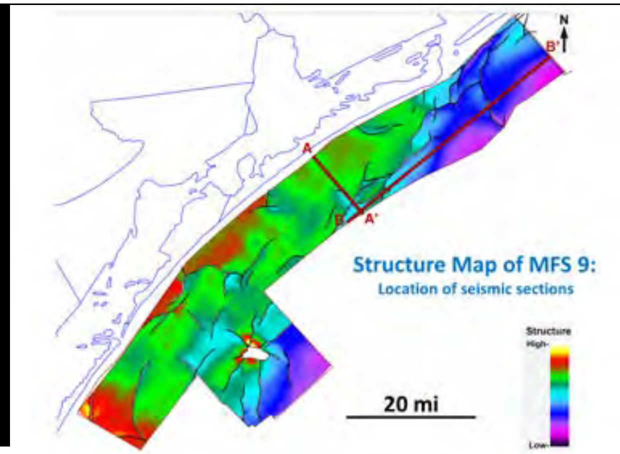
Next Steps

- Estimate static regional capacity - the distribution of storage capacity is influenced by the net sandstone thickness, total porosity and CO2 density
- Sandstone thickness map for the stratigraphic interval from *Amphistegina B* (MFS9) to *Robulus L* (MFS10)
- Integrate well log interpretation with seismic

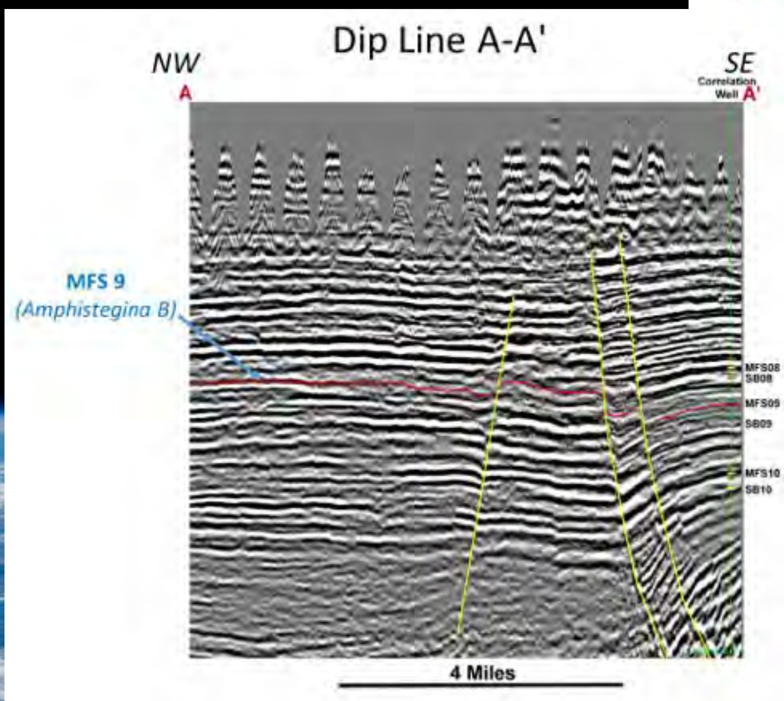




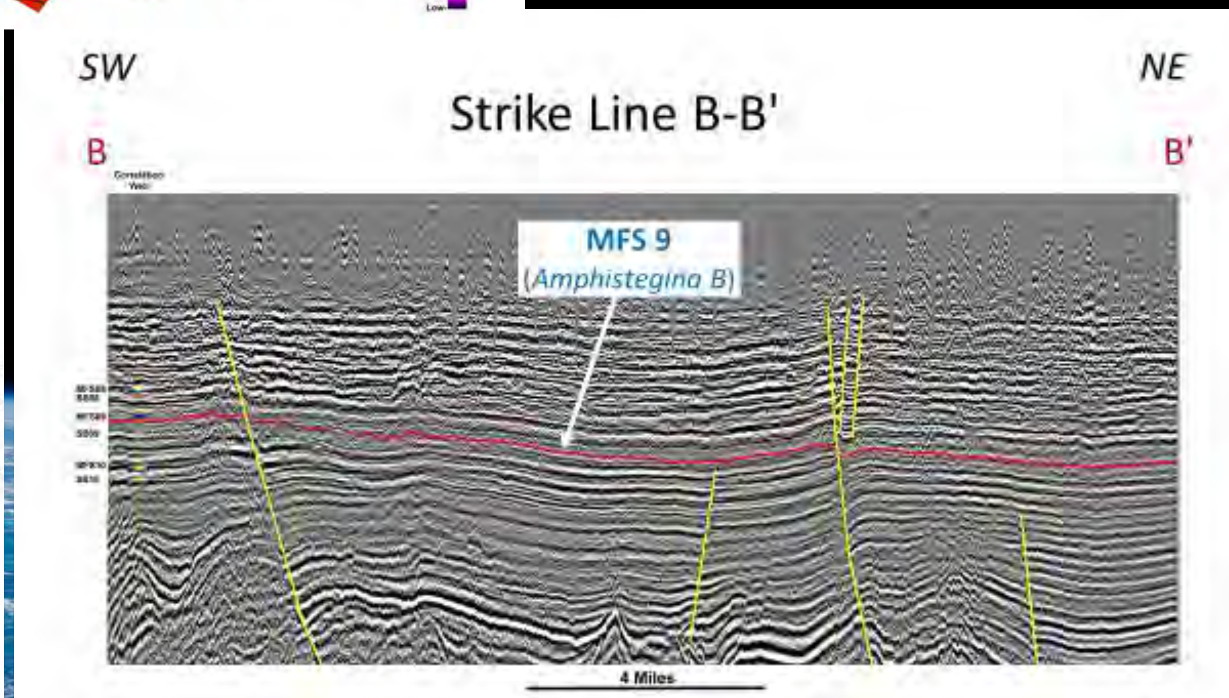
Next Steps



Structure Map of MFS 9:
Location of seismic sections
A
A'
B
B'
N
Structure
High
Low
20 mi



Dip Line A-A'
NW
SE
A
Correlation Well
A'
MFS 9
(Amphistegina B)
MFS08
SB08
MFS09
SB09
MFS10
SB10
4 Miles



SW
NE
Strike Line B-B'
B
B'
Correlation Well
MFS 9
(Amphistegina B)
4 Miles

Discussion via chat

Links to other tasks?

Suggestions/next steps?

Other resources?

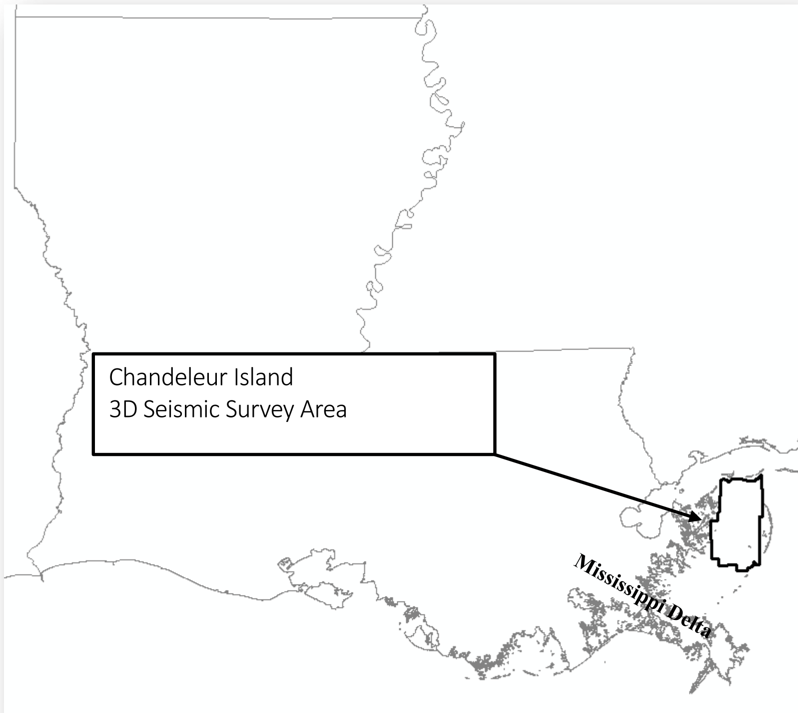
Chandeleur Island CCS Potential

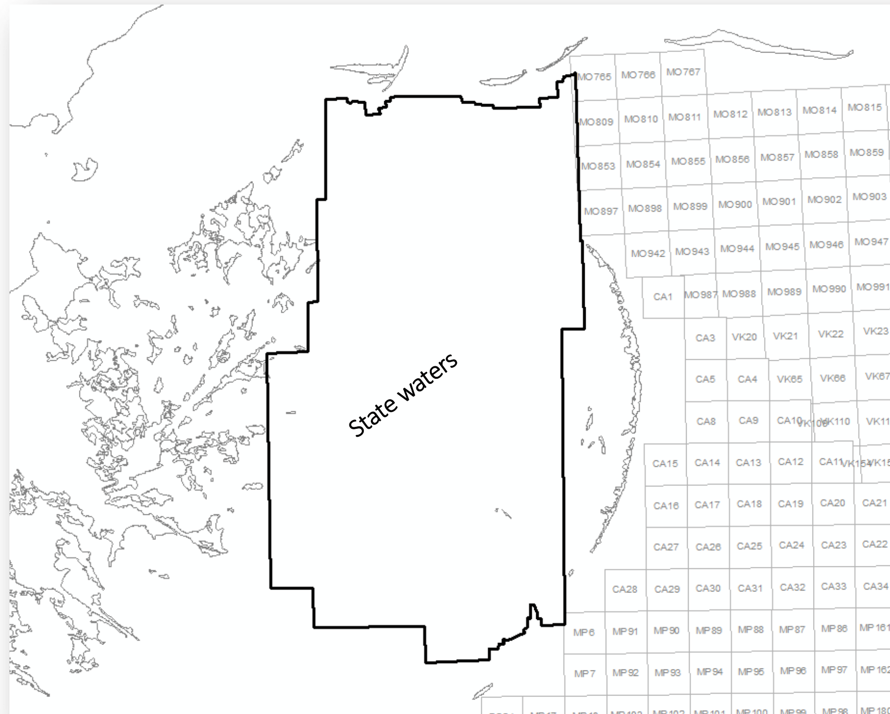
Update about offshore Louisiana

Marcie Purkey Phillips
University of Texas at Austin Institute for Geophysics

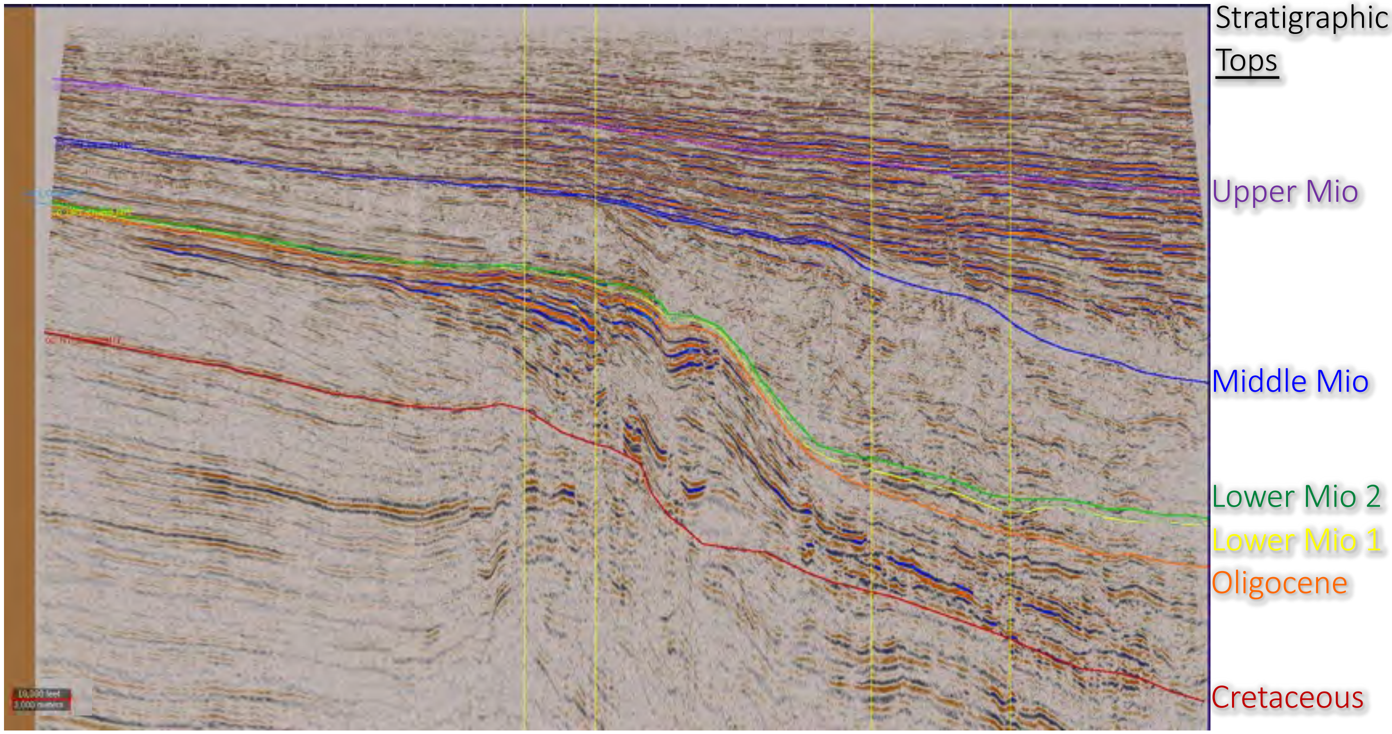
SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

Chandeleur Study Area



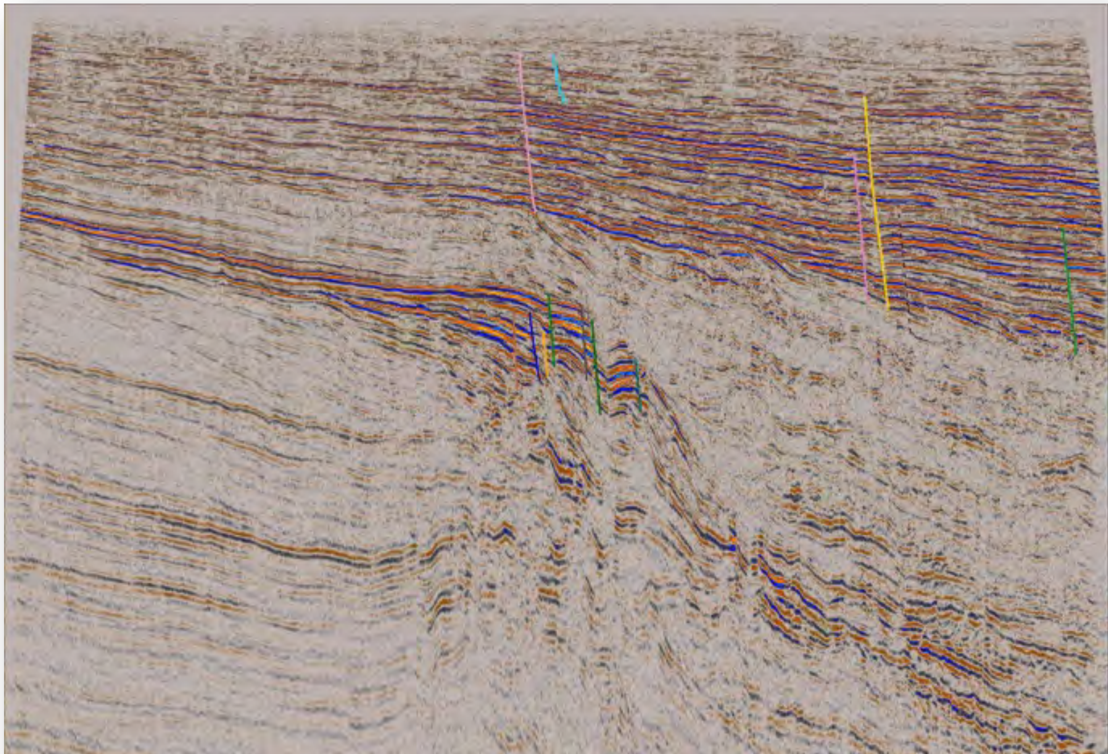


Stratigraphic Interpretation – 2nd Iteration



Seismic data owned or controlled by Seismic Exchange, Inc. (SEI). Interpretation is that of the University of Texas.

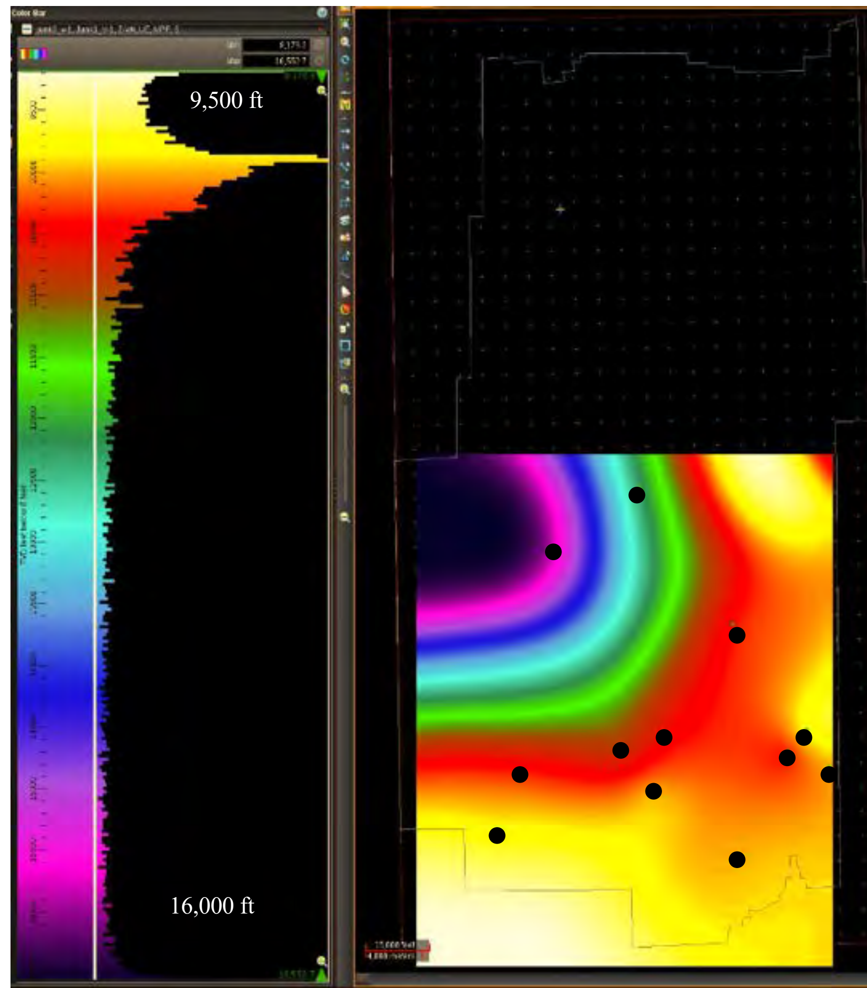
Fault Interpretation



Seismic data owned or controlled by Seismic Exchange, Inc. (SEI). Interpretation is that of the University of Texas.

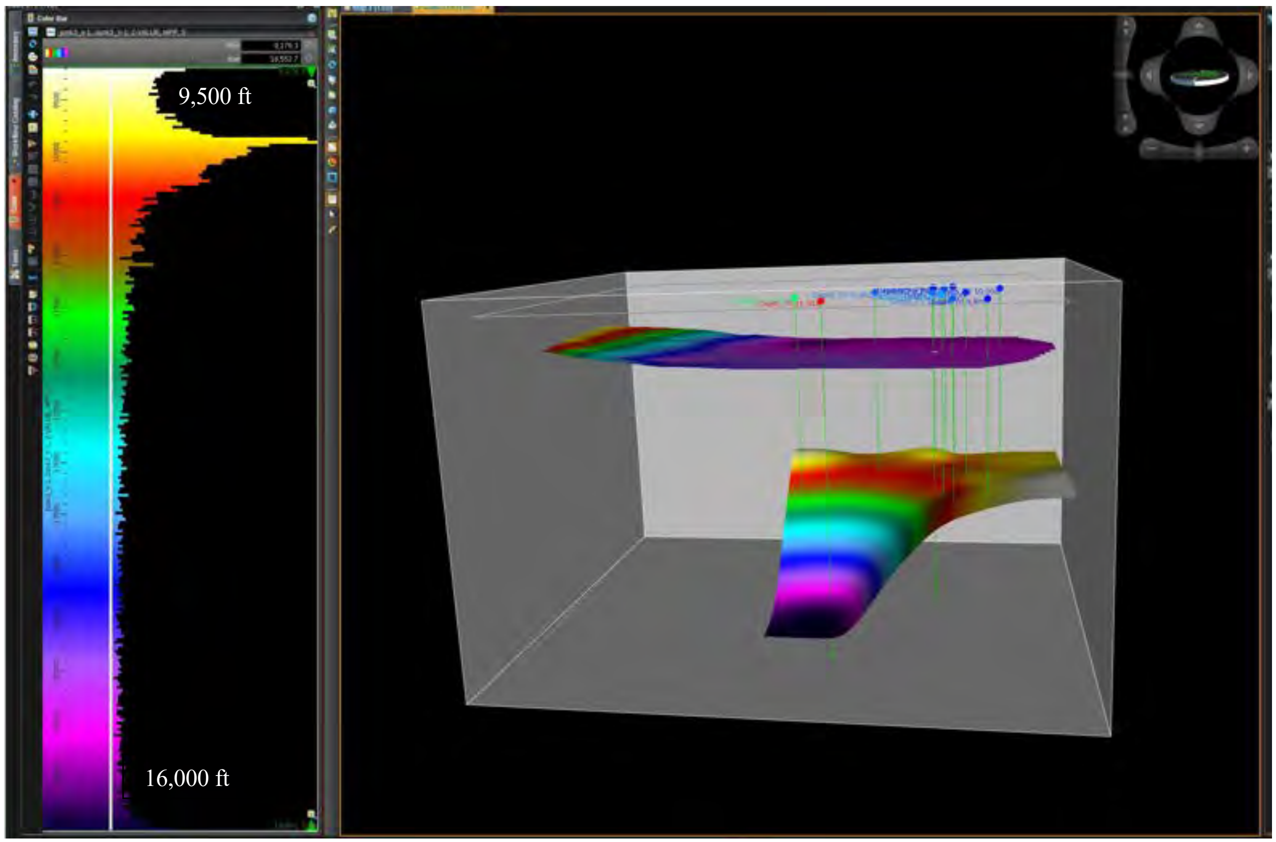
Pressure Gradient

- Top of overpressure = 0.70 psi/ft
  - $P=MW/c_2$ (Burke et al., 2012)
- 12 wells reached overpressure
  - 170 total wells
  - 122 w/logs



Seismic data owned or controlled by Seismic Exchange, Inc. (SEI). Interpretation is that of the University of Texas.

Pressure Gradient – Cube View



Seismic data owned or controlled by Seismic Exchange, Inc. (SEI). Interpretation is that of the University of Texas.

Supercritical cutoff ~1000' or top UM

Top of Overpressure

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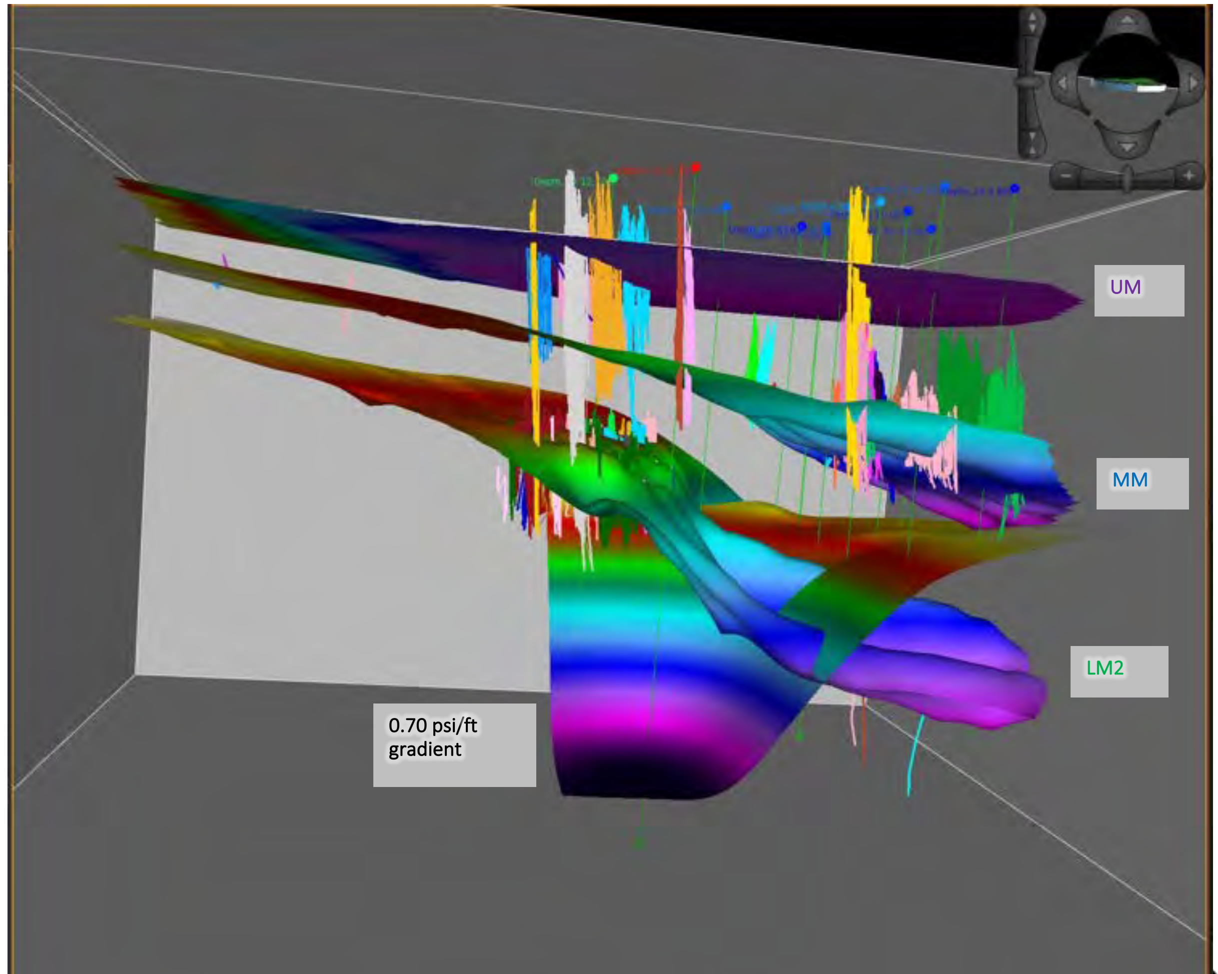
Cube View – Chandeleur Stratigraphy

- Miocene tops
- Pressure Gradient
- Faults



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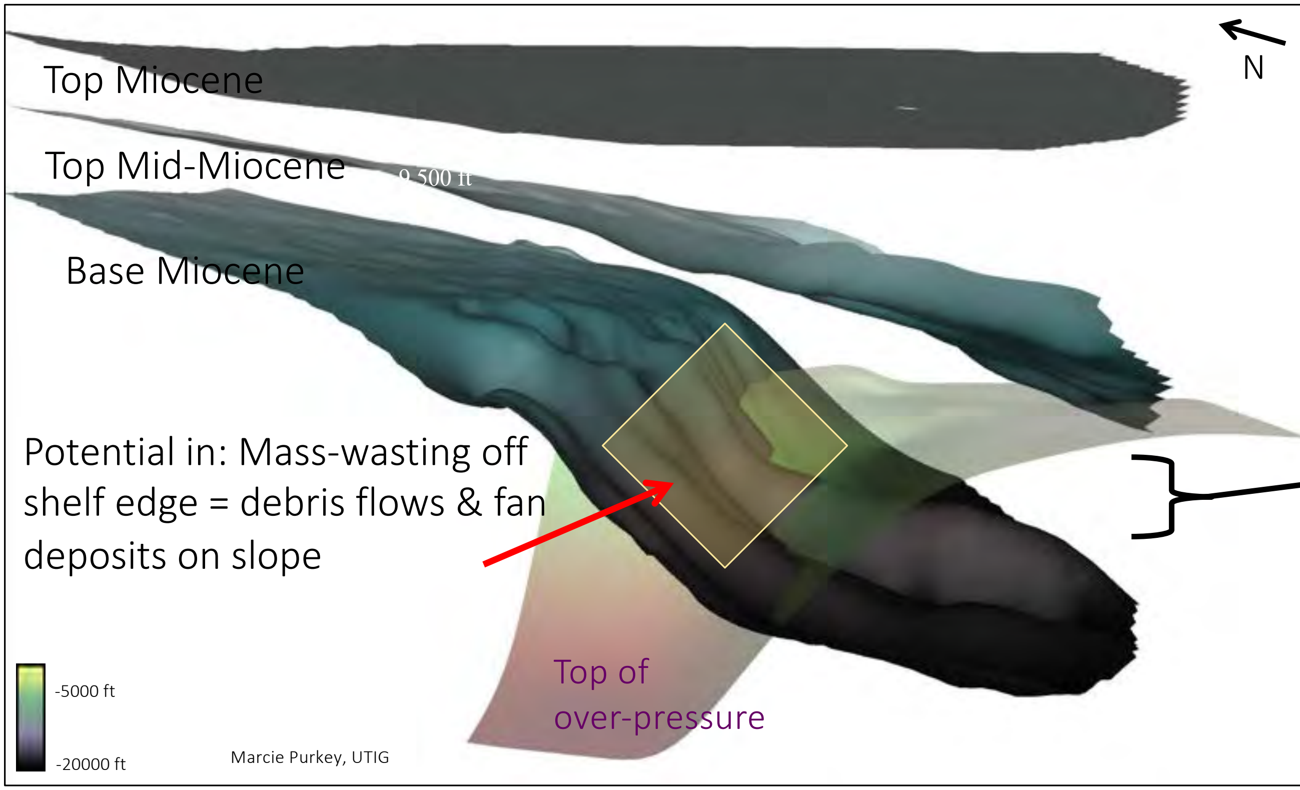
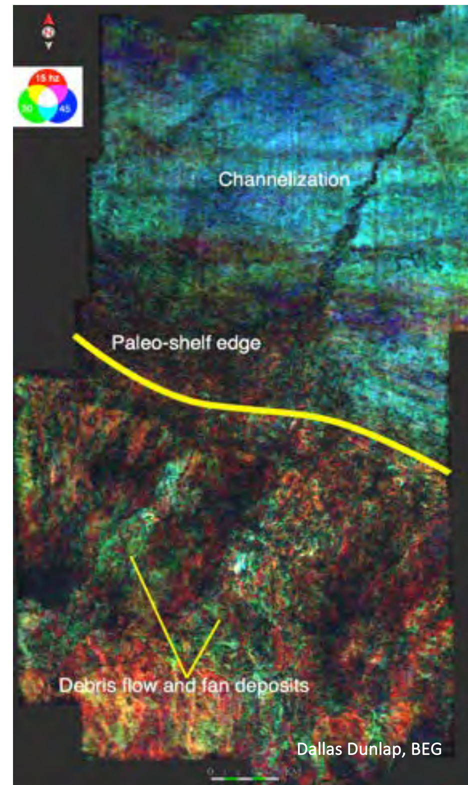
Storage Potential





Seismic data owned or controlled by Seismic Exchange, Inc. (SEI). Interpretation is that of the University of Texas.

Ongoing Work

- Estimate storage potential of debris-flow deposits in Chandeleur
- Identify shales and determine seal efficacy
- Determine which faults, if any, would be sufficient seals

Discussion

Task 2
Buoyant CO_2 Storage Assessment: Methodology and Estimating Input Distributions

Sean T. Brennan

U.S. Geological Survey, Eastern Energy Resources Science Center

SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

Problem

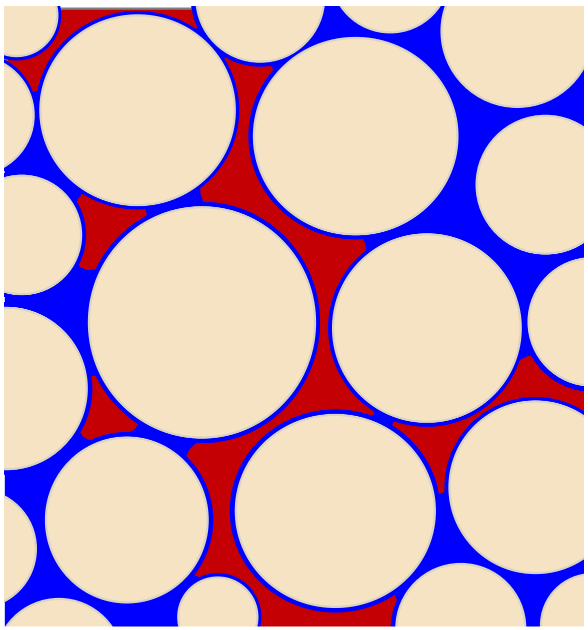
- The goal is to assess the buoyant CO_2 storage resource for the western portion of the Gulf of Mexico.
- The plan is to use a modified version of the U.S. Geological Survey CO_2 storage resource assessment methodology.
- The method was first applied to the lower Miocene strata as test using real data and some gross estimates.

- Realize that the buoyant storage resources is a small relative to the residual storage resource.
    - Pore volume within traps are orders of magnitude less than pore volume of saline formations
    - However more CO_2 will be stored in a smaller region relative to residual storage in saline formations

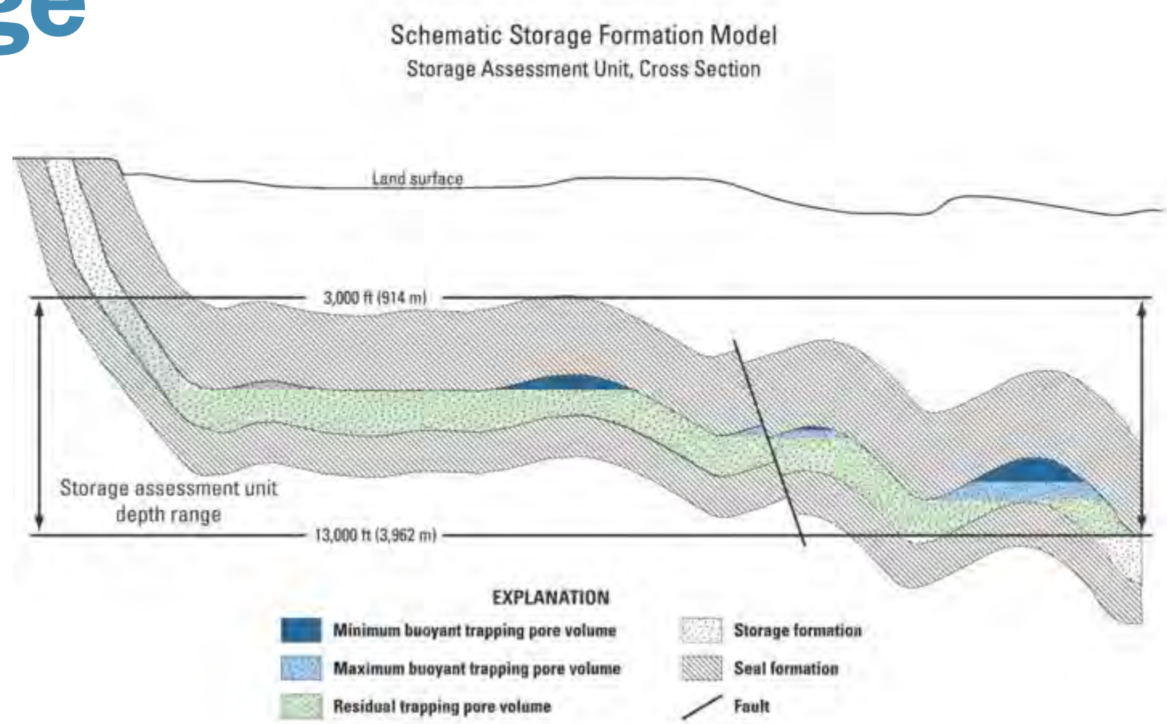
Buoyant Storage

Buoyant Trapping

CO_2 fills pore space, held in place by top and lateral seals



Beige = sand grains, Blue = water, Red = CO_2



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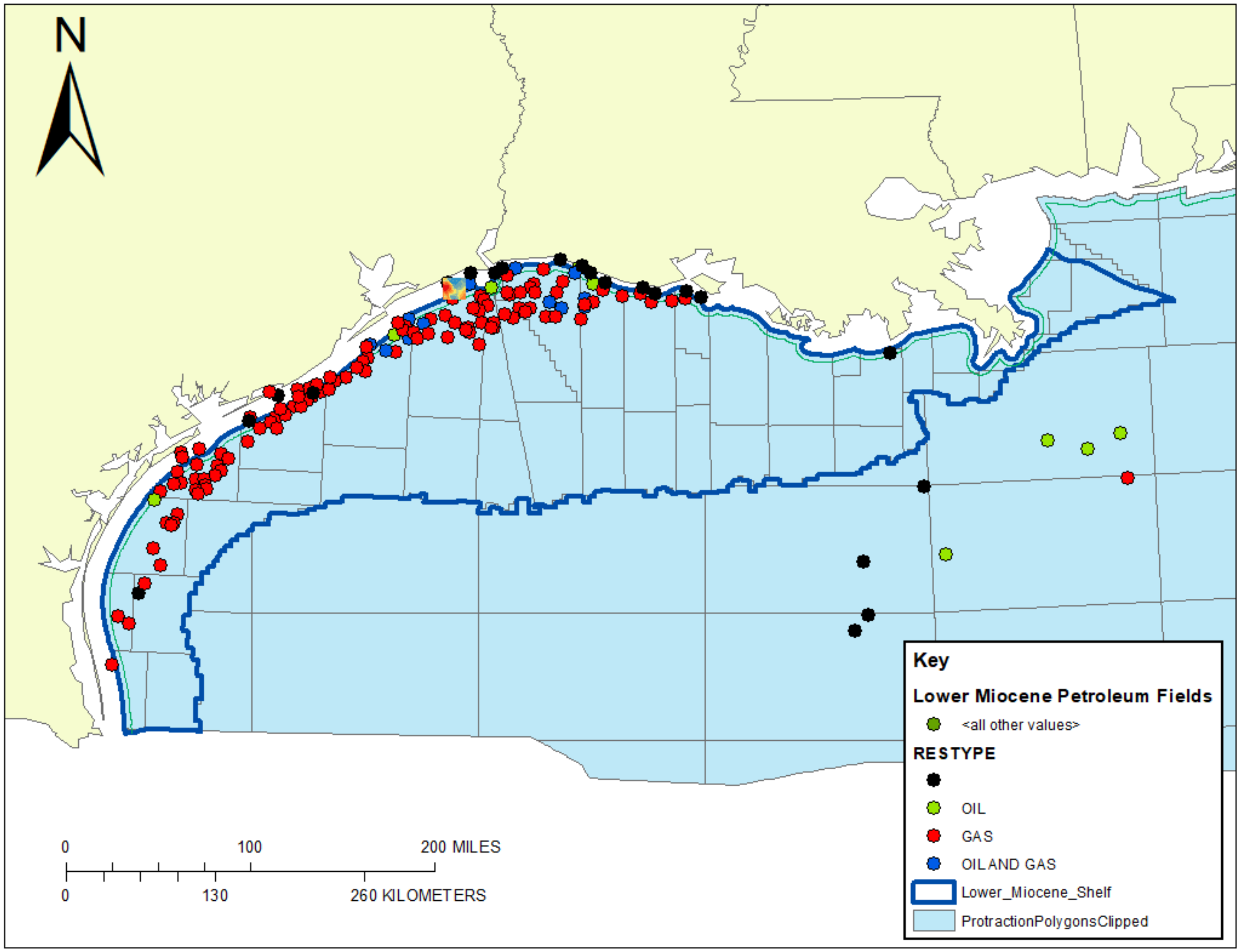
Approach

- The USGS buoyant CO_2 storage assessment methodology, like all USGS assessments, is fully probabilistic.
- This means that we use ranges for all inputs, and use those ranges to create probability distributions.
- These distributions are then sampled using a Monte Carlo simulator that choses values from those distributions for inputs into the storage equation.

The equation that is used here is basic:

Buoyant CO_2 storage = pore volume x storage efficiency x CO_2 density

- To get to these values we use data from existing petroleum production fields, structural maps, well logs, seismic, or any other available data.



Estimation of input values

The initial stage of estimating the buoyant storage is to use data from petroleum fields from the same strata in the assessment area.

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Estimation of input values

Buoyant pore volumes are estimated using known petroleum production values, estimates of undiscovered petroleum, and estimates of maximum possible pore volumes.

Production volumes are given at surficial conditions typically, so they need to be transformed into subsurface or in situ volumes.

