Characterization of Third Bone Spring Sand CO2 Storage Complex, Delaware Basin, West Texas: Progress Report

SEGEVOLVE Carbon Solutions

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1 Executive Summary

Several 'cookbook' methods have been described to outline the steps needed to identify a Geologic Carbon Storage Complex and calculate potential storage volumes. Using well log interpretations and existing literature, this work follows the 'cookbook' to define a Carbon Storage Complex in the Third Bone Spring Sand, Permian Basin of West Texas. The Third Bone Spring Sand (Leonardian; Permian) is one part of a larger potential stacked CCUS complex in Culberson and Reeves Counties, Delaware Basin.

The following 'cookbook' steps define the Third Bone Spring Sand CCUS storage volume:

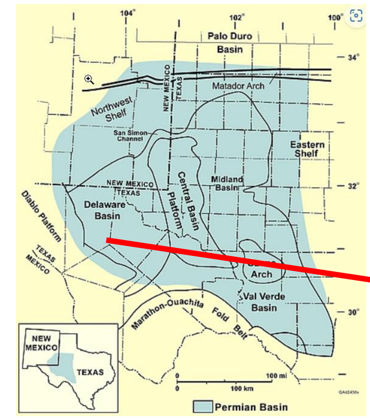
1. Containment (structural configuration of the reservoir, seal above the reservoir, potential leak points and geomechanical issues)
2. Injectivity (reservoir thickness, permeability and reservoir connectivity considering baffles, faults, and bottom hole pressure)
3. Storage amount (reservoir thickness, porosity and extent, storage efficiency and depth and impact on CO2 state (supercritical vs Gaseous).

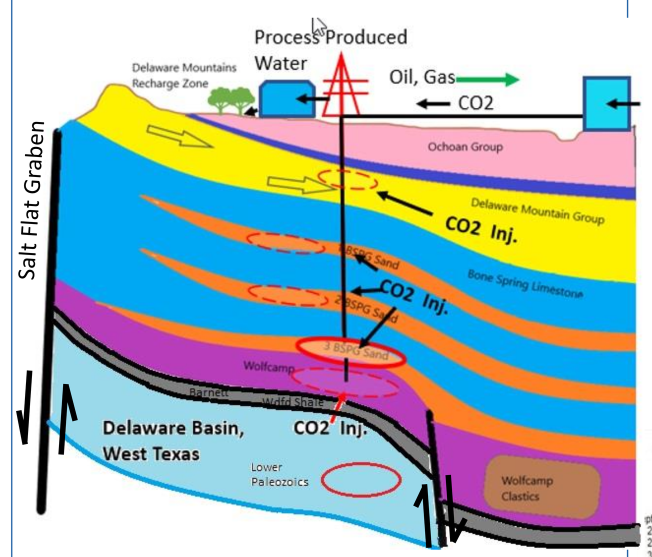
The Third Bone Spring Sand (Leonardian) is a fine grained thin bedded deep water sandstone to siltstone deposited in a flat bottomed 'bathtub' shaped Permian Delaware Basin, by submarine channels, turbidity currents and sediment gravity flows. It contains internal baffles of pelagic siltstone and mudstone. It varies from <50 to >400 feet thick in the study area, and pinches out to the southwest on the uplifted side (Alpine High) of the E/W trending regional Grisham fault of Permian age. Porosity in the study area varies from 3 to 10%. The overlying seal is the informally named Second Bone Spring Carbonate, a basinal deposit of impermeable shales and basinal carbonate debris flows.

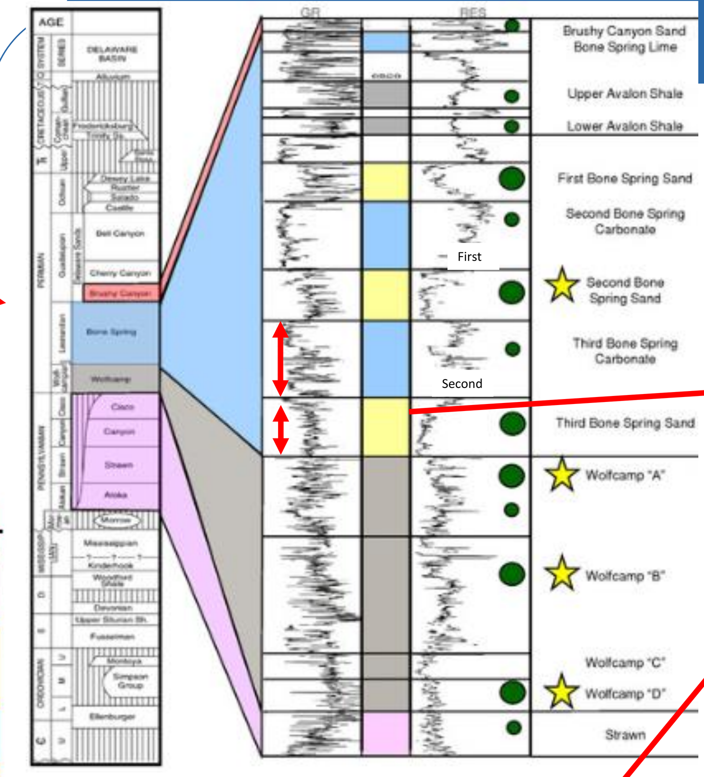
The Third Bone Spring Sand overlies thick Wolfcamp shales, organic rich siliceous shales, mudstones, and coarse grained clastic debris flows. From Permian (260 MYA) to Laramide Uplift (65-35 MYA) the thick Wolfcamp and overlying Third Bone Spring Sand formed a thermally mature, overpressured cell. Overpressure introduced microfractures into these low porosity and low permeability formations. During Laramide Uplift/ Rio Grande Rift formation, the entire Delaware basin was uplifted to the west. The microfractured porous Third Bone Spring Sand stratigraphic pinchout laps out onto present day 1.5 degrees of east structural dip. Overpressure leaked off to the west through the rift-related Salt Flat Graben fault system (Laramide age) and the Third Bone Spring Sand is currently normally pressured in the target CCUS area. Downdip hydrodynamic flow may occur from west to east across the target CCUS area.

