Offshore CO_2 Storage Resource Assessment of the Northwest Gulf of Mexico Inner Continental Shelf, Upper Texas – Western Louisiana Coast*

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Abstract

Carbon capture, utilization, and storage (CCUS) continues to be considered one of the most promising technologies for reducing atmospheric emissions from industrial sources of CO_2. CCUS research programs of the United States and European Union recognize the need to further develop offshore storage resources for successful global deployment of CCUS technologies. Offshore storage of CO_2 has several advantages: (1) Locating sequestration sites away from heavily populated, onshore areas reduces opposition from local populations. (2) Use of offshore sites reduces the difficulty of establishing surface and mineral rights at candidate storage sites; offshore surface and subsurface rights usually belong to a single governmental entity. (3) Offshore storage reduces the risk to underground sources of drinking water. (4) Offshore CCS may provide storage sites near heavily populated coastal areas where onshore sites are unavailable.

The challenge is to assess suitable offshore storage sites that will provide CO_2 emitting industries with a sound environmental alternative to the current practice of venting CO_2 to the atmosphere. The inner continental shelf of the northwestern Gulf of Mexico is an especially prospective CCUS area because it has abundant available geologic data accumulated from decades of hydrocarbon exploration near many large point sources of anthropogenic CO_2. An ongoing study of the area from Bolivar Peninsula on the upper Texas coast to Vermilion Bay on the Louisiana coast assesses prospective geologic storage resources of depleted oil and gas reservoirs and saline geologic formations for the approximately 8,000 square mile study area. The study, encompassing state and federal waters, utilizes (1) existing rock samples (e.g., whole cores), (2) well logs, and other data from existing or P&A wells, and (3) available 2D, a conventional regional 3D and a high resolution 3D seismic surveys to assess storage resources (e.g., faults, reservoir and seal units, etc.). The study utilizes the available geologic data resources to (1) assess the CO_2 storage capacity of depleted oil and natural gas reservoirs, and (2) assess the ability of saline formations in the region to safely and permanently store nationally-significant amounts of anthropogenic CO_2. The study also seeks to identify at least one specific site with potential to store at least 30 million metric tons of CO_2 that could be further considered in the future for a commercial or integrated demonstration project.

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Offshore CO_2 Storage Resource Assessment of the Northwest Gulf of Mexico Inner Continental Shelf, Upper Texas – Western Louisiana Coast "TXLA"

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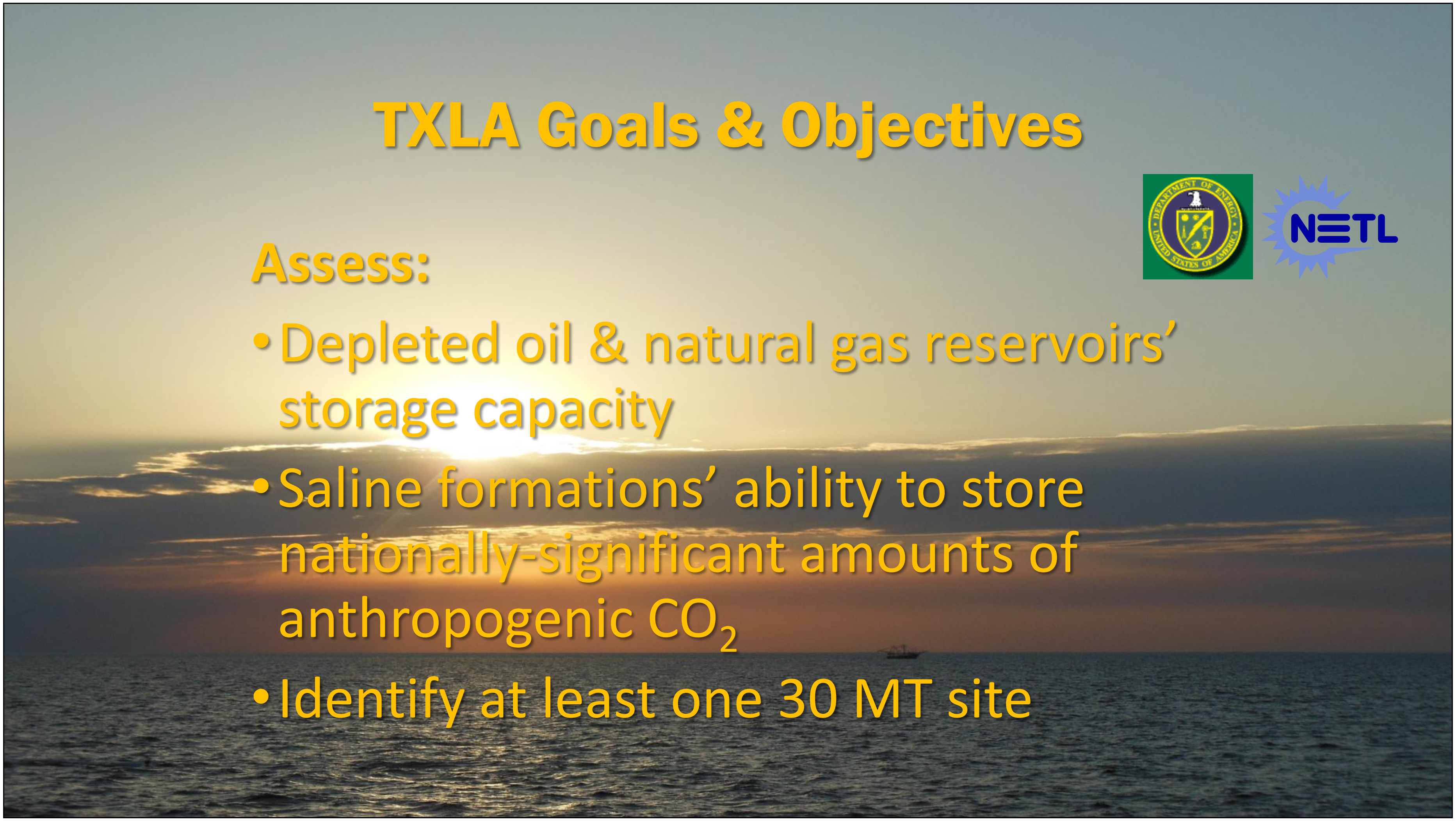
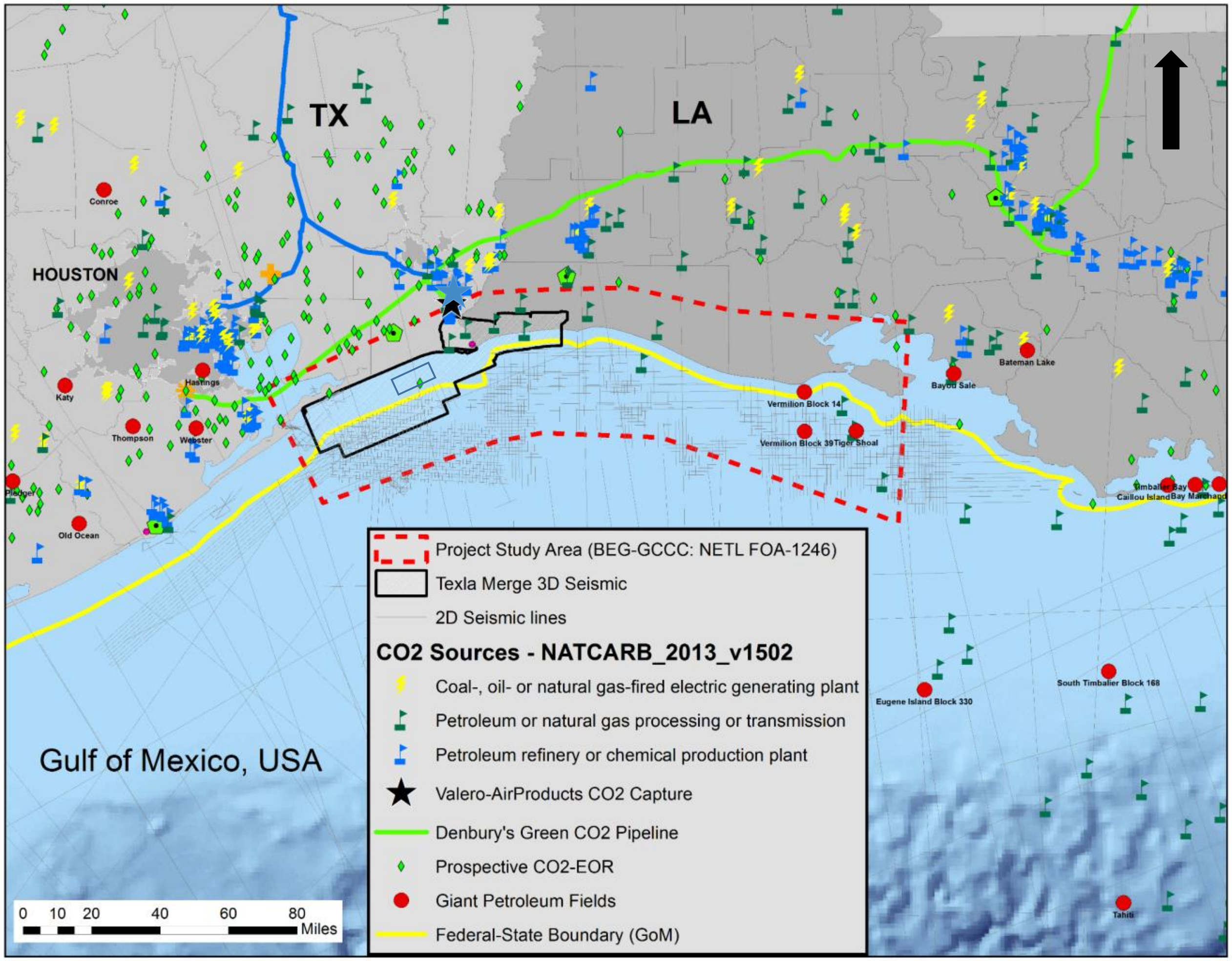
Presenter's notes: Introduce GCCC
Study GS part of CCS as a CO2 mitigation option for over a decade and PI, Susan Hovorka since 1999.