Titles	Calcs
Input	Outputs

Volumetric worksheet

		Min	Most likely	Max	
1) Oil KR	MBBLS	83,600	220,000	1,000,000	
2) Gas KR	MMcf	13,700,000	20,000,000	175,000,000	
3) NGL KR	MBBLS	320,000	480,000	1,100,000	
	Units	Min	Most likely	Max	@Risk F(x)
4) Oil FVF	Dec. Frac	1.05	1.4	1.9	1.41661922
5) Gas FVF	Dec. Frac	0.0037	0.0047	0.009	0.00669978
6) NGL FVF	Dec. Frac	1.5	2.5	5	3.43088099
		Min	Most likely	Max	
	Oil - In Situ Volume (ft^3)	664388745.6	1748391436	7947233799	
	Gas - In Situ Vol (ft^3)	91786980680	1.33996E+11	1.1725E+12	
	NGL - In Situ Vol (ft^3)	6159117550	9238676325	2.1172E+10	
	Total In Situ Volume	98610486976	1.44983E+11	1.2016E+12	

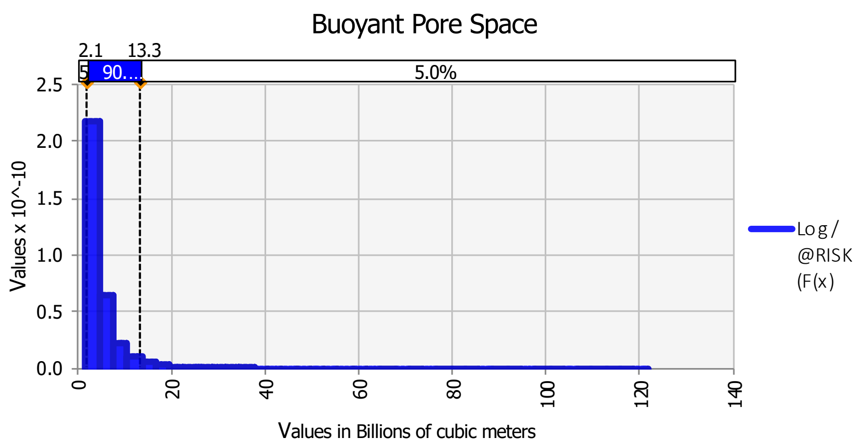
Estimation of input values

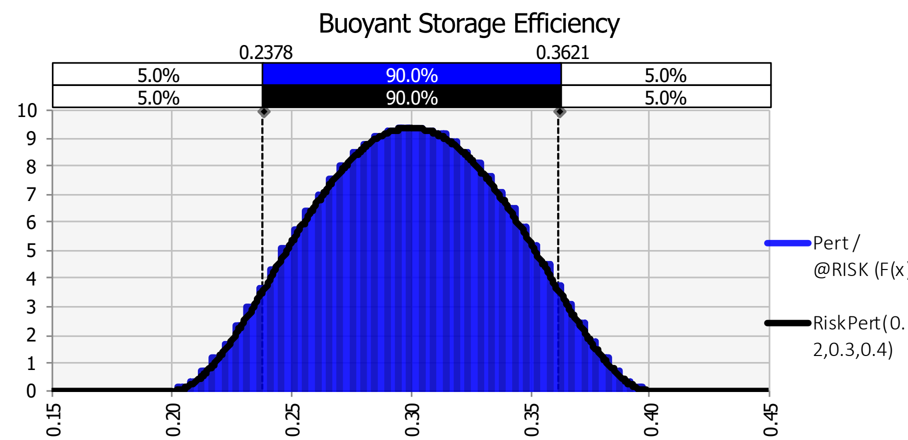
Once the buoyant volumes are transformed into subsurface volumes, they can be used to create the distributions that go into the Monte Carlo model to estimate buoyant CO_2 storage resource.

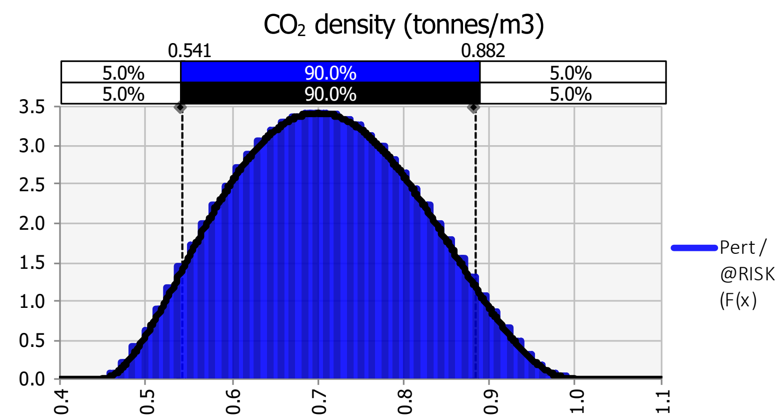
Titles	Calcs
Input	Outputs

	Min	Most likely	Max	μ	σ	mean	sd	@RISK (F(x))	
Buoyant Pore Volume	**2,710,124,641**	**3,987,976,112**	**33,031,019,188**	**21**	**1**	**1,277,833,448**	**2,945,019,542**	5,795,173,450	m3
Storage Efficiency	**20%**	**30%**	**40%**					0.300	storage efficiency (fraction)
CO2 Density	**0.450**	**0.700**	**1.000**					0.658	tonne/m3

Input value distributions







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Status and Results

- Currently I only have known petroleum production and undiscovered volumes to work with
- I will be getting more data on maximum possible buoyant pore volumes, which will help define the entire distribution

- If we decide to use a method that attempts to capture the total thickness of porous strata within traps I realized that I will need more data to estimate the most likely value for that buoyant pore volume. Using data from master’s theses on the High Island 10-L and 24-L blocks, as well as structural maps of the entire assessment area, should help estimating these pore volumes.

Add status and results here

Using the known produced and undiscovered petroleum in the assessment area, and an estimate of the maximum buoyant pore volumes the buoyant CO_2 storage resource for the lower Miocene in this assessment area in Gt is:

Mean	P95	P50	P5
1.11	0.39	0.77	2.89

If the most likely value of natural gas is increased from 20 TCF to 50 TCF, while keeping all the other inputs the same, the buoyant storage resource values would be:

Mean	P95	P50	P5
1.24	0.46	1.04	2.69

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Next Steps

- A more accurate accounting of most likely buoyant pore volume and estimates for maximum buoyant storage are needed to complete the assessment
- Once the lower Miocene is assessed, we need to move on to the other stratagraphic intervals and complete those assessments

Discussion via chat

Links to other tasks?

Suggestions/next steps?

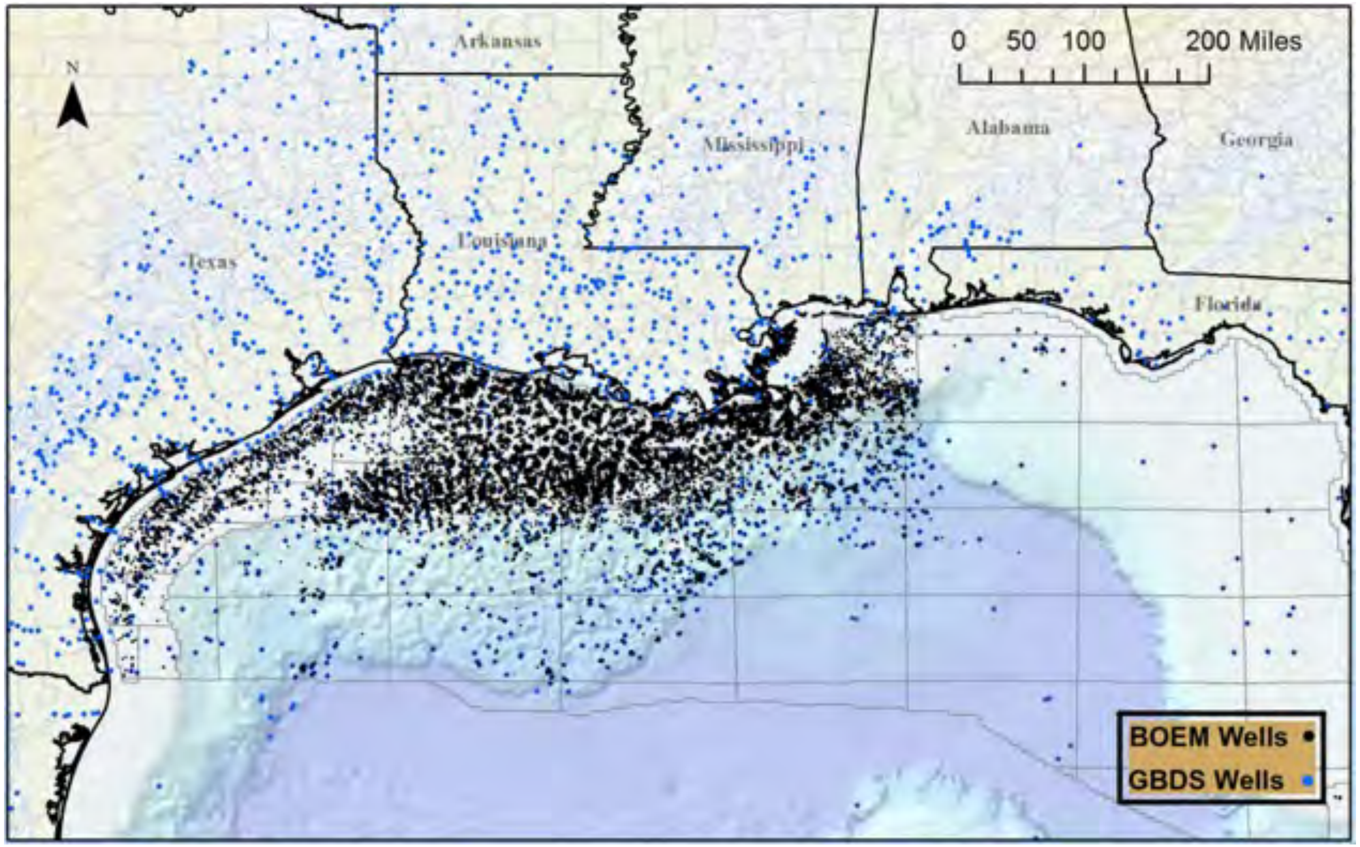
Other resources?

Mechanistic modeling of CO_2 leakage into the water column from off-shore CO_2 wells or pipelines

Curtis M. Oldenburg

Presented @ SECARB-GoMCarb Virtual Meeting March 26, 2020

Numerous wells in near-offshore region bring hazard of leakage through wells



Main Questions Being Addressed for CO_2 wells:

- **Under what blowout conditions will leaking CO_2 make it to the sea surface (not dissolve in the water column)?**
  - **Water depth, leakage rate, orifice, …**

- **What are the possible blowout flow rates for given reservoir-well conditions?**
  - **Orifice size, reservoir depth, water content, composition, …**

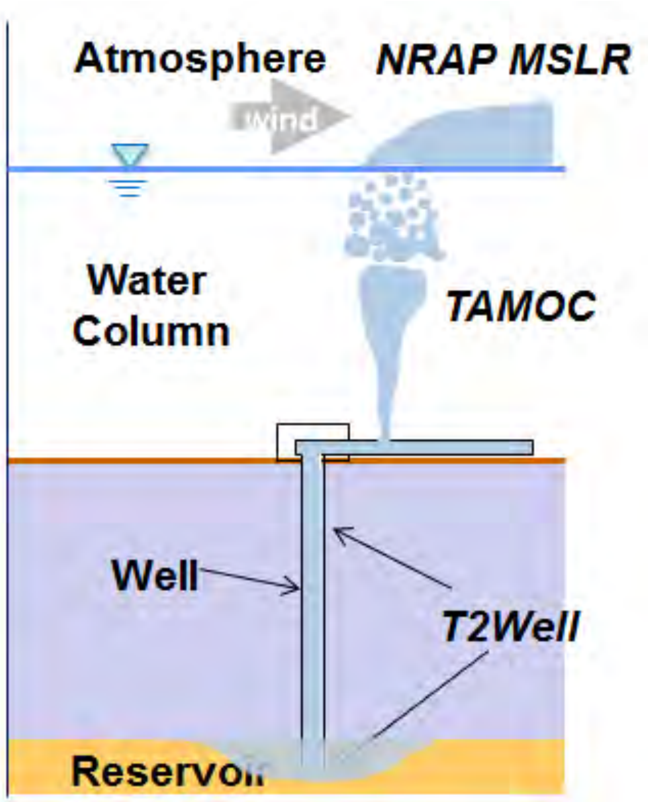
- **If CO_2 is emitted into the atmosphere, what are expected downwind safety distances?**
  - **CO_2 emission rate, wind, …**

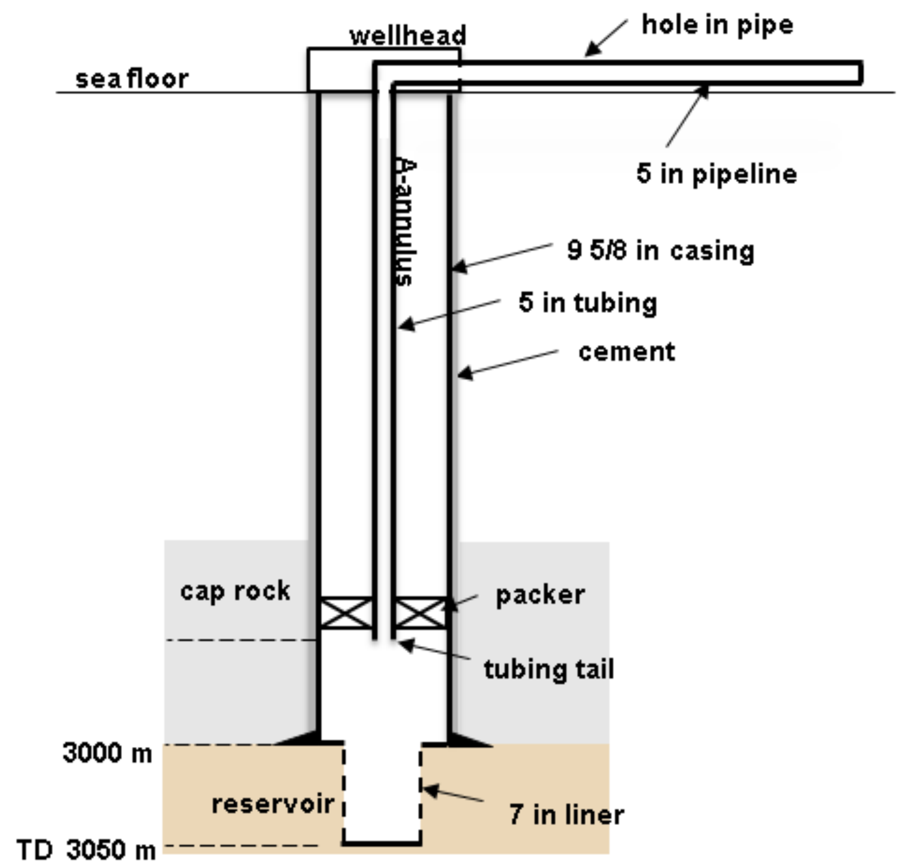
Sedco 700 Shallow Gas Blow Out 6 June 2009 11 35am

Nigeria

https://www.youtube.com/watch?v=NJiBS64RVVQ

Approach: Simulate offshore CO_2 blowout using T2Well and pass output to TAMOC





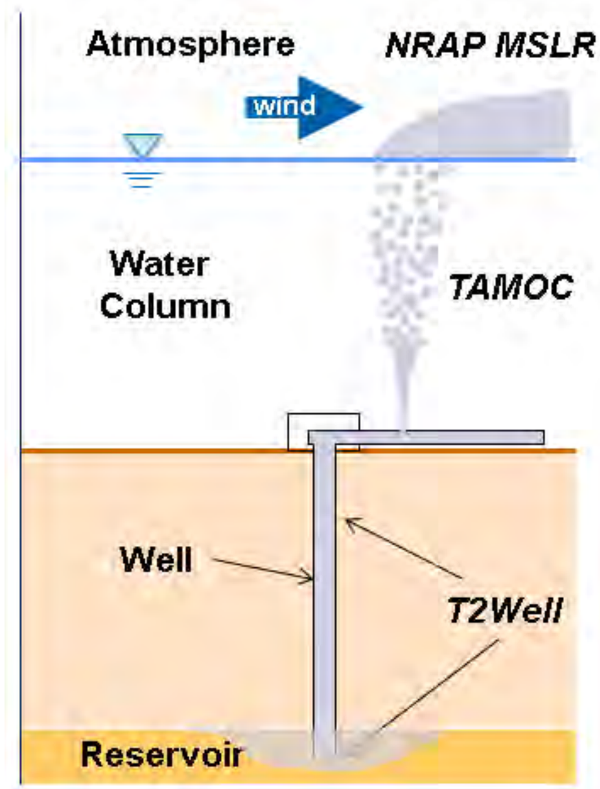
Offshore CO_2 well blowouts are strongly controlled by transport processes in the water column

Relative to ambient air, the water column provides

- **More resistance to flow**
- **Positive buoyancy for CO_2**
- **Vast source of heat to counter cooling caused by decompression**
- **Vast sink for CO_2 dissolution**

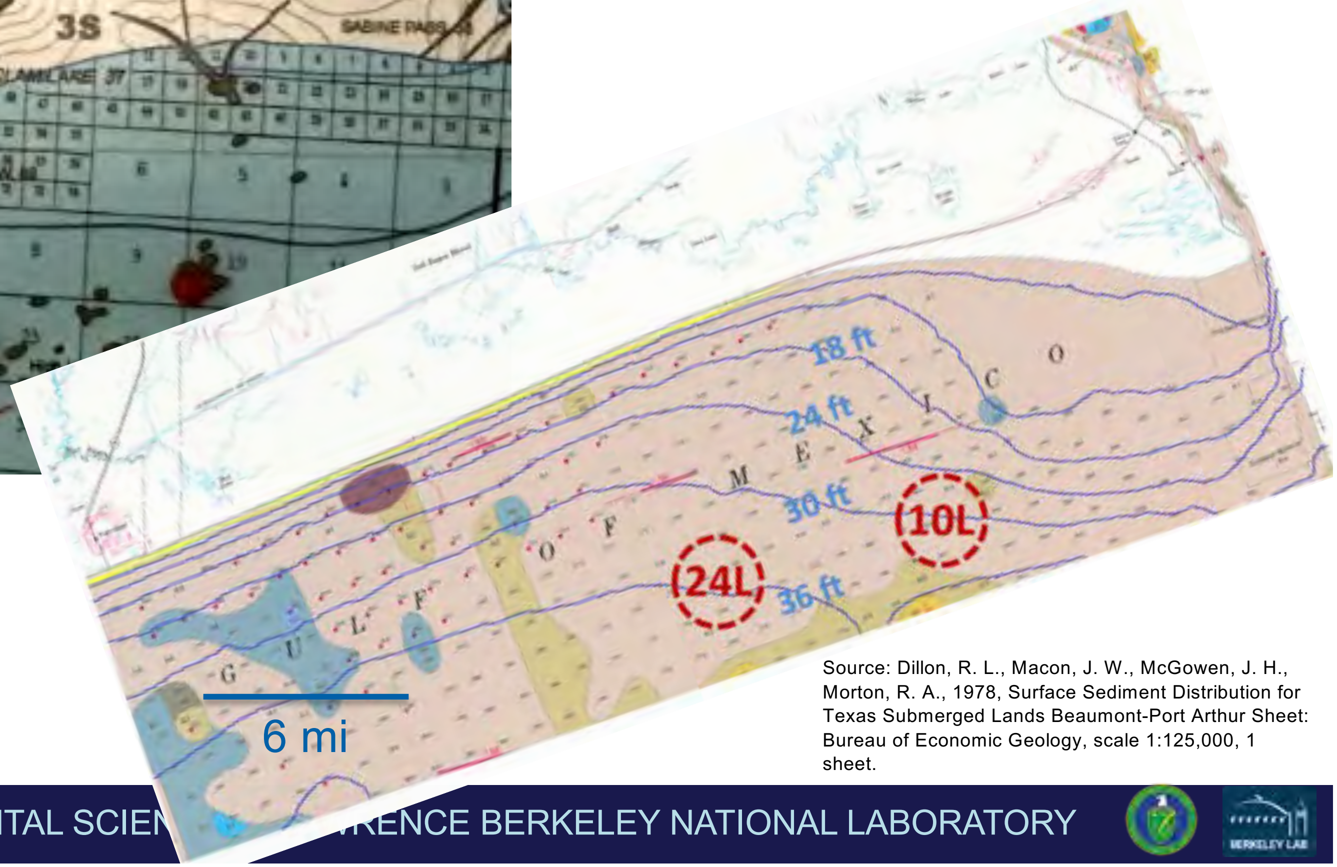
Loosely couple two existing models to understand consequences of sub-sea CO_2 leaks and blowouts

- **Reservoir-well flow (T2Well)**
- **Jet and buoyant plume flow in the water column (TAMOC)**



GoMCarb focus is on the High Island 10L and 24L blocks where the water depth is approximately 30-40 ft

Source: Gulf Coast Geomap Company, 2009, Extended Area Reference Map 380: Geomap Company.



Source: Dillon, R. L., Macon, J. W., McGowen, J. H., Morton, R. A., 1978, Surface Sediment Distribution for Texas Submerged Lands Beaumont-Port Arthur Sheet: Bureau of Economic Geology, scale 1:125,000, 1 sheet.

Approach to simulating CO_2 rise in the water column: TAMOC (integral model for gas jets and bubble plumes by Scott Socolofsky, Texas A&M)

TAMOC models complex physical processes using an integral approach:

- **Jet flow of gas into water column**
- **Transition from jet flow to bubbly flow**
- **Top-hat velocity profiles with fluid entrainment**
- **Buoyant bubble rise w/ dynamics based on bubble-size distribution**
- **Equations of state for multiple gases and gas mixtures**
- **Crossflow of seawater**
- **Stratification of seawater**
- **Salinity, pressure, temperature effects on density and solubility**

https://www.marine.usf.edu/c-image/component/k2/texas-a-m-oilspill-calculator-tamoc-modeling-suite-for-subsea-spills

Dissanayake, A. L., Gros, J., and Socolofsky, S. A. (2018). "Integral models for bubble, droplet, and multiphase plume dynamics in stratification and crossflow." Environ Fluid Mech, 18(5), 1167-1202.

The Rosin-Rammler distribution is used to describe the bubble-size distribution

Workflow to calculate bubble distribution:

Use discharge rate q (kg/s), density, and aperture to calculate U_a

$$U_a = u_g \sqrt{\frac{\rho_g}{\rho_a}}$$

Calculate M, B, l_M, to find We_m

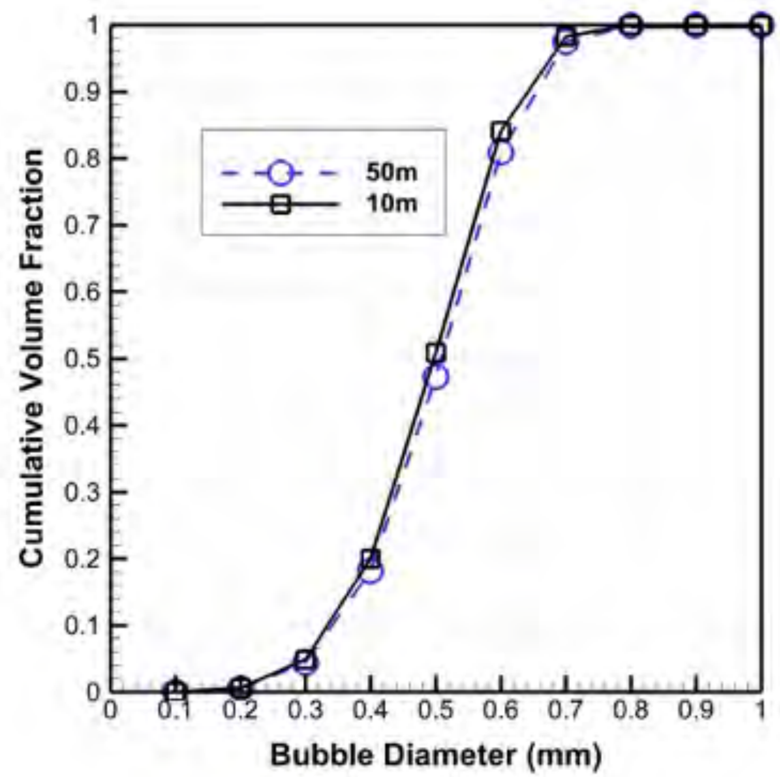
$$M = \frac{m_0}{\rho_a} \qquad B = \frac{b_0}{\rho_a} \qquad l_M = \frac{M^{3/4}}{B^{1/2}} \qquad We_m = \frac{U_a{}^2 l_M \, \rho_m}{\sigma}$$

Calculate d_{50}

$$d_{50} = l_M \; 4.3 \; We_m{}^{-3/5}$$

Calculate V(d)

$$V(d) = 1 - \exp\left[-k_{50}\left(\frac{d}{d_{50}}\right)^{\alpha}\right]$$



The well blowout is simulated using T2Well for the coupled reservoir-well flow

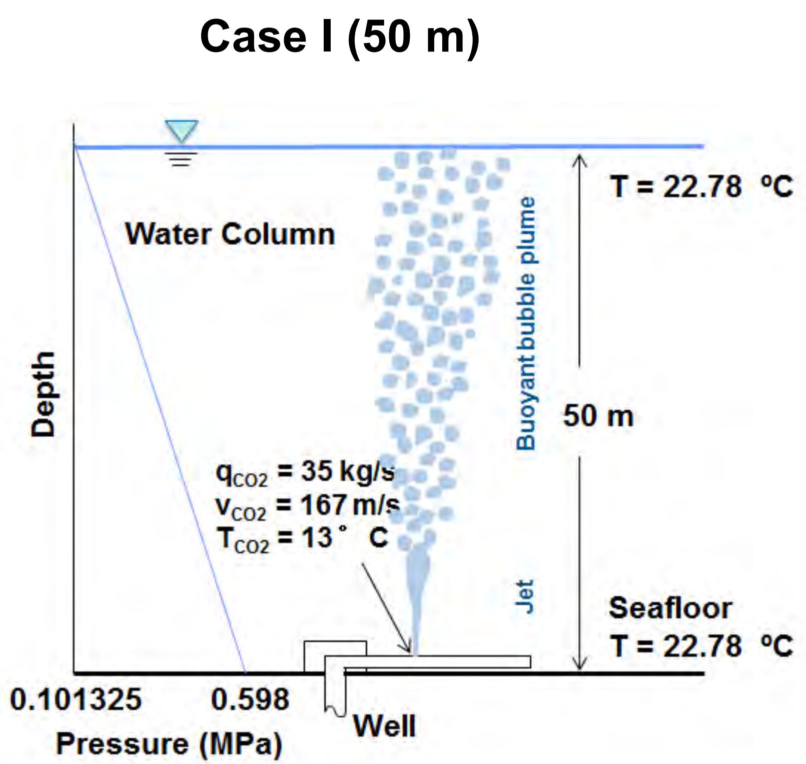
T2Well models three-phase flow in the reservoir and in the well for this problem

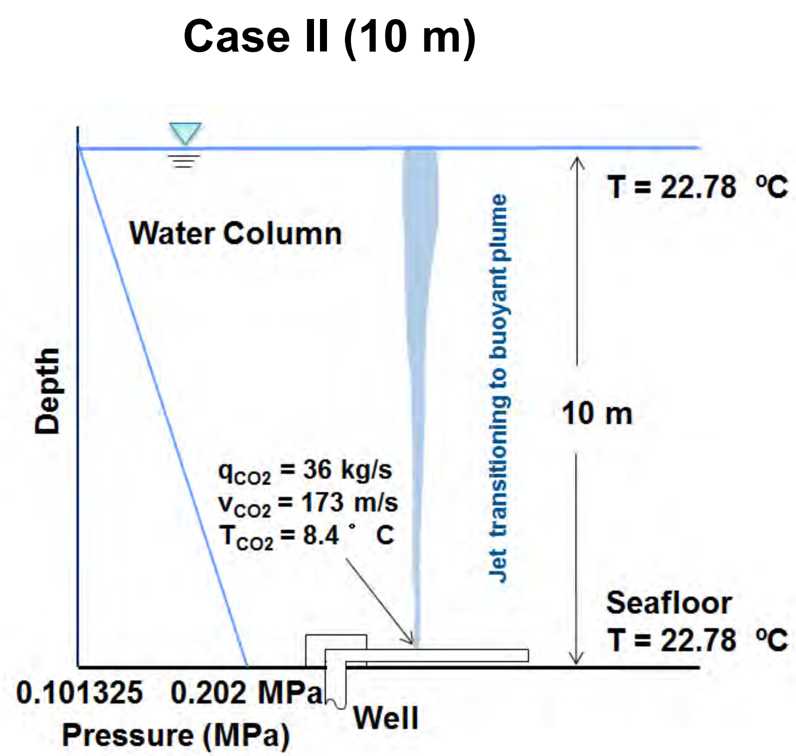
- **Three-phase Darcy's law for flow in the reservoir**
- **Drift-flux model for flow in the well pipe**
- **Friction in the well is a function of roughness and flow rate (Re)**
- **Continuous range of flow regimes depending on phase saturations and Re**
- **Equation of state for CO_2-brine mixtures was used here**
- **Salinity, pressure, temperature effects on density and solubility**

https://tough.lbl.gov/licensing-download/tough-related-codes-licensing-download/

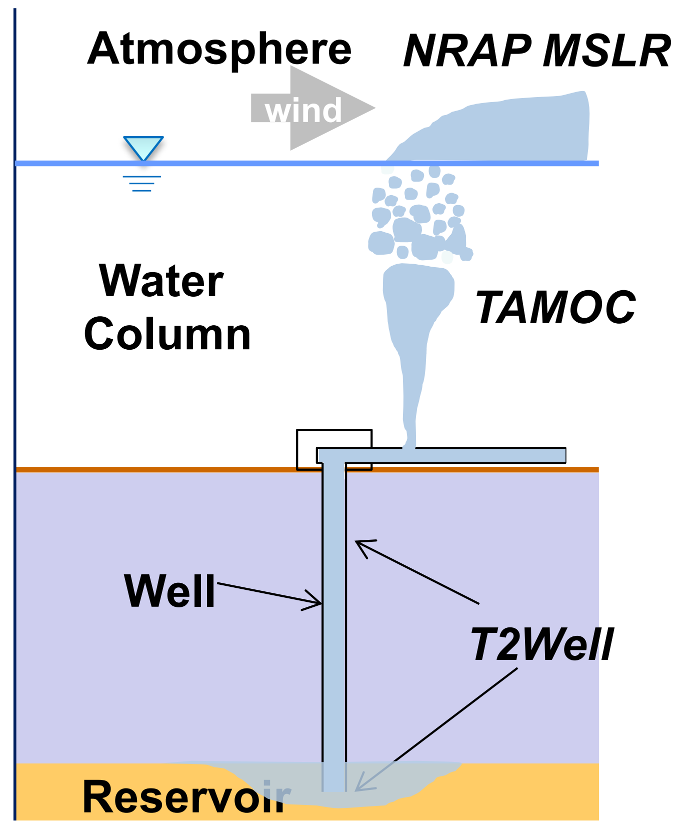
Pan, L. and Oldenburg, C.M., 2014. T2Well—an integrated wellbore–reservoir simulator. Computers & Geosciences, 65, pp.46-55.

To understand effects of water column (depth), we simulated a CO_2 blowout for two cases



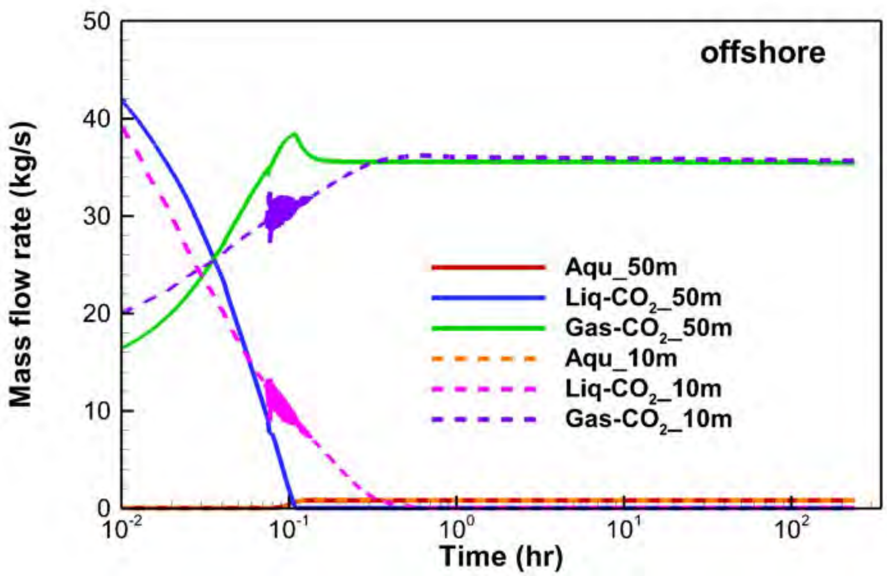


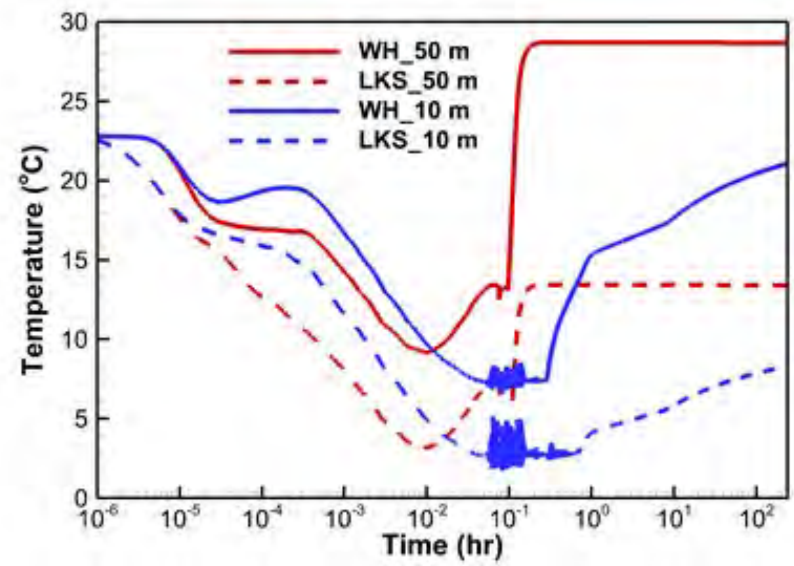
Results



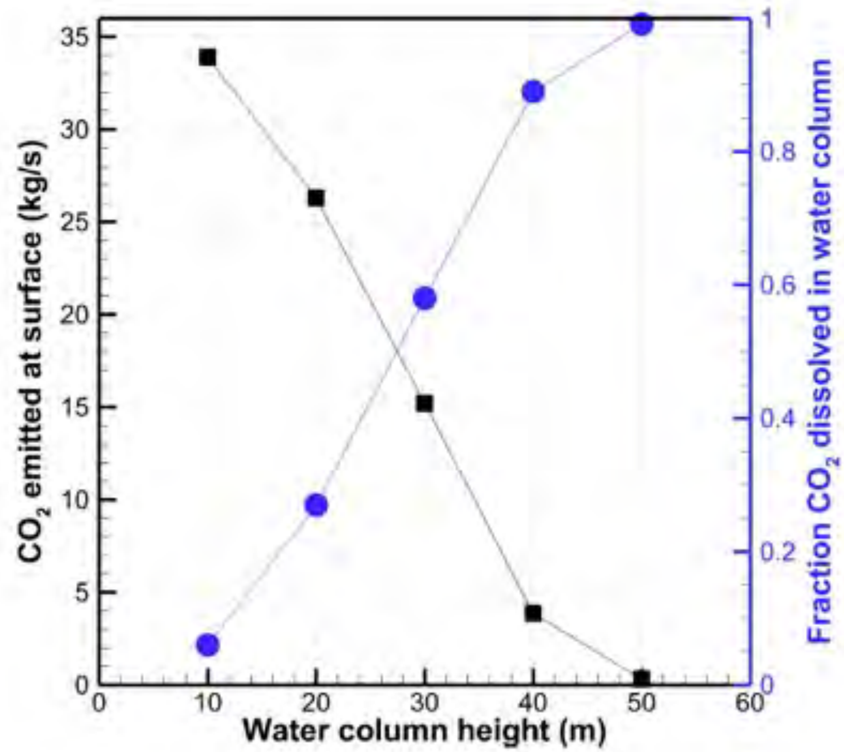
Atmosphere
NRAP MSLR
wind
Water Column
TAMOC
Well
T2Well
Reservoir

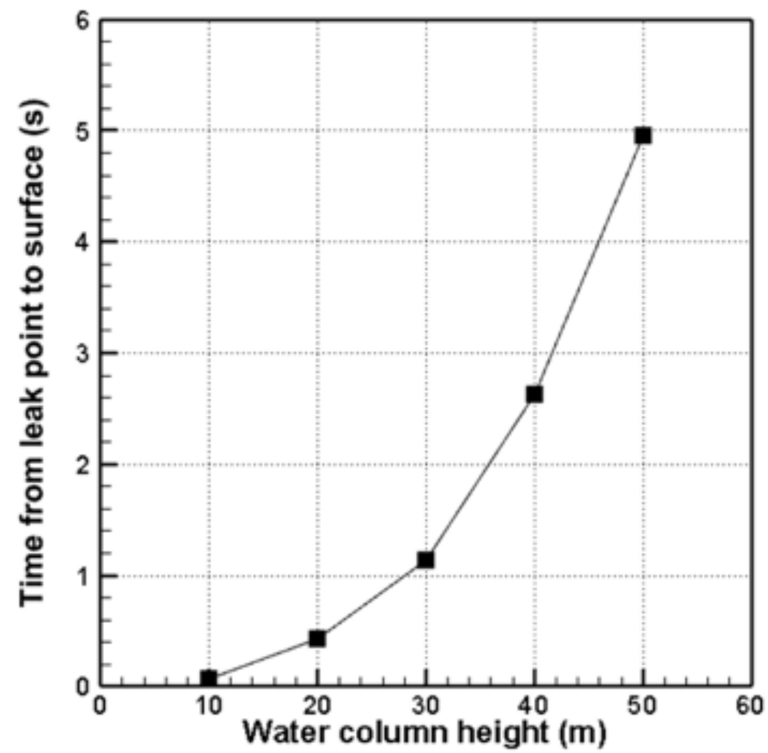
T2Well Results for Offshore CO_2 Blowout in 50 m and 10 m Depth



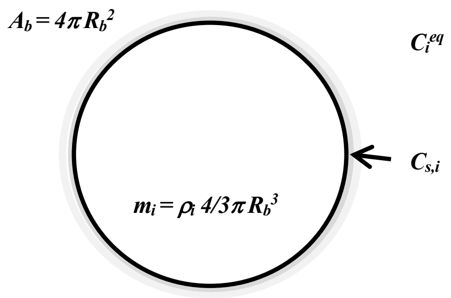


CO_2 blowout plume is almost entirely attenuated by seawater column if 50 m deep



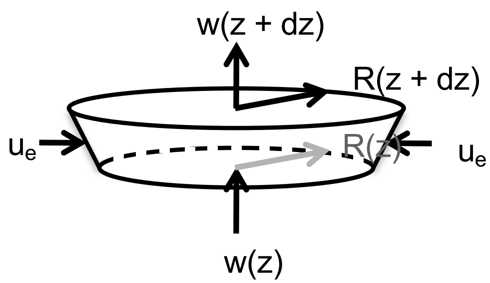


Simplified bubble mass transfer and seawater entrainment analysis confirms results



$$\frac{dm_i}{dt} = -A_b \beta_i \left(C_{s,i} - C_i^{eq}\right) \longrightarrow \Delta t = \frac{\Delta m_i}{A_b \beta_i \left(C_{s,i} - C_i^{eq}\right)}$$

- Using independently estimated mass transfer coefficients and solubility of CO_2 in seawater, the time to dissolve the median-sized bubble is 1.14 s.
- Rise time for 50 m water column is 5 s. Therefore the median-sized bubble easily dissolves during rise through water column.



$u_e = \alpha$ w $(\alpha \approx 0.1)$

- 36 kg CO_2/s * m^3 seawater / 2 kg CO_2 = 18 m^3 seawater/s (need to entrain at this rate to dissolve all of the CO_2)
- Dividing this vol. flow rate by the surface area of the conical plume, we get a required entrainment velocity. It turns out the actual entrainment velocity is ~70 times larger, i.e., easily enough seawater is entrained to dissolve the leaking CO_2.

Conclusions

- Offshore sites are being considered for GCS in the Texas Gulf Coast
- There is a need to understand risks of CO_2 blowouts at offshore sites
- Offshore CO_2 blowouts will behave differently from onshore blowouts because of the strong effects of the water column
- We loosely coupled two models for simulations of this system:
  - T2Well (reservoir and well or pipeline)
  - TAMOC (water column)
- Results for large blowout (~1 Mtonne/yr) show
  - Median bubble size diameter is estimated to be 0.5 mm
  - 99% of the CO_2 is dissolved in the seawater for a blowout at 50 m depth
  - 94% of the CO_2 is emitted at the sea surface for a blowout at 10 m depth
- TAMOC results can be rationalized independently by estimates of
  - Mass transfer rate from median-size bubble
  - Seawater entrainment rate needed to dissolve leaked CO_2
- The results agree qualitatively with model results from another group using totally different methods

Acknowledgments

We thank Scott Socolofsky (Texas A&M) and Jonas Gros (GEOMAR Helmholtz Centre for Ocean Research Kiel) for help with using TAMOC, and Margaret Murakami, Tip Meckel, Ramon Trevino, and Susan Hovorka (Texas BEG) for assisting with characterization of the near-offshore region in the Gulf of Mexico.

This work was supported by the GoMCarb Project funded by the Assistant Secretary for Fossil Energy (DOE), Office of Clean Coal and Carbon Management, through the National Energy Technology Laboratory (NETL), and by Lawrence Berkeley National Laboratory under Department of Energy Contract No. DE-AC02-05CH11231 .

Oldenburg, C.M., and L. Pan, Major CO_2 blowouts from offshore wells are strongly attenuated in water deeper than 50 m, *Greenhouse Gases: Science and Technology*, *10*, 15-31, 2020. DOI: 10.1002/ghg.1943

Task # 3

CO_2 dissolution trapping in saline aquifers

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Gulf Coast Carbon Center
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Outline

- Problem statement
- Background
- Approach
- Results and current status
- Prospective directions

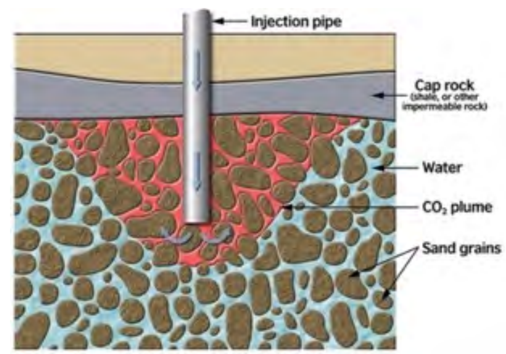
Problem Statement

- Dissolution trapping of supercritical CO_2 ($scCO_2$) in reservoir brine
- Dynamic dissolution of injected $scCO_2$ occurring within CO_2 plume during injection period
- Pore-scale simulation of multicomponent mass transfer (CO_2 and brine) in heterogeneous reservoirs
- Our study **benefit**: help us in risk assessment and capacity estimation

Background

- Accurate prediction of the long-term storage of CO_2 through understanding of trapping mechanisms

- Dissolution trapping is critical to the permanent containment of injected $scCO_2$ in saline aquifers.