While the target area has low regional dip and limited structural deformation, risks include potential unknown faults which could extend to the surface and could be related to basement structures. Other sources of uncertainty are water flow, and potential low injectivity rates due to low permeability. A small number of legacy wells are present in the proposed CCUS complex. Further work is needed to quantify fault risk, create seismic models, create engineering injectivity models, and economic models.

The potential CCUS Complex is bounded by the stratigraphic pinchout to the south, by reservoir depth to the west (to keep CO2 in supercritical state in the reservoir), to the north by the E/W trending Grisham Fault zone and recently seismically active areas, and to the east by both recent seismic activity along deep seated faults (Lower Paleozoic depleted gas fields), and by the presence of overpressure in the Third Bone Spring Sand. Based on this volumetric outline and the equation (Area* thickness) * Net/Gross * formation porosity, * CO2 density at depth,* efficiency factor of 1.5%, **the Third Bone Spring Sand could hold One Gigaton CO2 storage.**

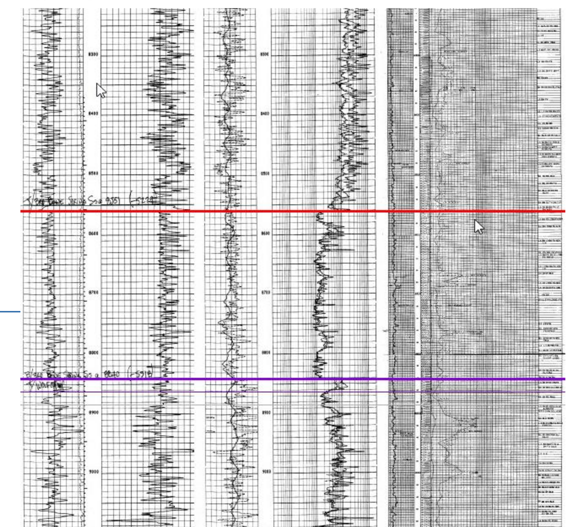




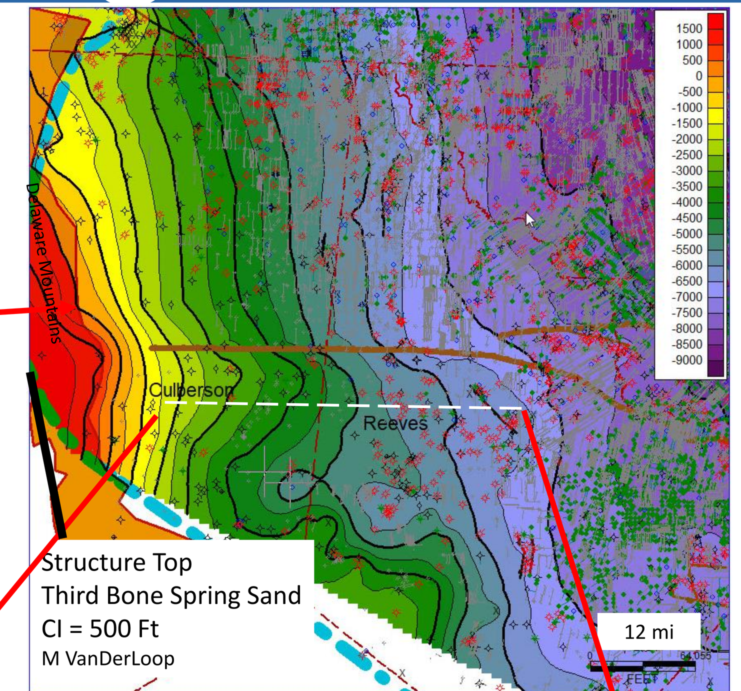


Type log Third Bone Spring from Matador investor presentation
matadoranalystdaypresent (sec.gov)

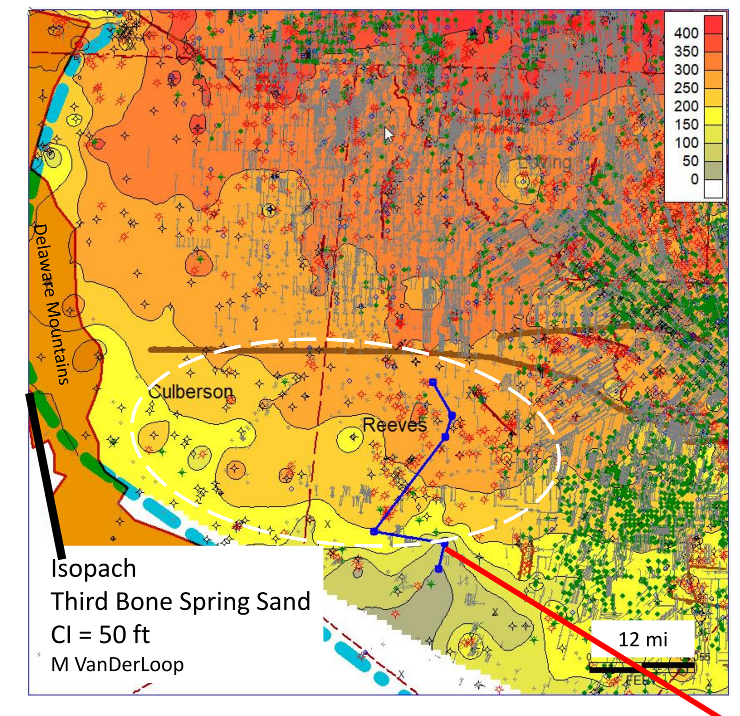
Type Log: Arco #1 Del Basin State, TD 17053, 42-109-30297, 1977