Presenter's notes: "The objectives of the proposed study are to 1) utilize existing data (well logs, records and sample descriptions from existing or plugged/abandoned wells, available seismic surveys, existing core samples, and other available geologic and laboratory data) from historical hydrocarbon industry activities in the heavily explored portions of the inner continental shelf portions of the Texas and Louisiana Gulf of Mexico coastal areas in order to assess the storage capacity of depleted oil and natural gas reservoirs, and 2) assess ability of saline formations in the region to safely and permanently store nationally-significant amounts of anthropogenic CO_2. We will identify at least one specific site with potential to store at least 30 million tons of CO_2 which could be used in a commercial or integrated demonstration project in the future. " (From Executive summary of PMP)

OUTLINE

- Background
- Methodology
  - Following Oil & Gas Play Concepts Model
    - Database Development (complete)
      - Wells
      - Seismic
      - Oil & Gas Fields Production
- Data Interpretation (Regional)
  - Well correlation (regional)
  - Seismic interpretation / Time → Depth
    - 2D / 3D / UHR3D (novel data – novel interpretation technique)
  - Rock Data (seal / confining zone) Analysis & (Positive Results)
  - Production Decline Curve Analysis (DCA)



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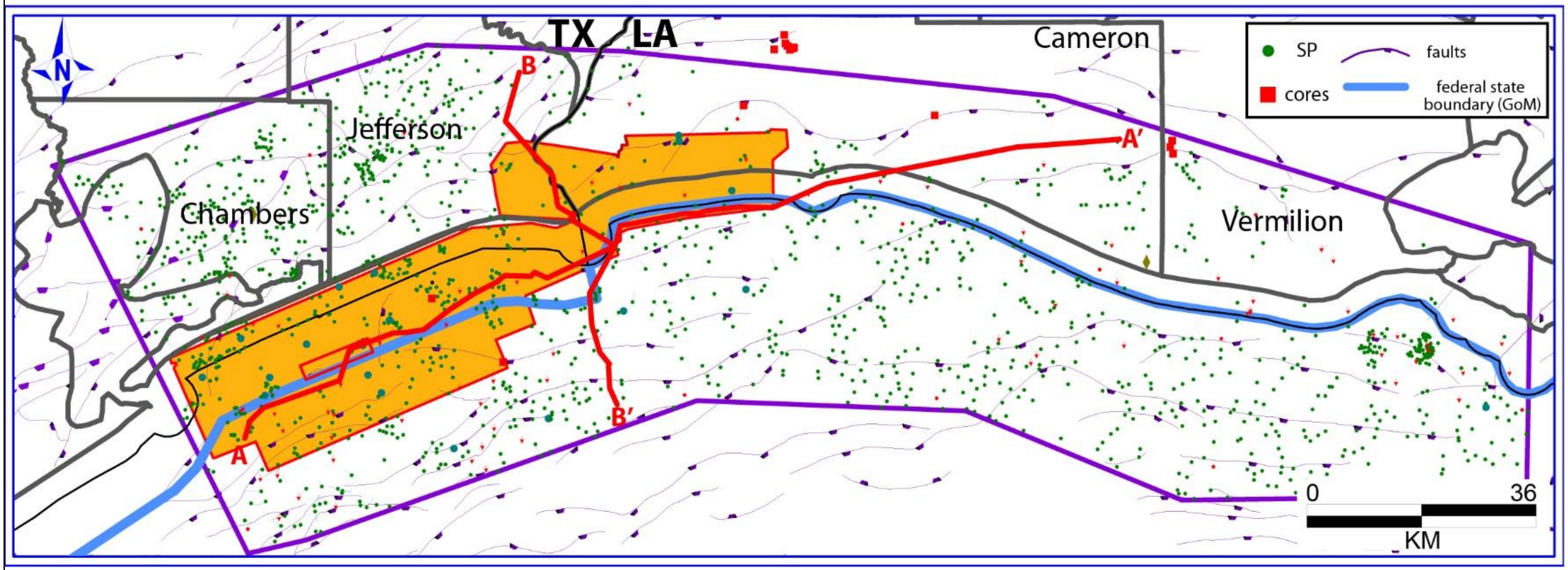
Presenter's notes: Note region's unique nexus between existing CO_2 sources, infrastructure and sinks (with tremendous amount of geological data available from O&G industry).

Study Area & Datasets



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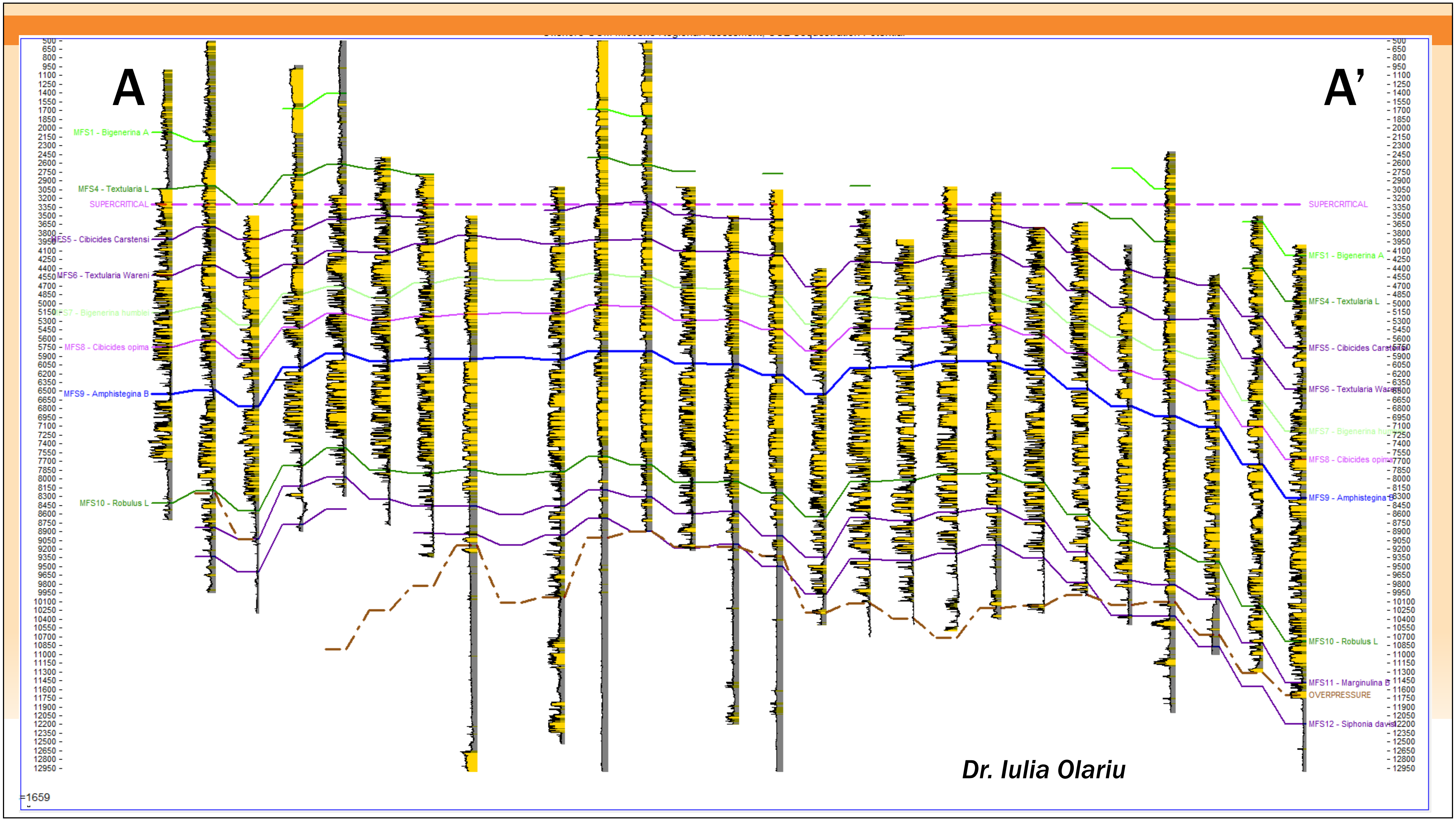
Presenter's notes: Map of the study area showing wells and primary 3D seismic dataset ("TexLa Merge" highlighted in orange). Also, UHR3D dataset (red polygon within TexLa Merge outline).