- Dissolution of CO_2 into brine occurs during 3 stages:
    - Dissolution of $scCO_2$ plume by local phase partitioning during injection period
    - Beneath $scCO_2$ plume under the caprock by convection
    - Along immobile, tailing edges of the $scCO_2$ plume during post-injection period

- More accurate prediction of CO_2 plume extent

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Approach

Two-phase multicomponent pore-scale simulation:

- Direct numerical simulation of the Naiver-Stokes and advection-diffusion equations
- Volume-of-fluid (VOF) method

Approach

- Momentum equilibrium

  ➢ Solving Naiver-Stokes equation for multiphase flow using volume-of-fluid (VOF) method

$$\rho\left(\frac{\partial u}{\partial t} + u.\nabla u\right) = -\nabla P + \nabla.\left(\mu(\nabla u + \nabla u^T)\right) + \rho g + f_{st}$$

u: velocity P: pressure
μ: viscosity ρ: density
f_{st}: interfacial forces

- Concentration equation (Advection-diffusion):

$$\frac{\partial C_b}{\partial t} + \nabla.(C_b.u_b) = \nabla.(D_b \nabla C_b)$$

C_b: concentration of species
D_b: diffusion coefficient

- Continuity of mass fluxes and chemical potentials at the fluid-fluid interface

  ➢ Using a partitioning relation such as Henry or Raoult laws

- **Simulation tool**: Implementation of mathematical model in the open source Computational Fluid Dynamics toolbox OpenFOAM.

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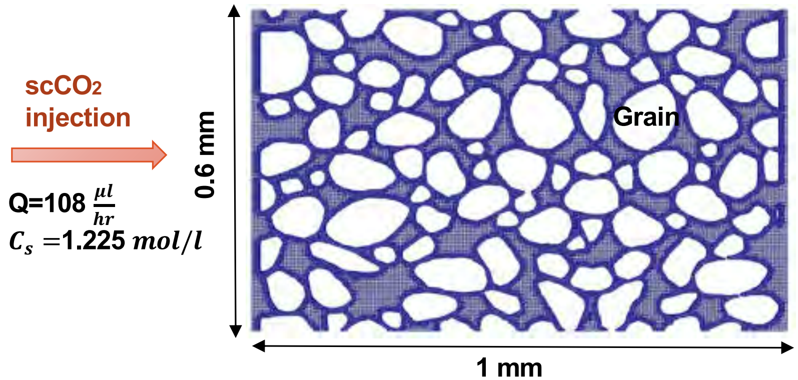
Status and Results

- Non-equilibrium scCO2 dissolution during drainage (injection period)
- Upscaling of sCO2 dissolution in brine

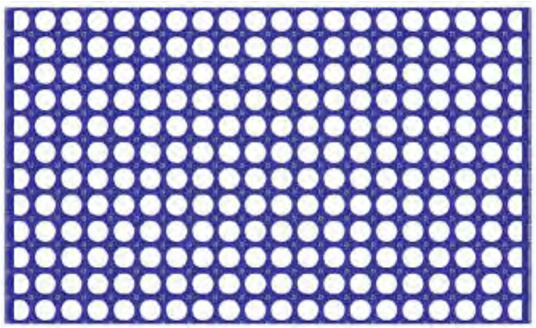
Results

- **Non-equilibrium $scCO_2$ dissolution during injection period**

Heterogeneous medium



Homogeneous medium



Initially saturated with brine

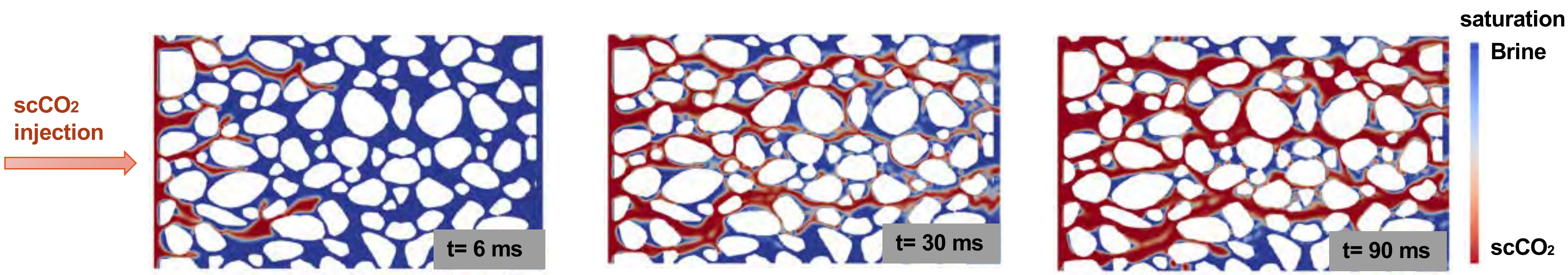
Property	$scCO_2$	Brine
Density $(\mathrm{kg/m^3})$	280	992
Viscosity $(\mathrm{m^2/s})$	2.3e-05	5.5e-04
Diffusivity $(\mathrm{m^2/s})$	0.0	1.6e-9
Interfacial tension$(\mathrm{mN/m})$	35	
Wettability	45°	
Henry's constant	1	
Porosity	45	

Goals:

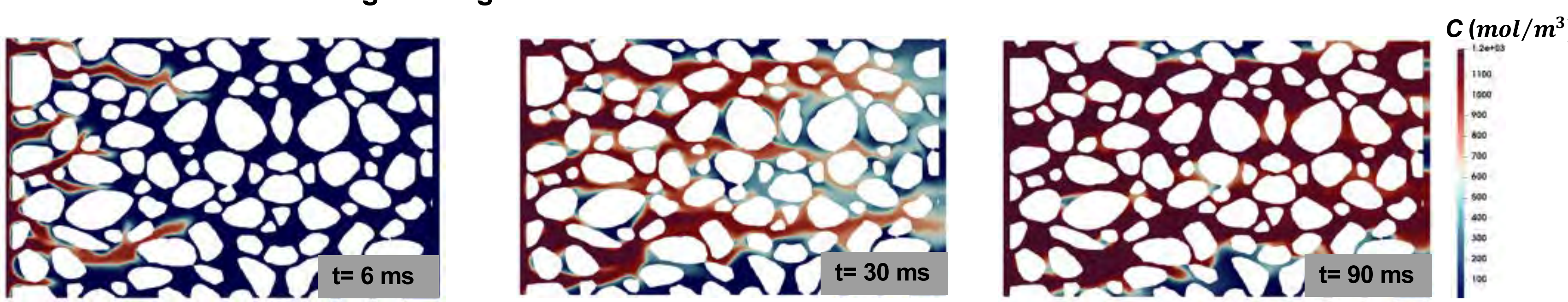
- Transient $scCO_2$ dissolution and mass transfer process at the pore-scale
- Effect of fine-scale rock heterogeneity on the dissolution process

Results

❖ **Phase distribution during drainage of scCO2 into the heterogeneous pore space initially saturated with brine**



❖ **Concentration distribution during drainage of $scCO_2$**



❖ CO_2 changes from supercritical state to the dissolved CO_2 ($dsCO_2$) at the $scCO_2$-brine interface.

❖ $dsCO_2$ mass transfer happens as it transports away from the interfaces to water-filled pores.

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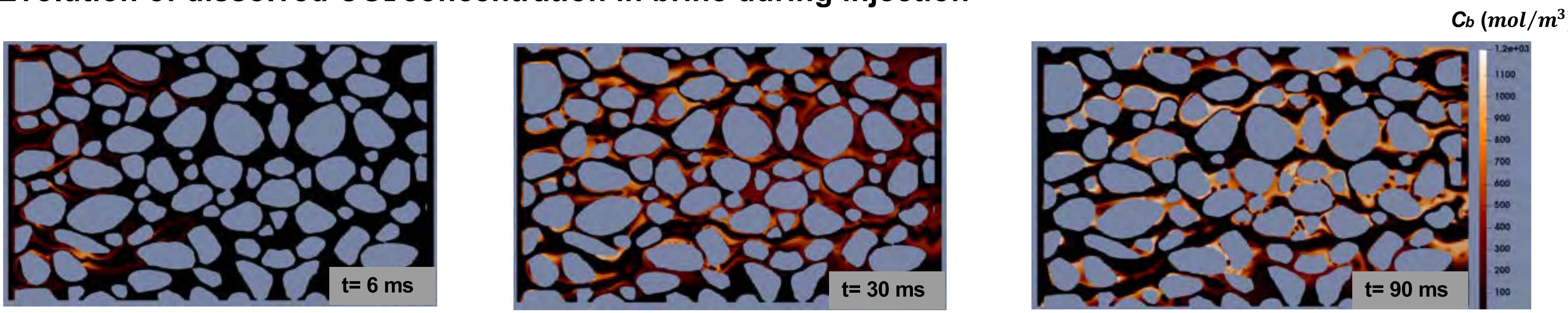
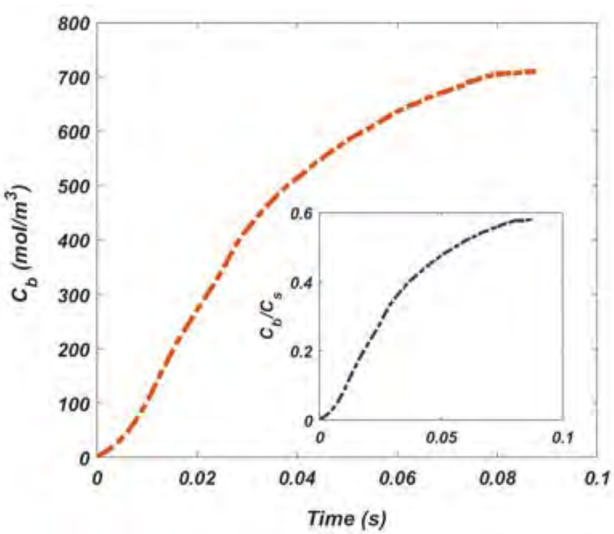
Results

❖ **Evolution of dissolved CO_2 concentration in brine during injection**





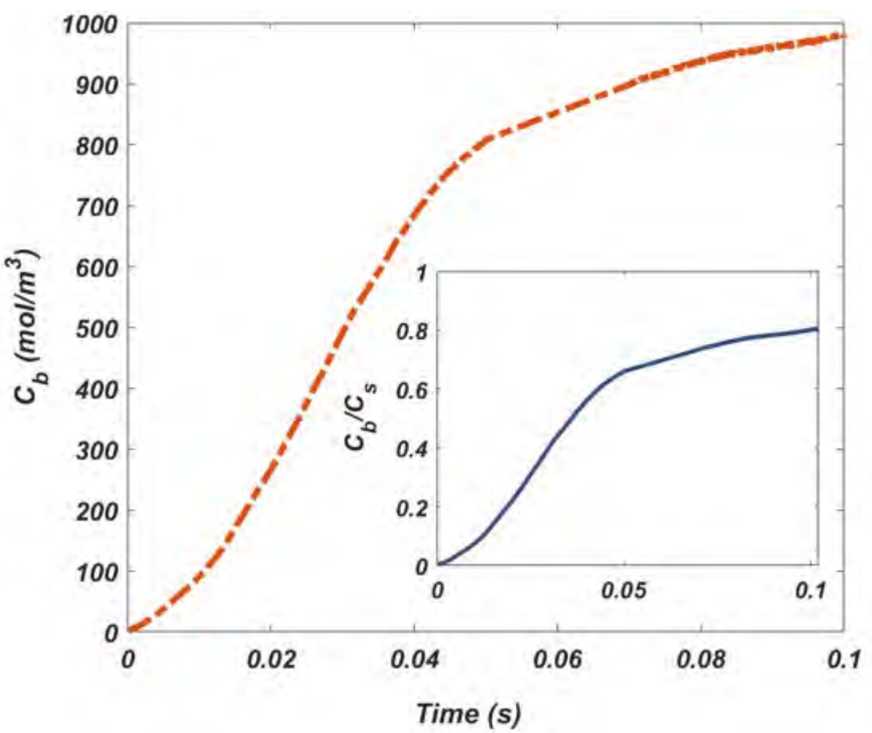
❖ Faster $scCO_2$ dissolution and phase equilibrium occurs around the percolating fingers as the advection is more effective.

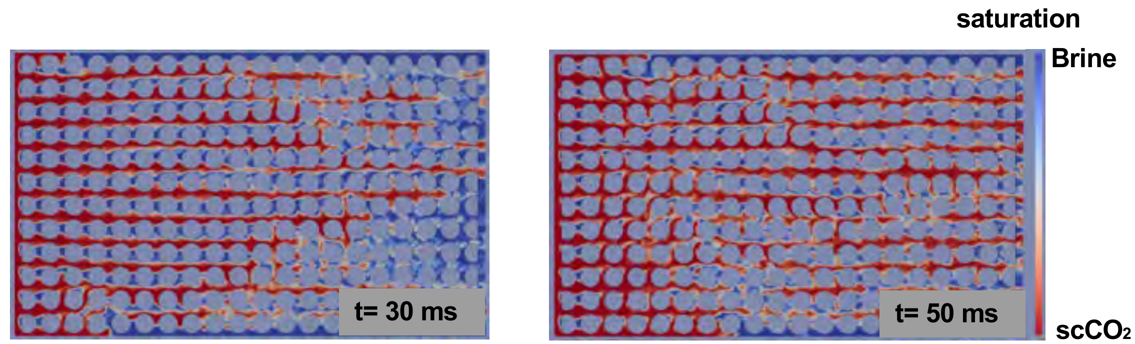
❖ The process for dissolved CO_2 concentration to reach the solubility value at the pore scale is not instantaneous.

❖ The observed non-equilibrium dissolution can be attributed to the limited interactions between $scCO_2$ and brine at the scale of individual pores and pore clusters.

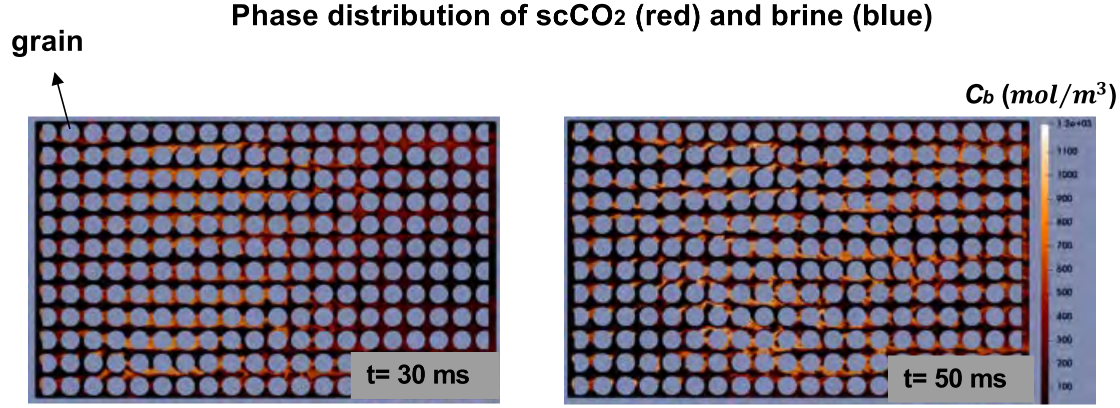
Results

❖Homogeneous medium:





Phase distribution of $scCO_2$ (red) and brine (blue)



Dissolved CO_2 concentration in brine

❖ **Homogeneous sample displays a better mixing and higher dissolution of CO_2 in brine.**

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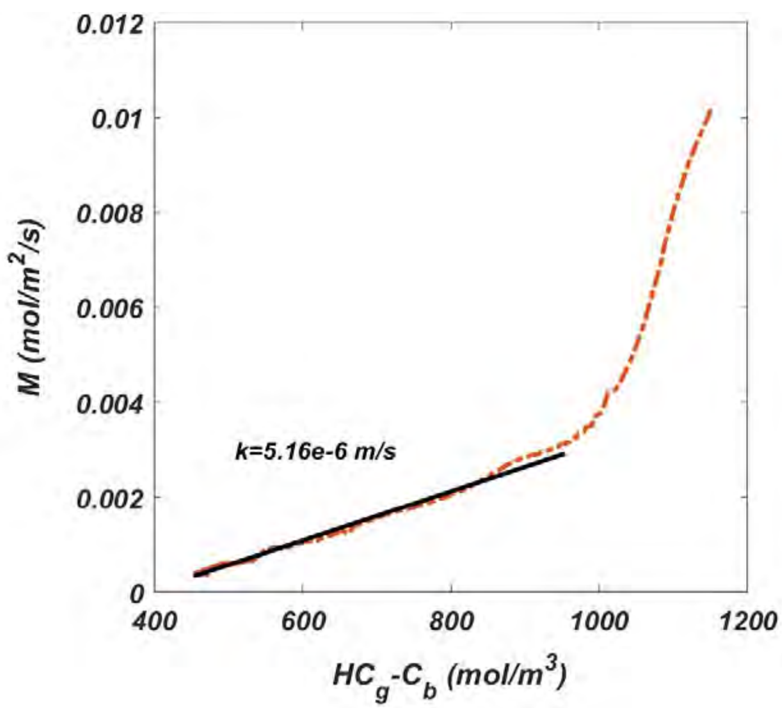
Results

❖Upscaling of CO_2 dissolution in brine



Mass transfer per interfacial area versus the concentration gradient in the heterogeneous sample

- ❖ Slope of the curve is representative of the mass transfer coefficient.
- ❖ The small mass exchange coefficient demonstrates the effect of incomplete mixing and non-equilibrium dissolution.

$M = k\left(HC_g - C_b\right)$

M: mass transfer per interfacial area

k: mass transfer coefficient

H: Henry's constant

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Key takeaways

- ❖ Our study helps to capture the complexity of $scCO_2$ dissolution process in brine reservoirs.
- ❖ $scCO_2$ dissolution process is dynamic rather than an equilibrium state.
- ❖ $scCO_2$ dissolution and mass transfer depend on the heterogeneity of rock.
- ❖ Subsurface heterogeneity leads to the incomplete mixing and non-equilibrium dissolution of CO_2 in resident brine.

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Prospective directions

- Investigate the effect of injection rate, wettability and salinity on CO_2 dissolution dynamics

Thank you!

Questions?

The Effect of Compressibility and Boundaries on Displacement Stability

Aura N. Araque and Larry W. Lake
Hildebrand Department of Petroleum and Geosystems Engineering

The Mobility Ratio

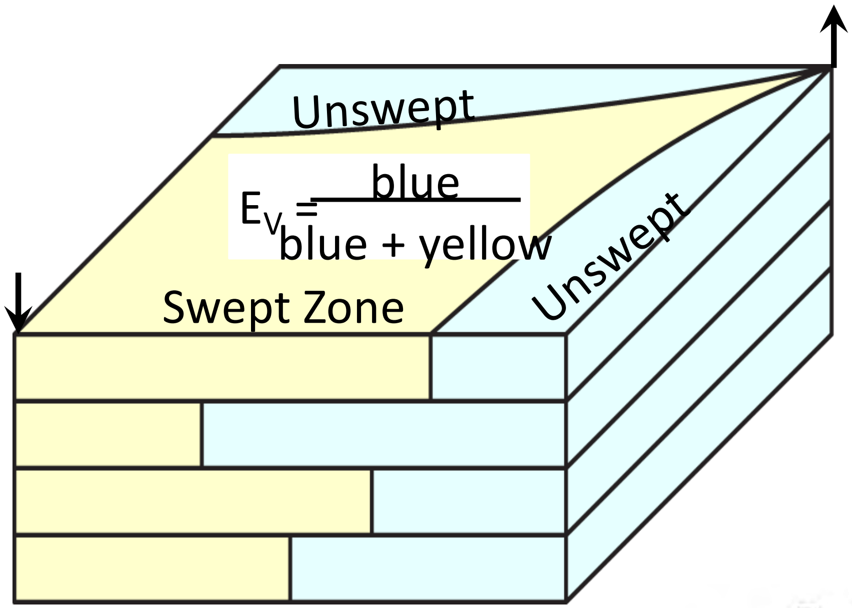
$$\text{Definition} \quad M = \frac{\text{Mobility displacing fluid}}{\text{Mobility displaced fluid}}$$

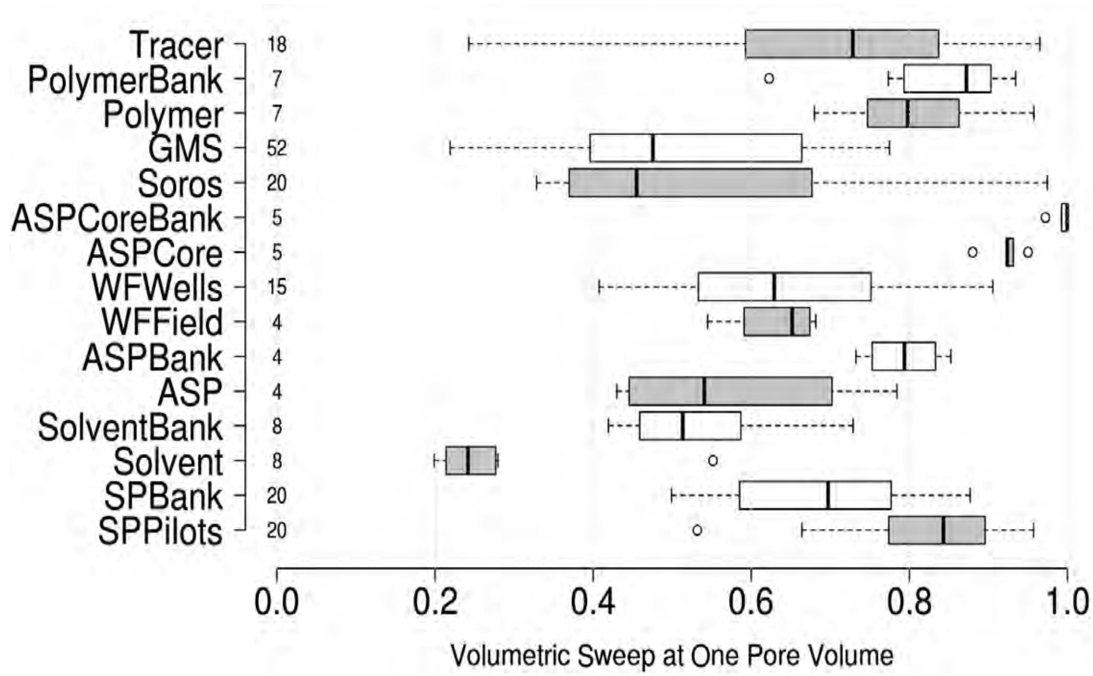
$$M = \frac{\left(\text{Relative perm./viscosity}\right)_{\text{displacing}}}{\left(\text{Relative perm./viscosity}\right)_{\text{displaced}}}$$

$$M = \begin{cases} 0.5 - 10 & \text{Light oil waterflood} \\ 10 - 20 & CO_2 \text{ flood} \\ 20 - 50 & \text{Methane flood} \end{cases}$$

No compressibility in this definition

Volumetric Sweep Efficiency Field Scale…

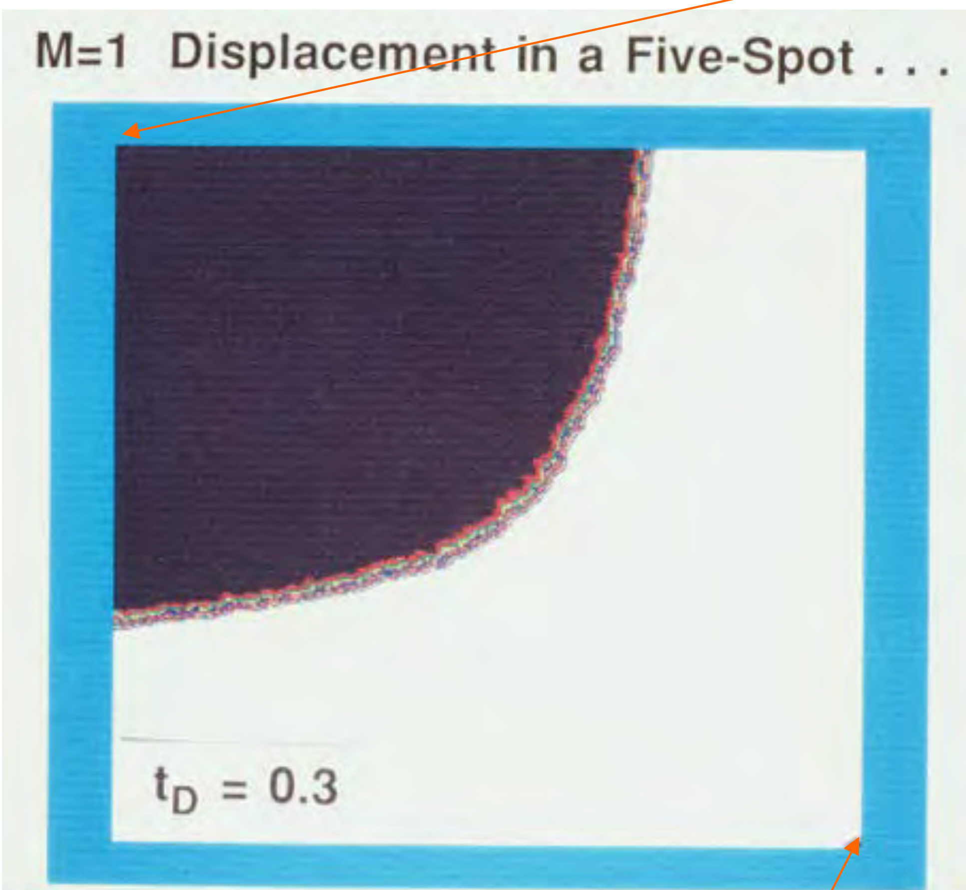


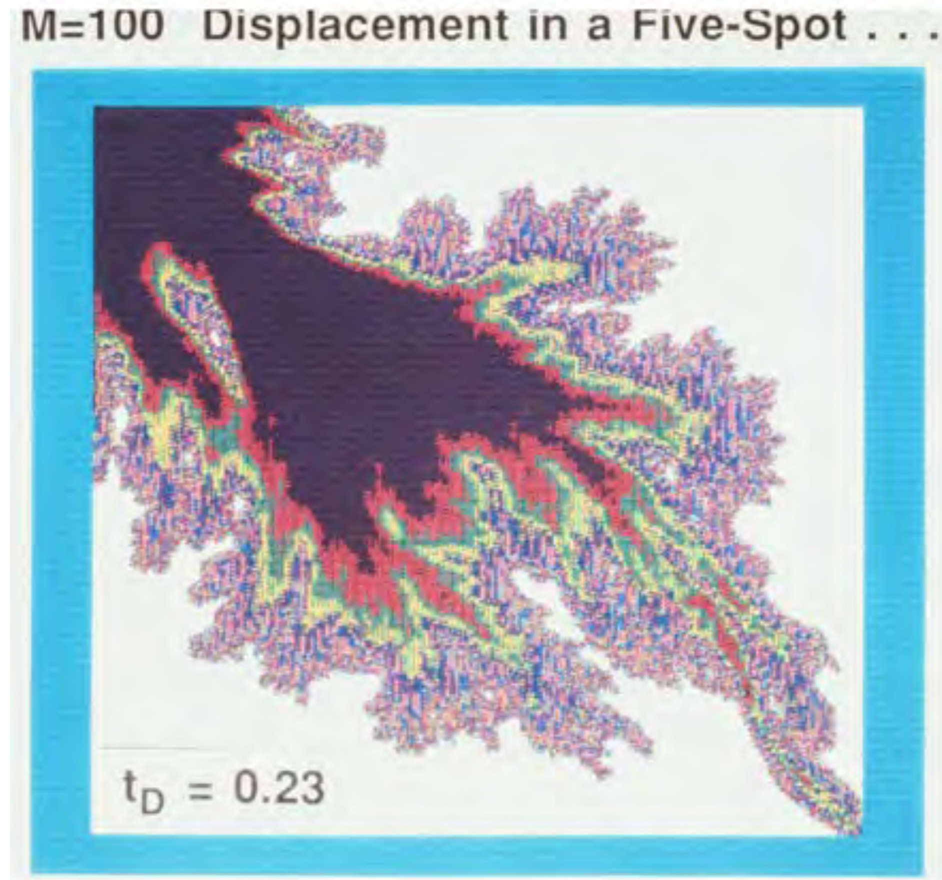


Simulated

Incompressible fluids (Simulation results from previous work)

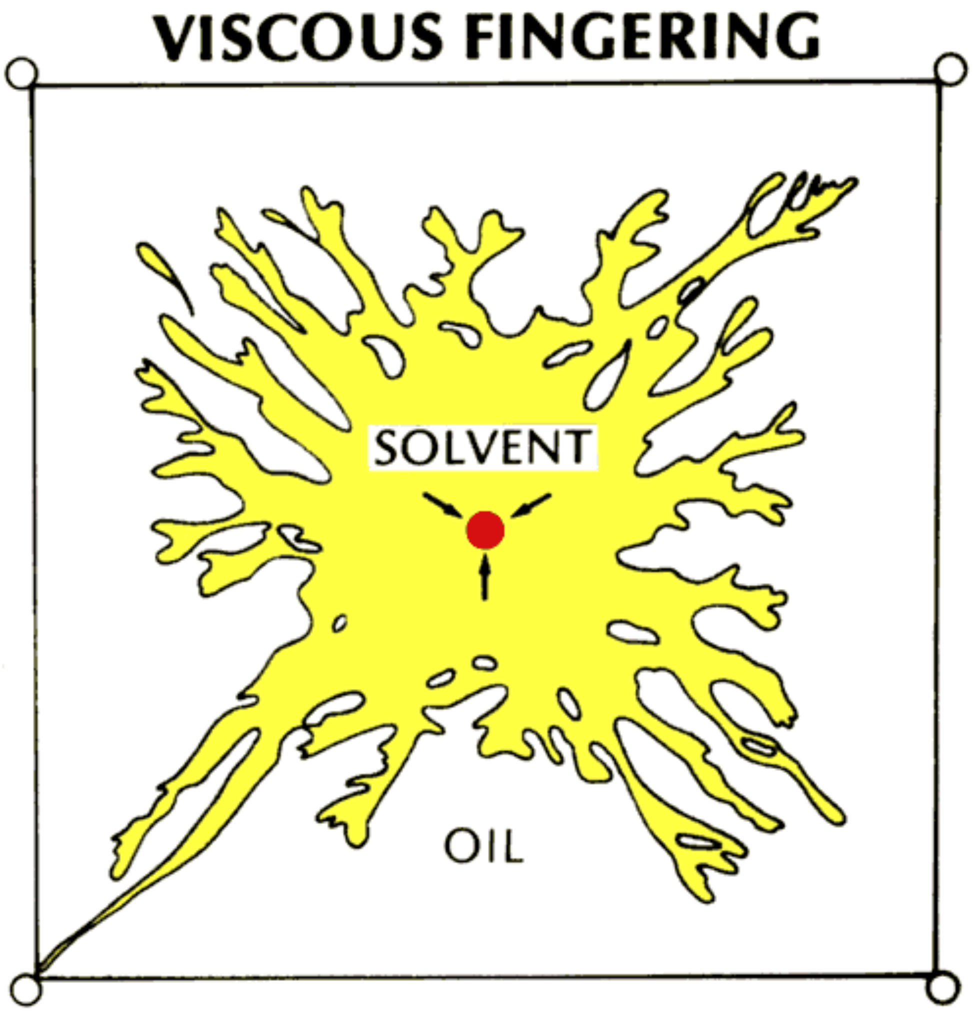
Injector

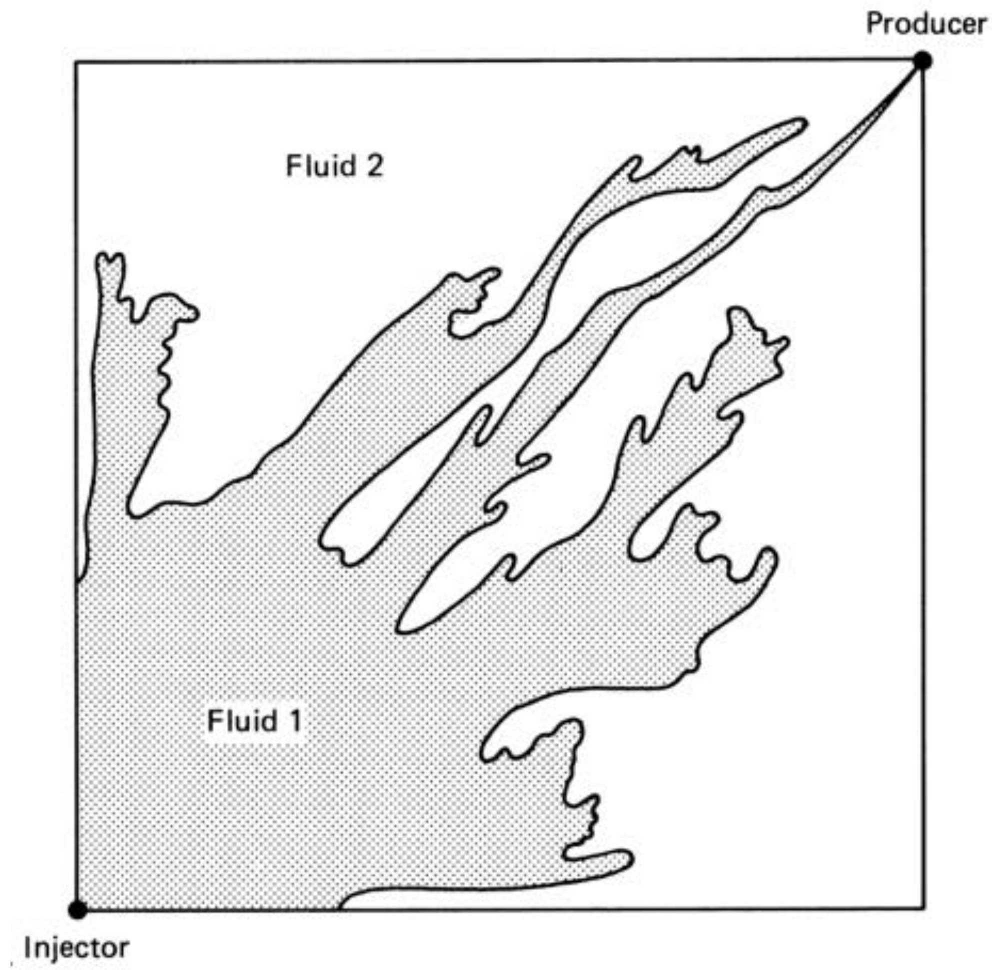




Producer

Experimental
Left Hele Shaw; Right M=17





The penetration of a fluid into a porous medium or Hele-Shaw cell containing a more viscous liquid

By P. G. Saffman and Sir Geoffrey Taylor, F.R.S.
Cavendish Laboratory, University of Cambridge

(*Received* 17 *January* 1958—*Read* 17 *April* 1958)

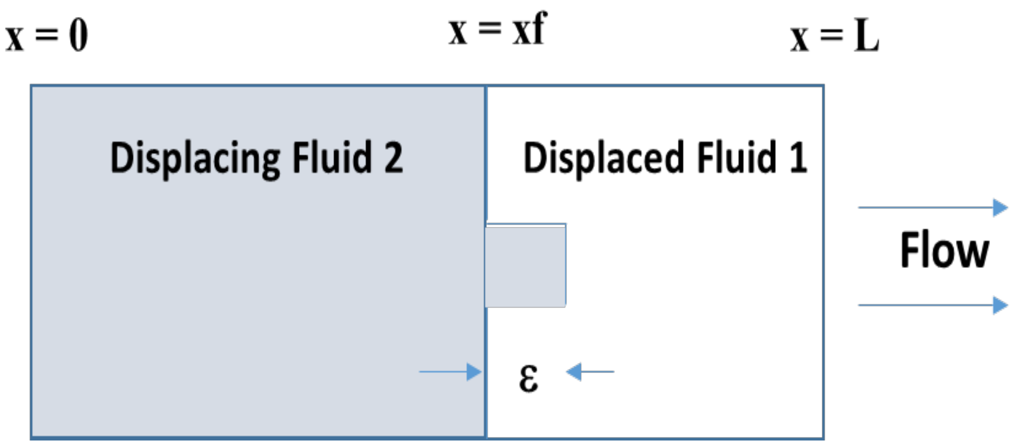
Channelling in packed columns

S. Hill, M.A., F. Inst. P., F.S.S.
Tate & Lyle Research Laboratory, Keston, Kent

(Received August 1952)

Chemical Engineering Science

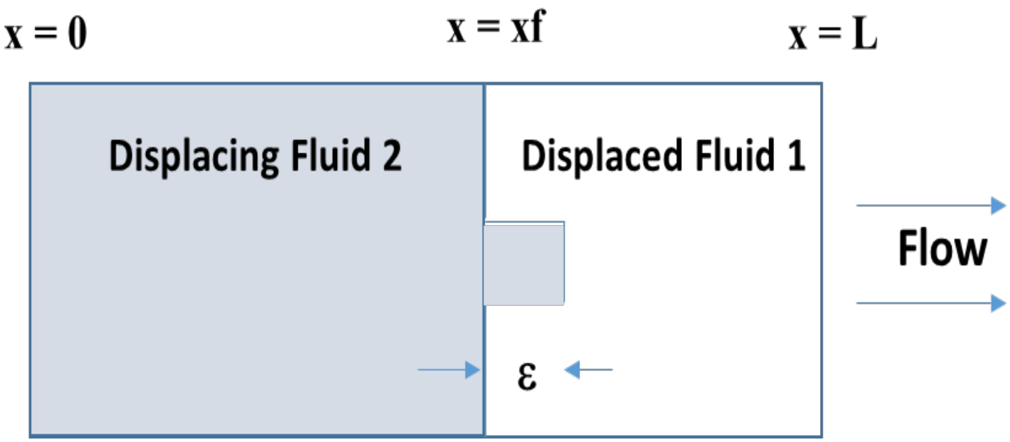
ST Instability



$$\dot{\varepsilon} \sim \begin{cases} < 0 & \text{dies out} \\ = 0 & \text{neutral} \\ > 0 & \text{grows} \end{cases}$$

$$M \sim \begin{cases} < 1 & \text{stable} \\ = 0 & \text{neutral} \\ > 1 & \text{unstable} \end{cases} \qquad u_{upstream} \sim \begin{cases} < u_{down} & \text{unstable} \\ = u_{down} & \text{neutral} \\ > u_{down} & \text{stable} \end{cases}$$

ST Instability

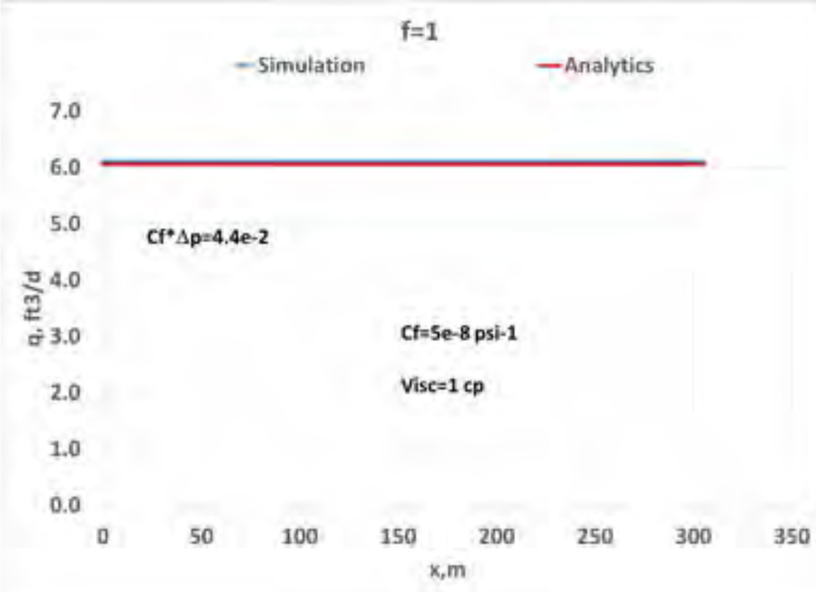


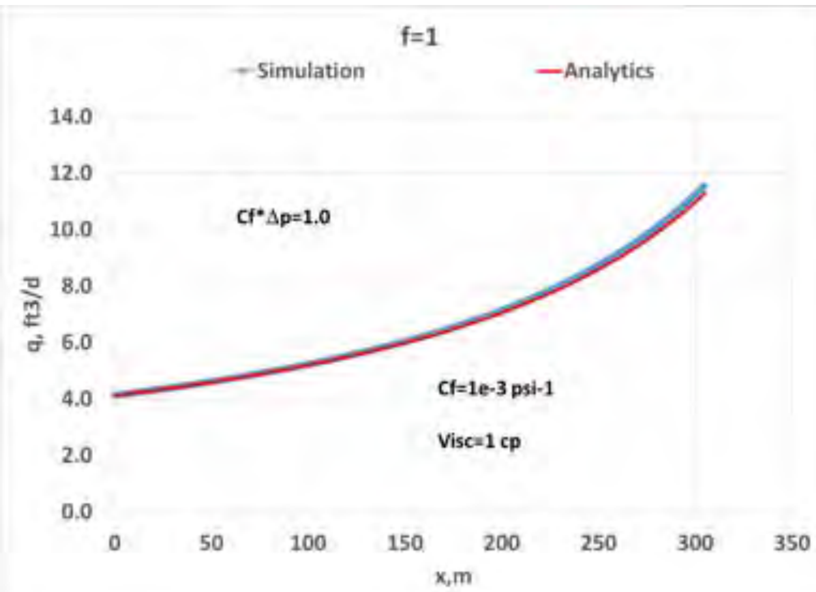
$$u_{upstream} \sim \begin{cases} < u_{down} & \text{unstable} \\ = u_{down} & \text{neutral} \\ > u_{down} & \text{stable} \end{cases}$$

$$f = \frac{(\rho u)_{outlet}}{(\rho u)_{inlet}} = \begin{cases} 0 & \text{sealed (SS)} \\ 0 < f < 1 & \text{partially sealed} \\ 1 & \text{transparent (SSS)} \end{cases}$$