2a Third Bone Spring Sand Reservoir Characterization; Structure, Stratigraphy, Depositional Environments

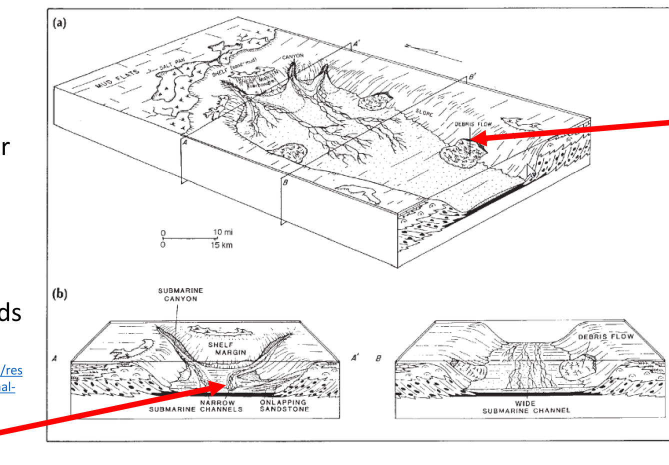


Structure Top Third Bone Spring Sand CI = 500 Ft M VanDerLoop



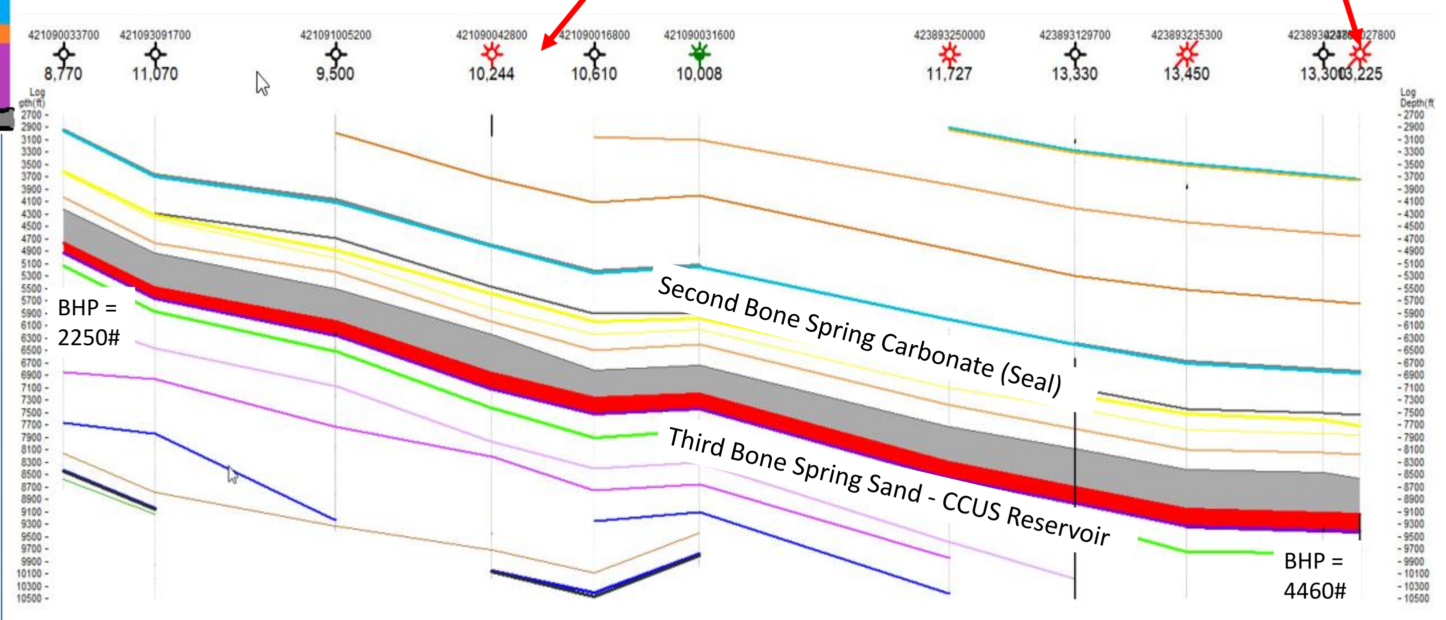
Isopach Third Bone Spring Sand CI = 50 ft M VanDerLoop

CCUS Reservoir Target, Third Bone Spring Sand core showing laminated sands : TX BEG https://www.beg.utexas.edu/research/programs/starr/regional-studies/bone-spring