Note lines of section A-A' and B-B'.

As of January, 2017:

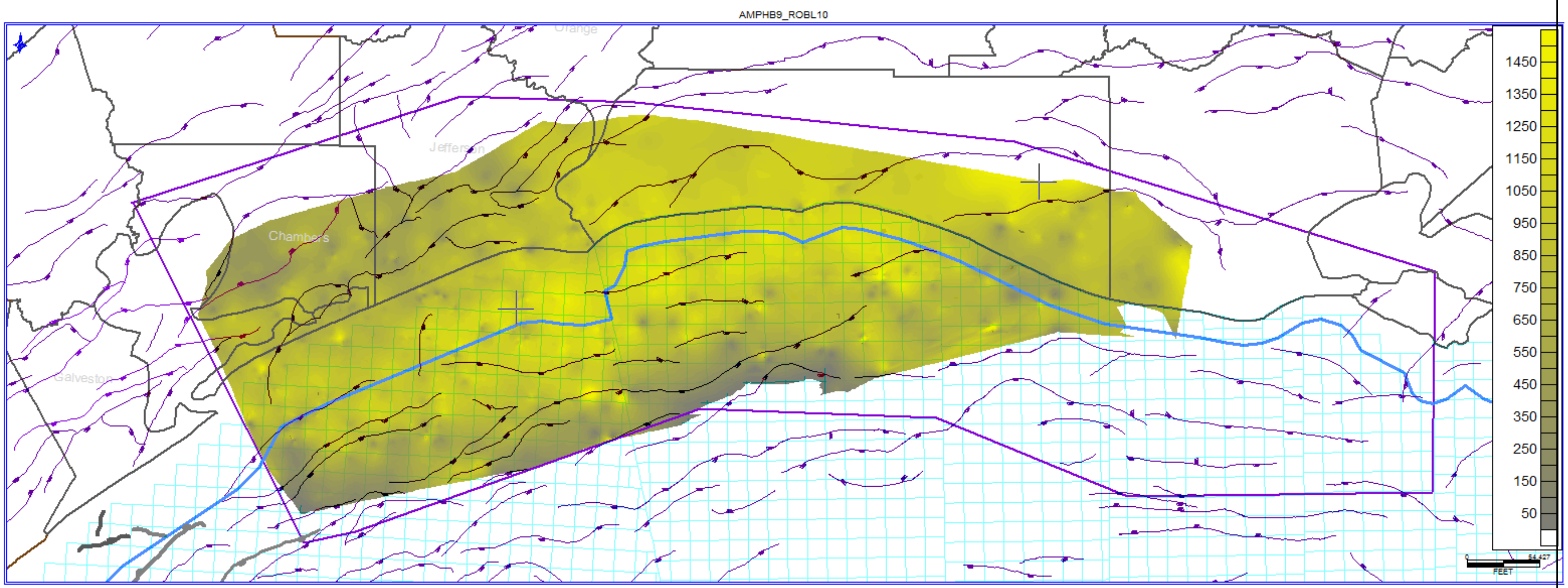
Total number of wells with LAS curves, 1746;

- 1700 SP (green dots)
- 84 GR (red rhombs)
- 20 either sonic or density logs (blue circles)
- 15 have whole core (red squares).



Presenter’s notes: Strike-oriented structural cross-section, offshore upper Texas and westernmost Louisiana coast (AA’ on study area basemap). The upper depth limit for CO_2 injection (SUPERCRITICAL – dashed purple line) is determined by the minimum temperature and pressure conditions at which CO_2 remains supercritical. In this region it is at 1006 m (about 3300 ft) (Wallace et al., 2014). The lower depth limit for CO_2 injection (OVERPRESSURE - dashed brown line) is determined by the depth at which the hydrostatic pressure in the subsurface is significantly exceeded. The top of overpressure is obtained from a U.S. Geological Survey geopressure-gradient model of the regional pressure system spanning the onshore and offshore portions of Texas and Louisiana (Pitman, 2011). The primary reservoir target intervals are sandstones (mostly fluvio-deltaic) between MFS 9 and MFS 10 and the primary sealing interval is the regional transgressive shale associated with *Amphistegina B*.

Net Sandstone Map *Amphistegina B* (MFS9) to *Robulus L* (MFS10)



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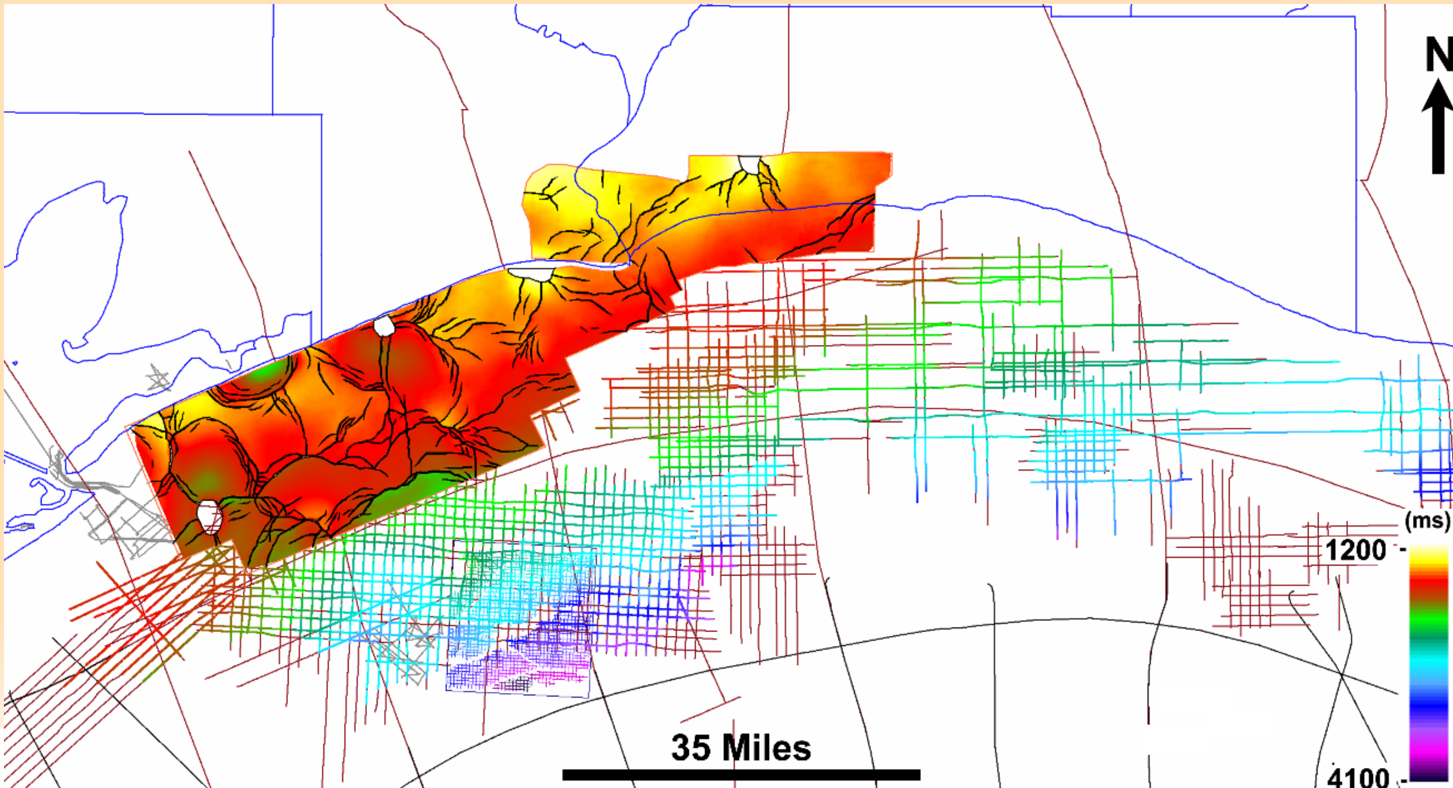
Presenter's notes: Net Sandstone map of the stratigraphic interval from *Amphistegina B* (MFS9) to *Robulus L* (MFS10)