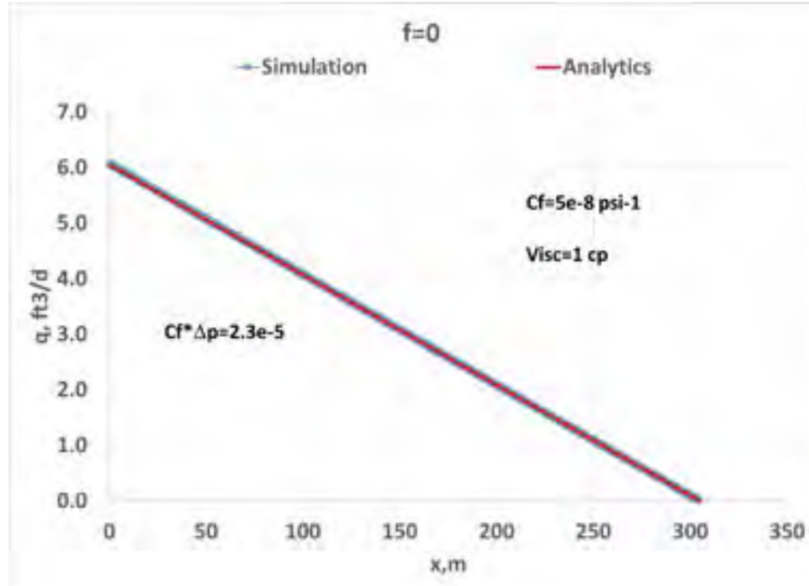
Velocity Profiles

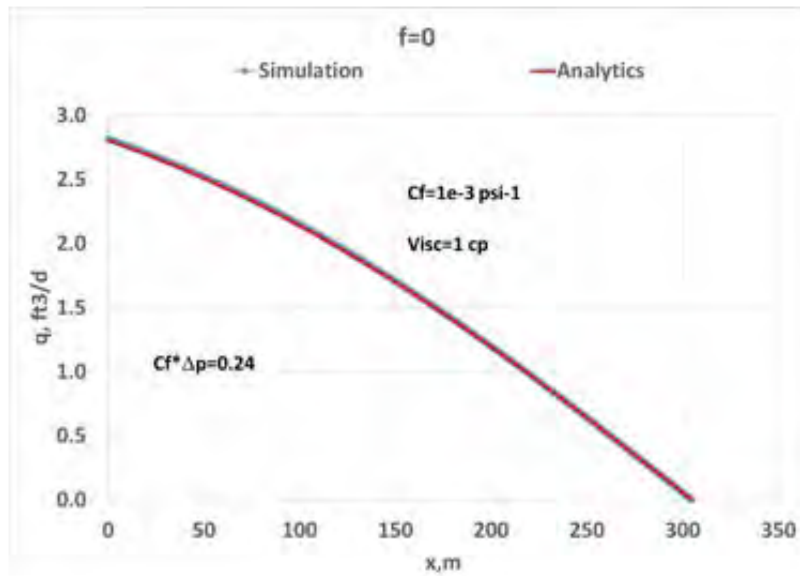
Transparent Boundary



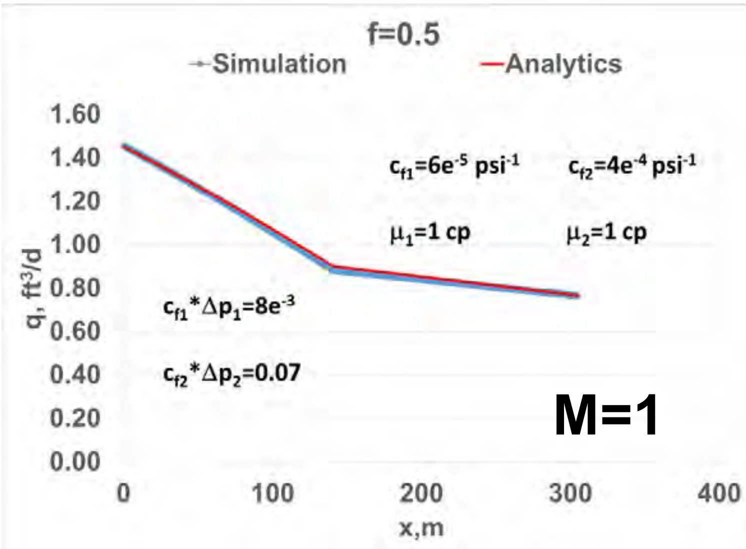


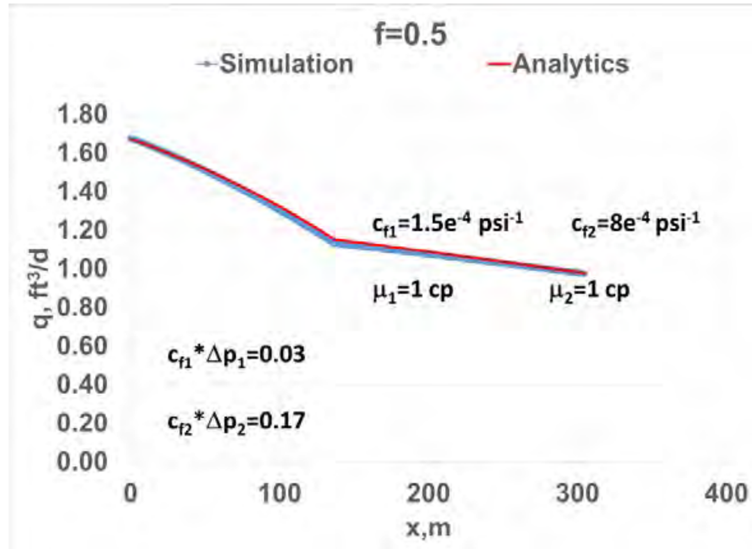
Sealed Boundary

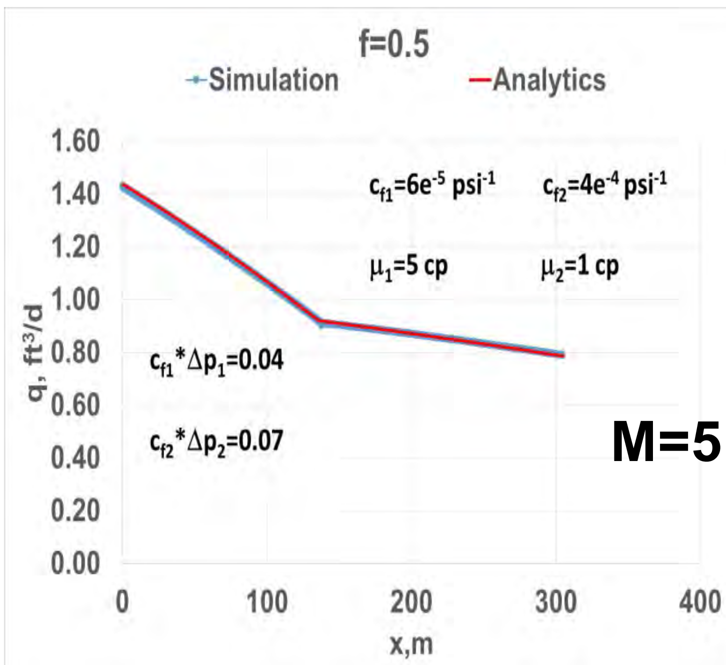


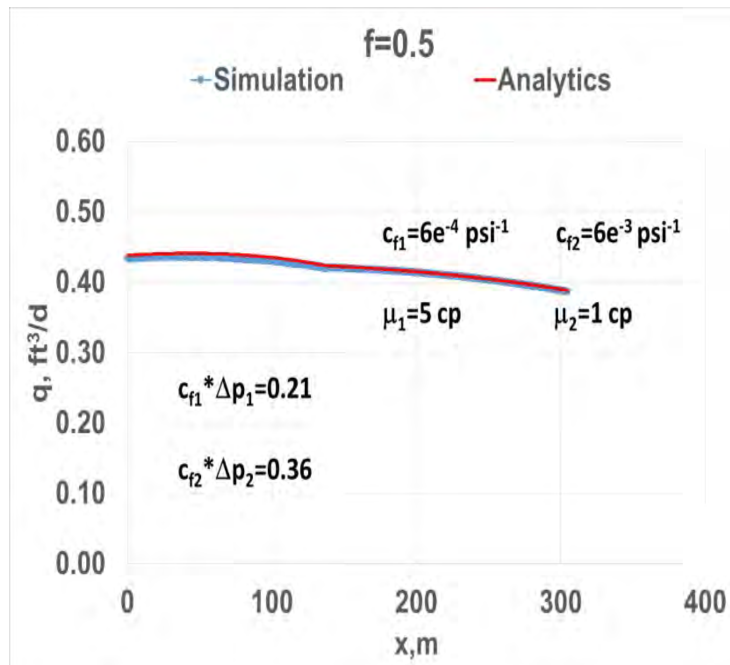


Velocity Profiles, partially sealed









Conclusions

- Derived an analytic solution for ST instability in compressible flow; agrees with simulation
- Behavior of fluid velocity is equivalent to perturbation analysis
- Increasing velocity toward external boundary leads to ST instability
- Open boundary compressibility always destabilizes
- Partially sealed external boundary stabilizes flow
- Sweep efficiency in CO_2 storage (no producers) should be greater than for CO_2 -EOR
- Commercial simulators do not work well in the high compressibility limit

The Effect of Compressibility and Boundaries on Displacement Stability

Aura N. Araque and Larry W. Lake
Hildebrand Department of Petroleum and Geosystems Engineering

Fault-conforming model for geomechanical simulation

Example of the HI24L block, Gulf of Mexico

Antoine Mazuyer, Josh White, Hervé Gross, François Hamon

Task 3: Risk Assessment, Simulation, & Modeling SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

Overall objective

Develop a geomechanical hazard assessment for potential storage targets in the Gulf-of-Mexico

Specific objectives

1. Estimate potential deformation of poorly-consolidated Miocene-age rocks

2. Refine understanding of how fault bounded structures could respond to injection

3. Make recommendations regarding further characterization efforts and geophysical monitoring designs

A key tool in this effort is a data-constrained geomechanical modeling.

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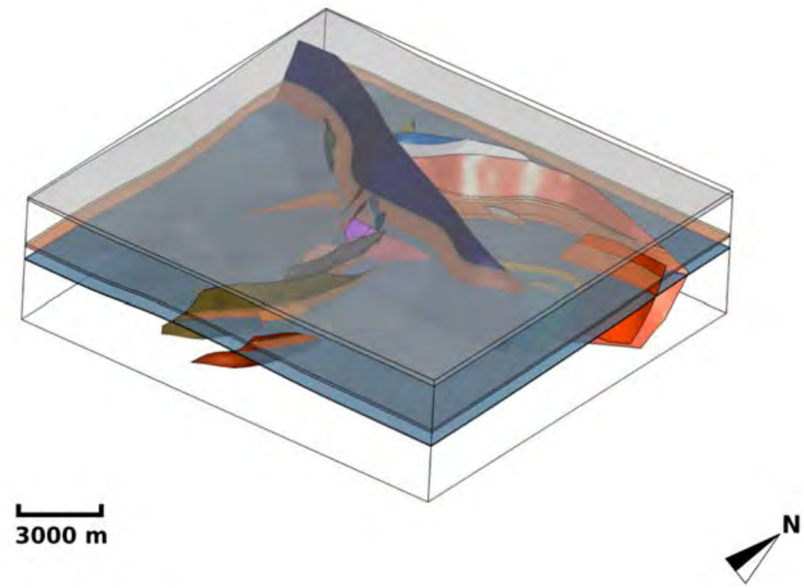
Problem statement

- Area of interest : **reservoir + overburden + underburden + sideburden**
- Flow simulation (track CO_2 **saturation** and **pressure evolution**)
- Mechanical simulation (**fault reactivation, deformation**)
- Accurate geological representation (**structures** + **property filling**)



How to create a reliable geological model and mesh for this kind of simulation?

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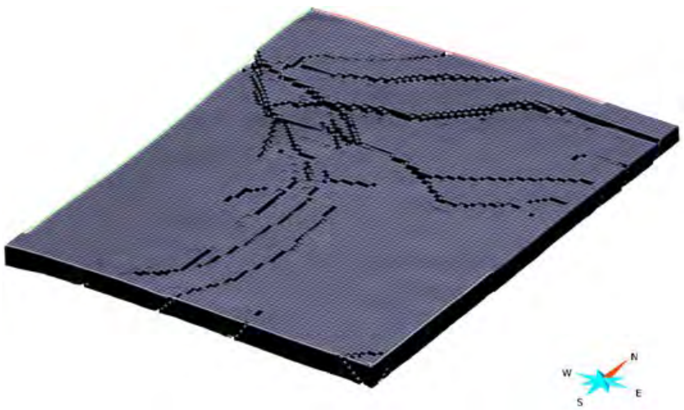
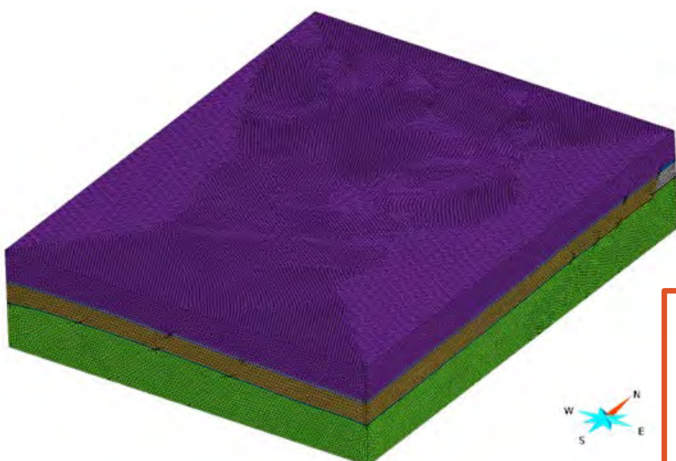
Limit of the “ classical” workflow





- Only the reservoir part is considered (no overburden, underburden)
- Faults with small throw can be ignored in the modeling process
- **Stair steps makes contact mechanics impossible and geology is approximated**

Proposition : generate a conformal tetrahedral mesh to solve both mechanical and flow equations

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The example of HI24L

•Analog model for CO2 sequestration, Gulf of Mexico

•Original dataset comes from UT Austin, BEG... Thanks for the data !

We highlight with this examples the challenges to generate a model suitable for multiphysics simulations

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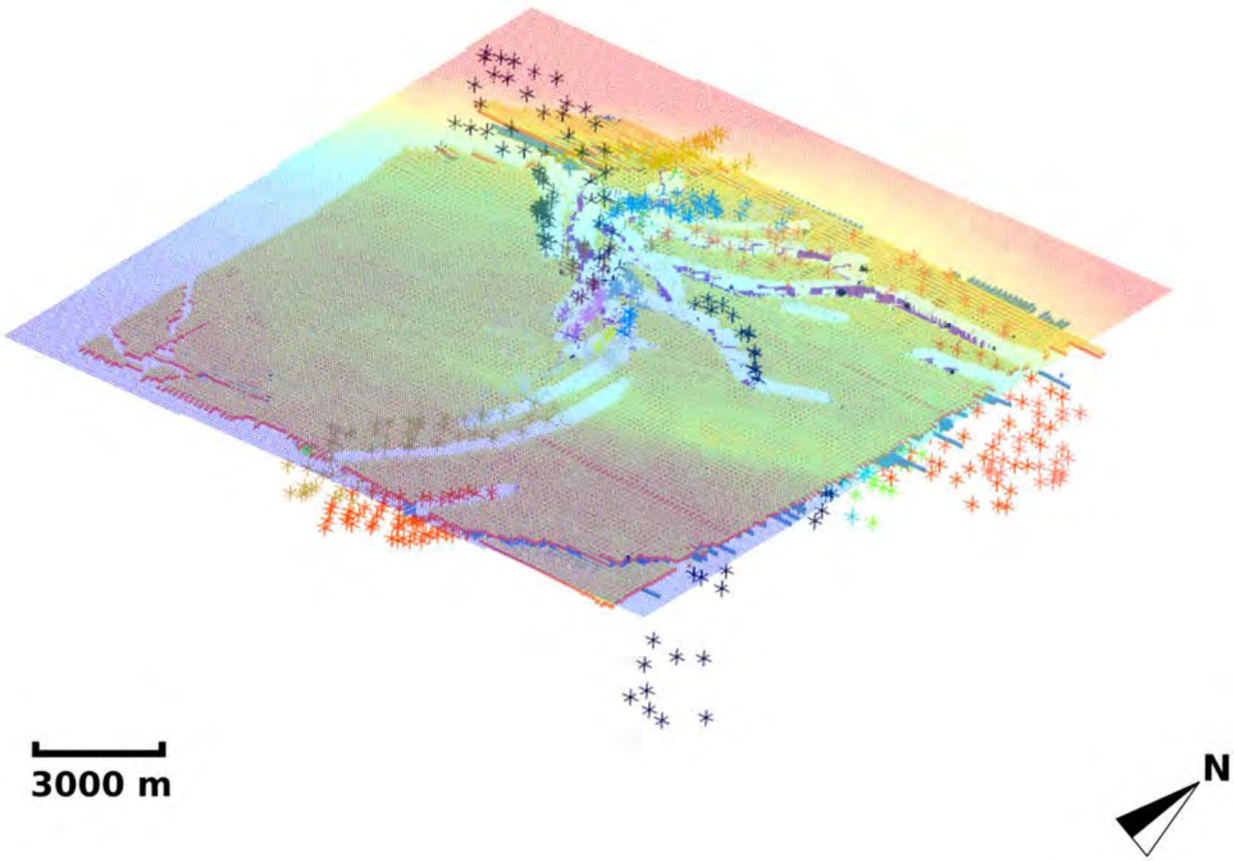
Input data

[DeAngelo et al., 2019, *Int. J. of Green. Has Ctrl.*]
[Olario et al., 2019, *AAPG convention*]



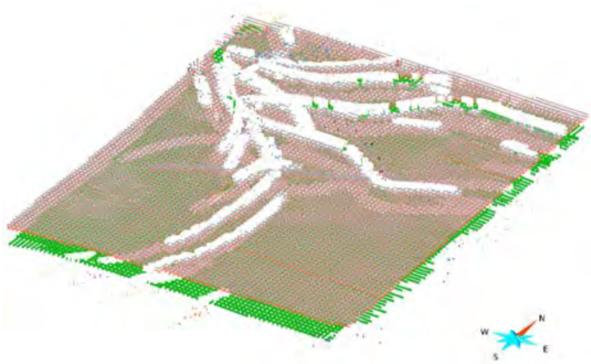
- •4 horizons
- •51 faults
- •35 wells

[UT Austin, BEG]

- •1 DEM

[National Oceanic and Atmospheric administration]

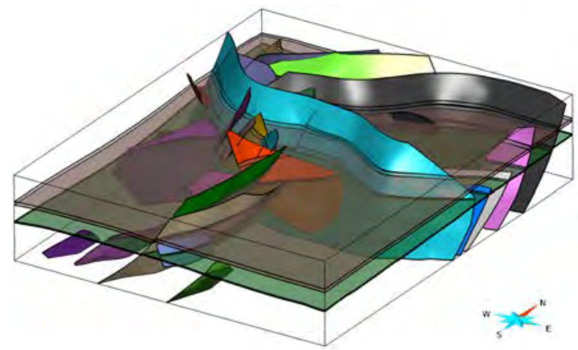
Implicit and explicit modeling



Data

- Pointset, seismic picking, etc..

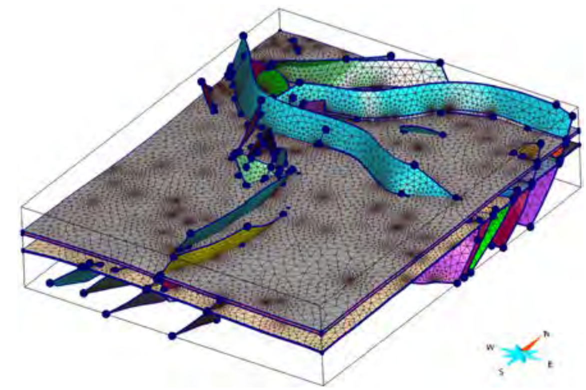
[UT Austin, BEG]



Implicit model

- **Horizons = isovalues of a scalar field**
- **Easy to edit faults/horizons connexion**

[Mallet, 2002, *Geomodeling*]
[Caumon et al., 2009, *Math. Geos.*]
[Collon et al., 2016, *Interpretation*]



Explicit model

- **Horizons = triangulated surfaces**
- **Support of the tetrahedral mesh**

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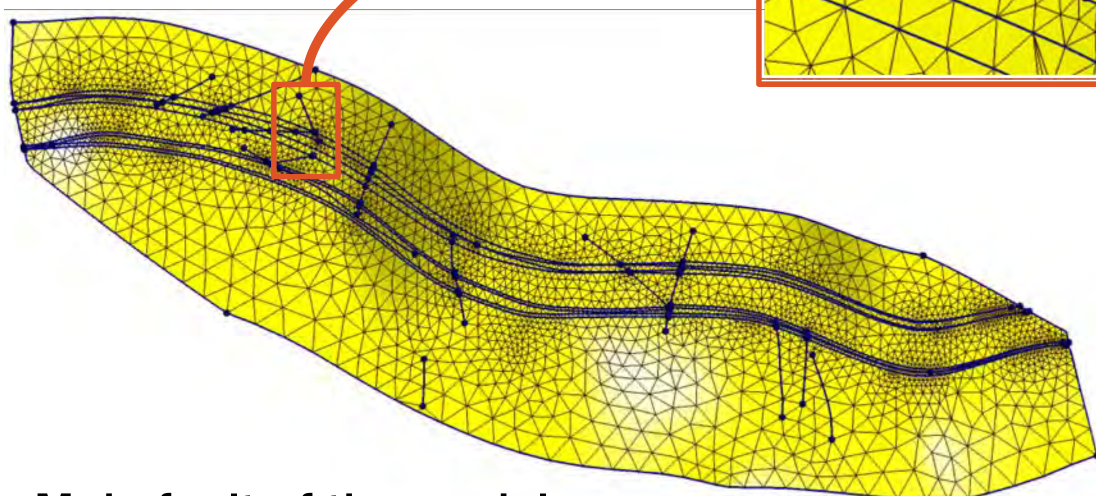
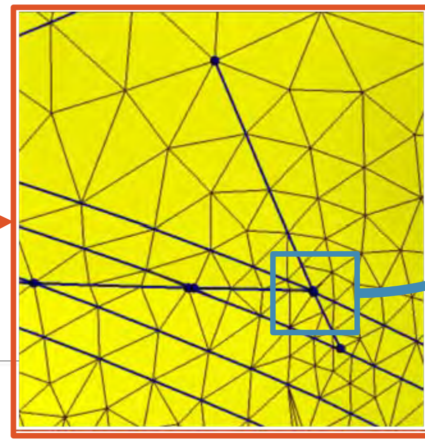
Explicit modeling : quality control

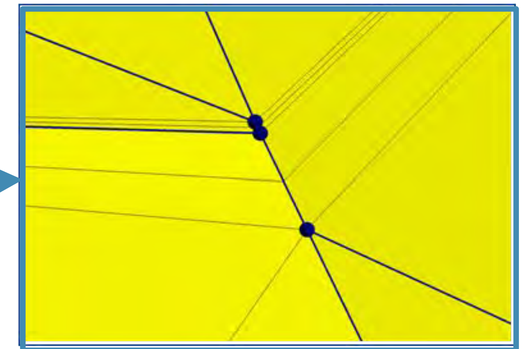
- Model simplifications must be done to properly mesh the model with tetrahedra



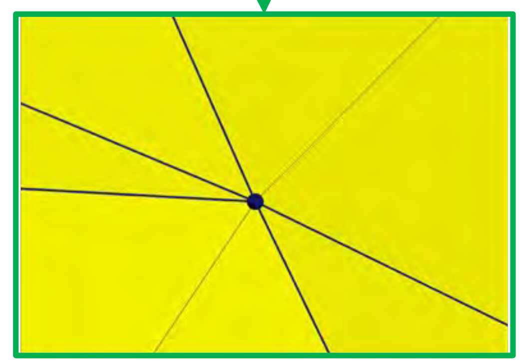
Main fault of the model



50 cm between the corners !



Topology simplification



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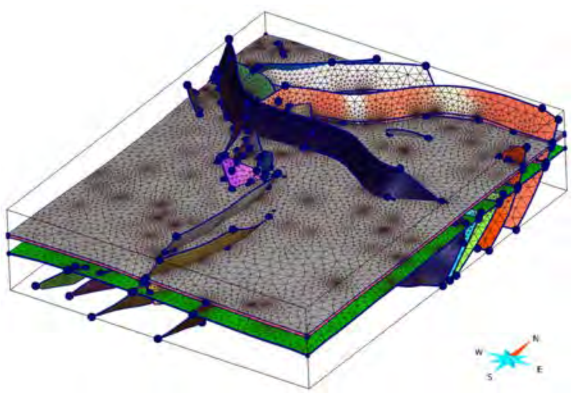
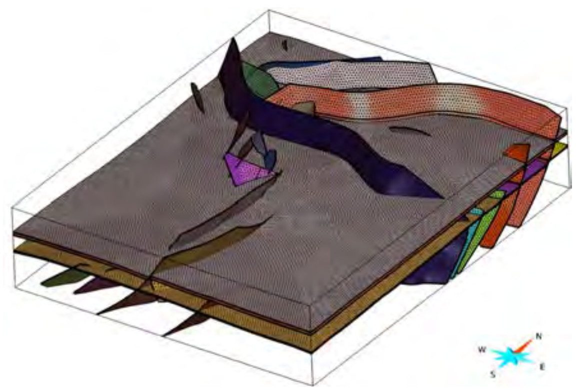
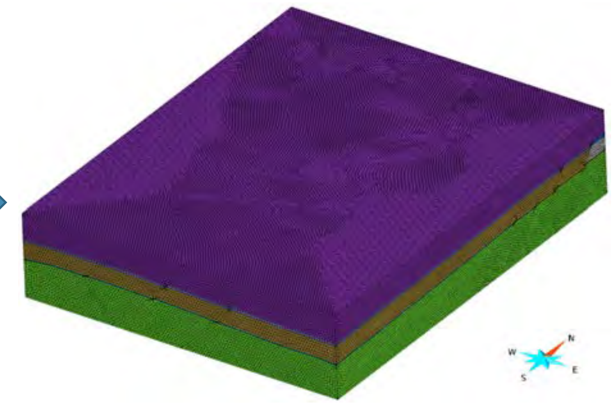
Volume meshing







Surface remeshing

- Mesh will be conformal to surfaces
  → need of good surface mesh
- Reparameterization method [Beaufort et al., 2020]
- Voronoi approach [Pellerin et al., 2016]

Volume meshing

- Easy if we start from a good quality surface mesh
- Tetrahedral mesh is conformal to fault and horizons surfaces

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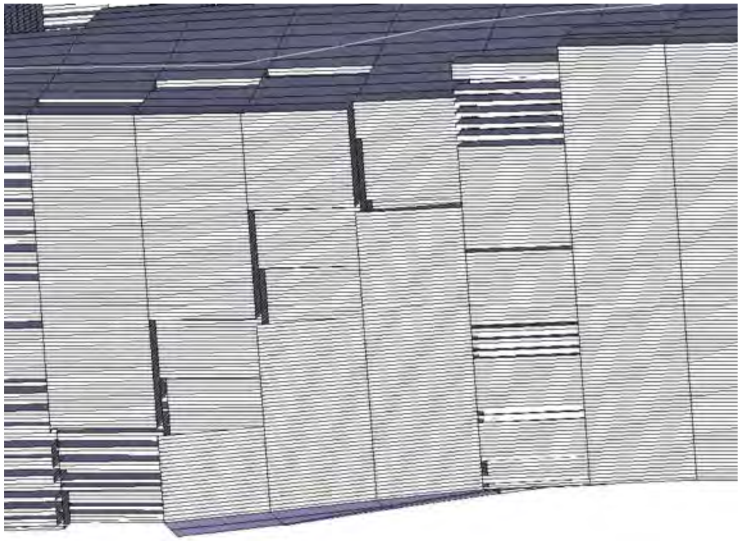
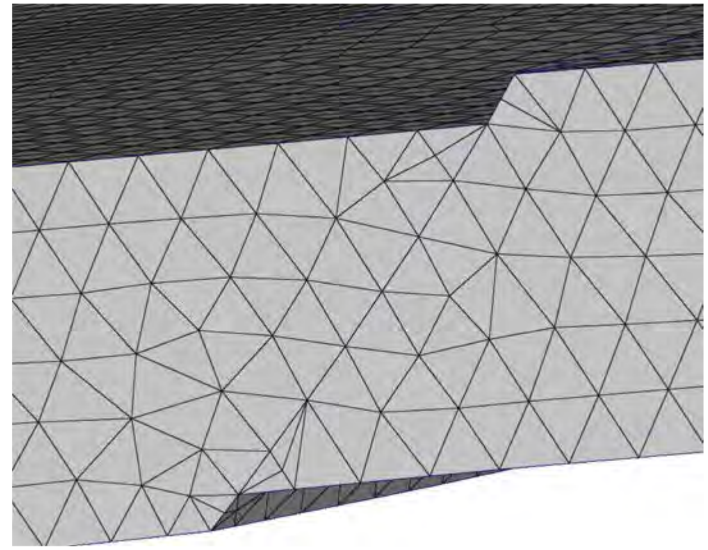
Volume remeshing



Corner Points Grids

- 6 m vertical resolutions
- Good enough to represent geological vertical heterogeneities

Both ~ 800K cells



Tetrahedral mesh

- 100 m vertical resolutions

Proposition : generate a tetrahedral mesh with an anisotropic mesh size

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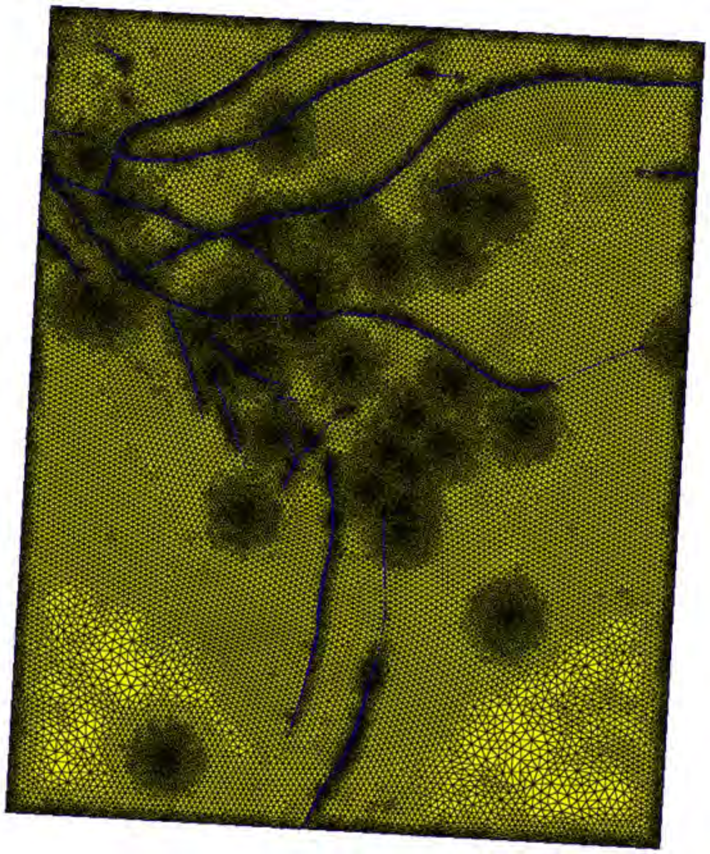
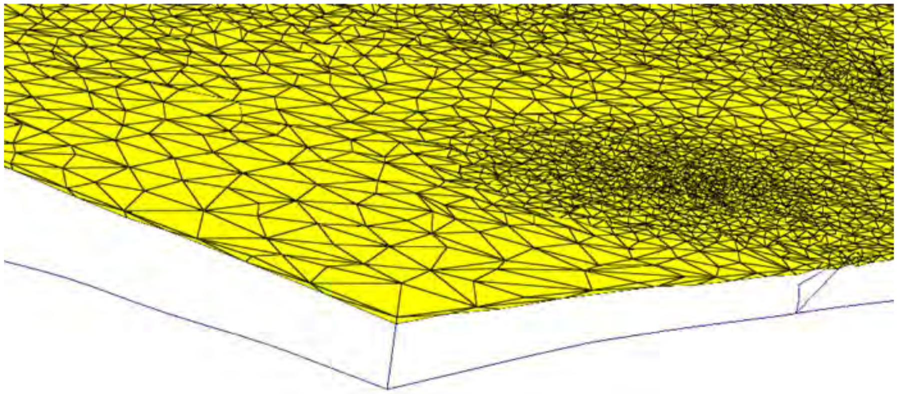
Volume (re)meshing



Top View

Remeshing done using the mmg software, prescribing an anisotropic metric tensor



Horizontal slice

~ 6M cells

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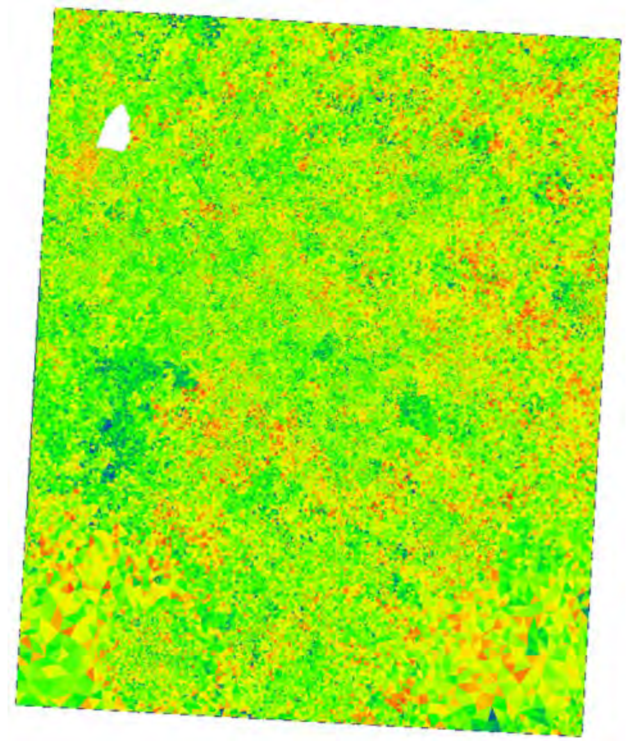
Geostatistical method adapted for unstructured grid

- No structured grid →Challenge for geostatistical algorithms
- Use of a novel method suitable for unstructured grid

[Biver et al., 2016, *Intl. Geostat. Congress*]
[Zaytsev et al., 2016, *Math. Geos.*]
[Biver et al., 2019, *Petroleum Geostats*]



Porosity

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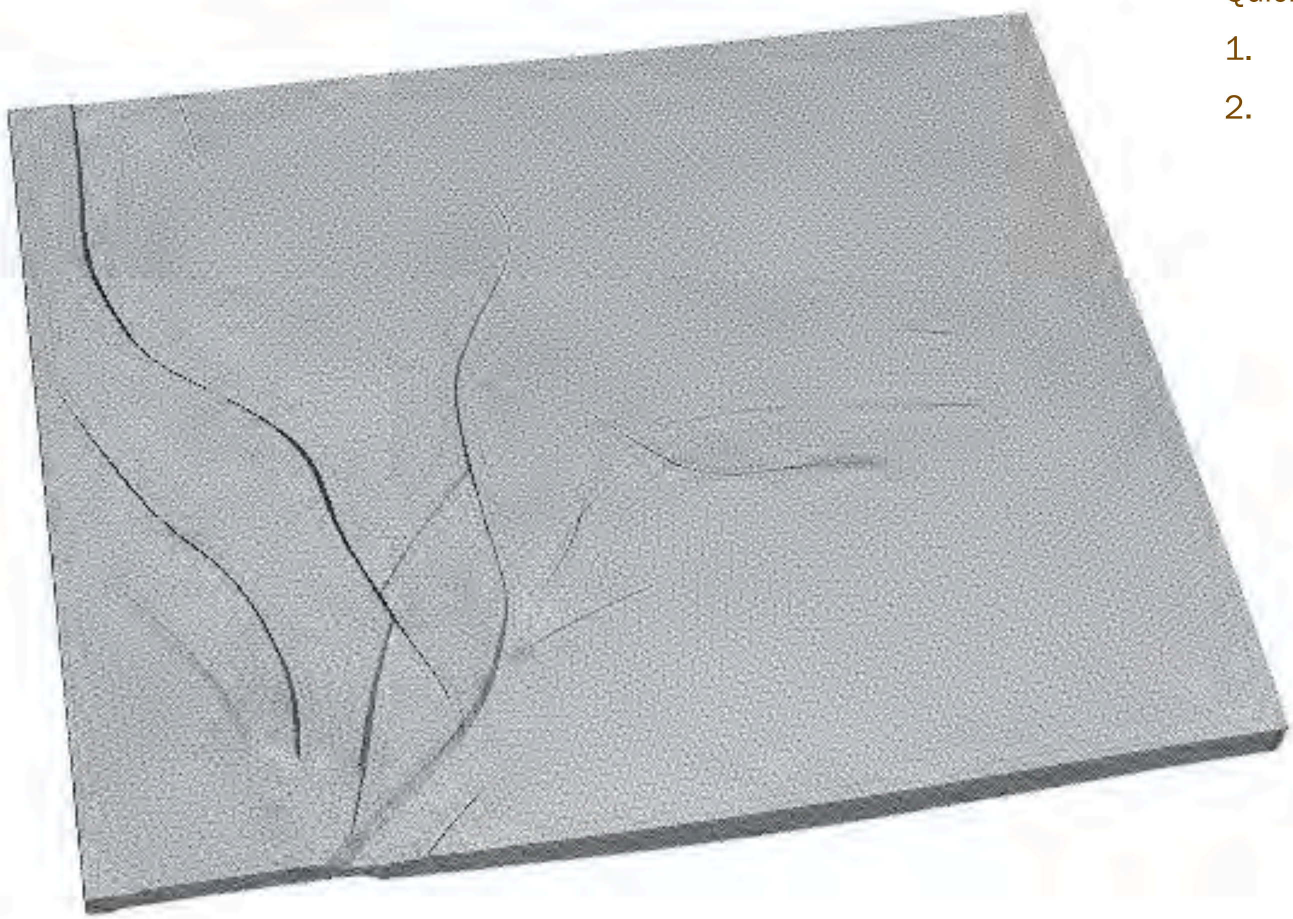

Quick check simulation … **not realistic**!

1. Injecting in all wells
2. Faults are transparent

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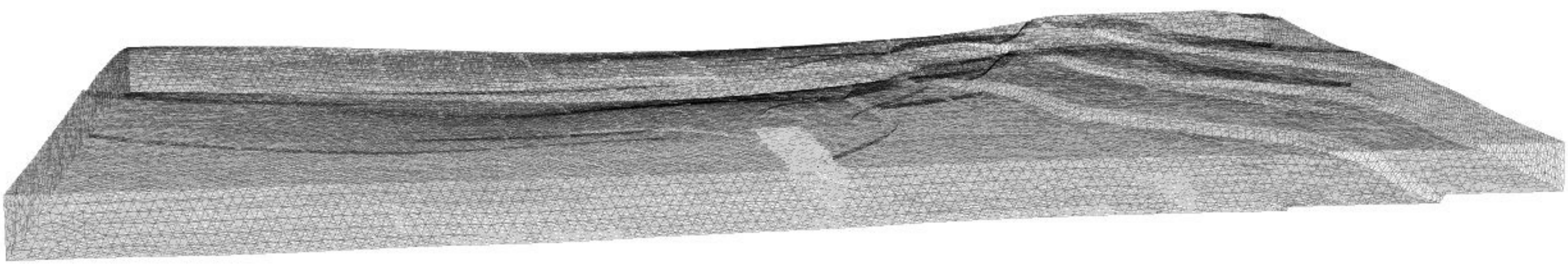
Quick check simulation … **not realistic**!

1. Injecting in all wells
2. Faults are transparent

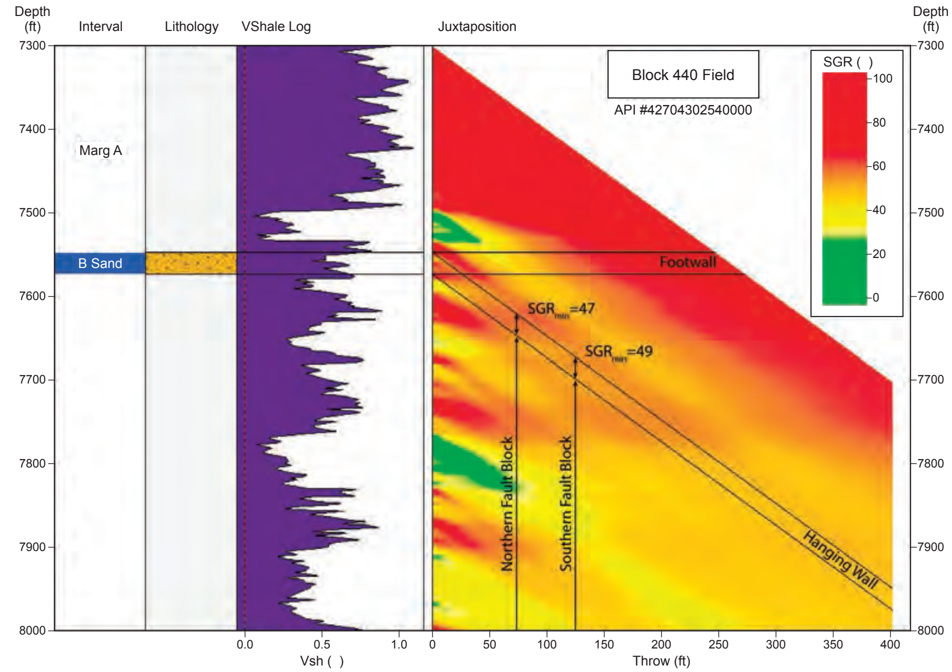


Next steps

1. Need to decide on target injection scenarios (wells and volumes).

2. Need to constrain fault seal behavior. Can leverage existing GCCC work.

3. Working on constraining geomechanical properties, but we will need to accept high uncertainties.



Fault juxtaposition analysis [Meckel et al.]