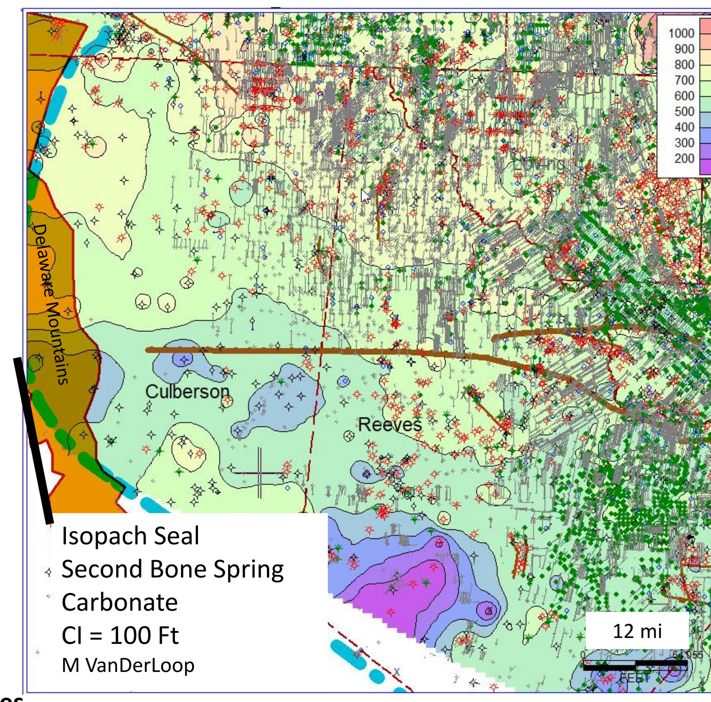


Third Bone Spring Sand depositional environment, basinal submarine channels, turbidity flows, and pelagic deposits, from Montgomery, 1997

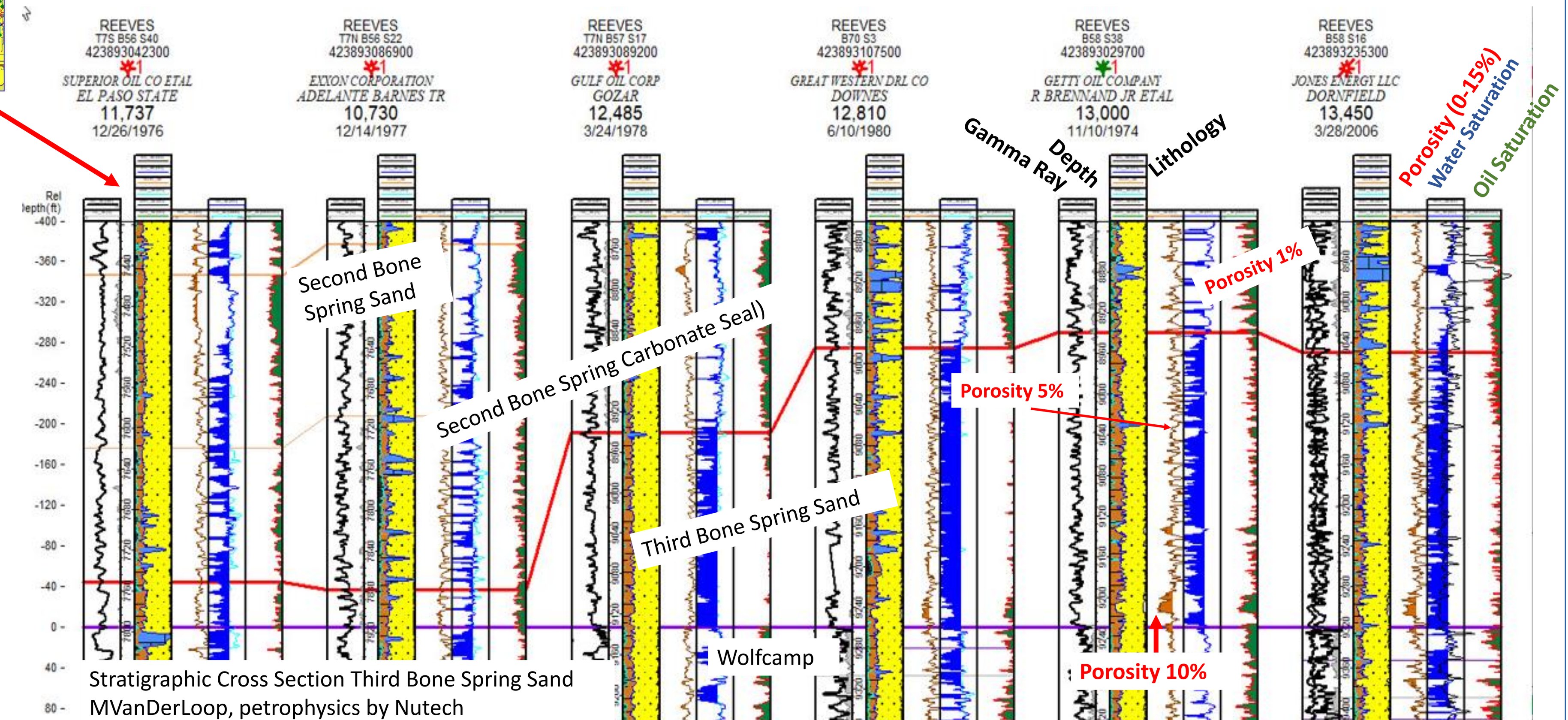
CCUS Seal, Second Bone Spring Carbonate Debris flows and pelagic deposits: TX BEG https://www.beg.utexas.edu/research/programs/starr/regional-studies/bone-spring



Third Bone Spring Sand Cross Section showing seal and structural dip of 125 feet per mile, about 1.5 degree dip over 40 miles