Seismic Datasets

MFS 9
Time
Structure



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Michael DeAngelo

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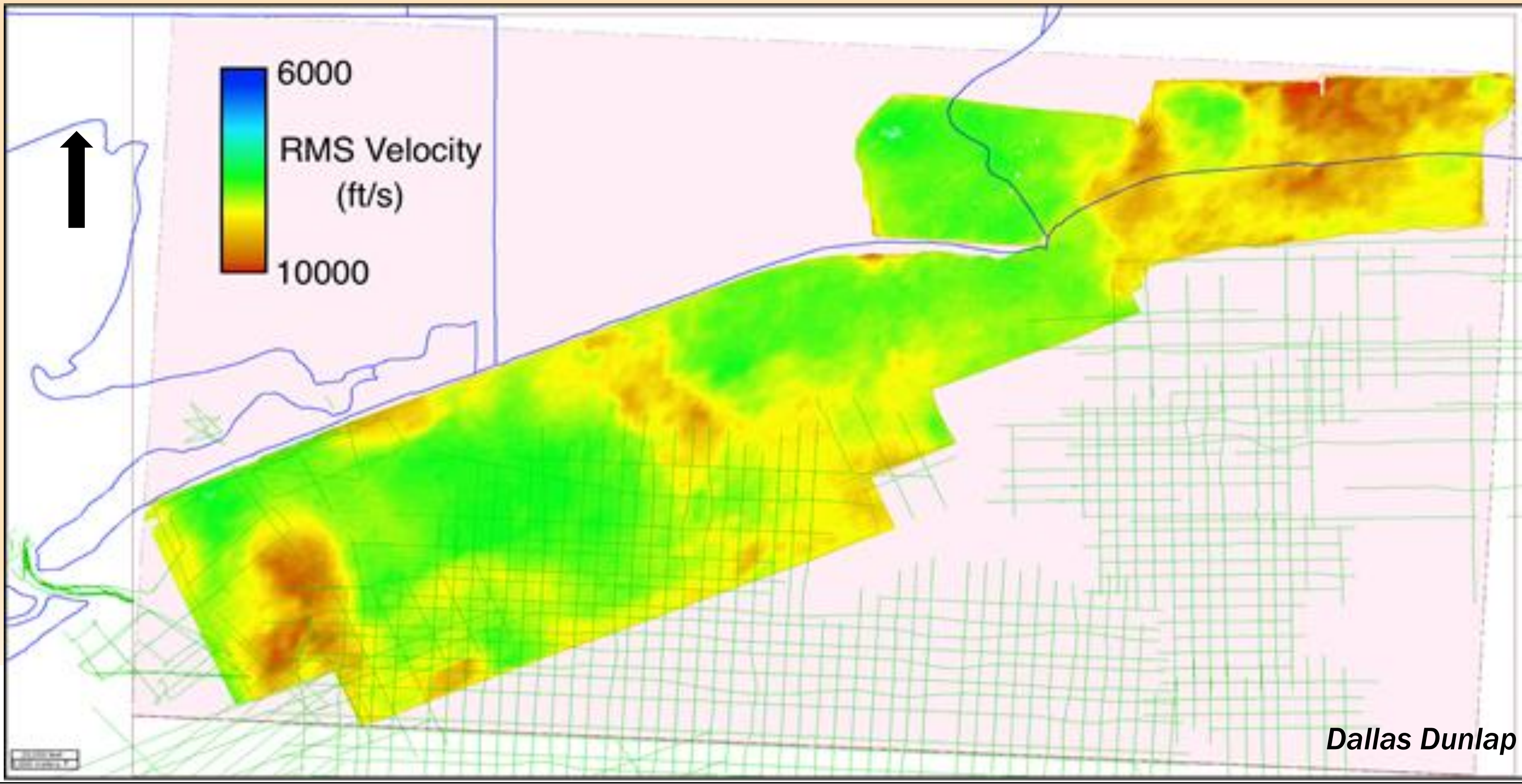
Presenter's notes:

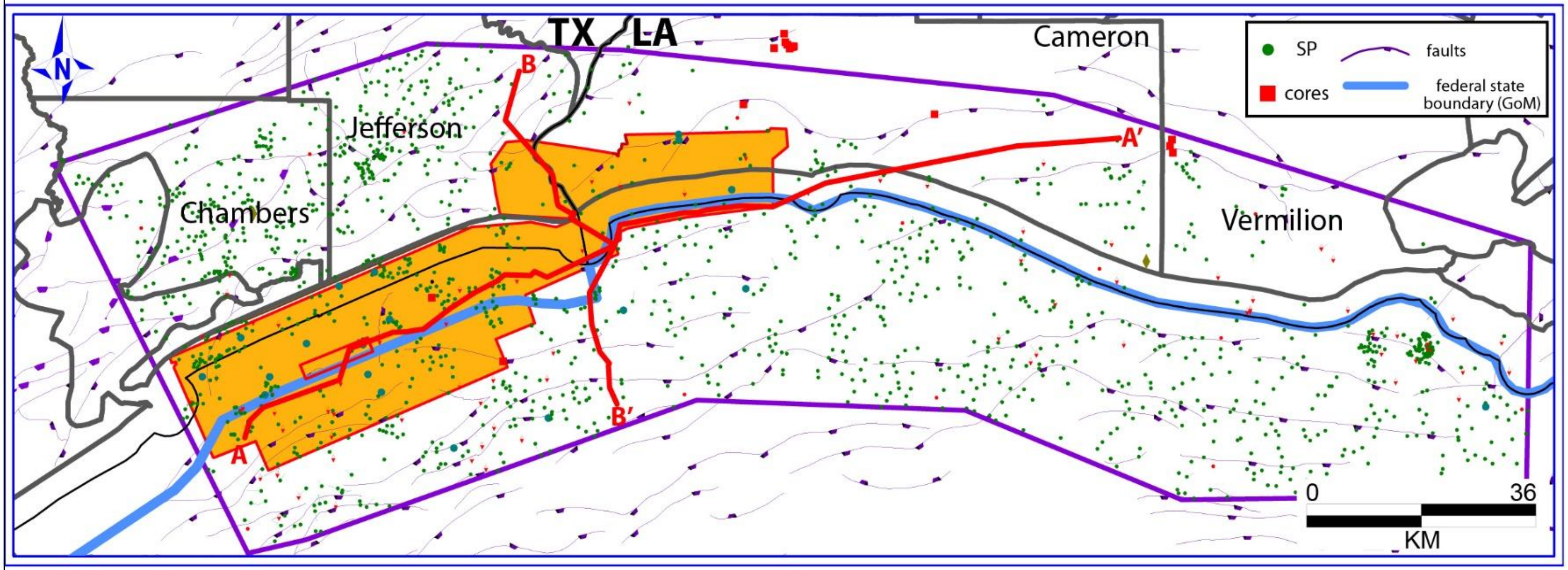
- Two-way time structure map of MFS09 with 2D/3D seismic interpretations.

RMS Velocity (time slice)



Presenter's notes: RMS Velocity (ft/s) time slice - time domain (at time-slice 3252 ms).
Hot colors represent areas of higher velocity and cool colors low velocity. Note the high velocities adjacent to areas of shallow salt in the southwest and northeast of the seismic study area.

Study Area & Datasets



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Presenter's notes: Map of the study area showing wells and primary 3D seismic dataset ("TexLa Merge" highlighted in orange). Also, UHR3D dataset (red polygon within TexLa Merge outline).