Extra Slides

Key Model Inputs

Input	"Path Forward"	Sources
Lithology + structure	Clear	GCCC Framework Model
Absolute perm + porosity	Clear	GCCC Framework Model
Relative perm	Maybe	Wallace et al. 2017
Fault seal behavior	Clear	Meckel et al. 2017, Nicholson 2012
Formation pressure, temp, salinity	Maybe	Well data?
Static elastic moduli	Clear	GCCC Framework Model (with dynamic/static correlation)
Inelastic properties	Unclear	Vastar and Atlantic Richfield Core? Analogue data?
Fault friction properties	Clear	Correlations + Limit Analysis
Stress orientation	Maybe	Regionally consistent
Stress magnitude	Unclear	Local stress indicators? Gas-trap and faulting constraints.

GoMCarb/SECARB Partnership Meeting, March 2020, Virtual Meeting

TOWARDS INTEGRATED SEISMIC MVA FOR NEAR-SHORE GCS: SEAFLOOR DAS FOR MONITORING

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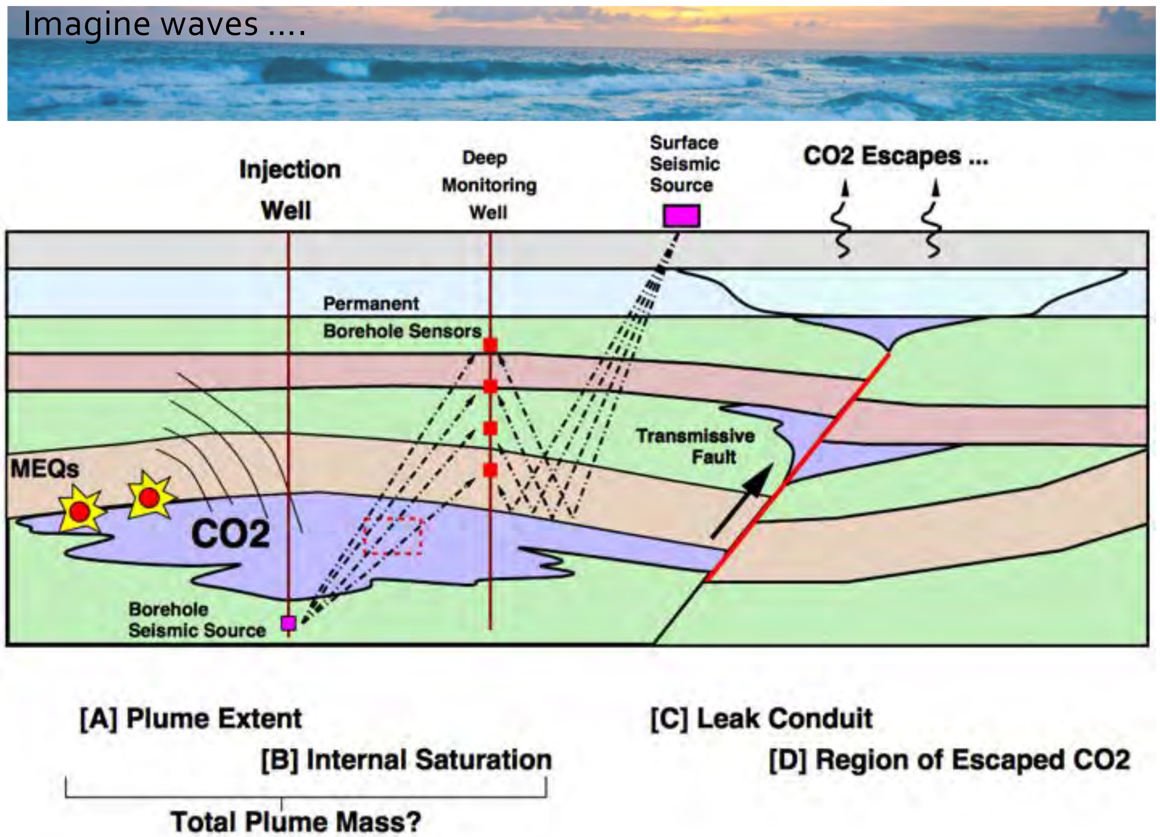
GCCC Gulf Coast Carbon Center

Partnership for carbon capture & offshore geologic storage GoMCarb

MVA Challenges in Shallow Offshore Environments

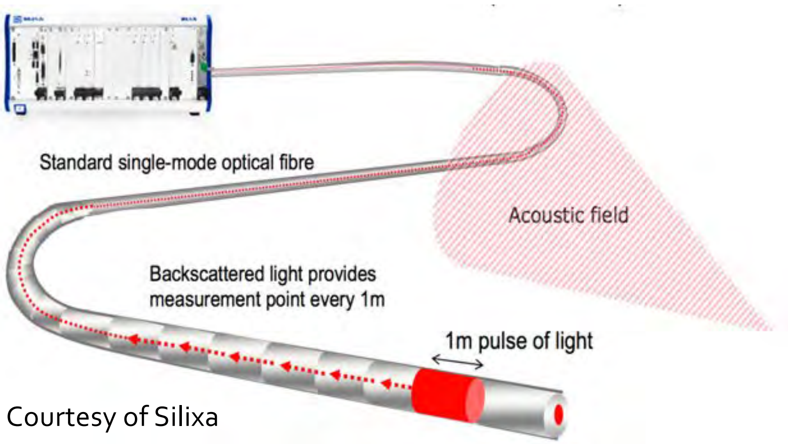


Challenges for GomCARB include ....

- Need to consider deep CO_2 movement (reservoir), intermediate/shallow leakage, seafloor expression, and water column (+ pipeline?).
- All in the context of a petroleum province with a dynamic seafloor, abundant natural gas seeps, storm impacts.
- Expensive wells (& completion ops) suggests less dependence on borehole monitoring beyond injector.
- Seafloor environment hostile to traditional long-term sensing (as well as costly), particularly for high sensor densities. Consider maintenance.
- Need to monitor seafloor and deep subsurface without direct access besides shallow draft vessel and ROV.
- One plus : Marine 4D simpler/high S/N than land.

Two New(ish) Technologies for MVA : DAS & Persistent Seismic Sources

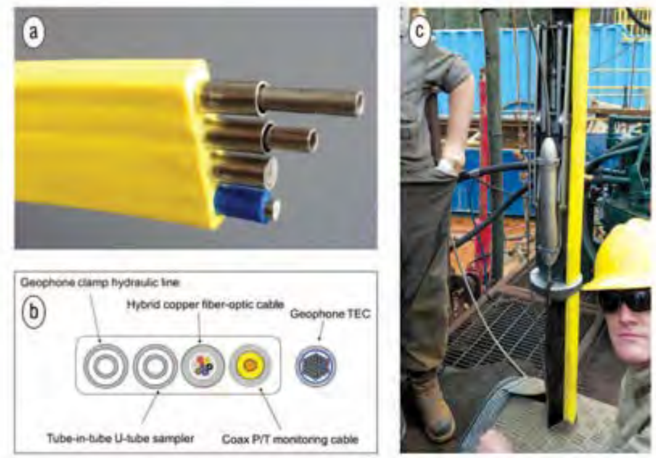
- **Distributed Acoustic Sensing [DAS]** is a rapidly advancing approach for measuring the seismic wavefield using commercial fibers (SM, telecom)
- Easy to deploy in wells, behind casing, seafloor, 1000s to 100,000s of channels available (big data) over 10+ km
- *Very low cost per "sensor"* : $/ft for cable
- *Rugged* : handles high/low T, high pressures, aquatic environments.
- Once fibers are there, other sensing modalities simple (DTS, DSS etc).
- ***LBNL Strengths*** : unique deployment packages, cable modifications, system integration, application domains, processing & inversion strategies.



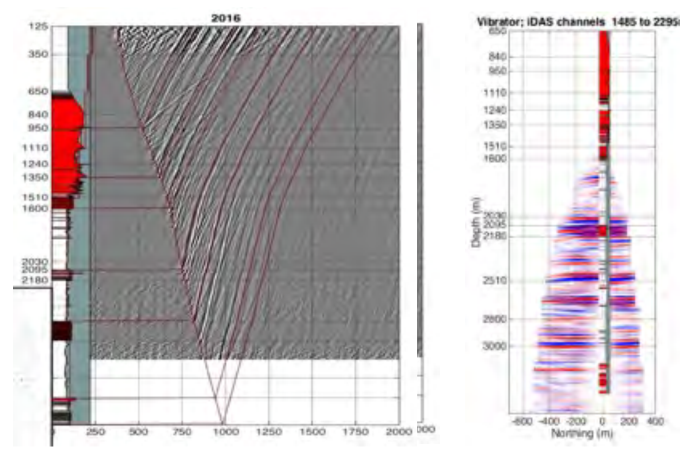
Courtesy of Silixa

For GCS:
Past LBNL deployments at Citronelle, Aquistore, Otway, CaMI, ADM for VSP (ADM only surface test, rest are borehole)

GomCARB:
- First time we are considering offshore
- First exploration of seabed
- First exploration of shallow/deep imaging combined

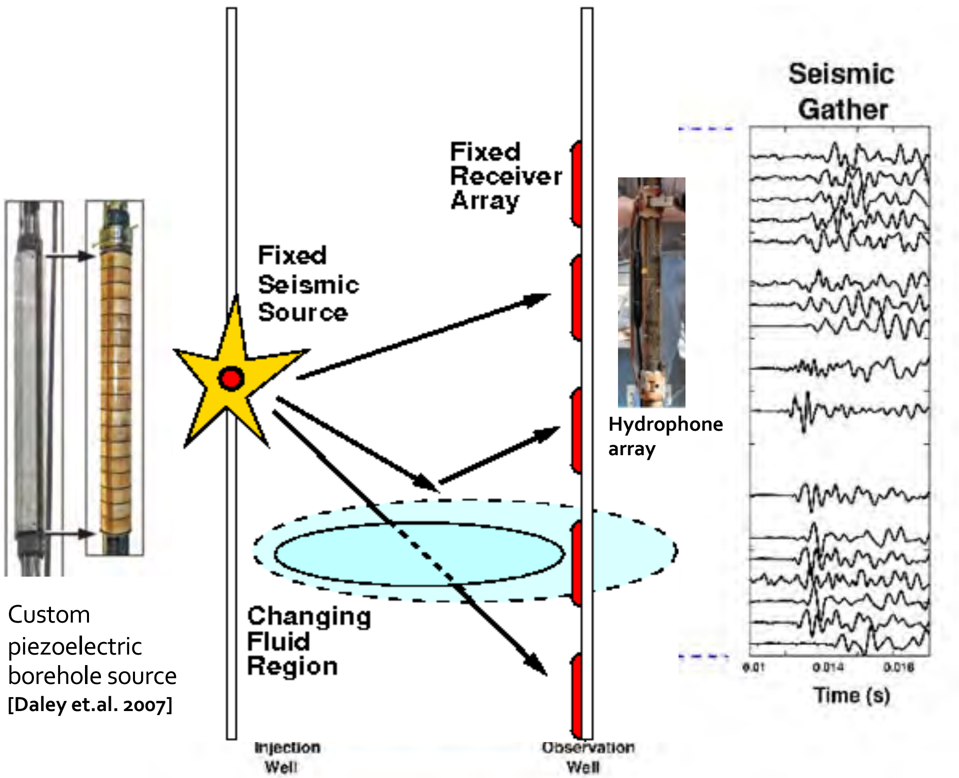


Daley et. al. 2016 (Geop Prosp.), Miller et al. 16, Daley et.al. 2013, (TLE)



Two New(ish) Technologies for MVA : DAS & Persistent Seismic Sources

- Large permanent seismic arrays (DAS) require sources (!).
- Need matching high-temporal resolution measurements in the field.
- For MVA, need sources to illuminate both deep (reservoir), near seabed, and water column perturbations.



Custom piezoelectric borehole source
[Daley et.al. 2007]

CASSM :
Continuous Active Source Seismic Monitoring

Fixed repeatable source & receiver array. LBNL has worked on piezoelectric and rotary source designs

- Temporal Resolution (< 5 min)
- Precise repeatability (~10 ns)
- Stacking -> Excellent S/N
- Real-time Acquisition
- Borehole & surface sources.
- Deployment to 10,500 ft & 120 C
- Largest deployment 22 S x 72 R
- Moving towards real-time seismic tomography

LBNL/EESA developed and fielded at 12+ sites to date.
GCS tests at Frio 2, Cranfield Phase 3 (borehole), Otway, ADM (surface) [Daley et al. 2007, Daley et al. 2011, Marchesini et al. 2017, Zhu et al. 2018, Zhu et al. 2019]

GomCARB :

- Opportunity to consider **water column** broadband sources
- Mount near platform for combined surface (shallow/deep) and VSP monitoring?
- Provide time points between 4Ds

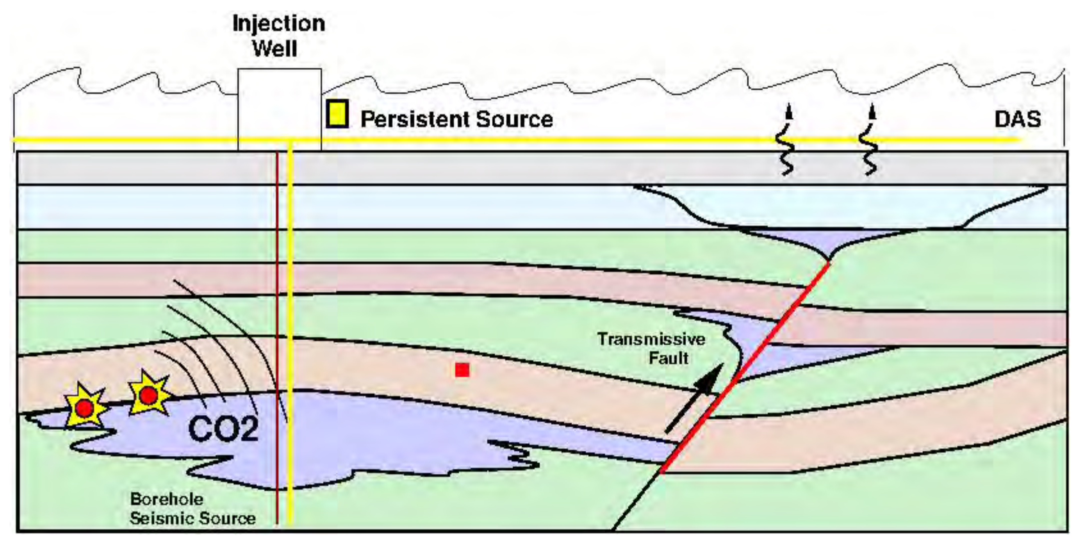
Concept : Integrating DAS + Marine Persistent Sources (CASSM) Near-Offshore MVA

- **Use DAS on the seafloor (and wellbore) as linear seismic array** for imaging
  - Near-surface anomalies (CO_2 leakage), Deep subsurface (CO_2 migration) & microseismic
  - Noise from relevant processes (bubble emission etc).
  - ***Ambient noise imaging***
  - Replaces OBS or seafloor hydrophone deployments.
  - Better time resolution than repeat streamer surveys, much cheaper than LoFS using cabled OBS. Also permanent receivers for 4D

[note : technology also has a potential role for pipeline monitoring in future tests]

- **Use fixed seismic source in the water column for high repeatability imaging** (Marine CASSM
  - highly repeatable timelapse monitoring of the near-seabed sediment, water column, and deep subsurface.
  - Considering novel swept source with resonance for combined reflection/transmission/VSP.

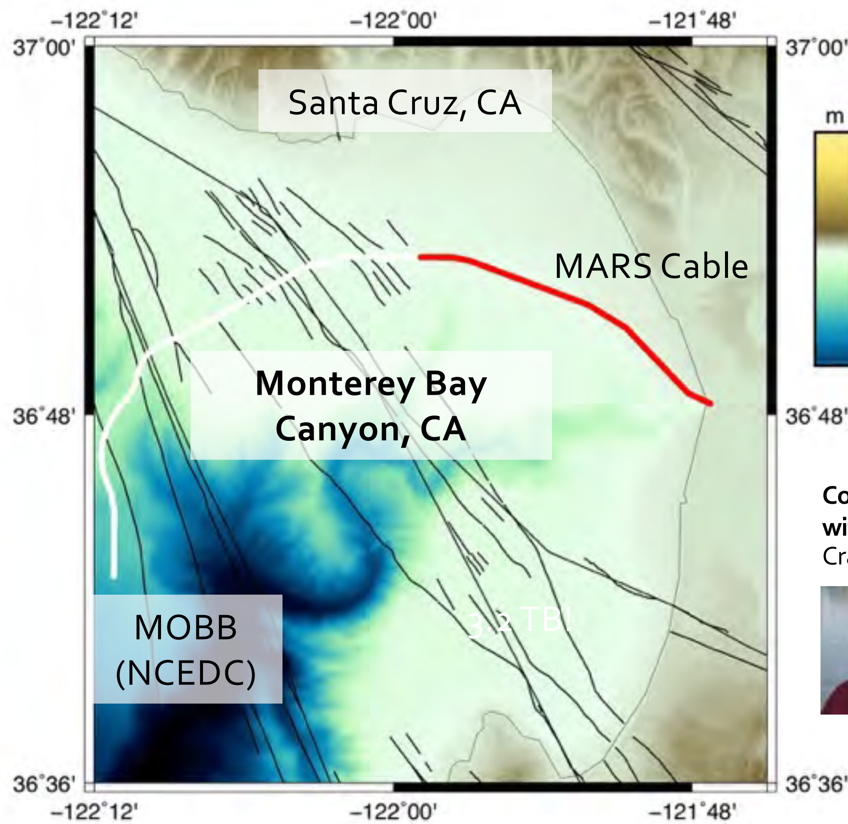
- **Combined system for seismic MVA with high (minute) time resolution in marine environment**
  - Unique aspect is combination of shallow (leakage) and deep (reservoir) targets.
  - Challenges are understanding deployment challenges for system elements



LBNL MVA Tasks (5 years)

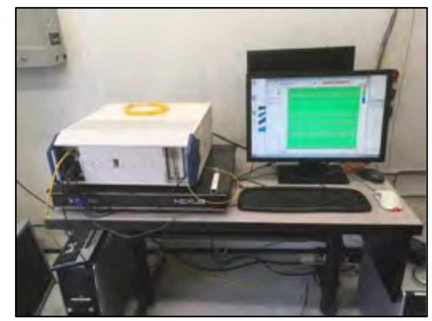
- ***Task 1 : Design and Modeling Stage***
  Design and modeling of the proposed source & integrated source/DAS system in a marine environment for CO_2 leakage tracking.
- ***Task 2 : Source Construction and Laboratory Tank Testing***
  Construction of prototype source/tank tests. Evaluate for (a) water column, (b) near-seafloor, and (c) deep subsurface imaging targets.
- ***Task 3 : Analysis of Seafloor DAS Dataset***
  Analysis of a DAS dataset acquired on an existing seafloor cable to examine noise characteristics and response in a near-shore environment. (datasets of opportunity!)
- ***Task 4 : Broad MVA Support***
  Collaborate with TX BEG more broadly to develop fit-for-purpose monitoring suited for the near offshore environment.
- ***Task 5 : Design and Execution of a Shallow Water Field Test***
  Near-offshore field test. Similar water depths to pilot. Possible short N_2 bubble release along a DAS profile illuminated by the persistent source, designed to test monitoring (a) near-seafloor subsurface velocity perturbations, (b) acoustic noise from release (c) changes in acoustic transmission in the water column.
- ***Task 6 : Evaluation of Fiber Optic Cables in the GoM Available for DAS***
  Our last task is evaluation of existing fiber optic cables in the GoM which might be leveraged for DAS recording as part of a near-shore GCS monitoring network.

DAS on Offshore Seabottom Cables? MBARI Evaluation Dataset (Task 3)



- A dataset of opportunity – 1st offshore cable DAS dataset (that I know of) processed for seismic.
- Umbilical cable to MOBB – offshore tethered observatory
- Explore passive signals recorded with ~20km MARS cable with Silixa iDAS at Moss Landing (MBARI headquarters)

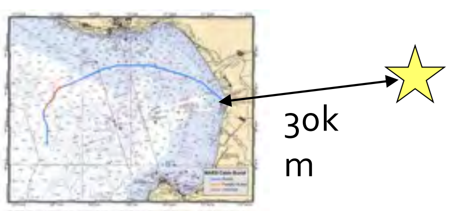
Collaboration with MBARI : Craig Dawe



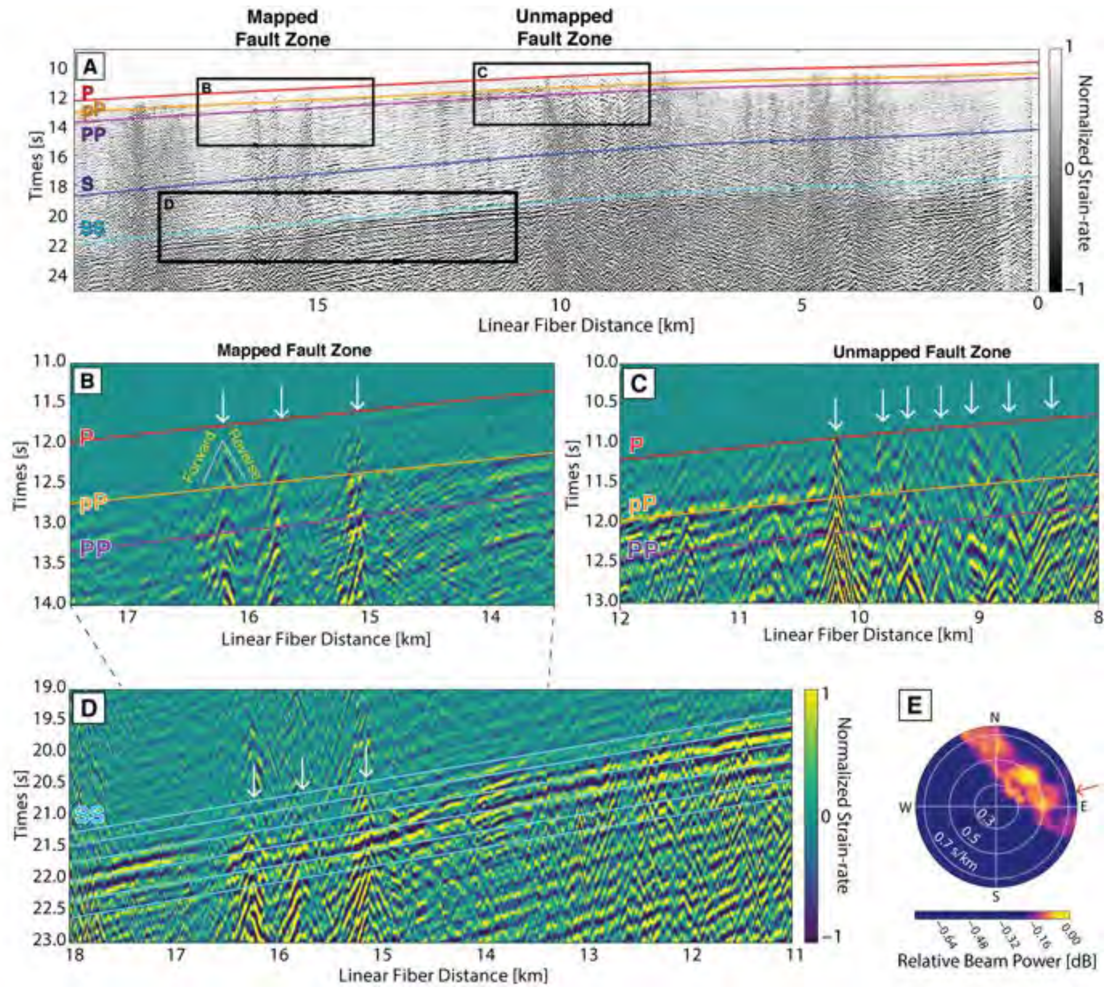
Detecting Seismicity & Faults Using Marine Dark Fiber

- Several on-shore EQs detected during short deployment. M3.4 in Gilroy (~30 km).
- Signal cleaner than on-shore recordings for local events.
- Smaller regional events (~M2) also detected.
- Body->surface wave scattering features which may correspond to offshore fault systems
- Fault locations validated on one profile using existing USGS seismic lines.
- Will be a powerful tool for probing near- offshore fault systems & ***induced seismicity***.
- Densest OBS (ever?)

Lindsey et al. 2019

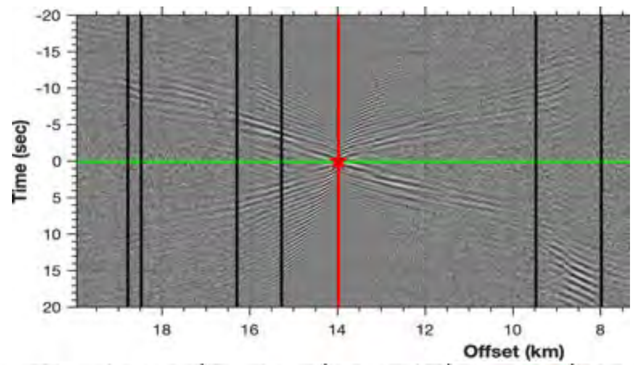


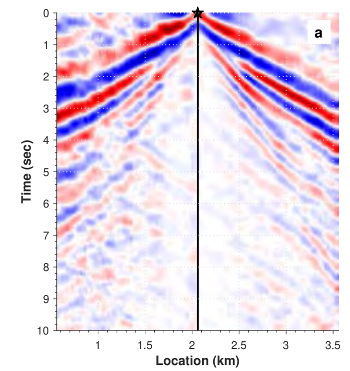
30k
m



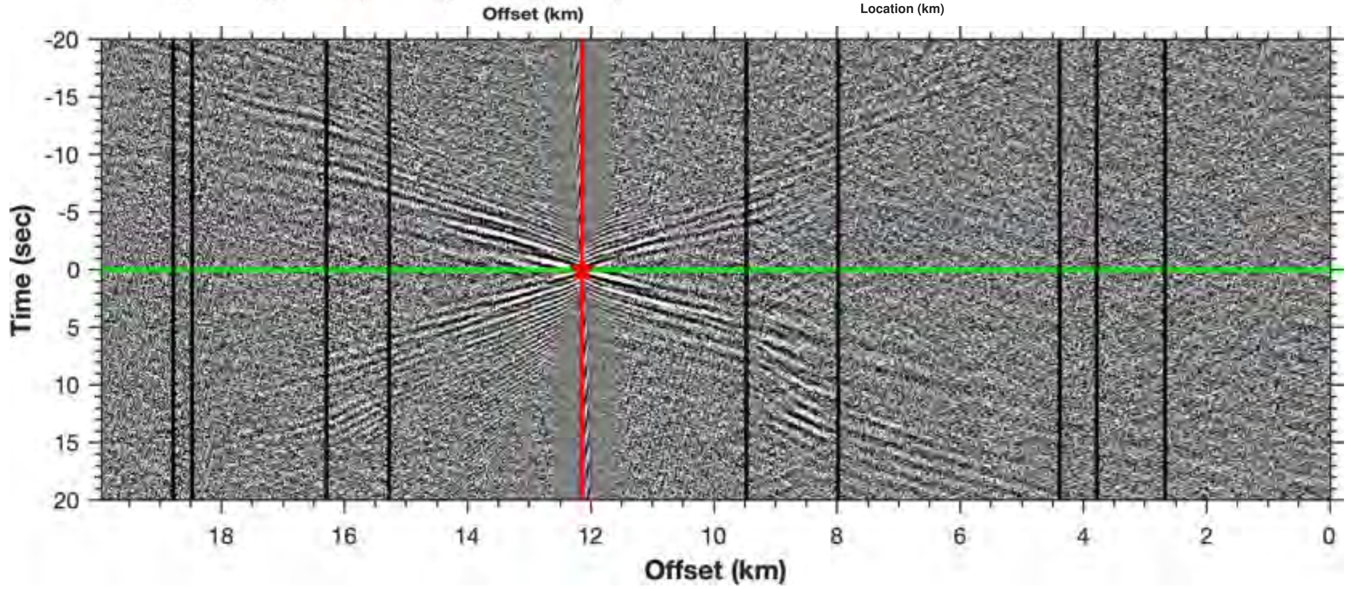
Ambient Noise Analysis for Offshore Structure?

- Since no CASSM source was deployed in this test, analyzing ambient noise Green's functions for evaluation of imaging.
- Approach utilizes cross-correlation of noise recordings to replicate what an active shot looks like – limited by noise spectrum & recorded modes.
- Targets are velocity variability and scattering features from seafloor fault zones.
- Computed 1000 gathers on sequential 20 m src points
- High-quality dispersive Scholte waves – perfect for Vs inversion.
- Evidence of Scholte wave scattering within fault zones – a potential imaging target.



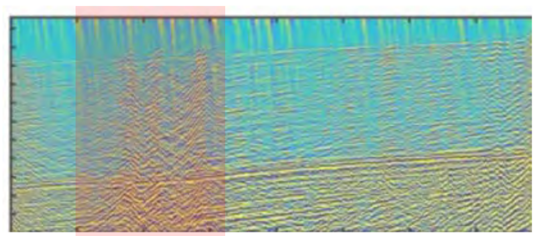


Cheng
In prep



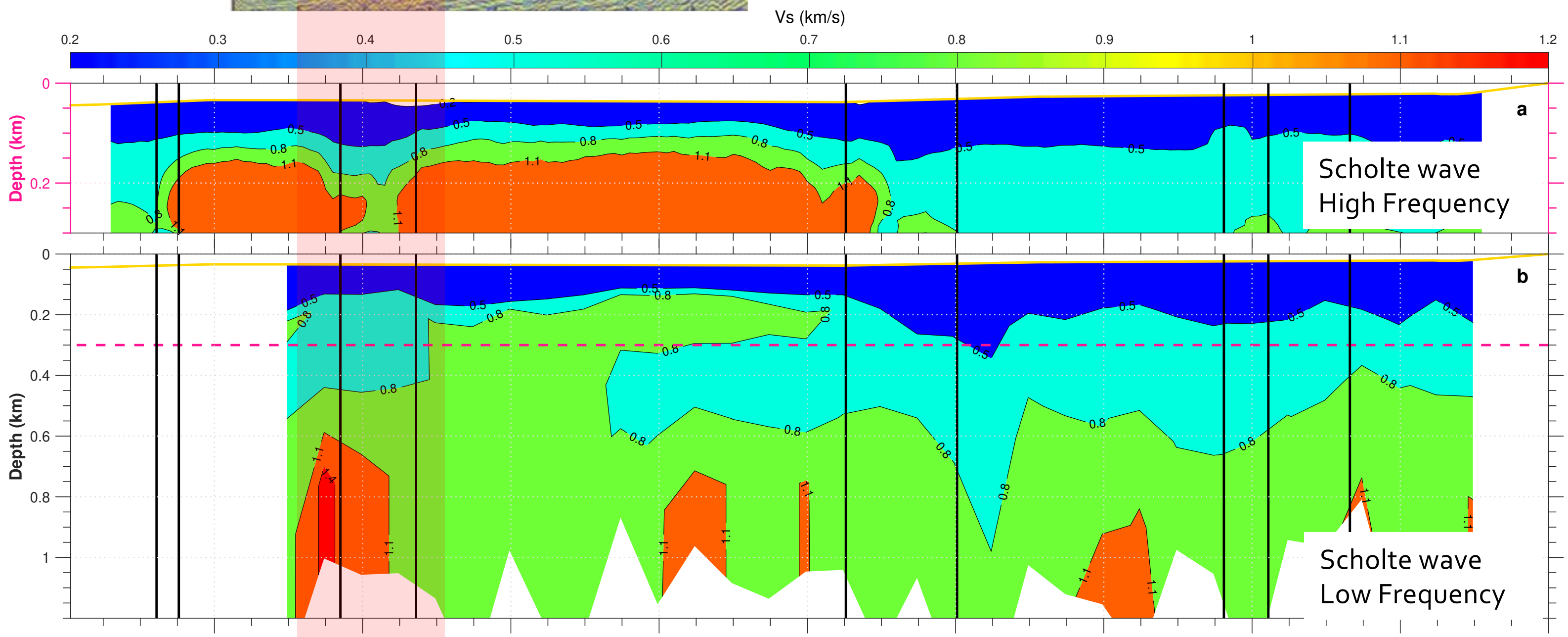
Scholte Wave Velocity Inversions : Seafloor V_s Variability

- Ambient noise gathers inverted for 1.5 D shear wave velocity (Vs) profiles in two frequency bands.
- Provide Vs model for near-surface structure from 0-250 m (high resolution) and coarser resolution to 1.2 km.
- Comparison of scattering observed from regional EQ (top) to Scholte wave velocity inversion (two frequency bands).
- Low Vs zone and reflection discontinuities ***consistent***.
- Further verification of fault zone ID.



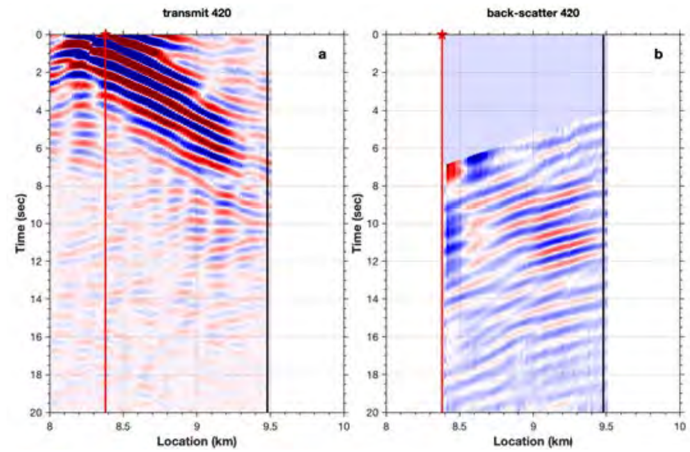
Regional seismic event showing scattering features.

Cheng
In prep



Scholte Wave Scattering for Fault Imaging?

- Observed significant scattering of Scholte waves from fault zones in ambient noise Green's functions.
- Extracted scattered wavefield and performed 2D migration in XY plane, wavelength to depth-conversion using Vs model.
- Provides higher resolution profile of the fault plane, potential ***possibilities for timelapse imaging of fluid perturbations.***



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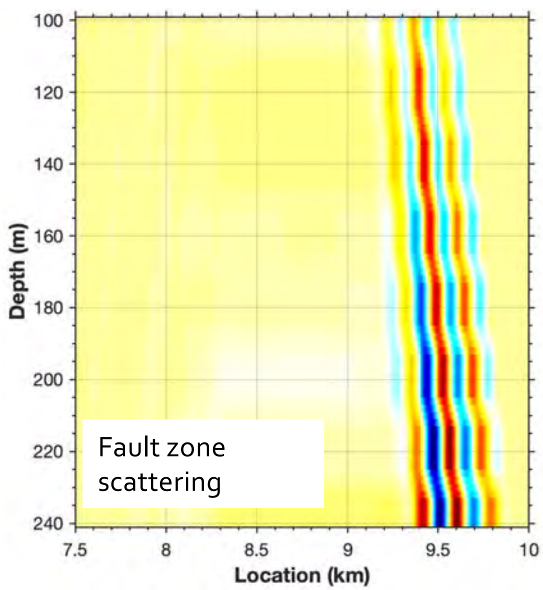
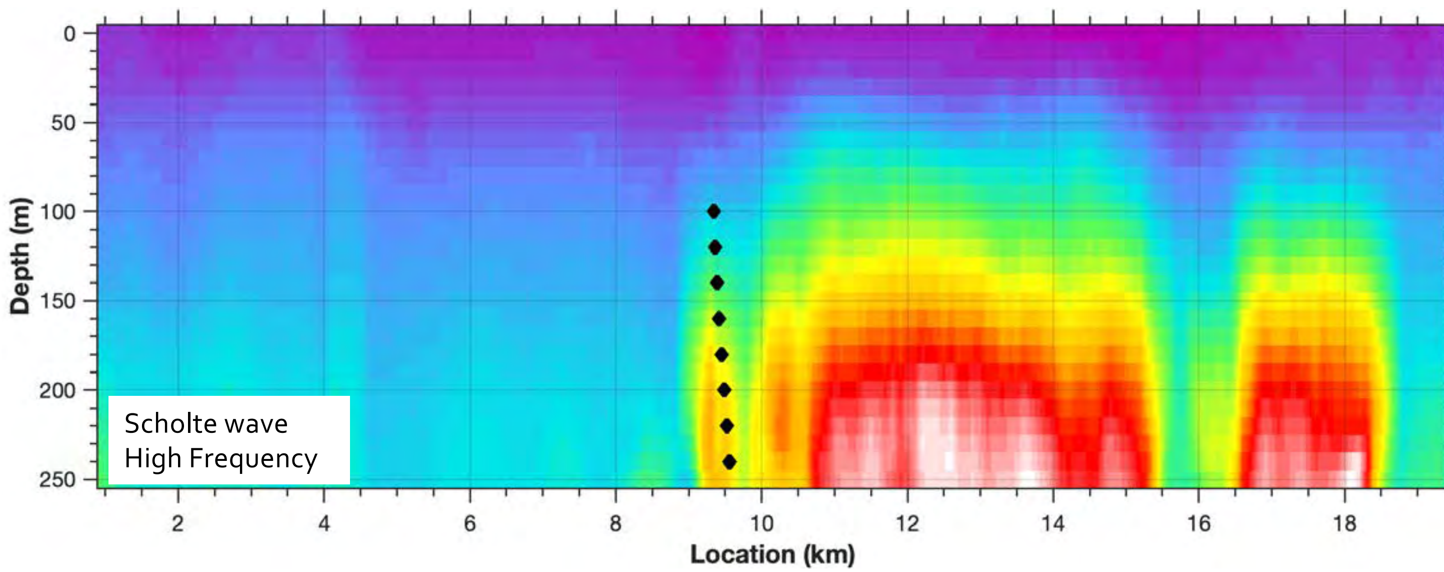




Moving Forward

- Initial seafloor DAS data seems to have potential for seismic recording
  - Demonstrated regional EQ recording
  - Ambient noise imaging of seafloor velocity structure at a range of resolutions
  - Identification and imaging of seafloor faults using scattered surface waves
  - Characterization of oceanic noise levels.
- Exploring how ambient noise approaches might be utilized in offshore monitoring context.
- Considering source & DAS cable design in the context of initial offshore DAS data (offset, install).
- Exploring options for acquiring offshore GoM DAS cable dataset for continued task 3 – temporary installation of near-shore cable.
- Developing persistent multi-purpose source design for water tank testing (Task 2) – work delayed by (1) lab build at Rice (finished in February) and now (2) COVID.
- Considering DAS design in context of possible “model” pilot sites

Thanks For Listening!

This work was supported by the GoMCarb Project funded by the Assistant Secretary for Fossil Energy (DOE), Office of Clean Coal and Carbon Management, through the National Energy Technology Laboratory (NETL), and by Lawrence Berkeley National Laboratory under Department of Energy Contract No. DE-AC02-05CH11231 .

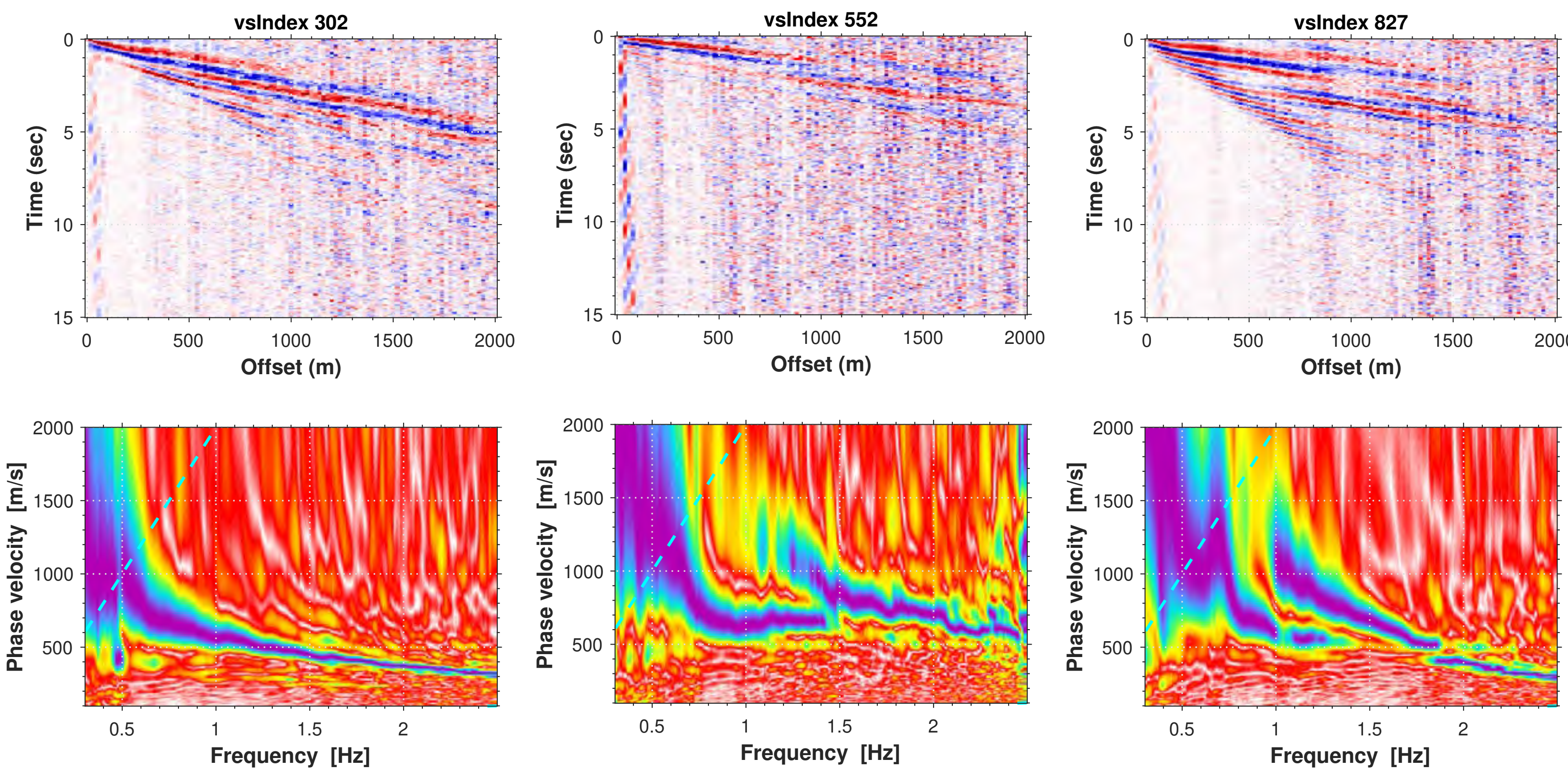
Laboratory Directed Research and Development Program

MBARI Acquisition

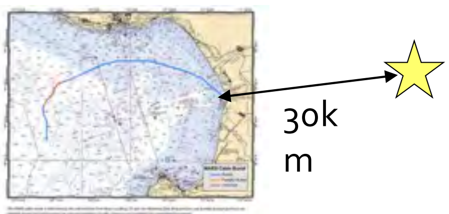
BACKUP

Ambient Noise Analysis for Offshore Structure?