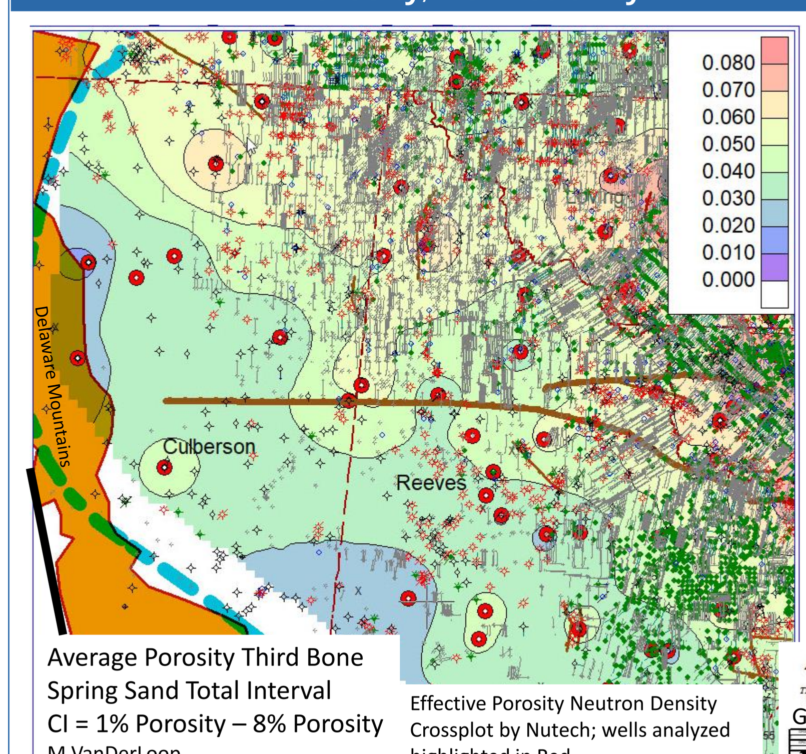


Isopach Seal Second Bone Spring Carbonate CI = 100 Ft M VanDerLoop



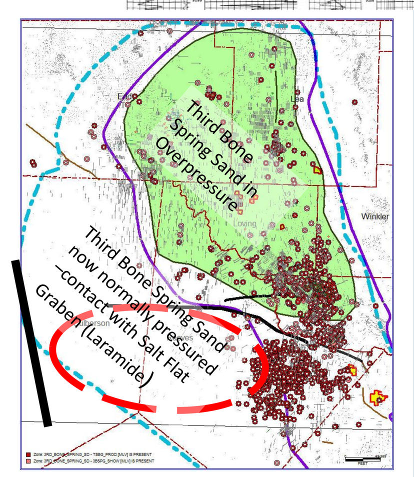
Stratigraphic Cross Section Third Bone Spring Sand MVanDerLoop, petrophysics by Nutech

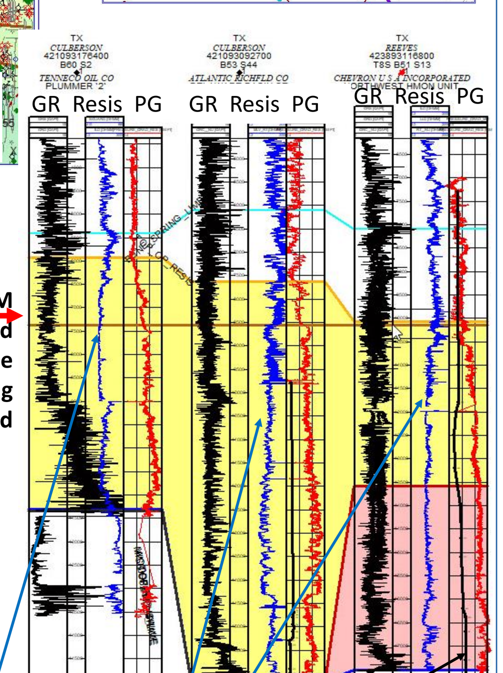
2b Reservoir Characterization Porosity/Permeability



Average Porosity Third Bone Spring Sand Total Interval CI = 1% Porosity – 8% Porosity M VanDerLoop

Effective Porosity Neutron Density Crossplot by Nutech; wells analyzed highlighted in Red





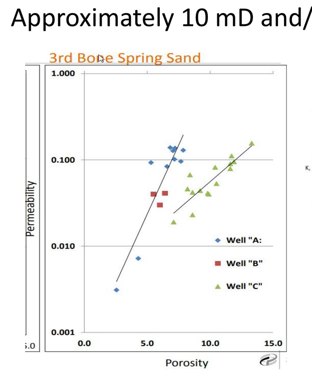
Note Resistivity decrease in overpressure

Mudweight Pressure Gradient.

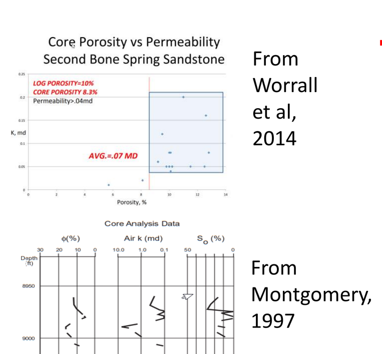
Resistivity derived Pressure Gradient

The target area was overpressured from 250 MYA to 65 MYA, which is evident on resistivity logs and mud log data (VanDerLoop 2019). Overpressure created a network of microfractures which increased porosity, permeability, and deliverability. This decreased electrical resistivity seen on logs. "The resistivity of rock mass is strongly influenced by the porosity being related to cracks and fractures. . ." (Matsui, 2016) In the CCUS target area, the Third Bone Spring is now normally pressured due to leakage to the west through the Salt Flat Graben Fault after Laramide uplift 65MYA.