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As of January, 2017:
Total number of wells with LAS curves, 1746;
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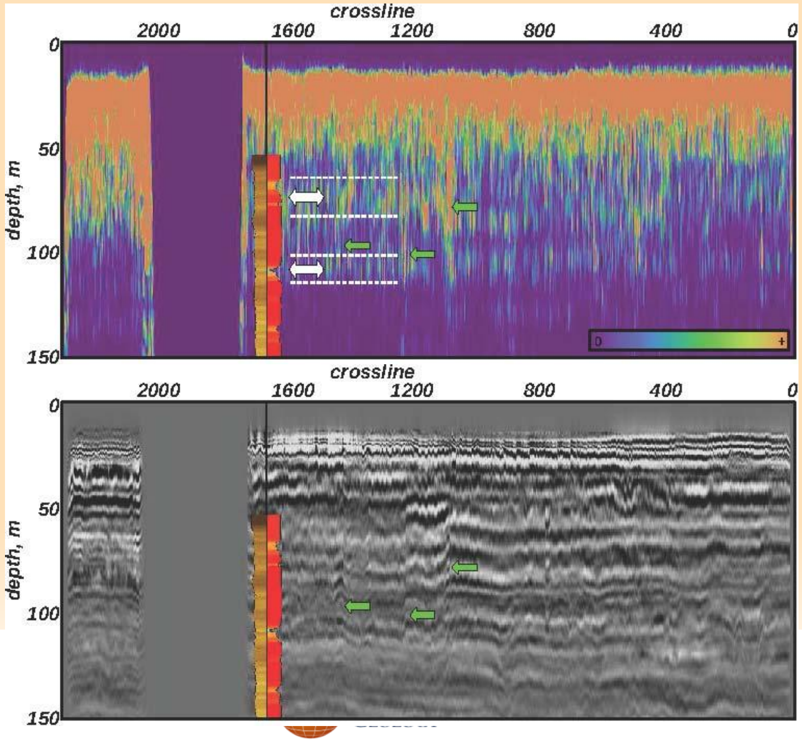
Hi-Resolution 3D Seismic Dataset
Diffraction Energy Analysis

Diffraction Energy Attribute

Reflection Amplitude Attribute



Ultra-High Resolution 3D seismic dataset (UHR3D)

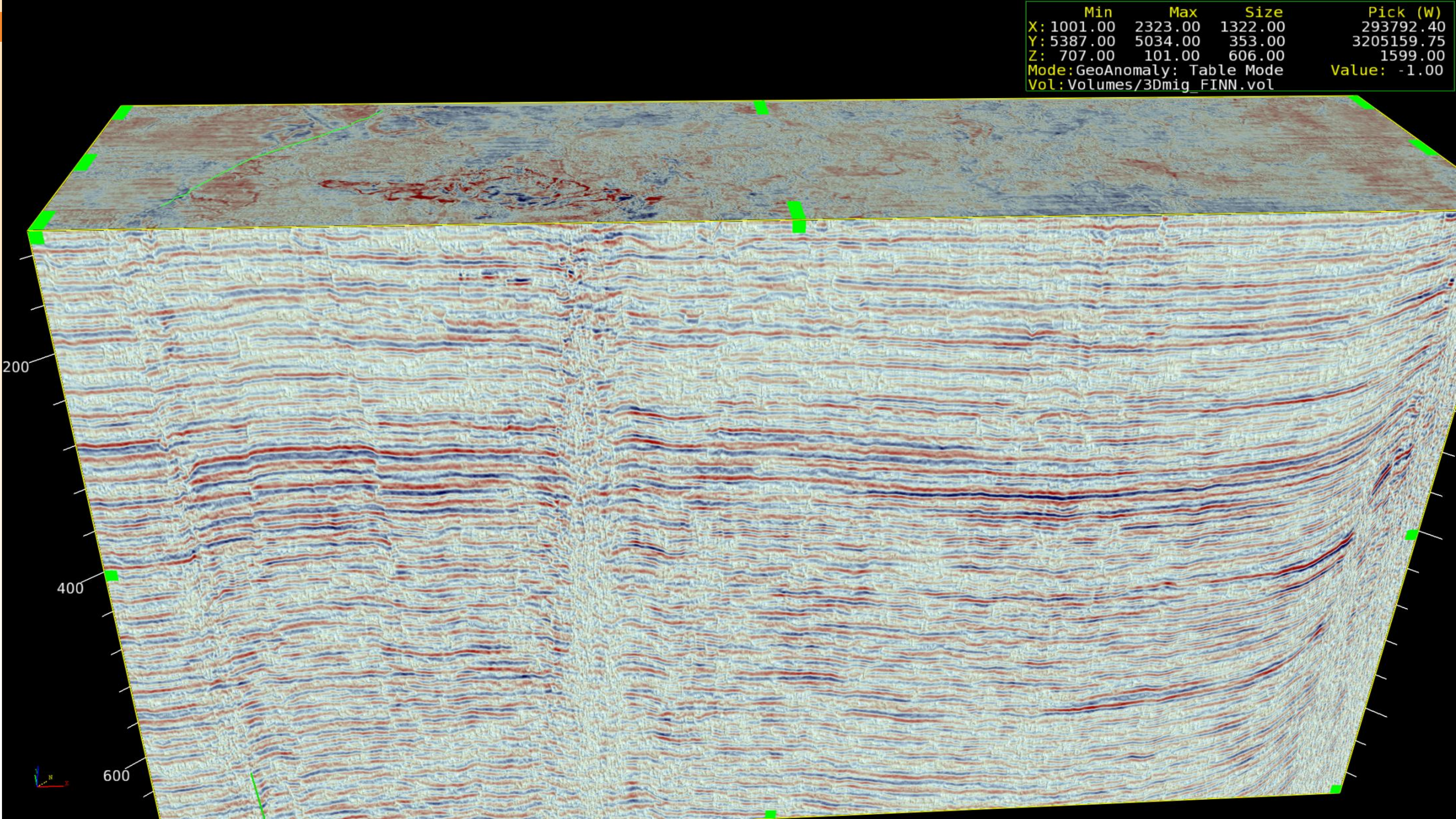
Dr. Alexander Klokov

(Klokov, et al. 2017)

Presenter's notes: Does diffraction energy allow better imaging of fluid migration? Some indication that it does.

Depth domain transect of an inline showing the diffraction energy attribute (top) and the conventional seismic image (bottom). The sections are overlaid by borehole logs (near crossline 1600): spontaneous potential log (left, dark colors indicate more shale content) and electrical resistivity log (right, mostly red color). White arrows in the diffraction energy section indicate two high-diffractivity intervals, which correlate with resistivity decrease in the well log. Green arrows show faults connecting those two intervals. The shadow area at crossline 1800 is a data gap that was caused by the need for the UHR3D survey acquisition ship to avoid an oil production platform.

With increasing depth, diffraction energy significantly decreases and displays uneven lateral distribution.


Min Max Size Pick (W)
X: 1001.00 2323.00 1322.00 293792.40
Y: 5387.00 5034.00 353.00 3205159.75
Z: 707.00 101.00 606.00 1599.00
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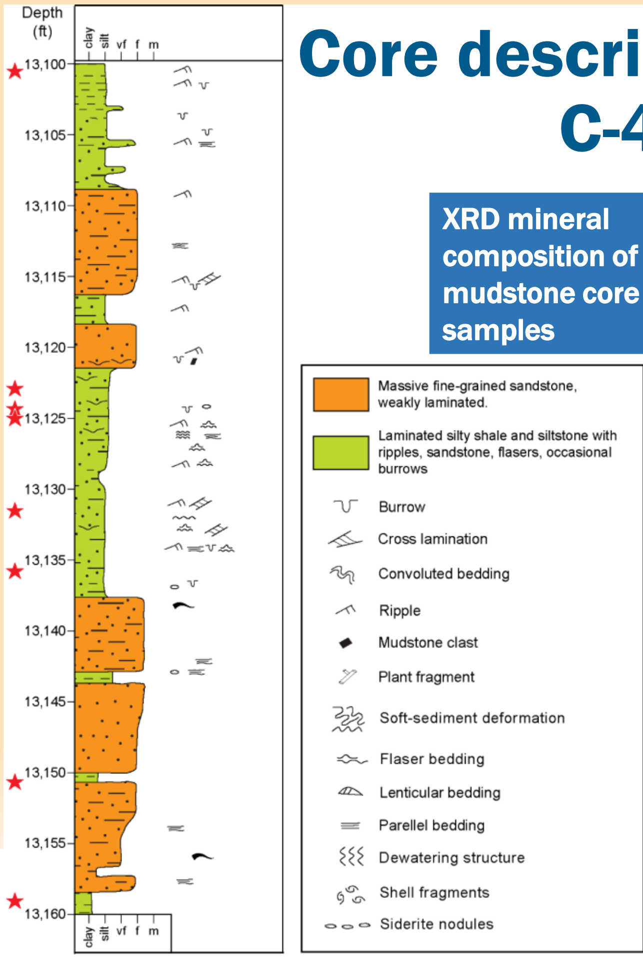
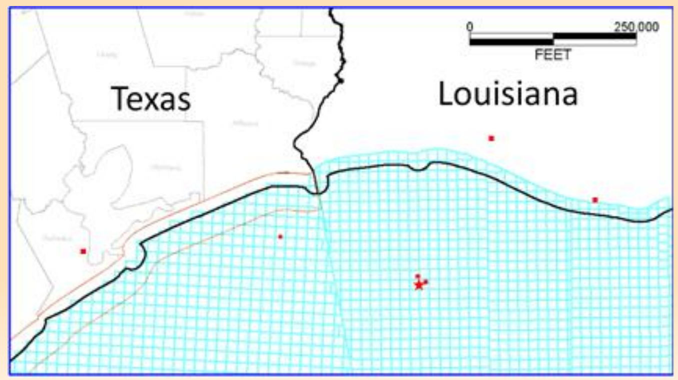
200
400
600