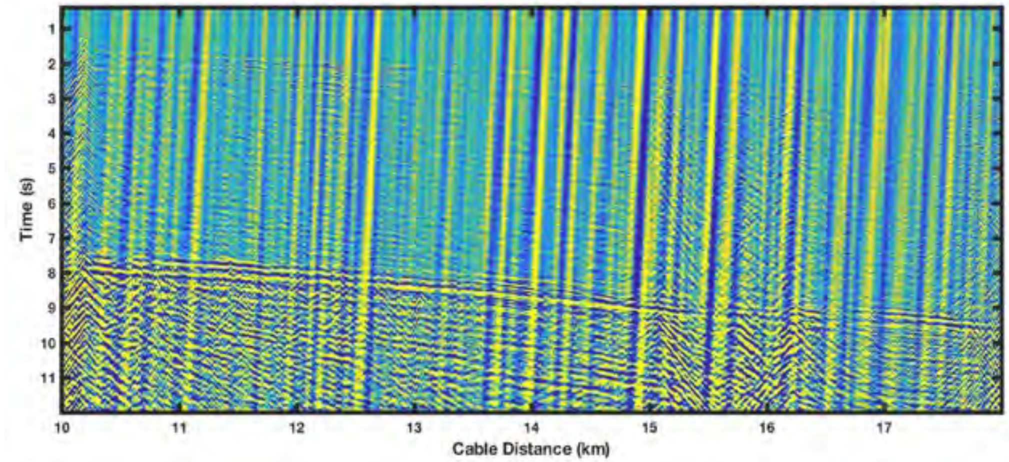
- Since no CASSM source was deployed in this test, analyzing ambient noise Green's functions for evaluation of imaging.



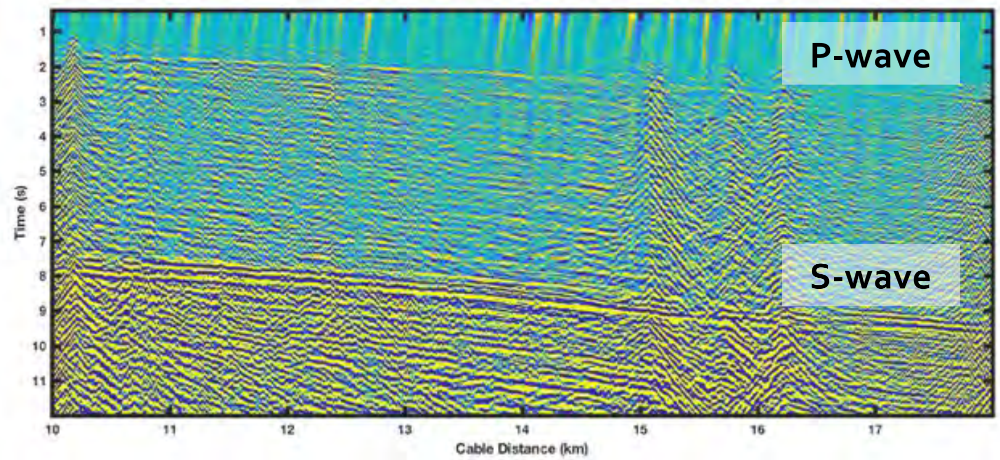
Results from Last Year : Detecting Seismicity Using Marine Seabed Fiber & DAS



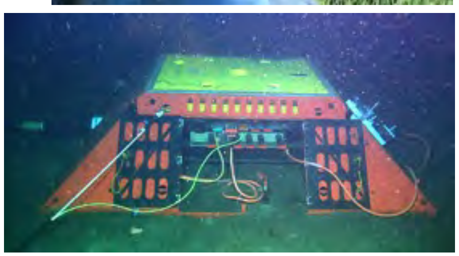
- Several on-shore EQs detected during short deployment. M3.4 in Gilroy (~30 km). Also picked up several smaller (M2) events, same hypocenter.
- Signal cleaner than on-shore recordings for local events.
- Wave motion (primary/secondary microseisms) overprint – easily removed.
- Scattering features which may correspond to offshore fault systems?
- Will be a powerful tool for probing near- offshore fault systems & potential **induced seismicity**.

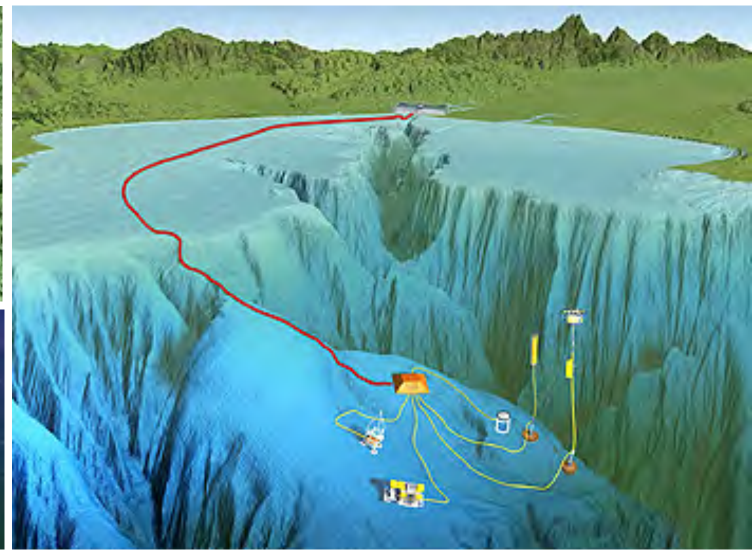


[2 m channel spacing, 10 m gauge, 20 km array, 10 k channels, 500 hz recording, **Densest OBS recording ever?]**



Ocean bottom seismology is a costly endeavor





Ocean Bottom Seismometer Deployments

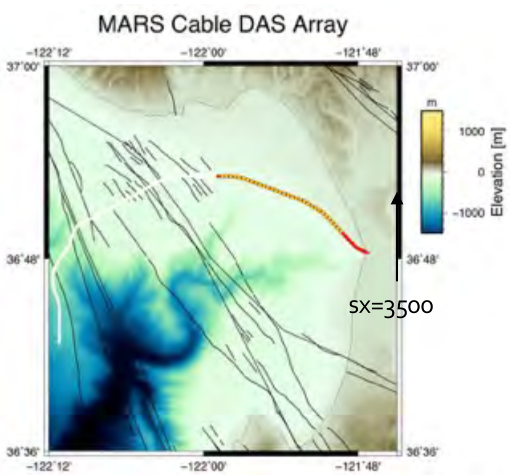
NSF 2016 OBS Pool = 247 (37% SP)
European 2014 OBS Pool = 450 (71% SP)
OBS battery life = 14 month +/-6 month
Data Delay (seconds to months)
Annual costs?

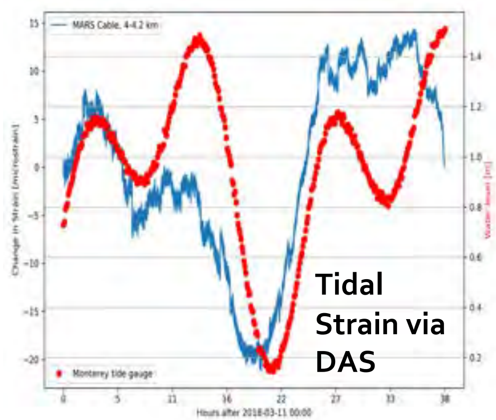
Cabled Observatories

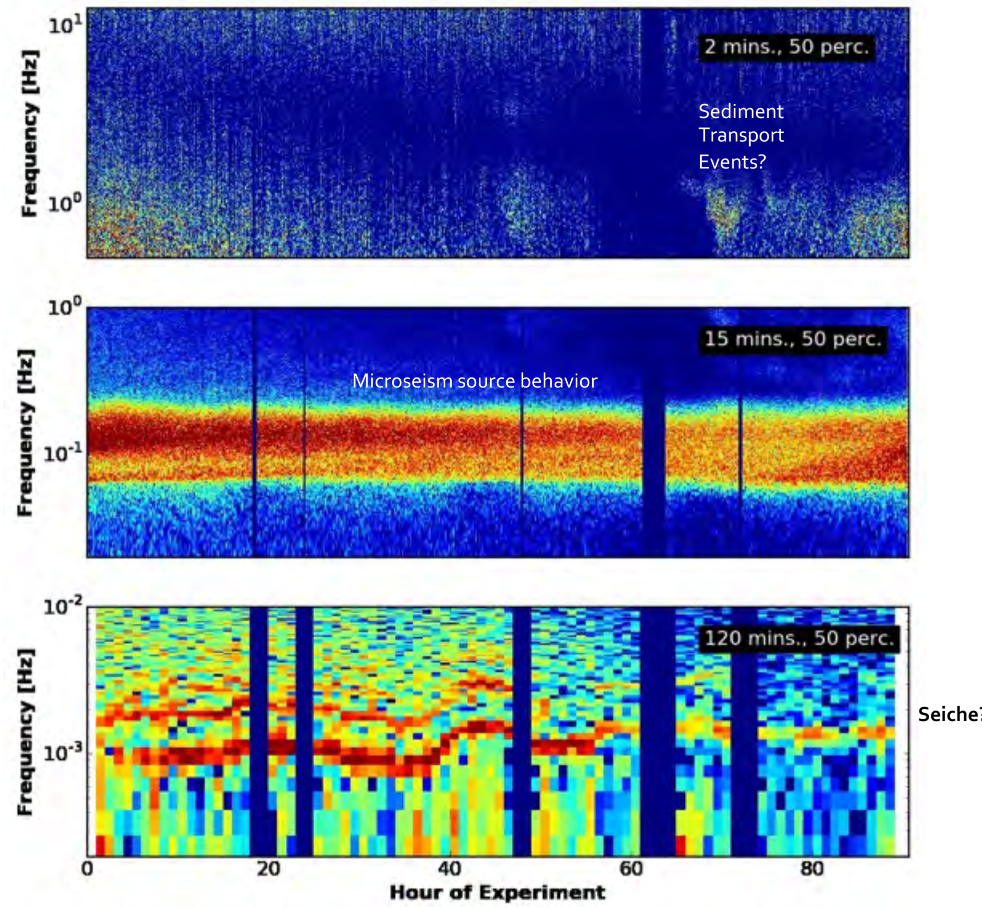
MARS Cable Laying 2002 – 2007
$11.75M investment
2 GB/s data transfer over 52km

Oceanographic Process Observations via Seafloor DAS?

- Surprisingly broadband (mHz to 100 Hz)
- Signal of oceanic wave processes down to the mHz range (1000 s)
- Can see microseism source behavior, infragravity waves (long period swell groups).
- HF noise which might be useful for imaging.
- Storm & tidal signals.
- **A possible GCS target, seafloor bubble emissions**
- **Ambient noise from platform another possibility, or deformation**







Lab for future tank testing .....

TASK 4.0: **Monitoring, Verification, and Assessment (MVA)**

P-Cable Update

High-resolution 3D marine seismic applications for offshore CCUS

TIP MECKEL
GoMCarb Task 4 – Monitoring, Verification, and Assessment (MVA)

SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

Problem

How can we evaluate the subsurface features and processes in the overburden between an injection reservoir and the seafloor?

1) Pre-injection characterization – identify and reduce risk (seal, fault)
2) Monitoring during injection – conformance, retention
3) Post-injection assurance – end of project & liability transfer

Approach

Identify a location for testing some combination of technology and geologic target at an analog injection site to provide insight into capabilities and optimization strategies.

Collect dataset: design, acquire, process, interpret.

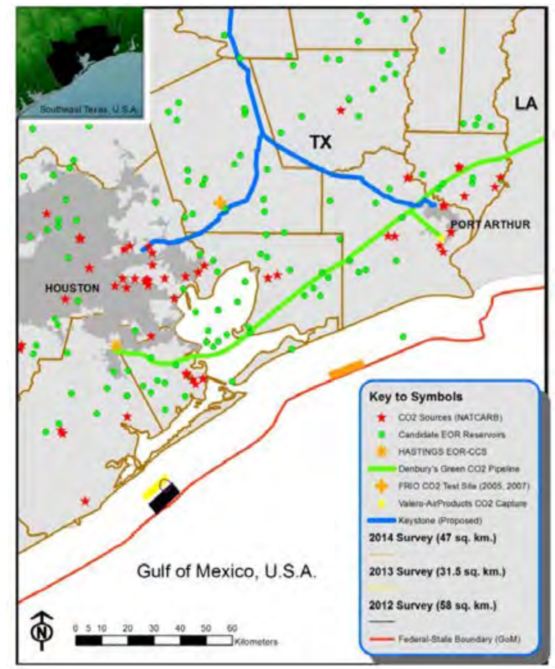
Approach: High-resolution 3D Seismic

Closely spaced short (25m) streamers allows for dense array and higher horizontal resolution (~6 m^2).

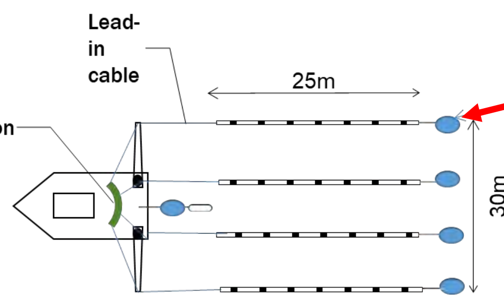
Recovery of high frequencies for relatively shallow intervals (< 1 km) allows for higher vertical resolution (2-5 m).

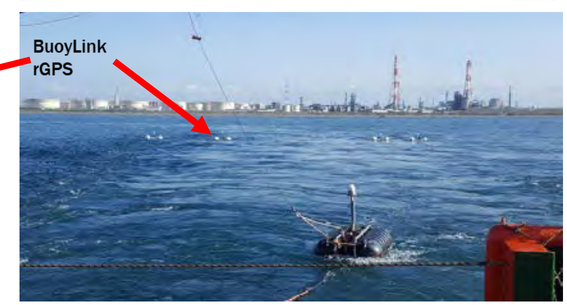
Technique developed and tested under prior DOE funding: 3 surveys in the inner shelf Gulf of Mexico (2012, 2013, 2014).

Technique deployed at an active injection site at Tomakomai Project in Japan (2018).



Meckel and Trevino, 2013, GHGT-12
Meckel and Mulcahy, 2016, Interpretation
Meckel and Feng, 2018, IJGGC





Subtask 4.1: MVA Technologies and Methodologies

This subtask will identify a suite of MVA technologies and methodologies for large-scale storage projects and evaluate suitability for the unique characteristics of the environments expected to be encountered in the region. Adaptations of existing, and novel-technologies will all be considered.

Subtask 4.1.1 Geochemical Monitoring of Seabed Sediments.

Subtask 4.1.2 Geochemical Monitoring of Seawater Column.

Subtask 4.1.3 UHR3D Seismic. The Recipient will refine concepts related to utilization of novel UHR3D (ultra-high resolution 3D) seismic for characterization and monitoring of injection reservoirs and overburden.

Subtask 4.1.4 Distributed Acoustic Sensors.

Subtask 4.1.5 Pipeline MVA.

Partnership for carbon capture & offshore geologic storage

GoMCarb

Refine HR3D concepts for characterization and monitoring

Use pre-injection survey to de-risk sites: faults and fluids

Draft Manuscript: *Use of high-resolution 3D seismic data for imaging the geologic overburden above typical prospective CO_2 storage sites offshore Texas, U.S.A.*

Unique processing workflows using multiple software strengths: optimal imaging

Merging conventional (deep reservoir) seismic with HR3D (shallow overburden): single data product

Potential for AUV deployment for streamers.

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Subtask 4.2: Plans for Testing of MVA Technologies

This subtask will incorporate the knowledge and lessons learned from previous and current offshore storage efforts (including international collaboration) to develop plans for testing of MVA technologies to support the most likely offshore geologic storage scenarios.

Based on the lessons learned from this subtask, a summary of MVA lessons learned will be developed in collaboration with the other awarded project from FOA1734 to ensure safe, long-term, economically viable carbon storage in offshore environments.

Subtask 4.2.1 A priority list for MVA technologies and their testing methods will be developed.

Subtask 4.2.1.1 High-resolution 3D seismics (HR3D). This subtask will assess locations and design modifications for deploying HR3D technology for MVA. Sites initially evaluated will be in the Texas State waters.

Subtask 4.2.1.2 Geochemical monitoring in the Seawater Column.

Partnership for carbon capture & offshore geologic storage

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Assess locations and design modifications

LOCATIONS:

1. Shallow salt dome (return to **San Luis Pass** area) – understand geology of salt flank seal.
   - Inner-shelf setting typical of near onshore and near offshore prospective storage sites on salt flanks.
   - Compare to existing field studies (La Popa, Mexico)
2. Fluid migration in **Auger Basin** – Natural hydrocarbon seep setting; Deep overpressure and migration. Lots of existing published research to leverage.
3. Taylor Energy **MC20 site** – Worst case scenario for CCS? Leaky well site; Accessibility?
4. Other sites

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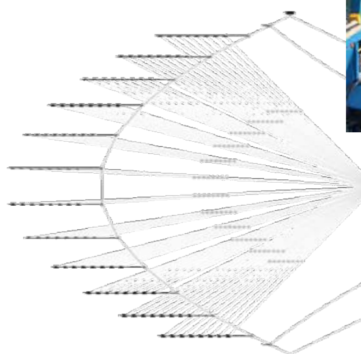
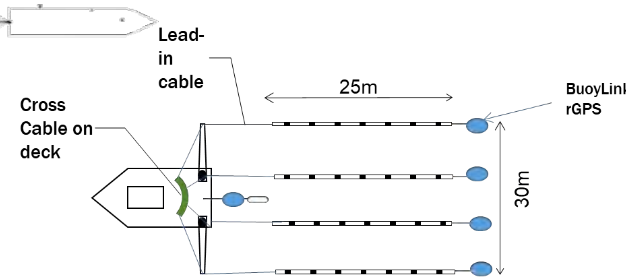
Assess locations and design modifications





<u>DESIGN MODIFICATIONS</u>:

Full array to compact array

Outrigger boom design

Positioning: Tail buoy design and construction

Hardware: cable voltage, GPS

Data stream management

Partnership for carbon capture & offshore geologic storage

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Subtask 4.3: Plans for Testing of MVA Technologies

Subtask 4.3 Testing MVA technologies

This subtask includes all activities to permit, contract a vessel, and acquire, process and interpret two to three (2-3) HR3D seismic datasets for CO_2 storage analog sites identified in Subtask 4.2.1.1.

Operational considerations

Research partner TDI-Brooks using vessel *R/V Brooks McCall*.

Vessel currently operational, but conversations regarding scheduling are ongoing.

Partnership for carbon capture & offshore geologic storage

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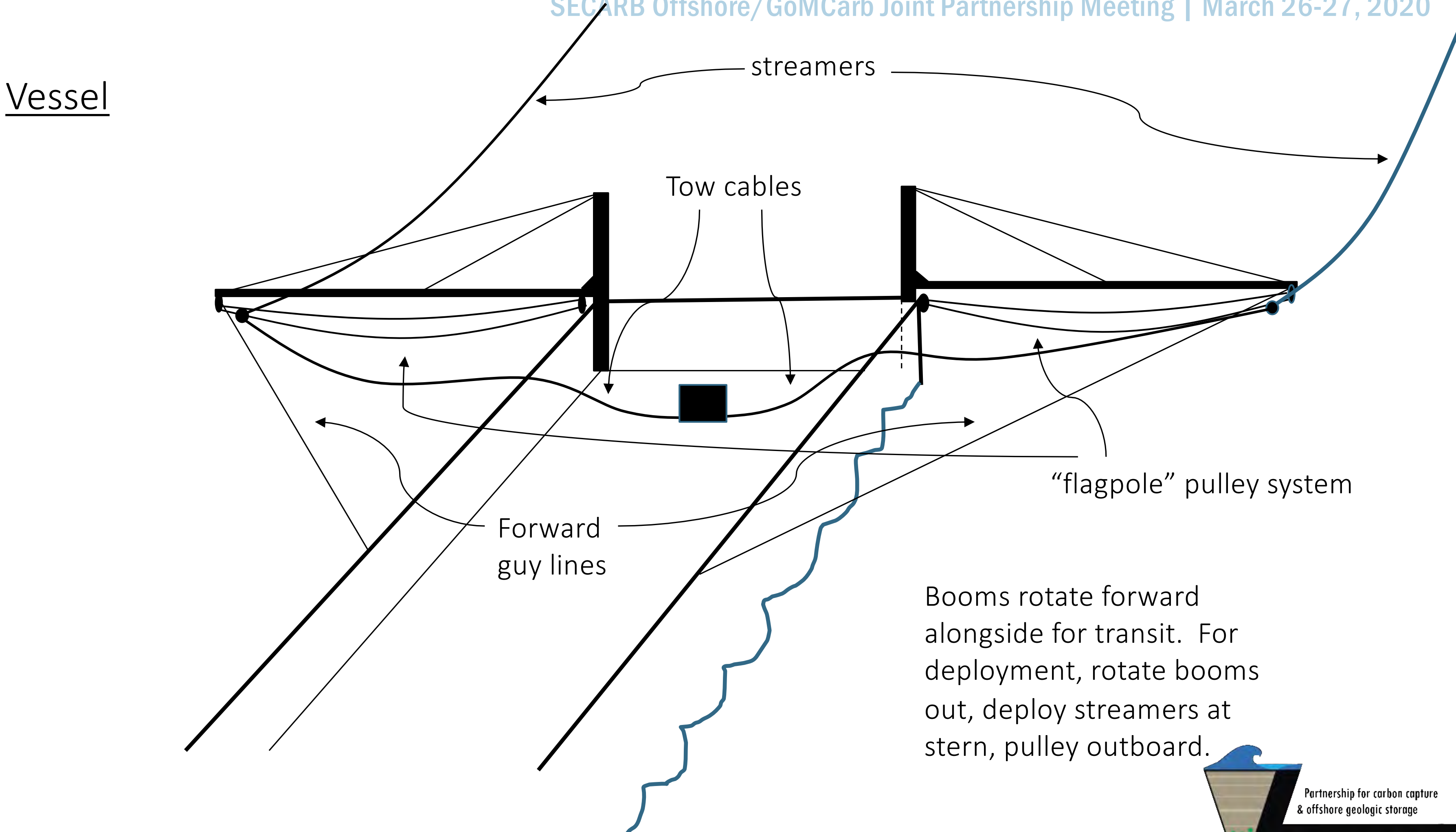
Status

Currently identifying optimal location for survey

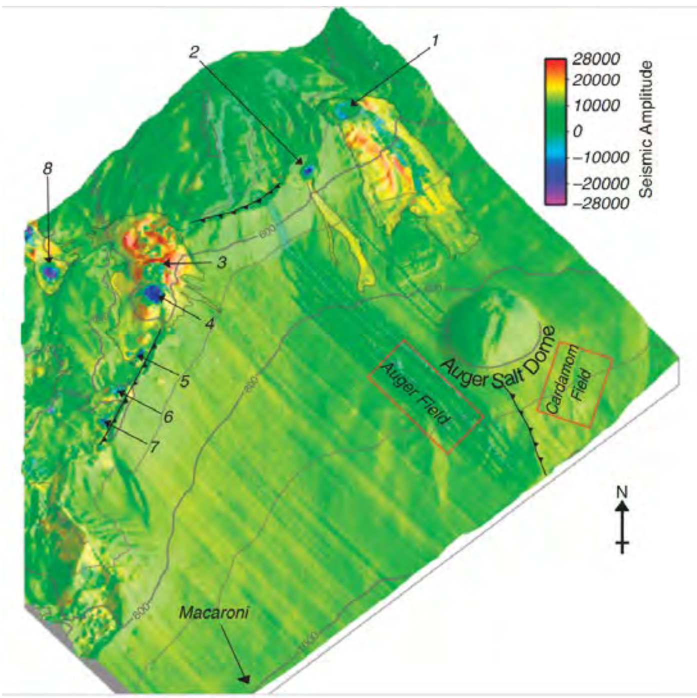
- Technology test – positioning, new tail buoy design.
- Target – leverage prior research and knowledge at a site
  - Geologic fluid system
  - Fault setting
  - Well setting

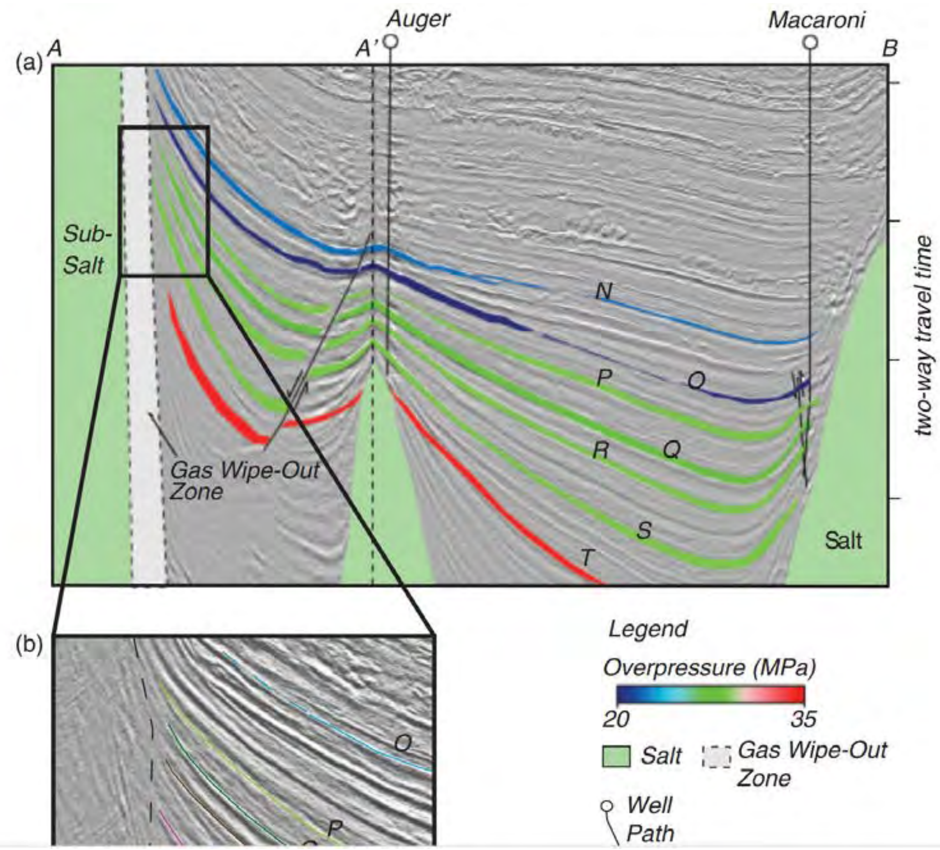
Discussion

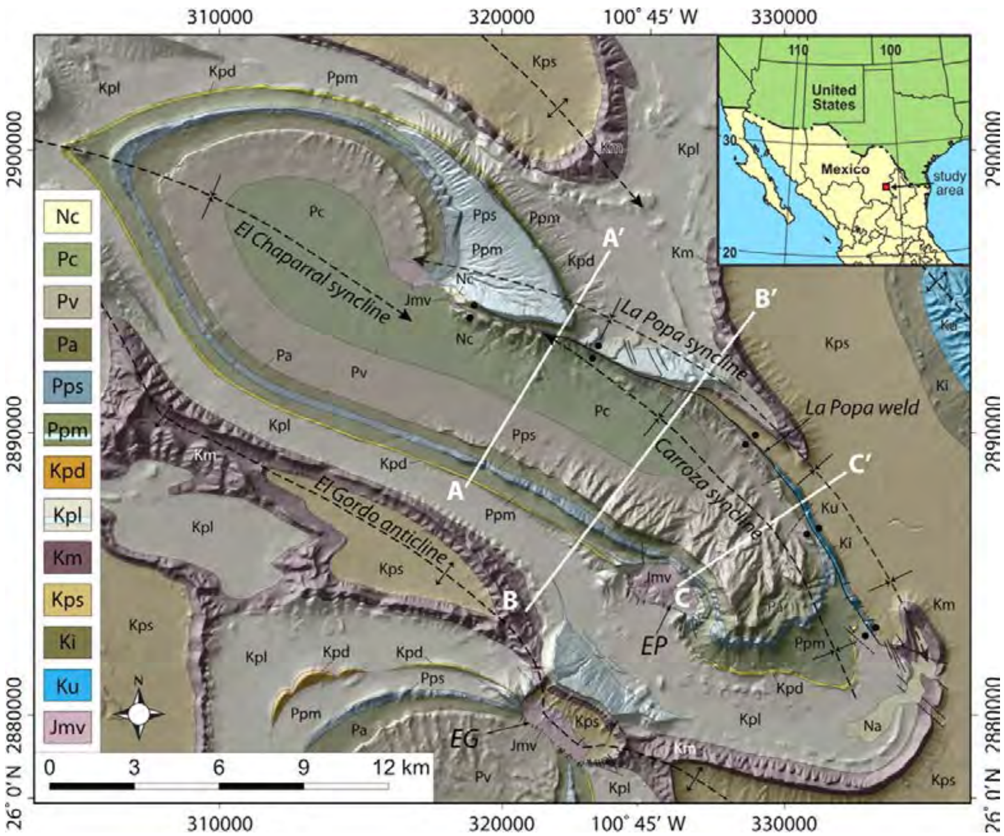


Booms rotate forward alongside for transit. For deployment, rotate booms out, deploy streamers at stern, pulley outboard.

Auger Basin setting







Near-salt deformation in La Popa basin, Mexico, and the northern Gulf of Mexico: A general model for passive diapirism

Mark G. Rowan; Timothy F. Lawton; Katherine A. Giles; Robert A. Ratliff

AAPG Bulletin (2003) 87 (5): 733–756.

https://doi.org/10.1306/01150302012

Taylor Energy MC-20 Site

Analog for worst-case scenario for CCS

The longest oil spill in U.S. history

Destruction of a **Taylor Energy oil platform** during **Hurricane Ivan.**

This resulted in between 25 and 28 leaking wells being buried beneath the sea floor, approximately 475 feet (145 m) below the surface.

BSSE Enforcement

https://www.bsee.gov/newsroom/library/incident-archive/taylor-energy-mississippi-canyon/ongoing-response-efforts

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CO_2 Transport and Delivery

Progress for the Infrastructure Subtask

Darshan Sachde, PhD
Katherine Dombrowski, PE
Ray McKaskle, PE
Joe Lundeen, PE
Trimeric Corporation
Task 5 - Infrastructure

SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

Disclaimer

Background

- Task 5: Infrastructure, Operations & Permitting (Trimeric, Lamar U., Aker)
  - Identify/evaluate existing infrastructure (pipelines, wells, platforms) for re-use
  - Feasibility of subsea templates in GoM
  - Risk assessment of early stage CO_2 transport operations (truck & barge)
  - Generate source-transport-sink networks for scenario optimization
  - Use analog sites (e.g., High Island area) to develop methods and analysis
- Trimeric
  - We provide Chemical and Process Engineering services to industry, government agencies, and consortia
  - 18 Chemical Engineers
  - Founded in 2003
  - Austin / Buda, TX location

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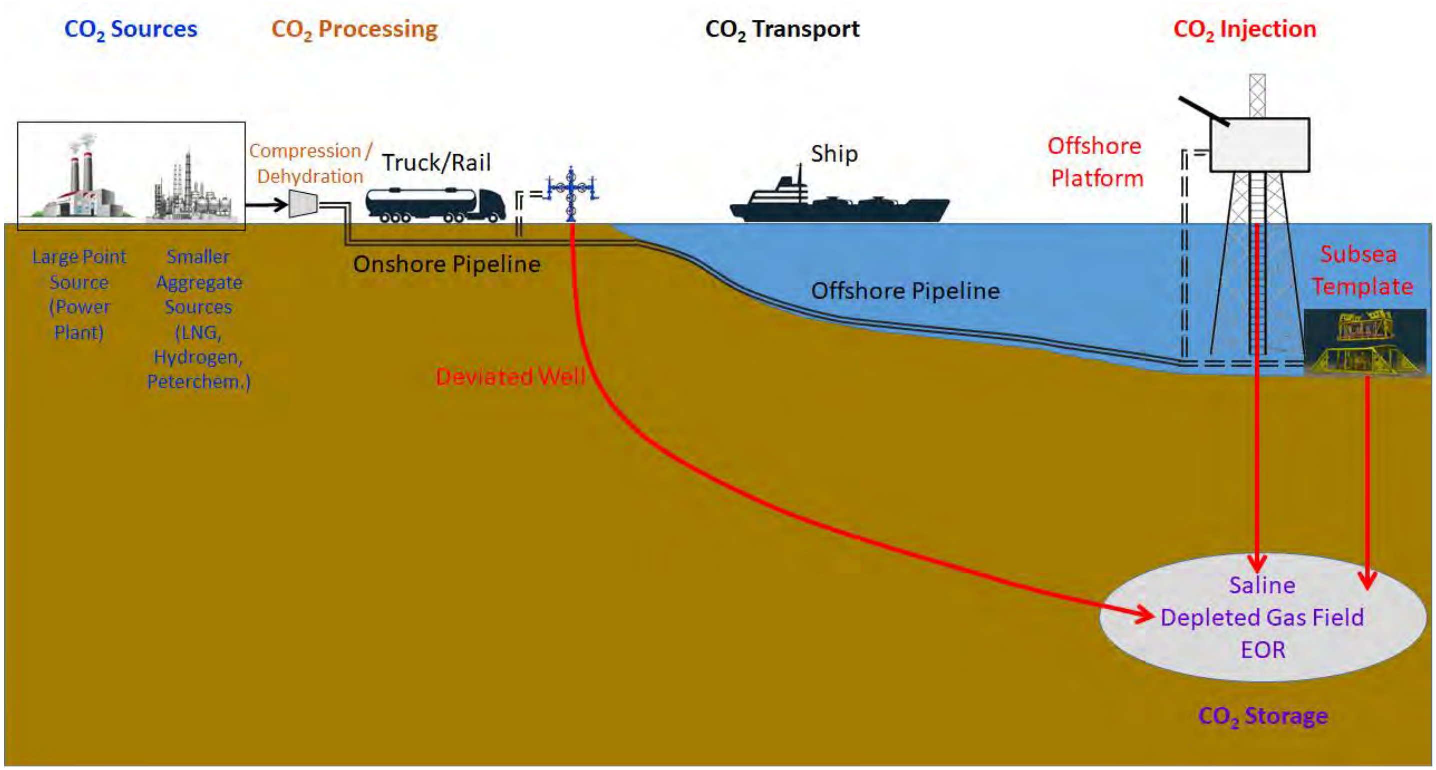
Outline of Near-Offshore Storage



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Infrastructure Re-Use Assessment

Infrastructure Re-use

- Wells, Pipelines, and Platforms for Oil and Gas Production = Potential Re-use Targets
- Goals:
  - Develop screening criteria to assess the scale of the opportunity
  - Identify high priority opportunities for more detailed assessment
  - Identify data gaps/needs/challenges
- For today's presentation – Focus on Pipelines as an example
  - Represent a high value re-use opportunity
  - Represent general challenges of re-use

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Pipeline Re-Use: Phase 1 - Screening

- Scope:
  - State and Federal Waters
  - Texas and Louisiana Coastline
- Screening Criteria
  - Age
  - Pressure Rating (keep CO_2 in supercritical state)
  - Diameter
  - Water Depth
  - Length
- Darrell Davis – O&G Industry – Lead on this effort

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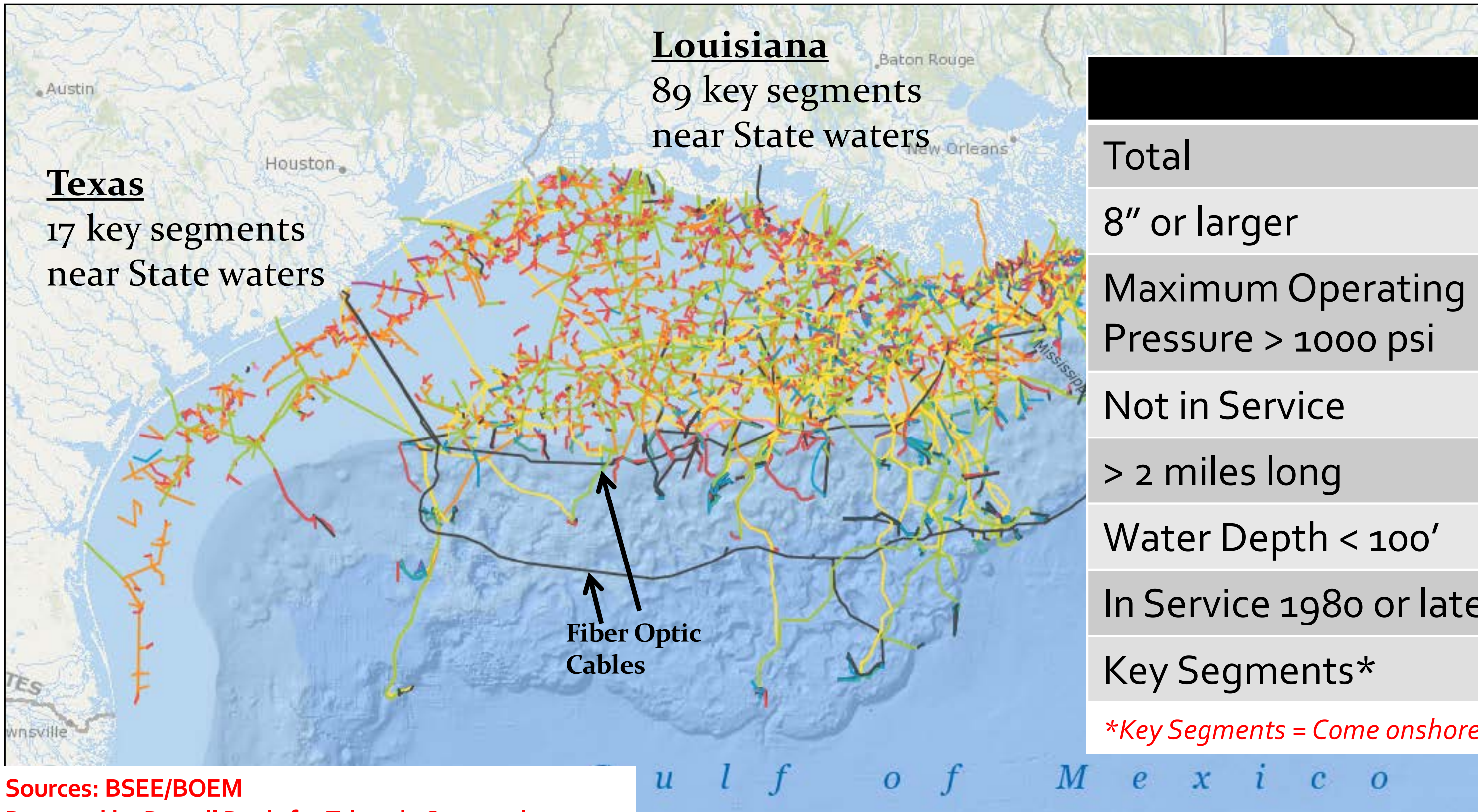
Pipeline Opportunity: Federal Waters



	# Segments
Total	20,274
8" or larger	4,614
Maximum Operating Pressure > 1000 psi	3,875
Not in Service	1,927
> 2 miles long	951
Water Depth < 100'	520
In Service 1980 or later	355
Key Segments*	11

**Key Segments = Come onshore and terminate near state waters*

Sources: BSEE/BOEM
Prepared by Darrell Davis for Trimeric Corporation

Pipeline Re-Use : Phase II - Workflow

- Goal: Develop framework to assess specific lines for re-use
- Industry Input
  - Operator: Provided Detailed Pipeline Evaluation Criteria
  - Broker: Useful life of pipelines up to 85 years
- Review Individual Pipelines for Public Data
  - Decommissioning procedures
  - As-Built/Survey Drawings
  - Leak/repair records
  - Identify Lines for “Case Study” or deeper dive