Estimation of Permeability in Third Bone Spring Sand: Approximately 10 mD and/or less in the target area



From Nickerson, 2014



From Worrall et al, 2014

From Montgomery, 1997

In the study area, there is no core data for a comparison of porosity and permeability measurements of the Third Bone Spring. The measurements above, in the Third Bone Spring and Second Bone Spring sands, are derived from core data from wells in the northern part of the Delaware basin.

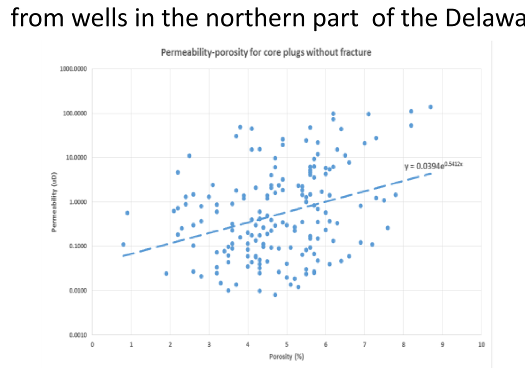
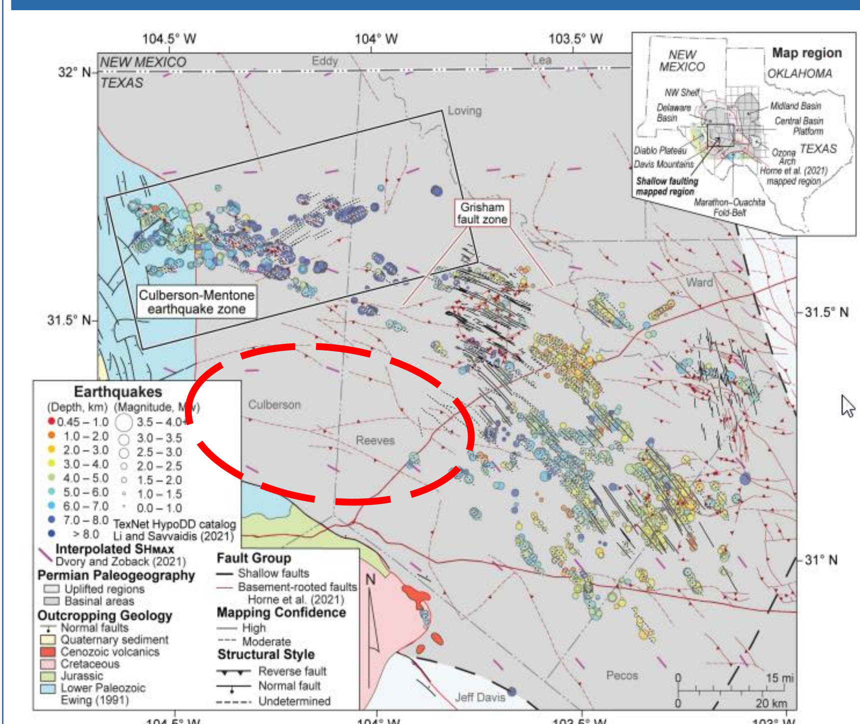


Figure 7 Relationship between permeability and porosity, without fracture.

Other tight formations such as the Middle Bakken Sandstone of North Dakota (average porosity 7% and permeability .005 mD) are successfully flooded with CO2 and result in increased oil recovery factor of 8% to 33%. "Carbon dioxide requires a lower injection pressure. . . which is one of the factors to consider carbon dioxide injection in tight reservoirs" (Wang 2019)

3 Risks, Volumes, Economics



DB1: Map of the central Delaware basin showing newly mapped shallow fault interpretations and basement-rooted fault traces from Horne et al. (2021). Earthquake relative relocations from Li and Savvaidis (2021), hypocentral locations are sized by magnitude and colored by depth of relocated event. Figure and caption taken from Horne et al. (2022).

Table 1 Basic properties of CO_2

Gas phase		Liquid Phase	
Density, kg/m3	Viscosity, mPa*S	Density,kg/m^3	Viscosity,mPa*S
0.08	0.02-0.08	0.5-0.9	0.05-0.1
Citical Temp. K	304.2	Critical Pressure, MPa	7.28

From Wang, 2019

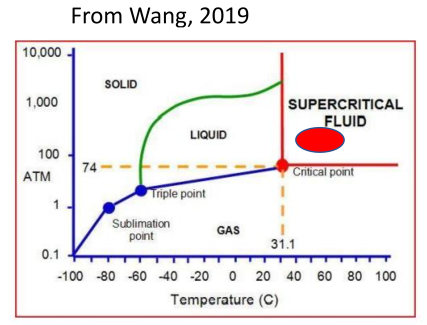
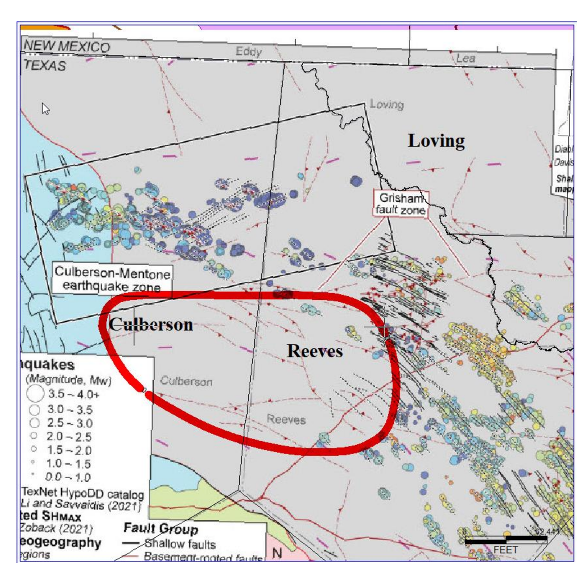