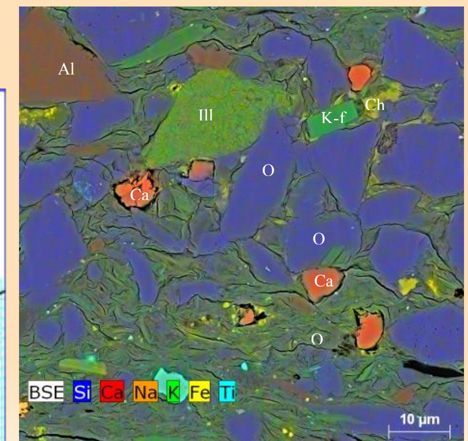
Core description & analysis of well OCS-G-3492 C-4, West Cameron Block 205



XRD mineral composition of mudstone core samples

Depth (ft)	Quartz	Calcite	Plagioclase	K-feldspar	Illite	Kaolinite	Chlorite	Anatase	Pyrite
13100.5	31.3	0.2	3.4	9.3	35.2	2.8	14.9	1.4	1.5
13125	29.8		5.2	8.4	33.5	2.5	17.9	1.9	1.0
13136	29.1	1.4	6.1	12.8	29.3	2.1	16.7	1.5	1.0





EDS map showing silt grains concentrated in upper part and highly aligned clays in the low half. Sample from 13,136 ft.

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Dr. Jiemin Lu

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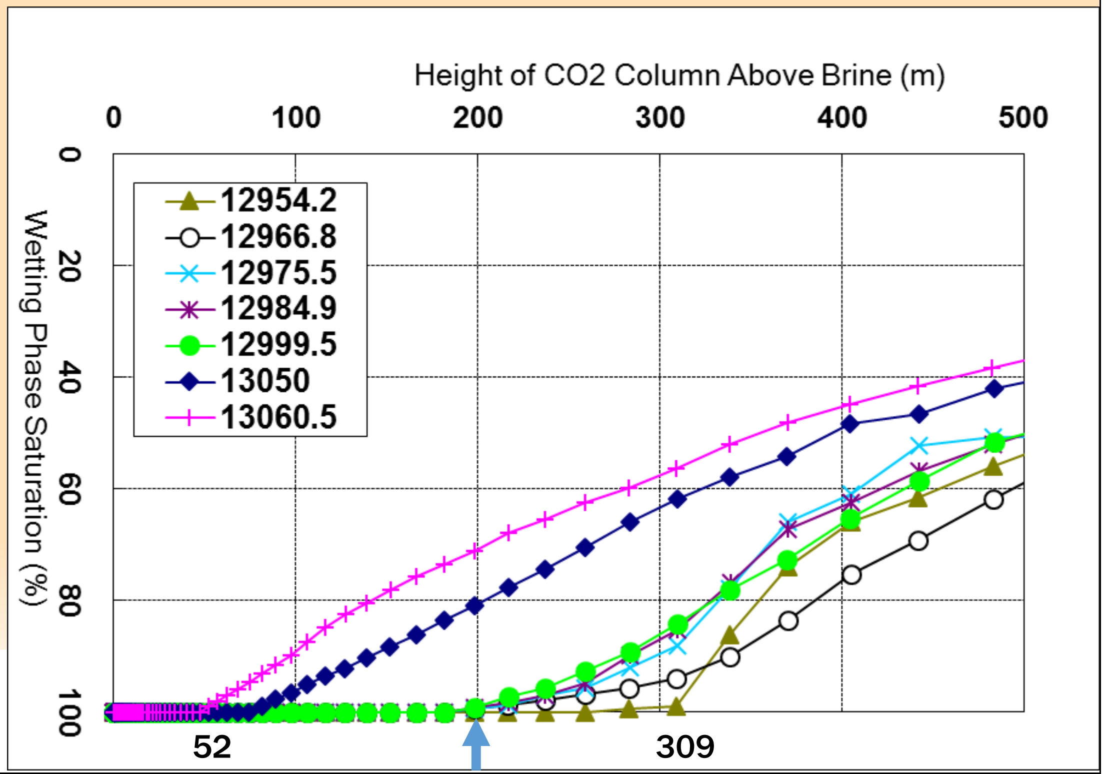
Presenter's notes: Analysis of the mudrocks (aka mudstones, siltstones, shales, etc.). Note the red stars on core description indicating sample depths.

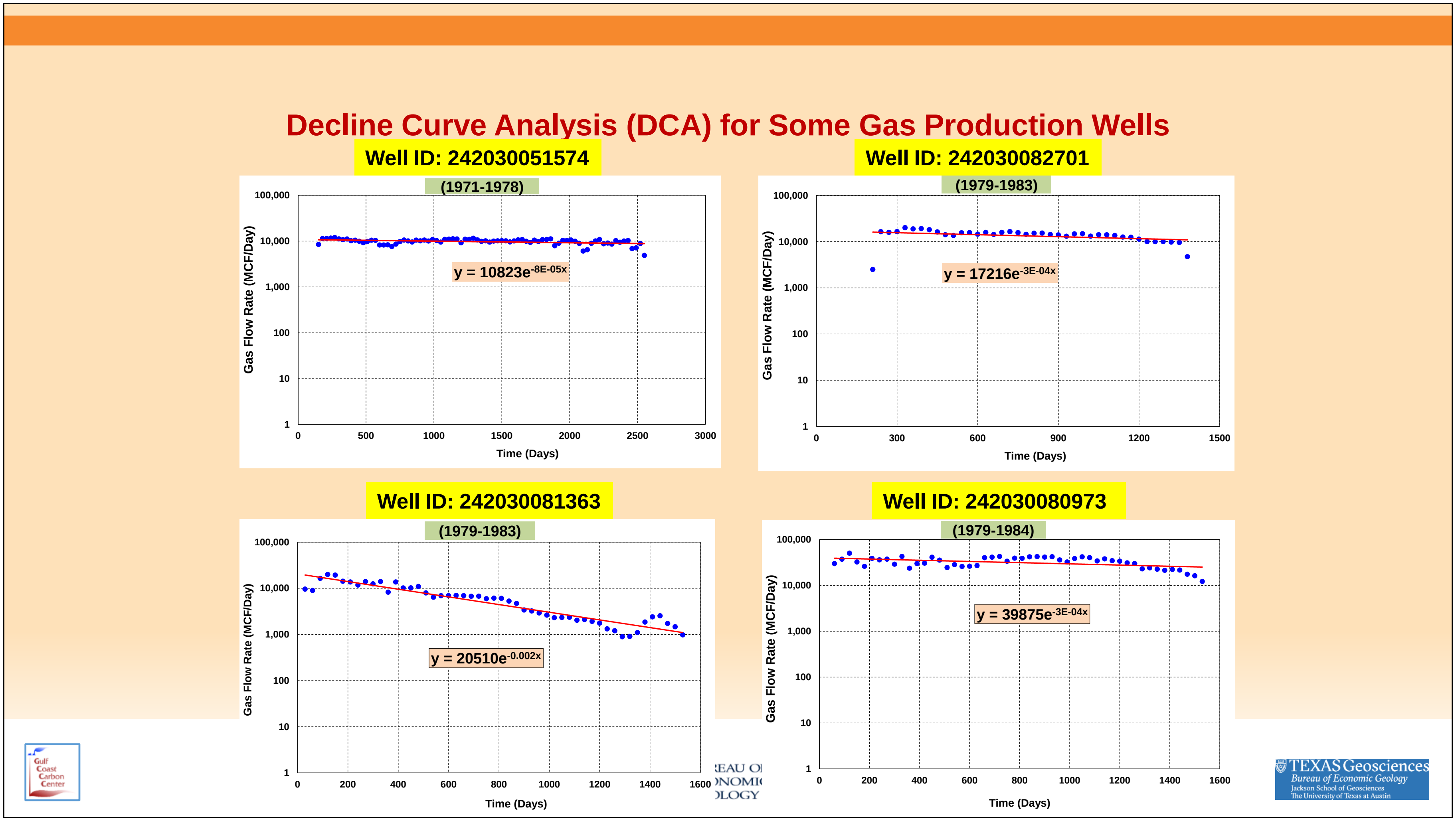
Mudstone samples - well OCS-G-3496 #A-3

- From MICP data at 70°C and 20 Mpa
- Samples petrographically consistent
- **Sealing should be excellent (for studied intervals)**