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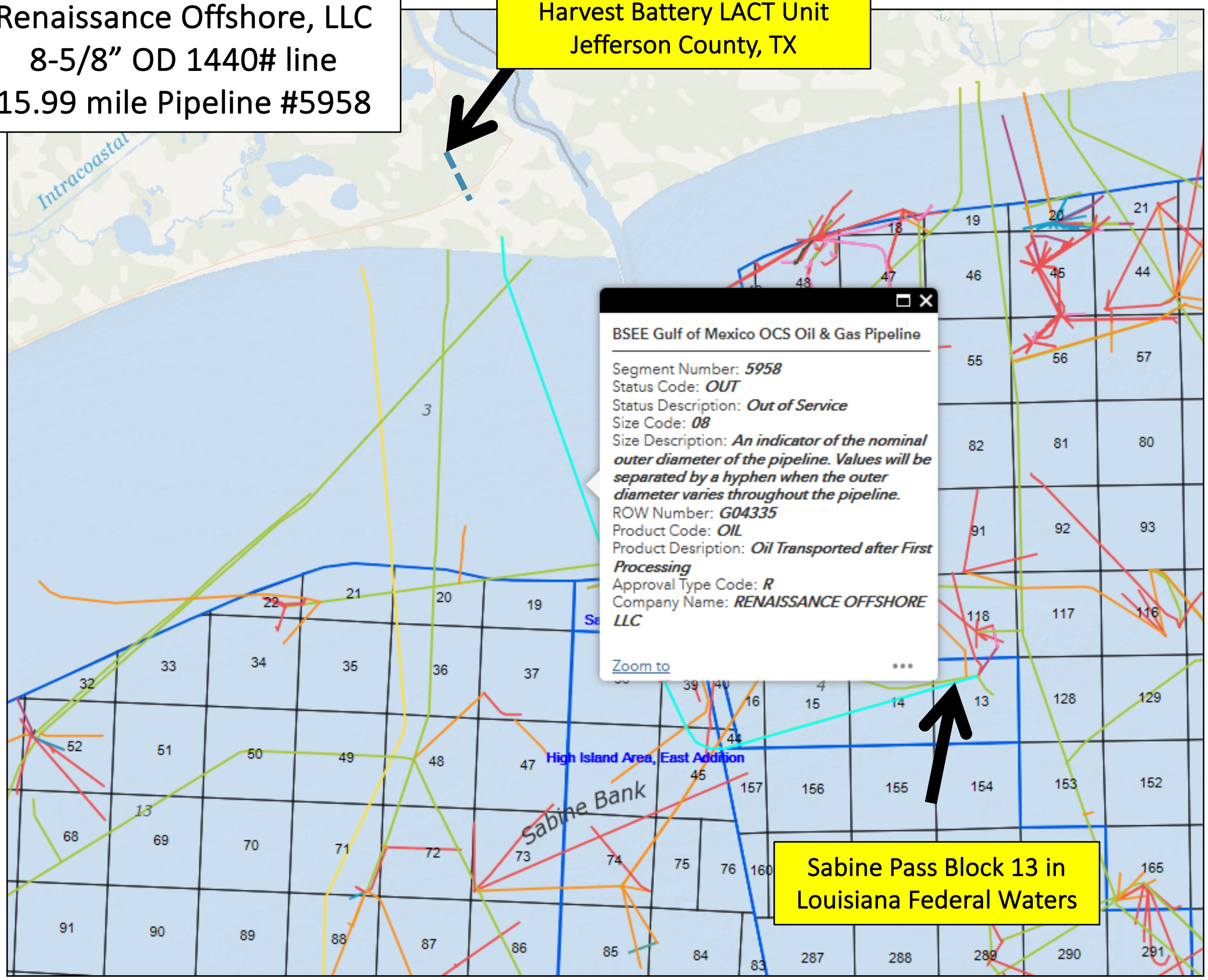
Pipeline Re-Use : Phase II - Workflow

- Three Specific Lines for Initial Deep Dive:

Region/Location	Line ID	Last Owner	In Service Date	Size	Max Oper. P (psig)	Length (miles)	Water Depth (feet)	Status
Louisiana (Vermillion/ White Lake)	5434	Columbia Gas Transmission	11/14/1984	36"	1253	6.27	10 - 32	Abandoned In Place
Texas (High Island)	5958	Renaissance Offshore	5/28/1981	8"	1440	15.99	39 - 50	OOS
Texas (Galveston)	7199/ 3489	Black Marlin	12/1984	16"	1367	23.87	48 - 61	Proposed Abandon

Renaissance Offshore, LLC
8-5/8" OD 1440# line
15.99 mile Pipeline #5958

Harvest Battery LACT Unit
Jefferson County, TX



Sabine Pass Block 13 in
Louisiana Federal Waters

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Next Steps

Task 5 : Infrastructure – Next Steps

- Continue parallel efforts into well, pipeline, platform re-use screening and workflow development
- Engage industry review/input of work products as they are developed
  - Leverage expertise of Aker
- Longer term:
  - Extend efforts into other transport options
    - *Shipping, deviated wells, subsea templates etc.*
  - Source/sink optimization with analog sites

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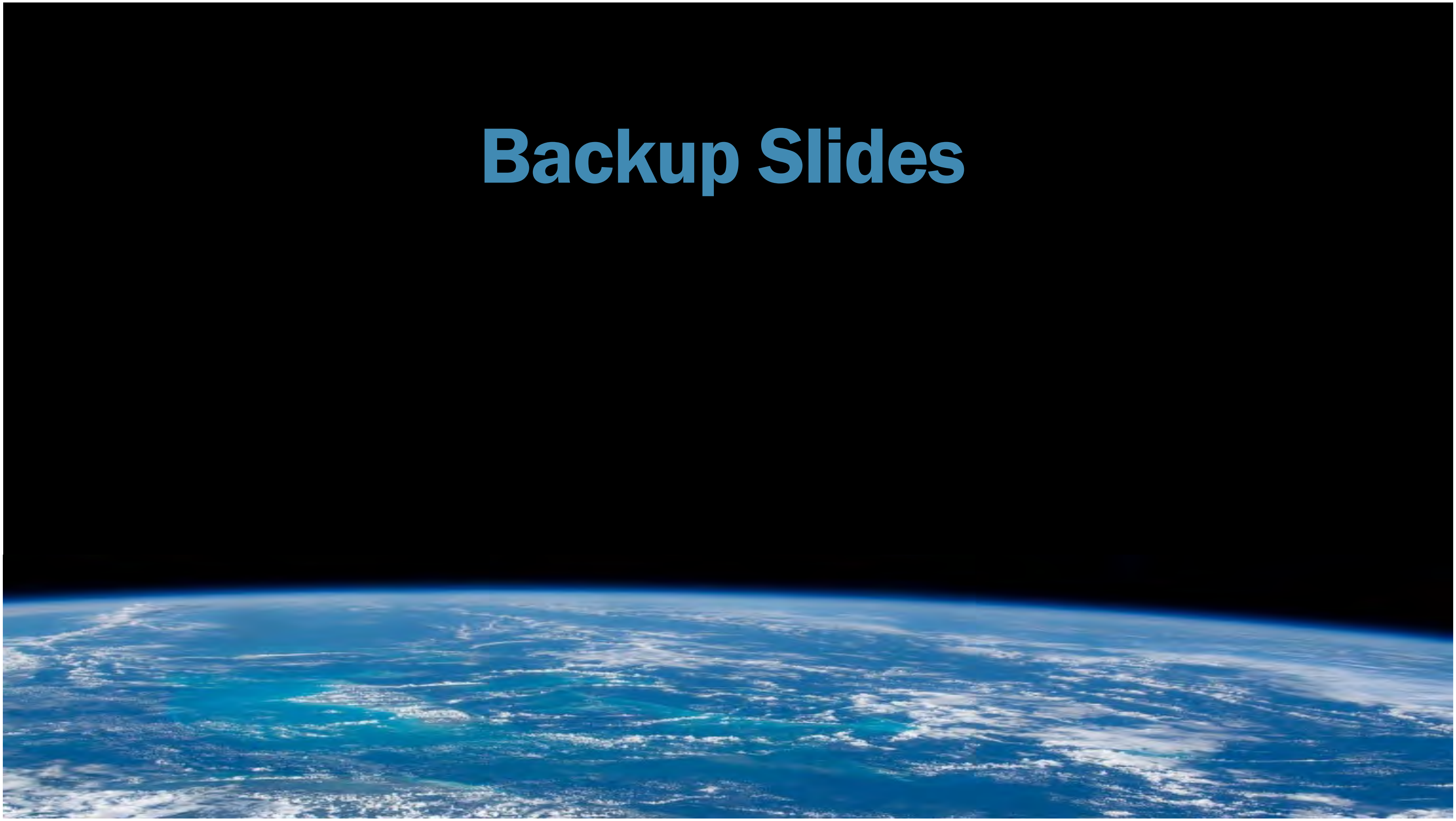
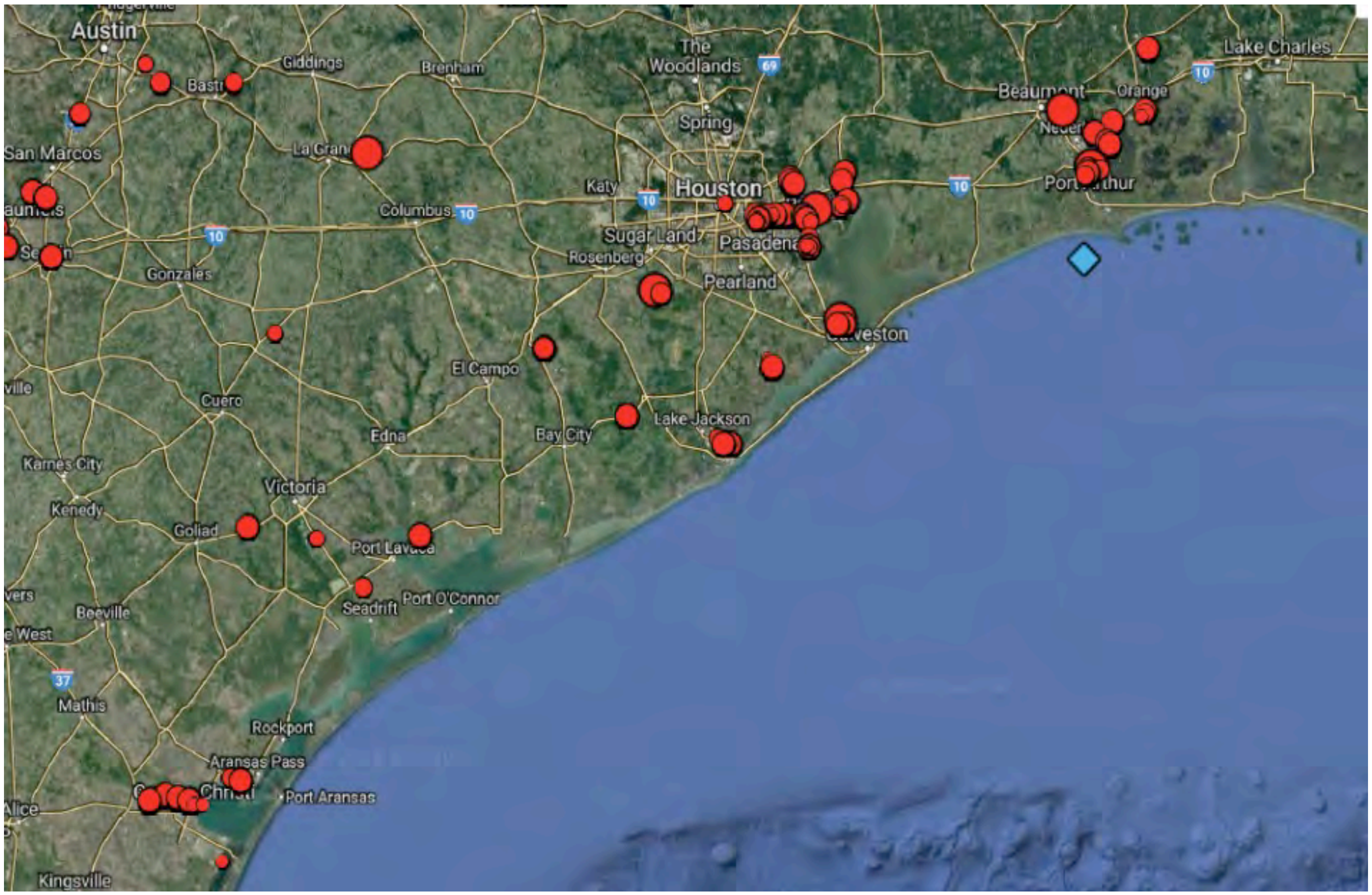
Discussion


Backup Slides

Potential CO_2 Sources: Texas Gulf Coast



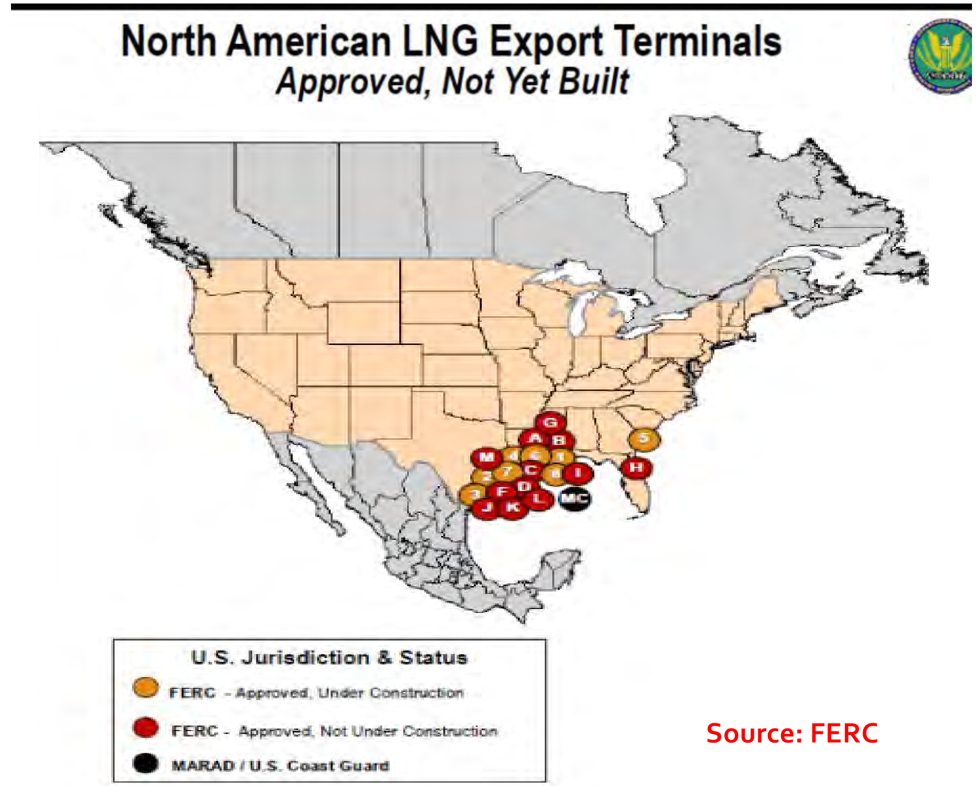
- Large Source = 400k+ tonnes CO_2/yr
  - Size of dot indicates scale of emissions)
- 148 Large Sources in Texas
  - ~75 within 50 miles of coastline
- Regions of Focus
  - Beaumont/Port Arthur
  - Greater Houston
  - Corpus Christi
- Data from EPA GHGRP 2017

CO_2 Sources: 45Q Tax Credits (2018 Revised)

- Capture and Sequestration Requirements
  - 500,000 tonnes/yr (Power Plant)
  - 25,000 tonnes/yr (Utilization)
  - 100,000 tonnes/yr (All Others)
- Progressive Tax Credit
  - U.S. $20 - $35+ for EOR/EGR and Utilization
  - U.S. $32 - $50 for Non-EOR
- Construction must start by 1/1/2024

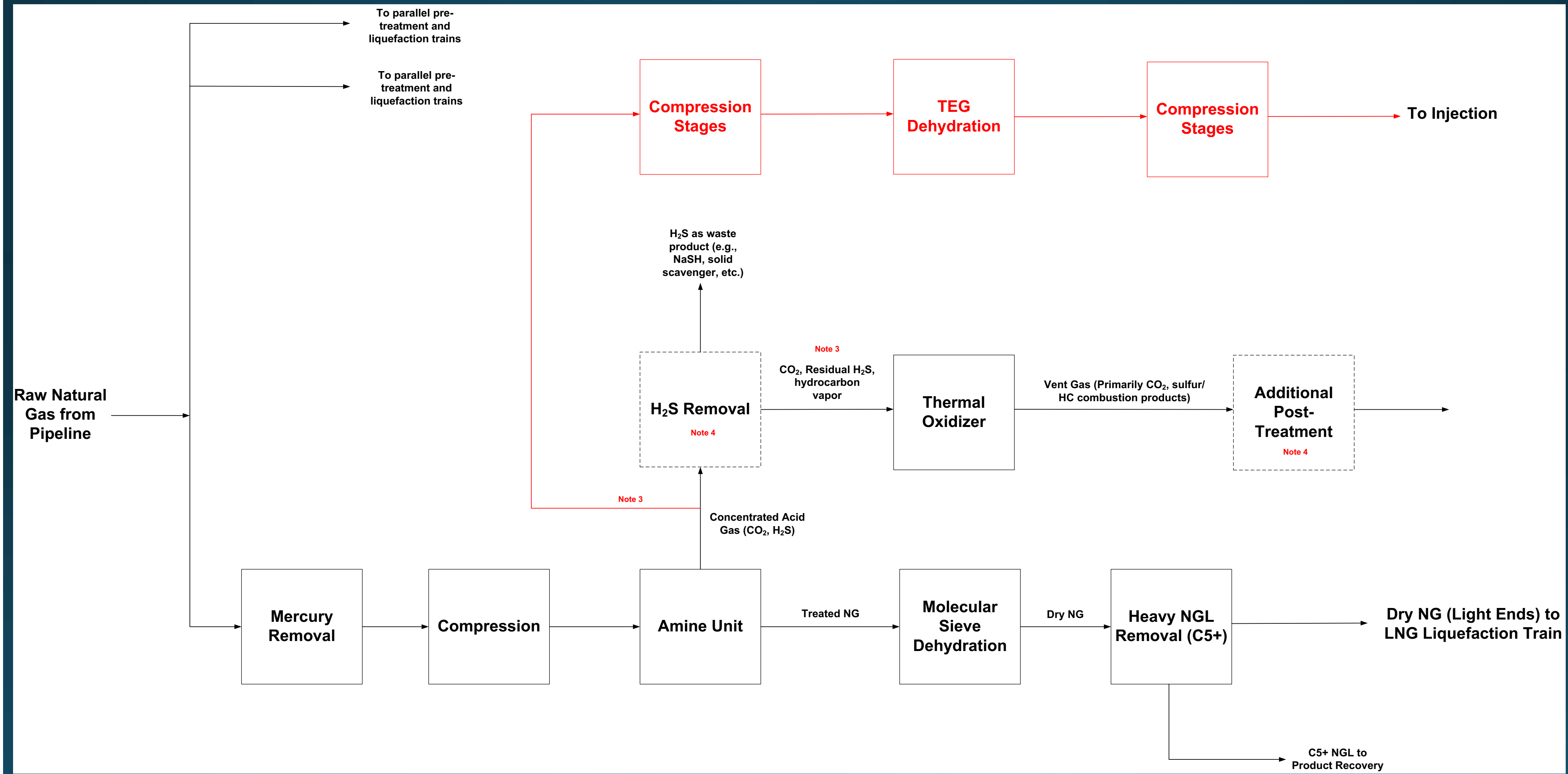
LNG Facilities: Emerging Opportunity?

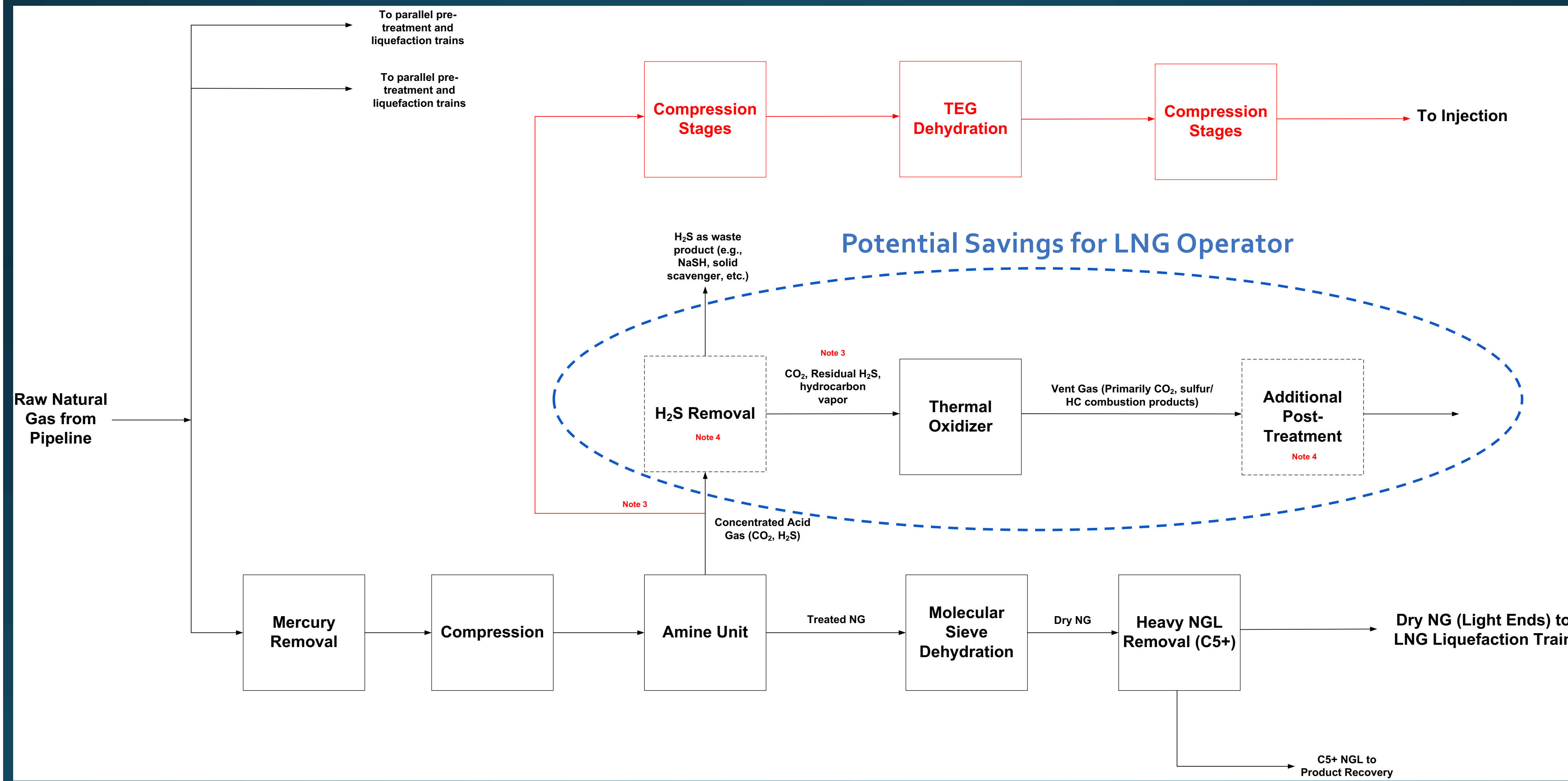
- High-purity CO_2 source
  - CO_2 generated as part of the purification of LNG
- Large CO_2 source
  - Public GHG PSD Application LNG Facility = 3 LNG trains
  - CO_2 emissions > 1.5 million tonnes/year
    - ~2 sources: gas turbines (dilute CO_2), AGRU (concentrated CO_2)
- Several facilities/projects in near-shore GoMCarb region
  - Trimeric tracking >10 facilities/projects
  - Operators have indicated openness to engagement with GoMCarb
- Potential benefits to LNG operators
  - 45Q tax credits
  - Eliminate/reduce load on pre-treatment processes (e.g., thermal oxidizer)



Source: FERC

UTCCS-5 Meeting, Jan. 28, 2020, Austin, TX

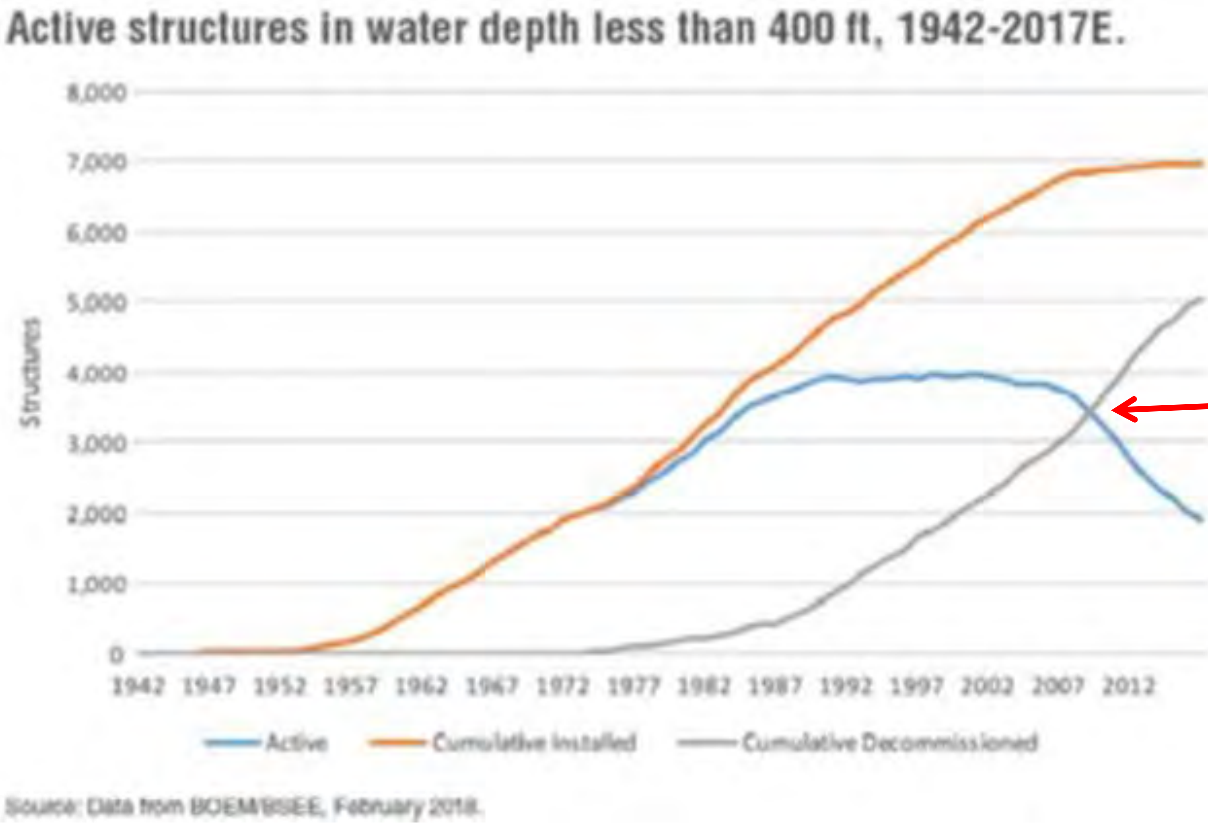



Raw Natural Gas from Pipeline
To parallel pre-treatment and liquefaction trains
To parallel pre-treatment and liquefaction trains
Compression Stages
TEG Dehydration
Compression Stages
To Injection
Potential Savings for LNG Operator
H_2S as waste product (e.g., NaSH, solid scavenger, etc.)
Note 3
CO_2, Residual H_2S, hydrocarbon vapor
H_2S Removal
Note 4
Thermal Oxidizer
Vent Gas (Primarily CO_2, sulfur/ HC combustion products)
Additional Post-Treatment
Note 4
Note 3
Concentrated Acid Gas (CO_2, H_2S)
Mercury Removal
Compression
Amine Unit
Treated NG
Molecular Sieve Dehydration
Dry NG
Heavy NGL Removal (C5+)
Dry NG (Light Ends) to LNG Liquefaction Train
C5+ NGL to Product Recovery

LNG Facilities: Challenges

- Impurities in AGRU CO_2
  - Hydrocarbons (e.g., methane, benzene, etc.), H_2S
  - Additional processing for transport offsets benefits of AGRU gas offtake
- Impact to LNG Facility
  - LNG Operators: Focus is on LNG production – ideally, CO_2 transaction handled separately by third party
    - CO_2 capture plan needs to start early in investment planning for LNG facility
  - Impact to production
    - What happens if CO_2 transport/storage goes offline? Design flare to handle AGRU offgas?

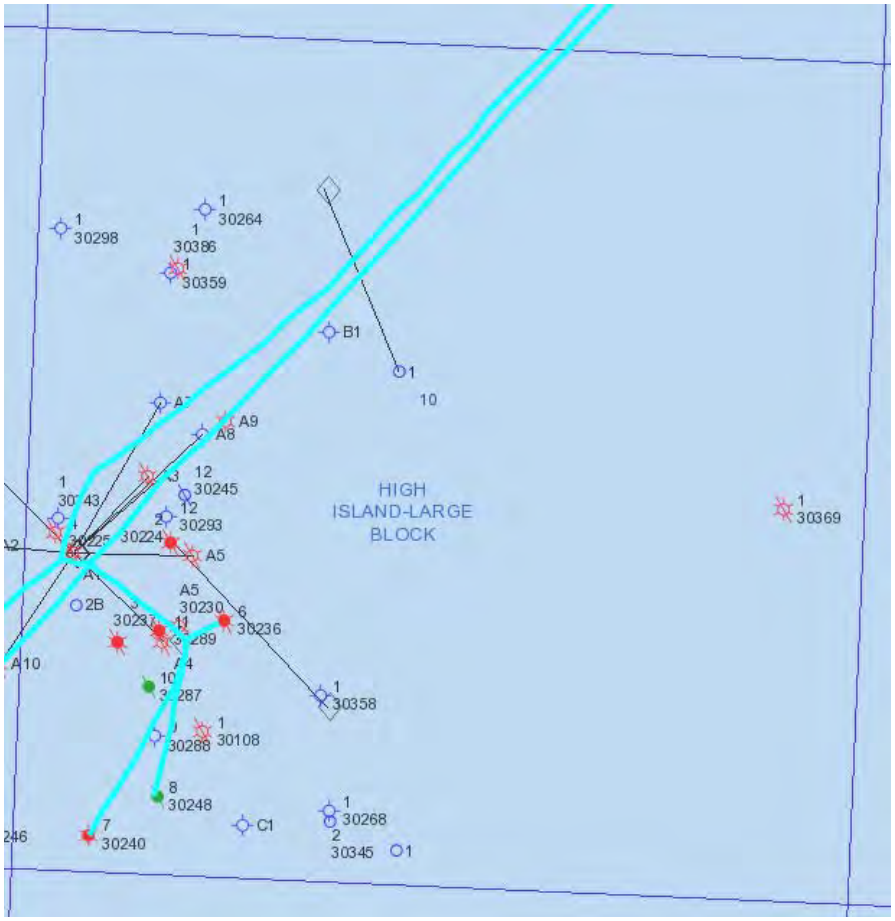
Re-Use Challenges–
Future Stock of Reusable Infrastructure



Inventory for Re-use Decreasing

Source: Kaiser and Narra, LSU Center for Energy Studies; Offsore Magazine, March 2018

HI-10L Wells



- Well map from TX RRC GIS
- TX RRC database is not complete and not easy to search
- UT has access to proprietary databases that are more complete
- HI-10L
  - 34 wells in TXRRC
  - 9 additional wells listed in UT database
  - None are operational
  - Half are plugged
  - Half are dry holes

Well Screening Criteria

1st Pass Criteria: Readily Available, such as from Databases	
Construction Date > 1970	Modern well construction HI-10L: 13 of 43 wells were pre-1970
Full API Number	Older wells do not have full API number HI-10L: 11 wells did not have full API in RRC GIS
Total Vertical Depth	Deeper wells = more expensive HI10L: wells terminate at 5,800-14,000 ft
Casing Diameter	Larger diameter accommodates modern tools HI10L: 5.5” to 10.8”, 5.5” sufficient for 3/8” tubing
2nd Pass Criteria: Available with more effort, such as Permit Searches	
Well design/completion history	Determine pressure specification Look for problems in completion
3rd Pass Criteria: Incur Significant Costs, such as Well Integrity Tests	
Well integrity tests: Make measurement/re-test upon re-entering well	All wells in field must have integrity assured Fewer wells reduces cost for assuring well integrity

Platform Re-Use

- Repurposing platforms for CO_2 storage could help offset cost of decommissioning idled platforms
- Potential platform re-use criteria
  - Location/proximity to preferred injection site
  - Age/general condition of platform
  - Space on platform (including slots for wells)
  - Regulatory/legal considerations
    - How does liability/decommissioning responsibility transfer?
    - "Rigs to Reefs" and other programs may be starting point
- Platform re-use unlikely to be a project driver
  - Reservoir, pipeline, and in some cases, wells will be prioritized ahead of platforms

Idle Iron Data – Existing Stock of Reusable Infrastructure

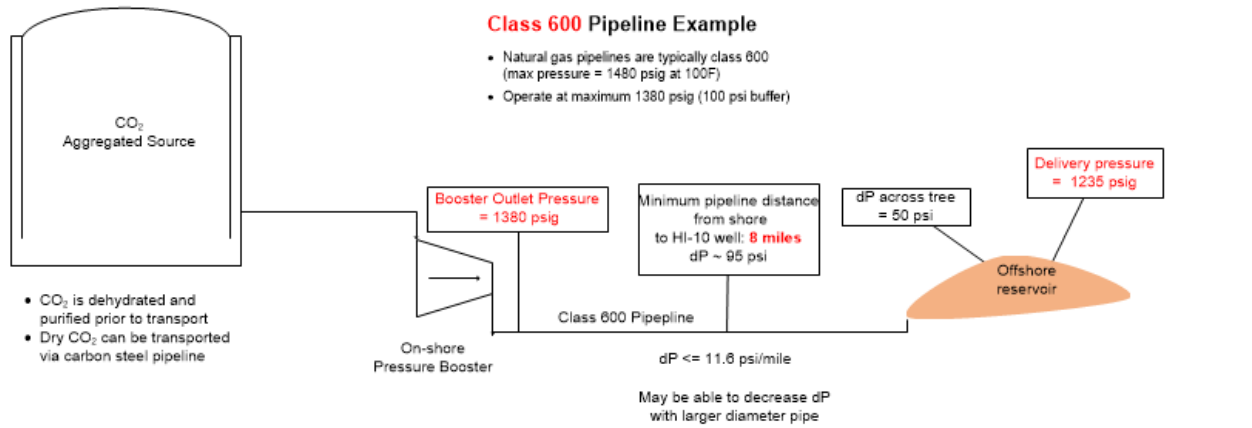
- Red Triangles = "Idle Iron"
- Yellow Dots = All other standing platforms
- Federal water only; state does not have robust platform data

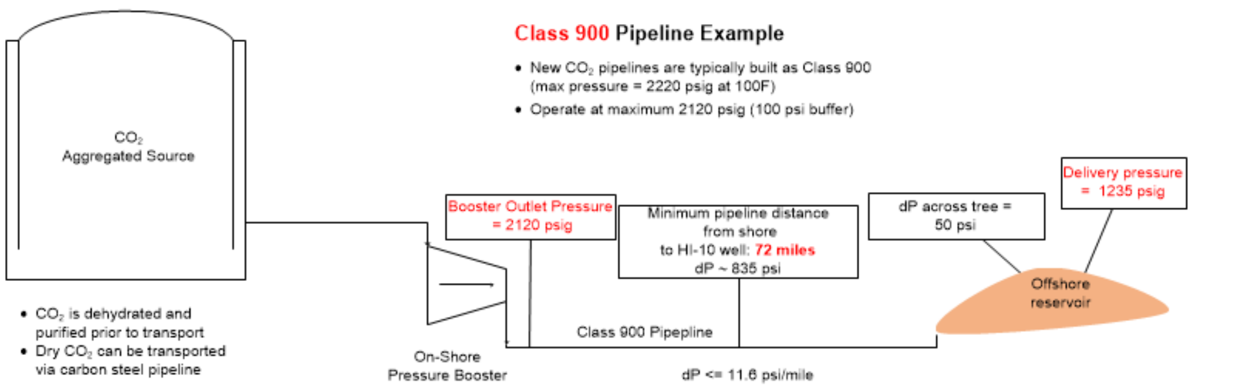
Source: Plough, A. (2017, August 3). American Idle: Decommissioning costs sink offshore drillers into latest crisis. Debtwire Investigations.

Pipeline Opportunity: New Offshore Pipeline Costs

Source	Fluid	Cost ($/in-mile)		Offshore Multiplier
		Onshore	Offshore	
NATGAS.INFO website	Natural Gas		$40,000 - $64,000	
Kaiser 2016	Oil, Natural Gas		$45,000 - $418,333	
JRC (Serpa, Morbee and Tzimas 2011)	CO_2		$67,600 - $89,600	
USAID and SARI/Energy 2006	Oil, Natural Gas			1.96
Brito and Sheshinski 1997	Natural Gas	$40,000	$100,000	2.50
Global CCS (Vermeulen 2011)	CO_2	$103,000	$144,800	1.41
Scottish Power Longannet	CO_2	$12,900	$49,900	3.87
IPCC 2005	CO_2			2
ZEP 2011	CO_2			1.38
JRC 2011	CO_2			2
NETL 2013 via Kinder Morgan	CO_2	$50,000	$700,000	14
			Average	**3.64**

Pipeline Challenges: Pressure Rating





Assessment of Large CO_2 Point Sources from Four Refineries of SE TX

Adhish Madugula and Tracy Benson, Lamar University

GoMCarb Task 5 – Infrastructure, Operations, and Permitting

Name
GoMCarb Task

SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

OBJECTIVE

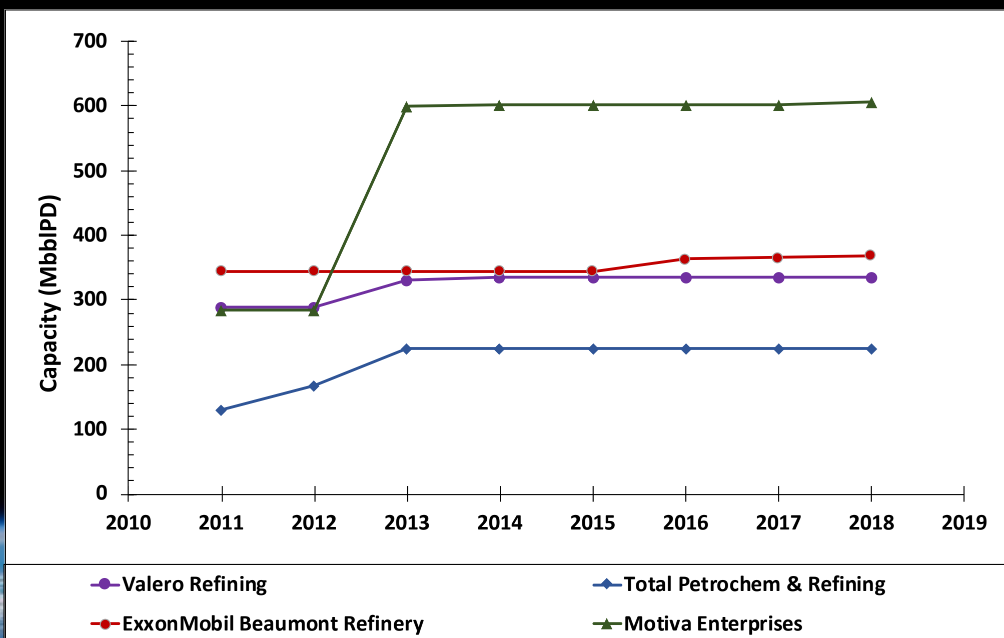
Evaluate the annual CO_2 production within a refinery (both from an overall perspective and from specific units within the refinery)