Figure 10 Phase diagram of CO_2

In Target area, 2250 to 4460 psi BHP = 150 atm to 300 atm BHP

Bottom Hole Temp = 40Deg C to 65Deg C

CO2 = Supercritical Fluid



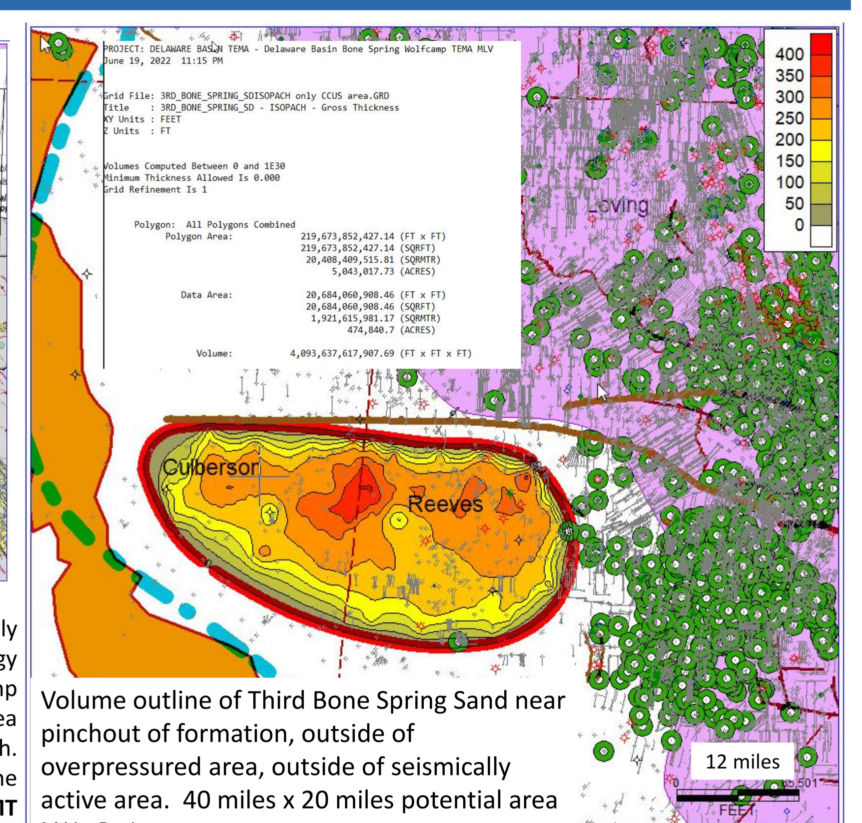
Outline of target area – limited to north by seismically active faults seen on TX Bureau of Economic Geology studies, by deep seated Grisham Fault seen at Wolfcamp and Lower Paleozoic horizons, by seismically active area to east, and by pinchout of formation to the south. Draw volume outline and calculate area and volume **Rule of Thumb: (Joyce 2022) approximately 1 to 3 MT CO2 per square mile. This is a 40X20 = 800 Square mile area so should store 800-2400 MT CO2.**

Calculation Result = 1.075 Gigaton CO2 Storage

CarbonCredits.com Live Carbon Prices	Last	Change	YTD
Compliance Markets			
European Union	€89.85	-	+12.31 %
California	$29.11	-	+0.14 %
Australia (AUD)	$34.25	-	+1.33 %
New Zealand (NZD)	$72.30	-	−5.39 %
South Korea	$10.17	-	−19.38 %
China	$8.22	−3.45 %	−3.11 %
Voluntary Markets			
Aviation Industry Offset	$2.37	-	−38.28 %
Nature Based Offset	$4.09	-	−11.09 %
Tech Based Offset	$0.85	-	−25.44 %

Carbon Credit Pricing by Type

Project Type:	Volume Sold (MtCO2e):	Average Price:	Price Range:
Wind	12.8	$1.9	$0.3 - $18
REDD+	11	$3.3	$0.8 - $20+
Landfill methane	7.9	$2	$0.2 - $19
Tree planting	3	$7.5	$2.2 - $20+
Clean cookstoves	3	$4.9	$2 - $20+
Run-of-river hydro	1.5	$1.4	$0.2 - $8
Water/purification	1.2	$3.8	$1.7 - $9
Improved forest management	0.8	$9.6	$2 - $17.5
Biomass/biochar	0.7	$3	$0.9 - $20+
Energy efficiency - industrial-focused	0.7	$4.1	$0.1 - $20
Biogas	0.6	$5.9	$1 - $20+
Energy efficiency - community-focused	0.6	$9.4	$3.3 - $20+
Transportation	0.5	$2.9	$2.2 - $6.8
Fuel switching	0.5	$11.4	$3.5 - $20+
Solar	0.3	$4.1	$1 - $9.8
Livestock methane	0.2	$7	$4 - $20+
Geothermal	0.1	$4	$2.5 - $8
Agro-forestry	0.1	$9.9	$9 - $11