Presenter's notes: The samples showed varied capillary entry pressure ranging from 1090 psi to 5900 psi. At a temperature of 70 °C and a pressure of 20 MPa (2900 psi), the mudstone samples are capable of retaining a CO_2 column of 52 to 309 m before any intrusion of CO_2 (Fig. 5). Among all the samples, the two deepest samples (13050 ft and 13060.5 ft) with highest silt contents, which are reflected by the highest quartz and feldspar contents, have the lowest sealing capacity (CO2 column < 80m). The rest of the samples are consistently able to hold a CO2 column greater than 200m. The results show that the mudstone interval have overall excellent sealing capacity.

The results show that the mudstone intervals of the Lower Miocene in the West Cameron area are consistent in terms of petrographic and petrographic properties through the depth of investigation. The sealing performance should be excellent for the studied intervals.



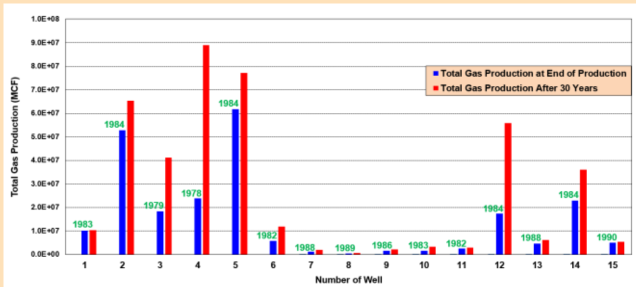
Presenter's notes:
Red curve = DCA
Blue dots are actual prod data.

Very good match

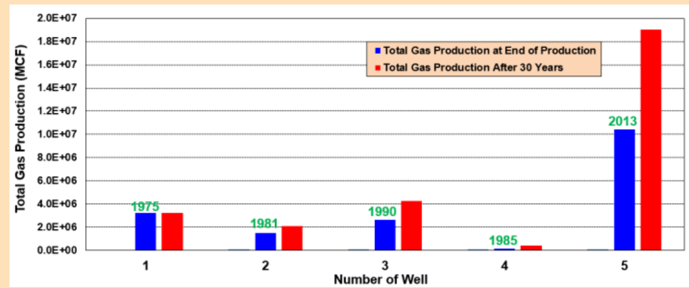
We can use the parameters (coeff. and exponents) for predicting future gas production ***<u>and consequently analog for CO2 injection</u>***.

Total Gas Production at End of Production and after 30 years for wells from different blocks

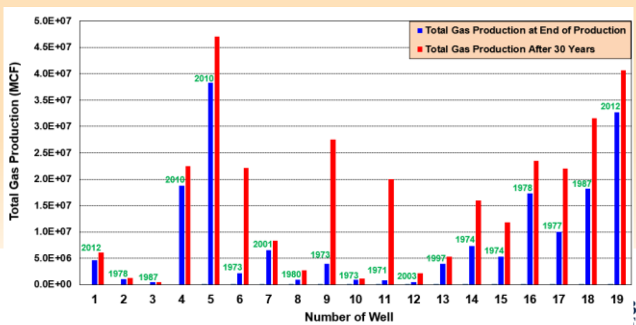
High Island Block 14-L (Texas)



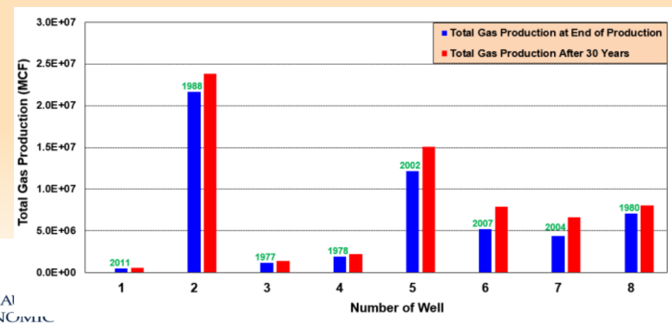
High Island Block 23-L (Texas)



High Island Block 52-L (Texas)



West Cameron Block 28 (Louisiana)



Presenter's notes: Four different blocks. Note the number of wells in each block. Most wells are now inactive.

Note the red bars are our predictions. Each plot in previous slide is related to one of these red & blue sets (bars). Some of the predicted production (after 30 years) (red) is significantly higher than the actual production at shut-in (blue bars). That indicates a potentially higher injectivity for CO2 (in future storage projects). May indicate strong aquifer drive.

Summary of Decline Curve Analysis (DCA) for Different Fields

- **Gas production history (231 wells from 11 blocks) – analyzed using DCA to predict future total gas production after 30 years. Further analysis underway.**
- **The analyzed wells are mostly gas production wells; their oil production was negligible.**
- **Next step, present a statistical investigation of production data in study area to gain further insight for predicting injection rate and potential for future CO_2 storage.**

Field Name	State	Number of Wells Analyzed using DCA
High Island Block 10-L	Texas	3
High Island Block 14-L	Texas	15
High Island Block 23-L	Texas	5
High Island Block 19-S	Texas	5
High Island Block 20-S	Texas	1
High Island Block 52	Texas	19
Crystal Beach	Texas	2
Galveston Block 176-S	Texas	7
West Cameron Block 28	Louisiana	8
West Cameron Block 33	Louisiana	22
West Cameron Block 45	Louisiana	136

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Presenter's notes: We have much more data (6 or 7 blocks) for a total of ~20 blocks.

Summary

- Regional correlation near complete
- Seismic Horizons Interpreted:
  - 6 horizons in time (3D seismic)
  - 4 in depth (3D seismic)
  - 3 horizons in time (2D)
  - Conversion of 2D to depth *in progress*
- **Diffractivity Attribute on UHR3D - promising**
- 7 wells with whole cores – 2 cores analyzed in detail
  - **Good confining properties** (in studied intervals)
- DCA - 231 wells from 11 blocks
  - Good match between DCA & production
    - Can be used for predicting CO_2 injection performance

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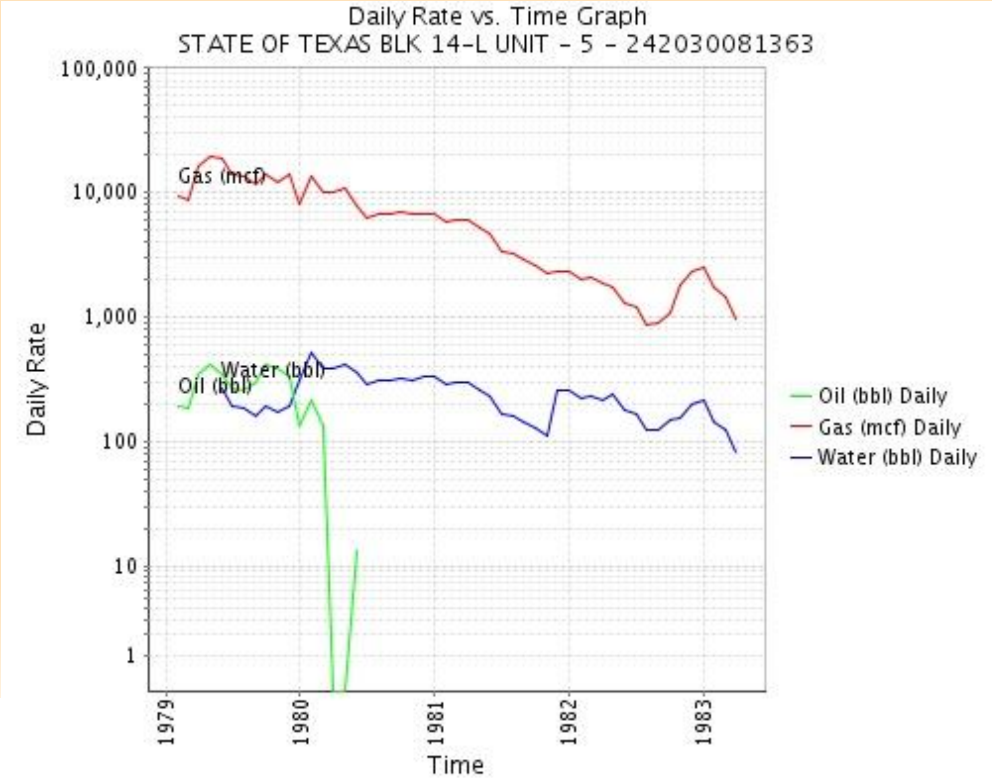
Presenter's notes: >1750 wells correlated

Acknowledgements

- Tip Meckel – PI
- Mike DeAngelo, Dallas Dunlap, Iulia Olariu, Alexander Klokov, Jiemin Lu, Ali Goudarzi
- Department of Energy, National Energy Technology Lab
- Landmark Software and Services, a Halliburton Company
- IHS Petra
- Seismic Exchange, Inc.