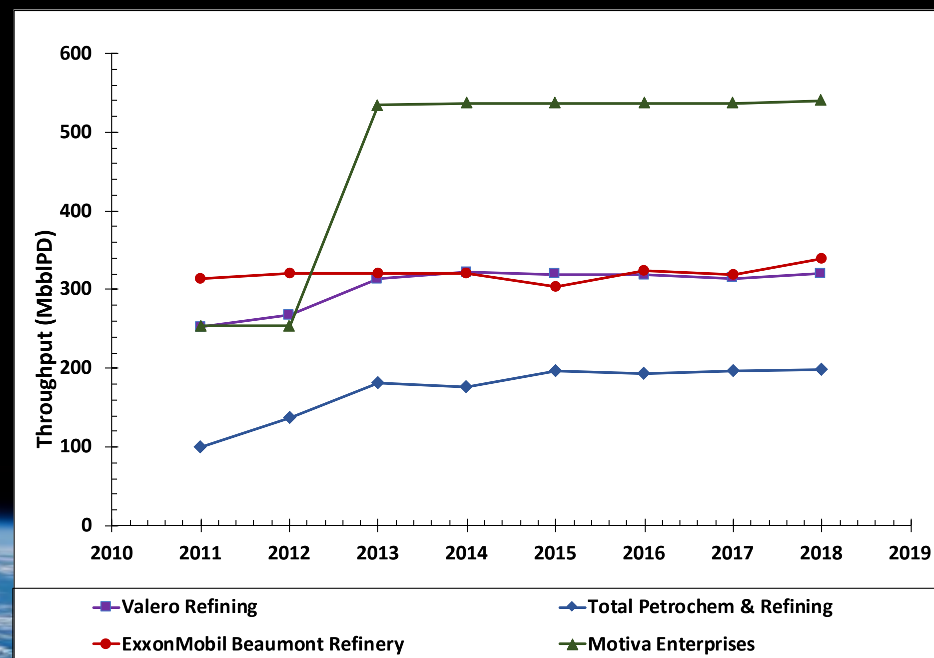
Motiva, Port Arthur, TX

ExxonMobil, Beaumont, TX

Total, Port Arthur, TX

Refinery Capacity vs Actual Production

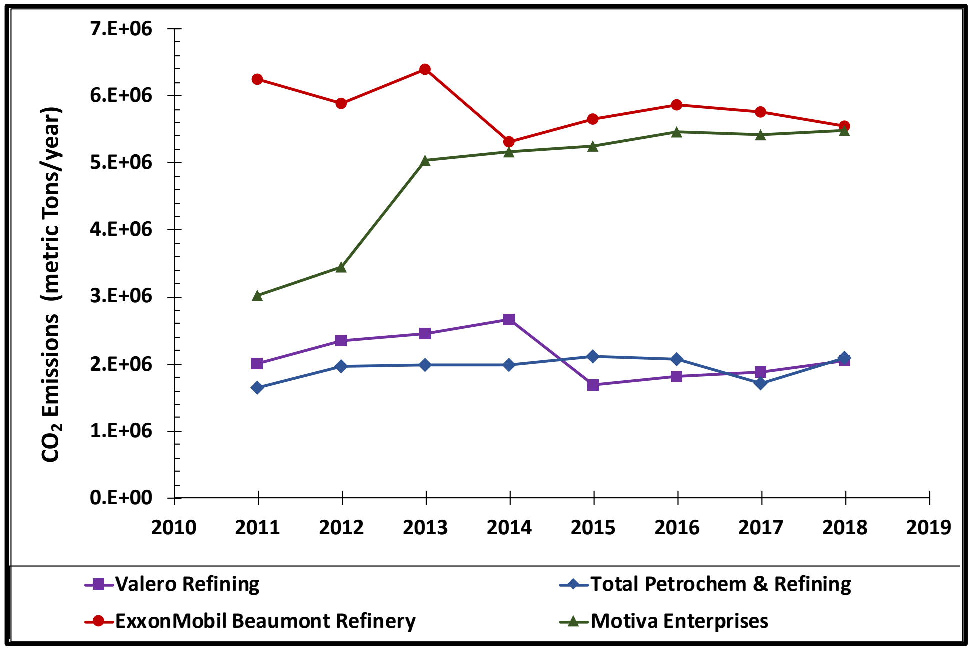




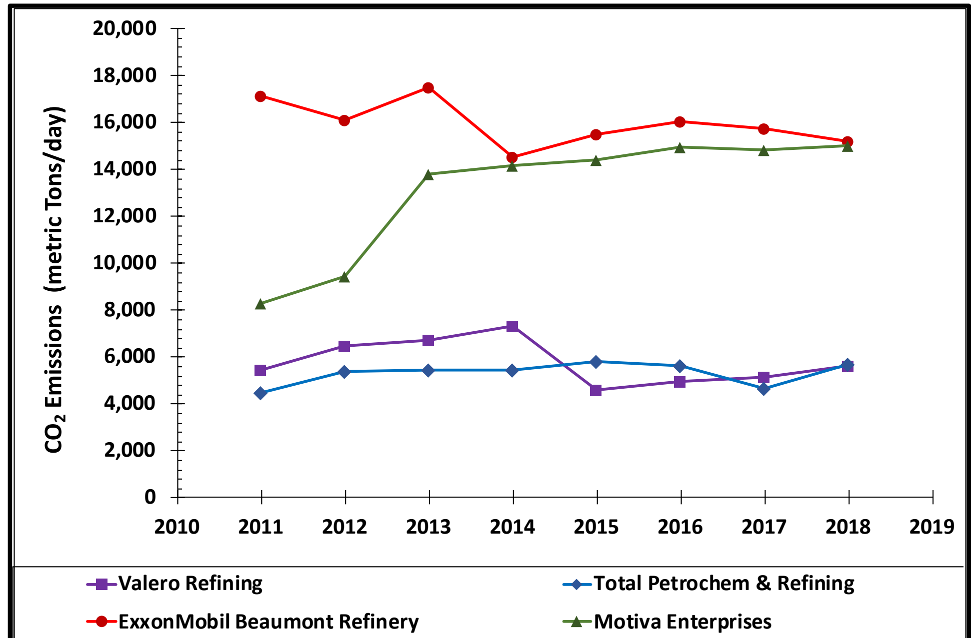
Corporate quarterly and annual reports

Overall CO_2 Emissions

YEARLY



DAILY



https://ghgdata.epa.gov/ghgp/main.do#

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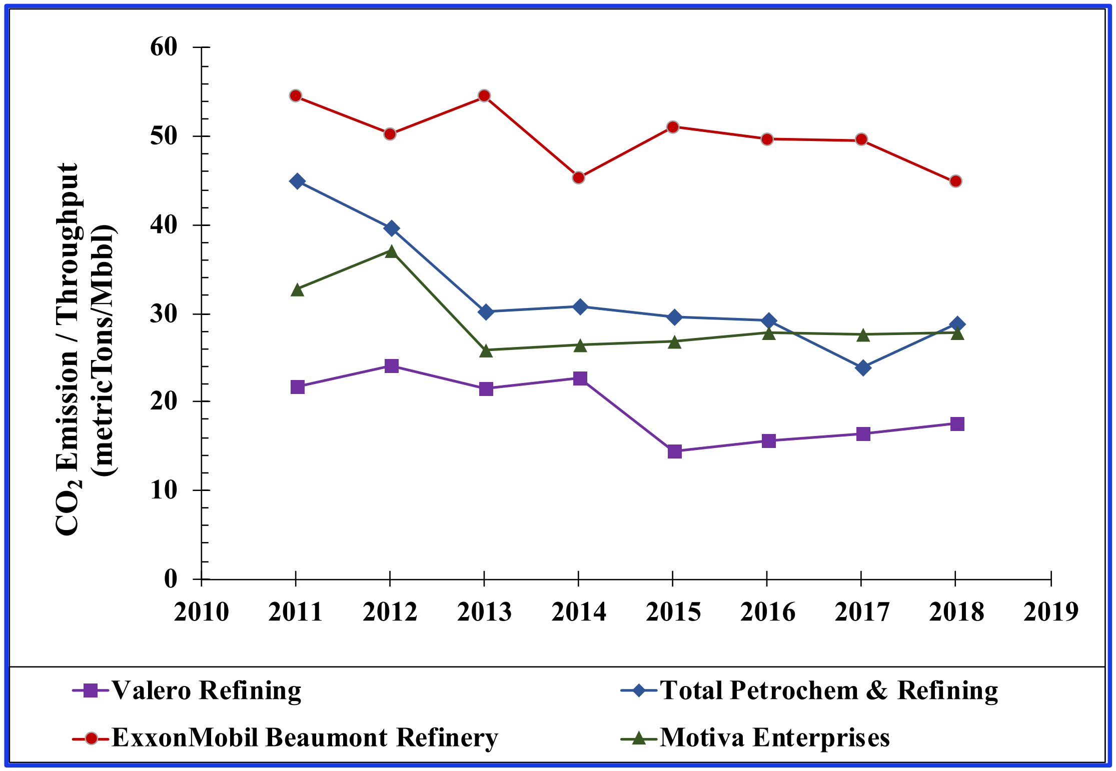
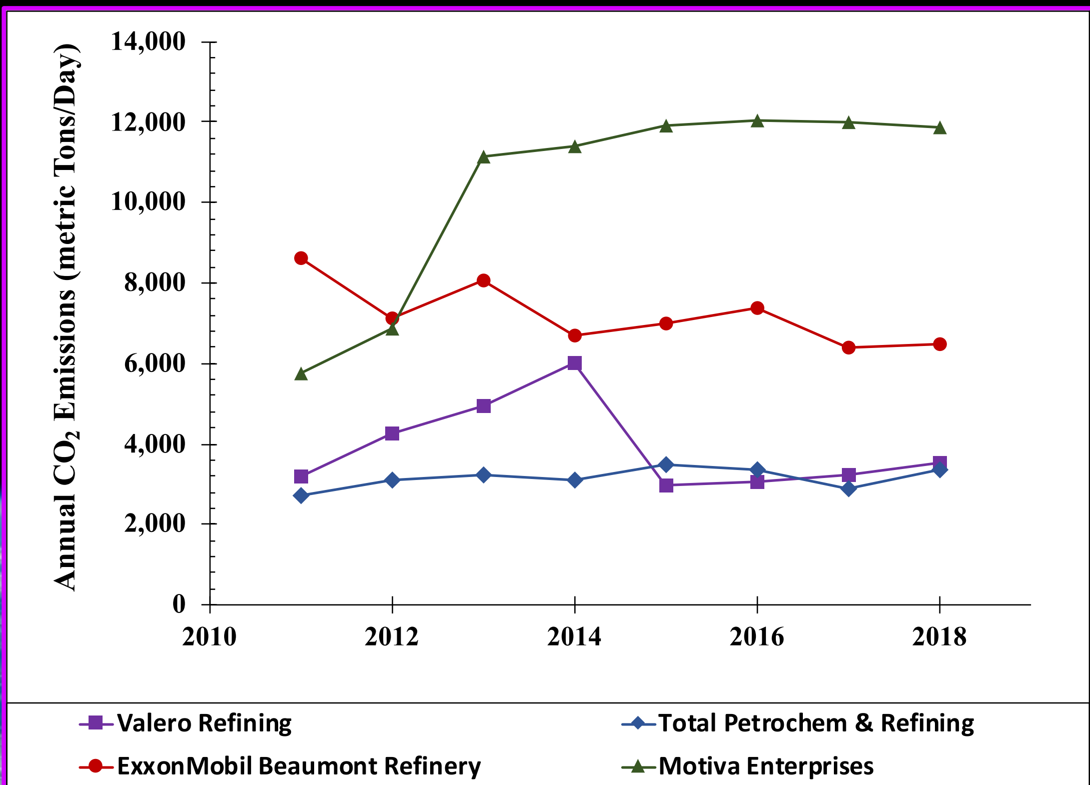
Types of CO_2 Emission Sources

Unit Type	% of CO_2 Produced
Stationary Fuel Combustion Sources	55 - 60
Catalytic Cracking & Reforming	25
Sulfur Recovery	7 - 10
Flares	minimal
Electric Power Generators	a
Process Vents	a

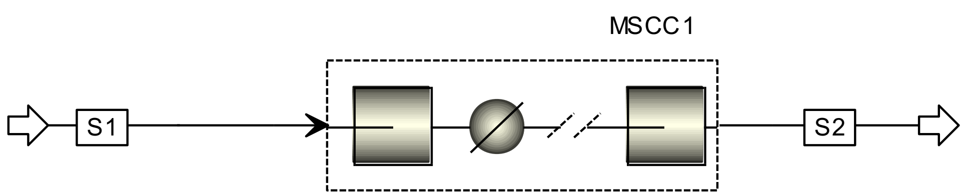
[a] **Only reported by ExxonMobil. No correlation to production.**



Stationary Fuel Combustion



Next Stage: Compressor Sizing and Energy Requirements



Multi-Stage Compression w/ Interstage Cooling

$$CR = (PR_T)^{1/N}$$

Centrifugal Compressor: CR → 1.5 - 2

Steam Methane Reforming Operations

0.5 MM tonnes CO_2/yr

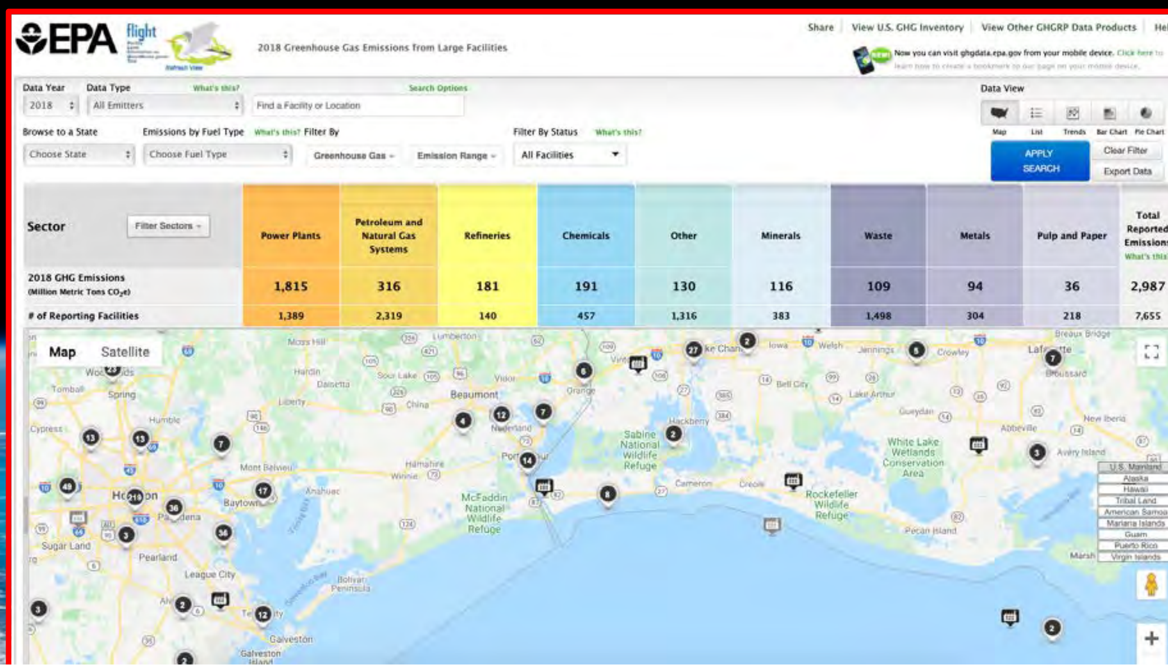
1 – 54 atm

Optimal # Stages: 6

Stage	Temp.	Press.	Compression ratio	Horse-power
	ºF	atm		hp
1	182	1.95	1.95	1,043
2	218	3.79	1.95	1,101
3	219	7.38	1.95	1,091
4	219	14.36	1.95	1,070
5	220	27.95	1.95	1,031
6	221	54.40	1.95	952

Closing Thoughts

- Neglecting hurricanes, CO_2 production is predictable, steady, and corelates with refinery capacity
- Motiva doubled its capacity in 2012 to 600,000 BPD
- ExxonMobil will edge out Motiva as largest refinery in the 2021 expansion



Discussion

The University of Texas at Austin
Stan Richards School of Advertising & Public Relations
Moody College of Communication

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Task 6. CCS Communication Research

RACHEL ESTHER LIM, PH.D. Postdoctoral Fellow, The University of Texas at Austin
LUCY ATKINSON, PH.D. Associate Professor, The University of Texas at Austin
LEE ANN KAHLOR, PH.D. Associate Professor, The University of Texas at Austin
HILARY CLEMENT OLSON, PH.D. Senior Lecturer, The University of Texas at Austin
EMILY MOSKAL, Research Program Coordinator, The University of Texas at Austin

SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

Motivation

Two audiences in CCS communication

- ✓ Key stakeholders: stakeholders directly involved in or impacted by CCS technology
- ✓ Lay citizens

Key stakeholders are important

- ✓ Engaging key stakeholders is imperative for the success of the CCS project
- ✓ Impact lay citizens perspectives on CCS technology

CCS Communication Approach

Objectives

- ✓ Understand CCS benefits and risks relevant to key stakeholders (Qualitative)
- ✓ Build CCS messages that resonate with key stakeholders (Quantitative)

Result. Rank Order Perceived Benefit

	CCS Benefits	N	M	SD
1	**Addressing climate change by reducing CO2 emissions into the atmosphere**	69	**2.96**	2.16
2	**Reducing air pollution**	79	**2.47**	1.33
3	Achieving environmental goals (e.g., Paris agreement)	56	3.96	2.24
4	Presenting economic opportunities for new businesses (e.g., sustains current jobs and creates new ones)	57	5.00	2.01
5	Keeping the US at the forefront of energy technology	47	5.11	2.46
6	Being ready to go now; there's no need for extensive R&D	42	6.48	2.38
7	**Bringing about better air quality** by reducing conventional air pollutants that threaten human health	79	**2.81**	1.55
8	Reducing asthma rates	48	4.83	1.72
9	Effectively managing heavy metals (mercury) and particulate matter	44	4.84	2.03

Focus group and in-depth interviews with stakeholders in Beaumont and Port Arthur, TX
Online survey (collected from mTurk) (N=81; the general public in the US)
**1- most important, 9- least important*

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Result. Rank Order Perceived Risk

	CCS Risks	N	M	SD
1	**Well blow outs and CO2 leakage through caprock**	64	**3.88**	1.76
2	Uncertainty of demonstrating 1000 years CO2 storage security	47	4.23	2.37
3	Micro-seismicity (small earthquakes)	53	4.38	2.50
4	High cost (e.g., individuals might see added surcharges to their energy bills)	62	4.21	2.62
5	Unclear liabilities on managing geological storage sites. (e.g., Legal repercussions from using private land and legal liabilities)	48	5.38	2.12
6	**Uncertainty in long-term maintenance of facilities and stored CO2**	59	**3.86**	1.90
7	Delay in transition to renewable energy	45	5.20	2.71
8	**Affecting underground water from storage leakages**	72	**2.86**	1.73
9	**A large inadvertent release of CO2 and its effects on a local area**	72	**3.10**	2.03

Focus group and in-depth interviews with stakeholders in Beaumont and Port Arthur, TX
Online survey (collected from mTurk) (N=81; the general public in the US)
**1- most important, 9- least important*

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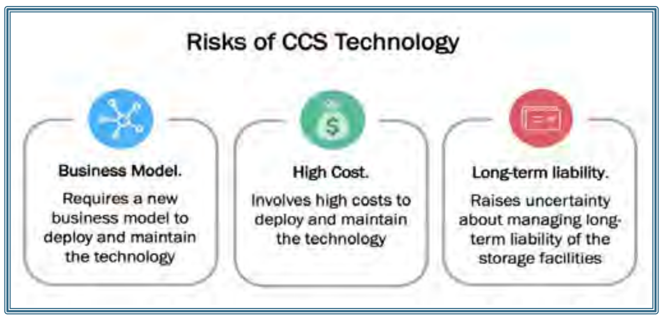
Next Step: Online Experiment

Benefit and risk messages
✓ Framing CCS benefits and risks relevant to key stakeholders (from qualitative work)

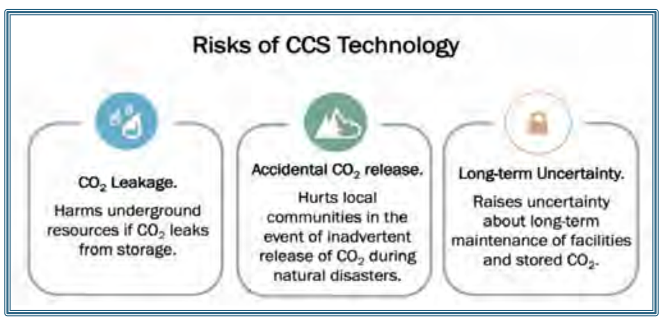
Source of information
✓ Source may impact how people view the information (from qualitative work)

Individual factors
✓ Psychological proximity of climate change affect how people engage into issues related to climate change (literature)

Benefits



Economic risks



Environmental / technology risks

Pretest: Stimuli Development

- **Preparing for the main test**
  - ✓ Testing stage
  - ✓ Constructing appropriate messages
  - ✓ Preliminary relationships
- **N=112 (student sample)**
- **Measurements**
  - ✓ **Manipulation check questions**
  - ✓ **DVs.** CCS support, concern toward CCS technology

Manipulation pretest results

- Messages were significantly different in terms of the manipulation scale (6-point scale):

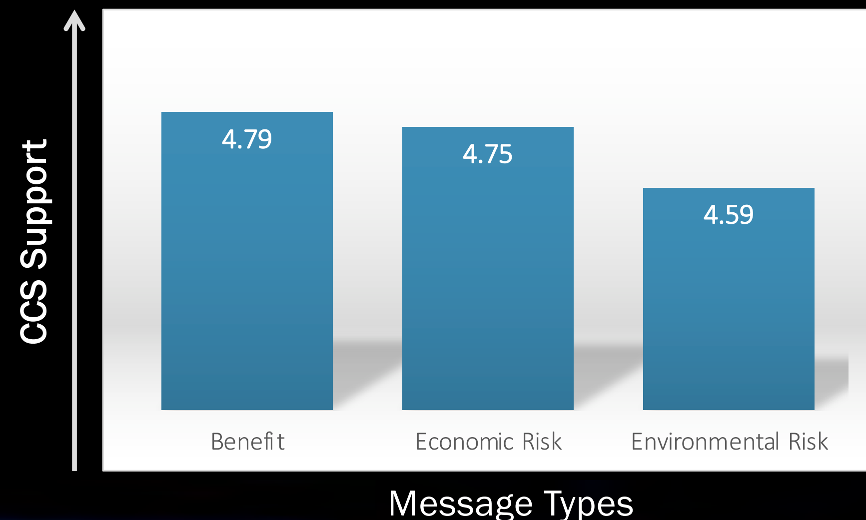
"This message communicated about the _______ of CCS technology."

- *Risks = 1, Benefits = 6*
- *Negatives = 1, Positives = 6*
- *Concerns = 1, Advantages = 6*
- *Harm = 1, Value = 6*

	Message Category	N	Mean	SD	df	F
Manipulation Check Scale	Benefit	38	5.57	0.77	1, 109	102.35***
	Economic Risk	40	2.69	1.39		
	Env / Tech Risk	34	2.02	1.14		

Pretest results

- ***<u>No significant differences among messages</u>*** on participants' intention to support CCS technology.
- A similar pattern is shown in perceived concern toward CCS technology.



Trusted Source

	Mean	SD
Oil & Gas	2.33	1.17
University Scientists	4.27	0.70
Industry Scientists	4.24	0.88
White House	2.61	1.13
EPA	3.80	1.03
DOE	3.62	0.98
State Gov.	2.89	0.99
Environmental Nonprofits	3.88	0.86
Local Gov.	2.92	0.93
Members of my community	2.76	1.00

How much do you trust each of the following as a source for information about carbon capture and storage?

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Individual factors

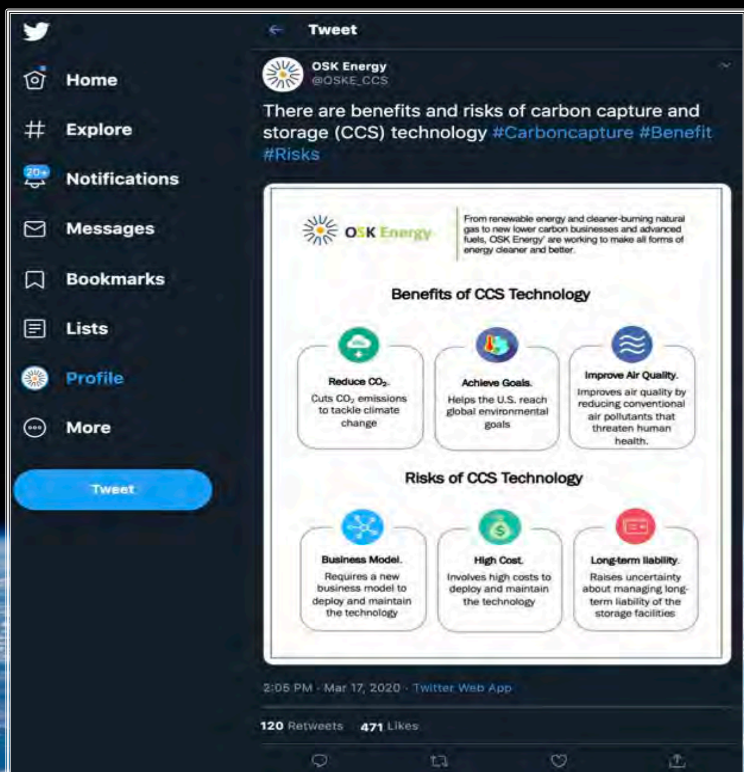
Psychological proximity to climate change

- ✓ The extent to which a person perceives that the event of climate change is psychologically close/ distant to the self
- ✓ Psychological proximity impacts how people process information and engage with the issue

CCS is a climate change mitigating technology

- ✓ How people view CCS messages may be impacted by a person’s perceived proximity of the climate change issue

Next Steps



- **Online survey.** 900+ N
- **Messages.** Benefit vs. Risk vs. Balanced messages (benefit-risk, risk-benefit)
- **Sources.** Oil & Gas Industry, University Scientist, Government
- **Individual factors.** Psychological proximity to climate change

➢ **To understand the extent to which messages, sources, psychological factors impact stakeholder response to CCS communication**

Thank you!

Questions?

Technical Outreach

Gulf of Mexico Partnership for Offshore Carbon Storage (GoMCarb)

Emily Moskal
Gulf Coast Carbon Center,
Bureau of Economic Geology
Task 6: Outreach

SECARB Offshore/GoMCarb Joint Partnership Meeting | March 26-27, 2020

The Goal

KNOWLEDGE

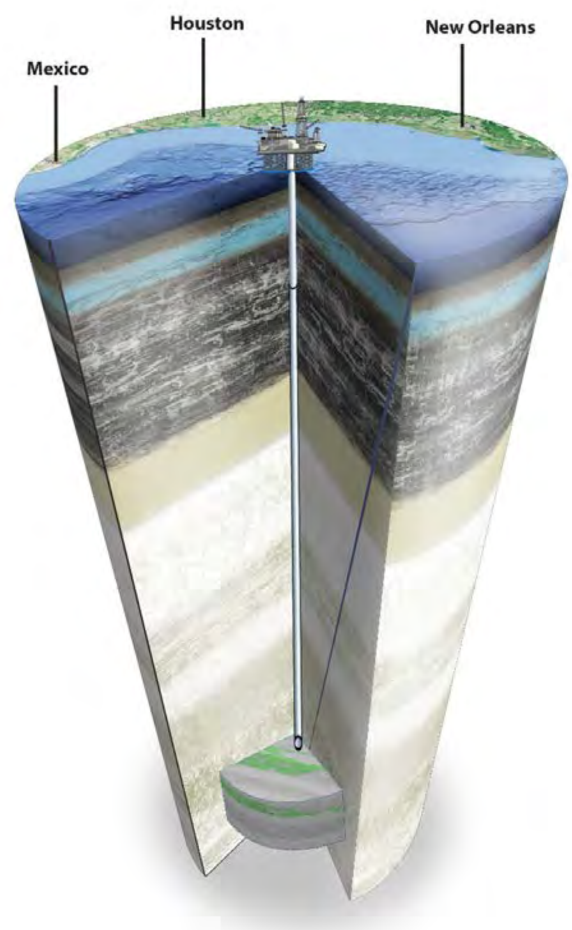
AUDIENCES

technical

public

regulatory

source industries engaged with large-volume storage resources



Meetings

Trading technical expertise and connecting with new groups loosely or directly engaged with CCS

Opportunities to share knowledge

- Oil & Gas Climate Initiative (OGCI) Investments Day (GCCC)
- iCCUS (GCCC)
- Carbon Capture, Utilization, and Storage at the D3 Revival - Energy Disruption Conference (GCCC)
- Port Arthur Chamber of Commerce 45Q meeting (Lamar University, GCCC)
- Also, AGU (LBNL, GCCC), SEG (GCCC), NETL (GCCC), Texas A&M (LBNL)

More opportunities

- Offshore Technology Conference (LBNL, Trimeric, GCCC)
- Gordon Research Conference on CCUS (GCCC)
- CLIMIT Summit (GCCC)
- American Beach and Shoreline Preservation Association and American Shoreline Podcast (GCCC)
- Alex Bump will talk about STEM-CCS and the 4th international offshore workshop

Source Industries & Regulatory Agencies

Trimeric: Several LNG facilities are starting up in TX and LA. LNG is a good source for CO_2.

Trimeric: Insight gained from expert interviews includes: large pipelines are in use already and pipelines reused for EOR require multiple booster stations to limit pressure during transport, which would increase project costs.

PIPELINE RE-USE

BOEM
Bureau of Ocean Energy Management

BSEE
Bureau of Safety and Environmental Enforcement

RRC
Railroad Commission of Texas

Texas General Land Office
Established 1836

work done by:

Trimeric Corporation

Partnership for carbon capture & offshore geologic storage
GoMCarb

Papers

- Lindsey, N., Dawe, C.T., and **J.B. Ajo-Franklin**, "Illuminating seafloor faults and ocean dynamics with dark fiber distributed acoustic sensing". *Science*, Vol. 366, No. 6469, pp. 1103-1107. doi: 10.1126/science.aay5881
- **Oldenburg, C.M.** and Pan, L. (2020), Major CO_2 blowouts from offshore wells are strongly attenuated in water deeper than 50 m. Greenhouse Gas Sci Technol, 10: 15-31. doi:10.1002/ghg.1943
- Ringrose, P.S., and **T.A. Meckel**, 2019, Maturing global CO2 storage resources on offshore continental margins to achieve 2DS emissions reductions: *Scientific Reports*, v. 9, p. 17994, doi:10.1038/s41598-019-54363-z
- **Meckel, T.A.**, Y.E. Feng**, R.H. Treviño**, and D. Sava. 2019. "High-Resolution 3D Marine Seismic Acquisition in the Overburden at the Tomakomai CO2 Storage Project, Offshore Hokkaido, Japan." International Journal of Greenhouse Gas Control 88 (September): 124–33. doi: 10.1016/j.ijggc.2019.05.034
- **DeAngelo, Michael V.,** Reynaldy Fifariz, **Tip Meckel**, and **Ramon H. Treviño.** 2019. "A Seismic-Based CO2-Sequestration Regional Assessment of the Miocene Section, Northern Gulf of Mexico, Texas and Louisiana." International Journal of Greenhouse Gas Control 81 (February): 29–37. doi:10.1016/j.ijggc.2018.12.009
- Feng, Ye E., **Tip Meckel**, and Thomas Hess. 2019. "Processing Techniques and Challenges for High-Resolution 3D Marine Seismic Data: Case Studies from the Gulf of Mexico and Japan." In SEG Technical Program Expanded Abstracts 2019, 3969–73. San Antonio, Texas: Society of Exploration Geophysicists. doi:10.1190/segam2019-3215171.1
- Part I of a final report on Compressibility Effects on Viscous Instability Under Sealing and Partially Sealing Boundaries was submitted. See Appendix I in latest quarterly report.
- Goudarzi, Ali**, Timothy A. Meckel, Seyyed A. Hosseini, and Ramón H. Treviño.** 2019. "Statistical Analysis of Historic Hydrocarbon Production Data from Gulf of Mexico Oil and Gas Fields and Application to Dynamic Capacity Assessment in CO2 Storage." International Journal of Greenhouse Gas Control 80 (January): 96–102. doi:10.1016/j.ijggc.2018.11.014.
- Li, Pengchun, Linzi Yi, Xueyan Liu, Gang Hu, Jiemin Lu, Di Zhou, **Susan Hovorka**, and Xi Liang. 2019. "Screening and Simulation of Offshore CO2-EOR and Storage: A Case Study for the HZ21-1 Oilfield in the Pearl River Mouth Basin, Northern South China Sea." International Journal of Greenhouse Gas Control 86 (July): 66–81. doi:10.1016/j.ijggc.2019.04.015

Going Forward

Engaging Hispanic communities

Gulf Coast Carbon Center

Since 1998

Bureau of Economic Geology

Dr. Scott W. Tinker, Director

The University of Texas at Austin Jackson School of Geosciences

GoMCarb Newsletter

February 2020

Exploring the Gulf of Mexico subsurface for CO_2 storage

April 1, 2018 - March 31, 2023

New Quarterly Report Summaries Via Email

Starting this year, the quarterly reports for GoMCarb will be released to partners via this newsletter. The goal is to share research findings across tasks so that other GoMCarb researchers keep up-to-date on the latest findings as we move forward in the year. The aim is to provide a newsletter with each quarterly report release. To orientate you to the goings-on of other researchers, the newsletter will provide a brief overview and then the amended report (removing proprietary data) will be attached. You can always find a list of all quarterly reports and other meeting materials on the GoMCarb Partner Portal on the right sidebar of the GCCC website.

Save the login:

[redacted]

If you have a research update, paper, or event you'd like to share with the group, please send the update to GCCC research program coordinator Emily Moskal, the newsletter curator: emily.moskal@beg.utexas.edu

GCCC

GULF COAST CARBON CENTER

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GoMCarb Partner Portal

- About GCCC
- Industrial Affiliate Portal
- GoMCarb Partner Portal
- Publications
- Educational resources
- GCCC blog
- News ›
- Areas of research ›
- CO2 brine database data matrix ›
- Research themes
- Sponsors
- Staff and students ›

gulfcoastcarbon.org

Partnership for carbon capture & offshore geologic storage

GoMCarb

Discussion in Chat

Report on STEMM-CCS & 4th International Offshore Workshop

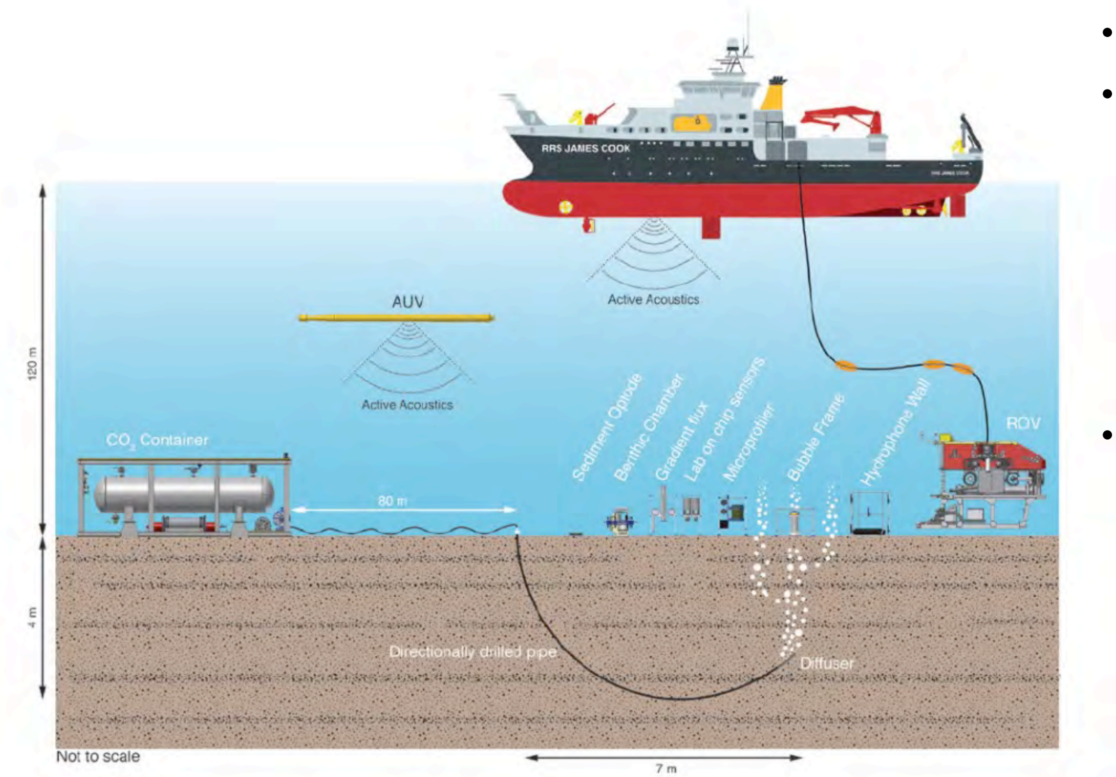
Held in Bergen, 11-12 February, 2020

Alex Bump
Task 6: Outreach

2 days, 10 sessions, ~150 people

Partnership for carbon capture & offshore geologic storage

Monitoring: STEMM-CCS Project



- 14-day controlled release of CO_2 sub-seabed
- Monitor dispersal, experiment with detection
- Accomplishments
  - Development of “lab on chip” sensors
  - Quantification of chimney permeability
  - Acoustic quantification of leakage
  - CSeep method for stoichiometric leakage source attribution
- Application
  - Many tools for reliable leak detection
  - To be cost-effective, monitoring needs to be risk-based, tiered and triggered

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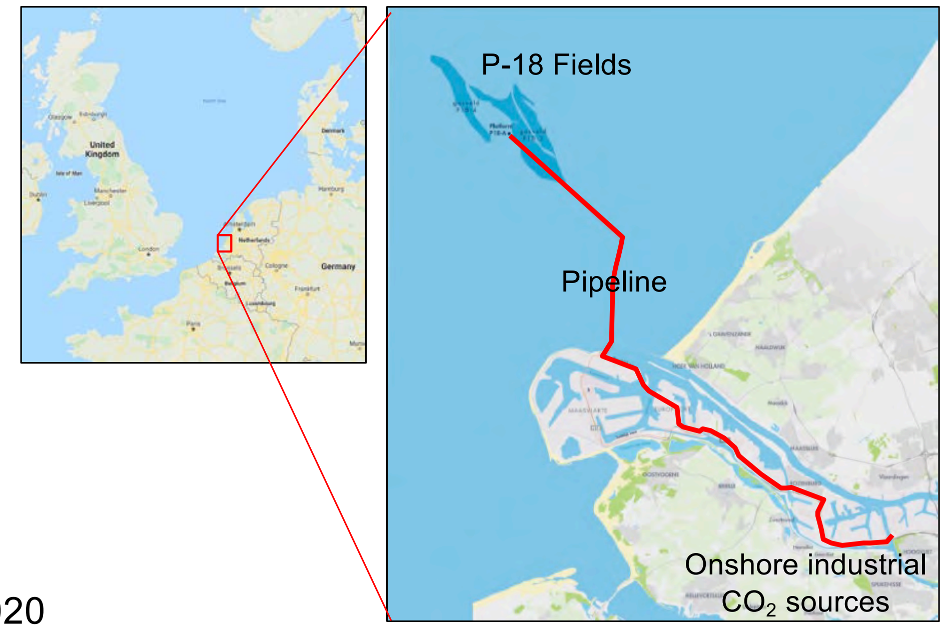
Commercial Offshore CCS: Porthos

- Part of Dutch effort to cut GHGs by 95% by 2050
- Joint venture: Port of Rotterdam, EBN & Gasunie
- CAPEX ~ € 450M
- Commercial CO_2 transport and storage business
- Open access to onshore suppliers
  - Shell, ExxonMobil, Air Liquide and Air Products currently interested
- Transport via 54 km pipeline
- Storage in P-18 fields with capacity of ~37 Mt
- Currently in permitting and FEED studies
- EIA and agreements with CO_2 suppliers due in 2020
- Formal FID 2021, operational 2023
- EU recognition as a Project of Common Interest



(Filip Neele, TNO; https://www.rotterdamccus.nl/en/the-project/)

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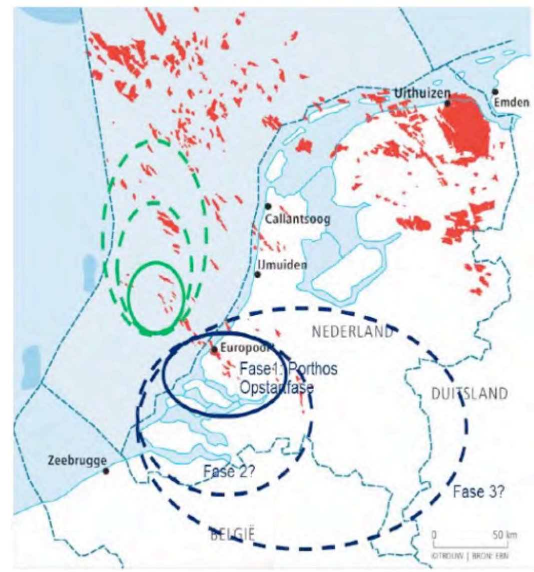
Phased Design: Porthos

- Porthos positioned as a future CCS hub
  - Initial injection of 2-2.5 Mt/yr; design capacity of 10 Mt/yr
    - Transport system is deliberately over-sized for Phase 1
  - Phase 2: domestic sources beyond Port of Rotterdam
  - Phase 3: foreign sources, including Belgium, Germany
    - Updates to London Protocol now permit export of CO_2
  - Storage would expand into neighboring depleted fields as needed
  - Plan to learn and adapt as business grows

- Other projects following a similar model
  - Athos, Northern Lights, Net Zero Teeside, Acorn
  - Potential for broad applicability



(Filip Neele, TNO; https://www.rotterdamccus.nl/en/the-project/)

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Global Offshore CCS Challenges

- Re-use of infrastructure
  - Financially attractive, technically difficult
  - How to extend use beyond design life? Adapt to handling different fluids?
  - How to assess and mitigate risk of legacy well leakage
- Monitoring
  - Must be efficient and cost-effective but also trustworthy
  - Risk-based with further monitoring triggered by exceptions
- Legal
  - CCS is a new use of the sea, not covered by international oil and gas law
  - How to align existing O&G licensing, facilities, decommissioning laws with CCS?
    - Parallel licenses? How to transfer facilities and liabilities?
    - What if there is a time gap between production and storage? Who is responsible in the interim? Who maintains the facilities?

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Conclusions and Recommendations

Insights and trends

- Moving from decarbonizing just oil and gas to broader energy systems and industries
- More and more offshore projects are being planned
- Many projects are considering hubs with phased sources –need to oversize the transport initially

Recommendations

- Change our language to be more positive, e.g. “containment” instead of “leakage”
- Develop a road map for CCS implementation of CCS and work backward to identify research needs
- Educate regulators and legislators on CCS—benefits, boundaries and framework are needed
- Work to create an investment-friendly framework for CCS (i.e., de-risk investment)

One to watch

- Role of CCS in country updates to the Paris Agreements (due in mid-2020)

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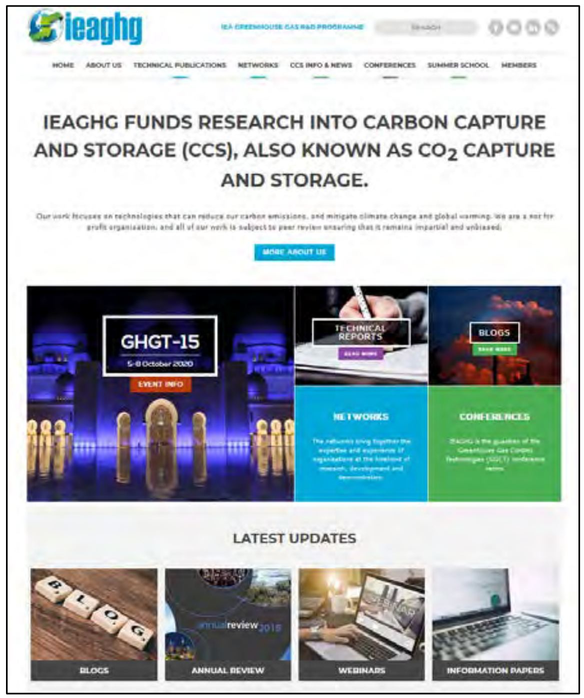
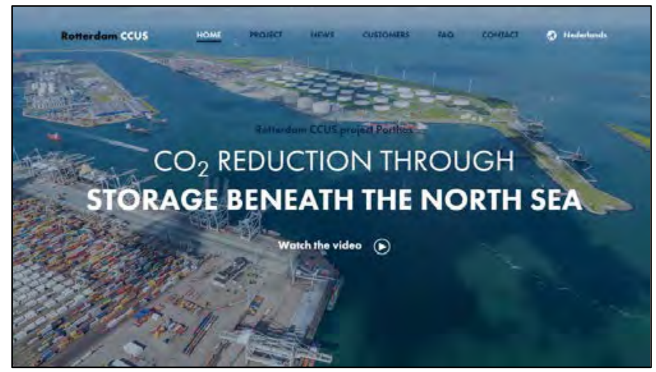
More Information

http://www.stemm-ccs.eu/



www.ieaghg.org



https://www.rotterdamccus.nl/en/

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