Volume outline of Third Bone Spring Sand near pinchout of formation, outside of overpressured area, outside of seismically active area. 40 miles x 20 miles potential area

$$\text{CO2 storage capacity} = Vr * N/G * \sigma * \rho * E$$

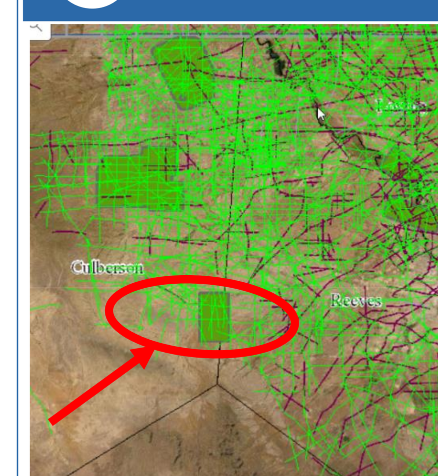
(Pore Volume: $Vr * N/G * \sigma$; Density: ρ; Efficiency: E)

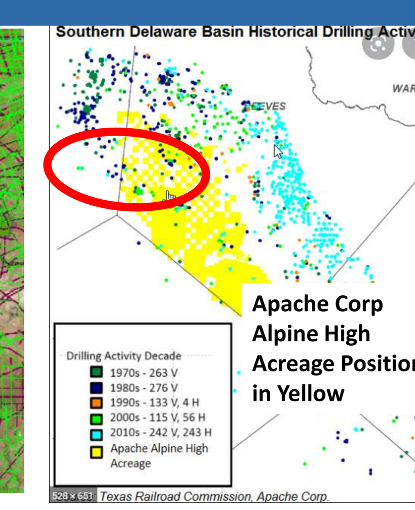
(Area	Gross Thickness)	Vr Bulk Volume	*	Net/Gross	*	Porosity	*	Density	*	Efficiency Factor	=	CCUS Potential
		4,093,637,617,907		0.5		0.05		0.7		0.015		1,074,579,875
5,043,018 acres	Maps above	4 trillion cubic feet		Estimated		% (Nutech)		Avg from graph and BHP		Estimated 1.5%		1 Gigaton Carbon Dioxide Storage Potential

Average Voluntary Carbon Market	$2.44	$2,621,974,894
Average Carbon Credit Pricing, Multiple Sources	$5.34	$5,738,256,531
Average Compliance Carbon Market	$41.00	$44,057,774,863
US 45Q tax credit, Saline Formation CO2 injection	$85.00	$91,339,289,350
Cost to build a CO2 processing and injection facility the size of Exxon's Shute Creek, Kemmerer, Wyoming or Oxy's Century facility, Val Verde County, TX: $1.1 Billion		

Exxon ShuteCreek Facility, Kemmerer Wyoming Capacity 8 MT CO2 Injection/yr

5 Communication



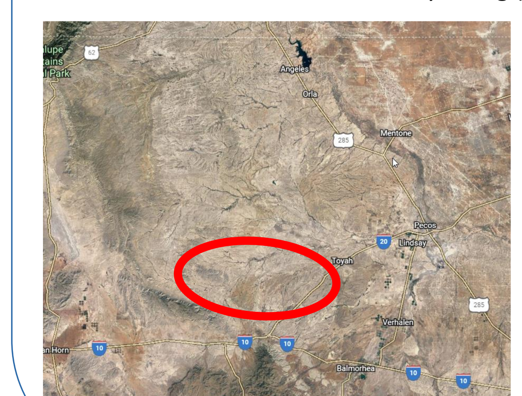


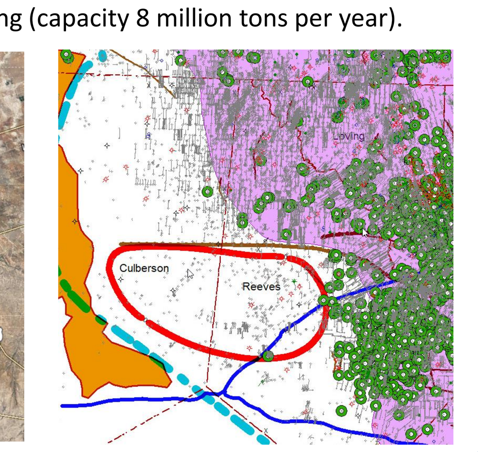
Apache Corp Alpine High Acreage Position in Yellow

This work defines a Carbon Storage Complex area in the Third Bone Spring Sand in West Texas Culberson and Reeves Counties. The target audience is Apache Corp and other potential CCUS investors. The following recommendations are proposed; acquisition or donation of 3D seismic data (the Salt Draw 3D seen above) for seismic interpretation and modeling of CO2 injection response; further log analysis by Nutech and identification of residual oil zones; further work documenting permeability in the microfracture network; and an engineering analysis and modeling of CO2 storage. This area could serve as a potential Department of Energy pilot project under the recently passed (2022) Inflation Reduction Act to economically test injection of Carbon Dioxide into tight formations.

6 Conclusions

The Third Bone Spring Sand potential CCUS Complex is bounded by the stratigraphic pinchout to the south, by reservoir depth to the west (to keep CO2 in supercritical state in the reservoir), to the north by the E/W trending Grisham Fault zone and recently seismically active areas, and to the east by both recent seismic activity along deep seated faults (Lower Paleozoic depleted gas fields), and by the presence of overpressure in the Third Bone Spring Sand. Based on this volumetric outline and the equation (Area* thickness) * Net/Gross * formation porosity, * CO2 density at depth,* efficiency factor of 1.5%, the Third Bone Spring Sand could hold one Gigaton CO2 in saline aquifer storage. This target could take advantage of a number of different economic incentives to finance a CO2 injection project of a size similar to Exxon's Shute Creek, Kemmerer Wyoming (capacity 8 million tons per year).





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7 Acknowledgements

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