Thank you

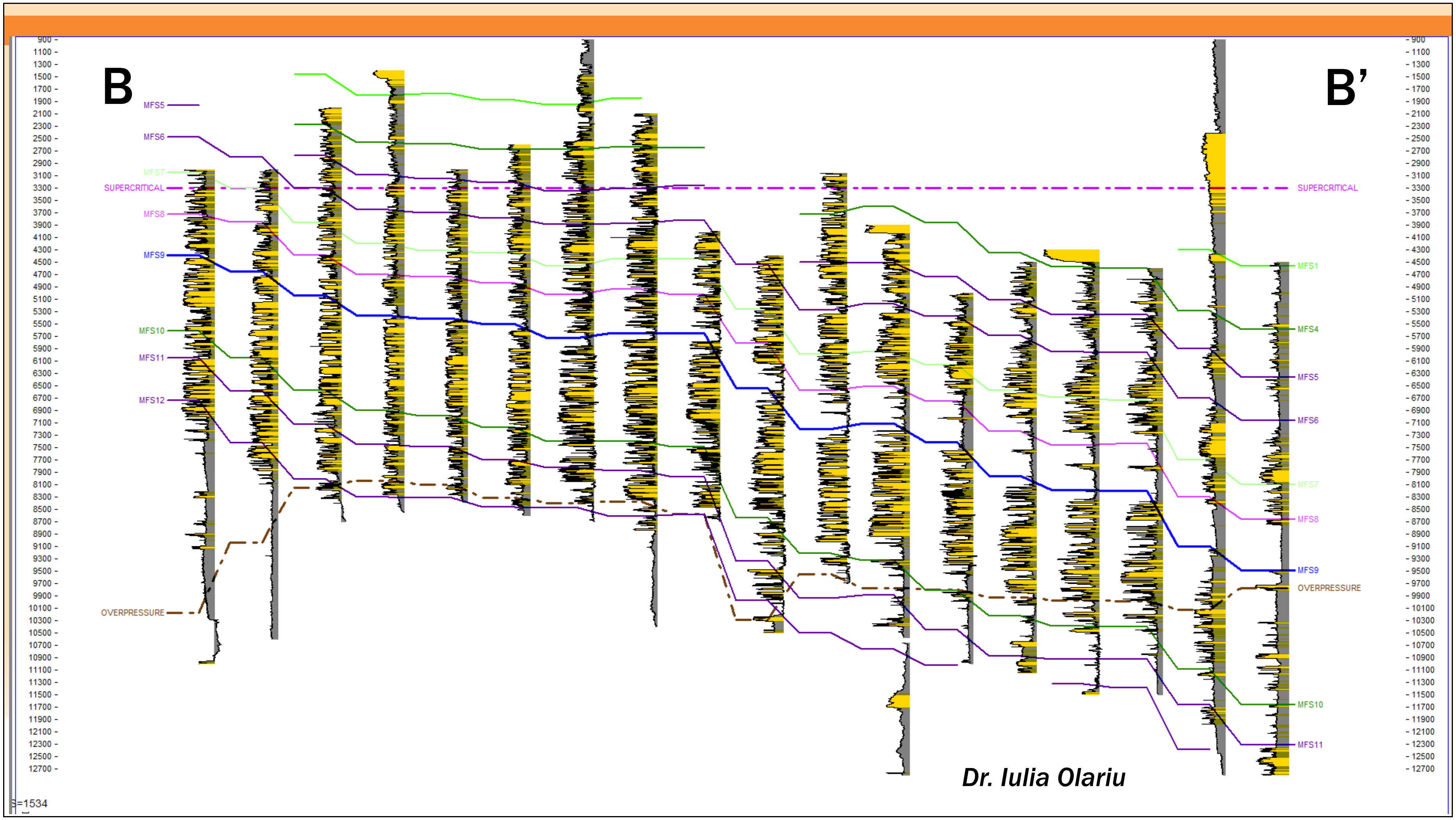
Decline Curve Analyses (DCA)



Dr. Ali Goudarzi

Presenter's notes:

- Production decline analysis - a traditional means of predicting well performance based on actual production data; for GS used as a means to predict reservoir performance & capacity (i.e., amount of void space available for potential carbon storage. Will be used as input for EASiTOOL dynamic capacity estimation.
  - Gas/Water/Oil production data for well from High Island Block 0014-L (**well-242030081363**). Located offshore Sabine Pass along Texas / Louisiana state boundary.



Presenter's notes: Dip-oriented structural cross-section extending along the border between Texas and Louisiana (BB' on study area basemap) Multiple normal faults offset the stratigraphy (purple lines in Fig. 2.1.1).The top of the overpressure coincides roughly with MFS12 updip, but due to section displacement and expansion seaward it corresponds to MFS10 and even MFS9 farther downdip. The seal interval associated with MFS9 (*Amphistegina B)* can in some instances reach a thickness of about 250m.

Next slide is net sand map of Amph B to Rob B (point out on section).

Wells and Well Correlations

- Wells correlated to date
- Total number of wells with LAS curves, 1746
  - 1700 SP
  - 84 GR
  - 20 either sonic or density logs
  - 15 have whole core

X-Ray Diffraction analyses wells OCS-G-3492 C-4 & OCS-G-3496 A-3, West Cameron Block

Well	Depth (ft)	Quartz	Calcite	Plagio-clase	K-feldspar	Illite	Kaolinite	Chlorite	Anatase	Pyrite	Anhydrite	Siderite	Dolomite
OCS-G-3496 #A-3	12954.2	21.4	7.1	4.8	7.9	34.8	4.2	16.0	1.8	0.5	1.2		0.4
	12975.5	22.4	2.9	2.1	7.0	40.2	4.2	16.7	1.6	0.6	1.1	1.3	
	12984.9	19.7	6.1	2.7	9.1	37.2	3.6	17.4	1.5	0.6	1.9	0.3	
	12999.5	20.8	3.4	2.6	8.4	41.3	3.5	16.3	1.5	0.7	1.7		
	13050	26.8	4.2	5.7	10.8	31.7	3.4	14.0	1.3	0.4	1.7		
	13060.5	24.1	3.4	4.9	11.7	35.6	2.6	14.3	1.3	0.4	1.7		
OCS-G-4392 #C-4	13100.5	31.3	0.2	3.4	9.3	35.2	2.8	14.9	1.4	1.5			
	13125	29.8		5.2	8.4	33.5	2.5	17.9	1.9	1.0			
	13136	29.1	1.4	6.1	12.8	29.3	2.1	16.7	1.5	1.0			

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Presenter's notes: The samples contain similar mineral compositions and contain ***greater than 50% clays*** with total ***clay abundance varying from 50 to 60%.*** Clay minerals are dominated by ***illite***, which is ***over 30% in all the samples***. Chlorite is the second most abundant clay at 14-18% and kaolinite is less than 5%. Quartz abundance in the samples ranges from 20% to 31%; the combination of plagioclase and K-feldspar varies between 9% and 18%. Calcite is the predominant carbonate mineral, up to 7%; although, trace amounts of siderite and dolomite may exist in the OCS-G-3496 well. The OCS-G-4392 well contains 0% to 1% calcite. Small amounts of anatase and pyrite exist in both wells. Additionally, 1-2% Anhydrite was found in the OCS-G-3496 well. The main mineralogical differences between the two wells' samples are the existence of anhydrite in the first well and low calcite content in the second well. Overall, the mudstone samples from the two wells are mineralogically very similar.