Geologic Sequestration in Saline Formations
Frio Brine Storage Pilot Project, Gulf Coast, Texas

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Frio Brine Pilot:
Tapping the Potential for Large Volume Sequestration

Project Goal: Early success in a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration.

• Demonstrate that CO$_2$ can be injected into a brine formation without adverse health, safety, or environmental effects.

• Determine the subsurface distribution of injected CO$_2$ using diverse monitoring technologies.

• Demonstrate validity of conceptual models.

• Develop experience necessary for success of large-scale CO$_2$ injection experiments.
Outline

- Geologic setting
- Depositional system and lithology
- Structure
- Petrophysical properties
- Aquifer model
- Conclusions
Texas Gulf Coast Regional Geologic Setting

![Diagram of geologic setting with various formations and depth markers.]

- **Sandstone dominated units**
- **Mud-dominated units**
- **Carbonate dominated units**

Layers include:
- **Cretaceous shelf**
- **Plio-Pleistocene**
- **Oakville-Fleming Miocene**
- **Catahoula-Frio-Vicksburg**
- **Queen City**

Depth markers indicate:
- Sea level
- -3000 m
- -2000 m
- -1000 m

**Pilot site**

**Base meteoric system**

**Major growth fault zone**
Frio Depositional Systems
Texas Gulf Coast

- Shelf
- prodelta, and upper slope
- Major fluvial axis
- Minor fluvial axis
- Delta system
- Shelf, prodelta, and upper slope
- Basinward limit of Frio paleomargin
- Slope system
- Shore-zone system

Modified from Galloway (1986)

Pilot Site

Greta/Carancahua Barrier/Strandplain System
Outline

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Upper C Sandstone Core Description

- Reworked fluvial channel
- Distributary channel

Grain Size and Sedimentary Structures:
- G: Grain Size
- VC: Vesicular Composite
- C: Cross Bedding
- M: Muddy Laminations
- F: Fossil Bearing
- VF: Very Fine Sand Grain Size
- ST: Straight-Tabular Cross Bedding
- MD: Medium- to coarse-grained sandstone

Graph showing depth, gamma ray (API), porosity (fraction), and permeability (md) over a range of values.
“C” SANDSTONE ISOPACH

Pilot area

Area of control

Legend:
- >40 ft
- 30-40 ft
- 20-30 ft
- 10-20 ft

0 1500 ft
Frio Sandstone Lithology

- General Frio Lithology
  - Subarkose
    - (> 70% quartz, and Feldspar)

Diagram:
- Quartz
- Subarkose
- Sublitharenite
- Arkose
- Lithic arkose
- Feldspathic litharenite
- Litharenite
- Feldspar
- Rock fragments
**Reconnaissance: Seismic Resolution**

- **Area of 3-D:**
  - Square Miles: 13.46
  - Acres: 8600
  - Shot in the early 1990’s
  - Dynamite source
  - Bin Size: 82.5 X 82.5 ft

- **Resolution:**
  - Max Freq: 80 Hz
  - Tuning thickness: 43 ft

- **Calibration:**
  - 2 sonic logs
  - One Check shot

- **Surfaces Mapped**
  - Top of Anahuac
  - Base of Anahuac
  - Maximum flooding surface 47
Structure Components
Seismic Mapping
Time structure on top of MFS-43

Salt dome

Injector
Monitor
Outline

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Upper Gulf Coast Frio Porosity

Porosity (fraction)

Number of Samples

Injection well core mean

Injection well core range
Permeability Distribution

Upper Gulf Coast Frio Formation

Geometric mean 243 md

Frio injection well core

Permeability (md)
Dykstra Parson Coefficient Probability Plot: Injection Well Core Data

DP = 0.15

\[ y = 0.0135x + 2.4089 \]

\[ R^2 = 0.7005 \]
Permeability-Porosity relationship
Upper Gulf Coast Frio Formation

Porosity - Permeability Relationship

Porosity (fraction)
Permeability (md)

Series1
injection well
Vertical/Horizontal Relationship as a Function of Porosity

Porosity is 0.28; when the ratio equals 1.0

\[ y = 22.679x - 5.3601 \]
\[ R^2 = 0.6817 \]

Porosity (fraction)

kV/kH Arith. Mean: 0.622
Porosity (Boyle's law) Arith. Mean: 0.2638
kV/kH geo. Mean: 0.5602
Anahuac Shale Character

- Entry pressure nearly 4,000 psi
- Bulk Mineralogy
  - 41% clay
  - 28% quartz
  - 20% calcite
  - 12% other
- Clay Mineralogy
  - 75% illite/smectite
  - 11% illite & mica
  - 11% kaolinite
  - 3% chlorite

![Diagram showing capillary pressure vs. wetting phase saturation with sample data]
Capillary Pressure Character
Upper Frio Formation

Clean Sandstone
- Depth 5051.75
- Permeability 837 md
- Porosity 0.308
- $S_{wi} = 0.08$

Shaly Sandstone
- Depth 5051.2
- Permeability 44.8 md
- Porosity 0.244
- $S_{wi} = 0.53$
Comparison of Frio Sgr With Published Data

\[ y = -0.3136 \ln(x) - 0.1334 \]

\[ R^2 = 0.8536 \]

Porosity (fraction)

Residual gas saturation (fraction)

\[ \text{N} = 143 \]

Gas Residual saturation to water (fraction)

Frio Barrier bar

Log. (Gas Residual saturation to water (fraction))

\[ y = -0.3136 \ln(x) - 0.1334 \quad R^2 = 0.8536 \]
Relationship Between Natural Gamma and Porosity

Core gamma ray vs. Porosity (fraction)

- **Sandstone**
- **Shale**
Liberty Vshale–Porosity Model

\[ r = -0.91 \]

\[ \phi_{sc} = 0.357 - 0.3824 \times Vsh \]
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Proportional Cell-Layering Character Applied to Liberty Model

Proportional layering

Genetic unit (Sequence) Boundaries

A Sandstone
B Sandstone
Upper C
Lower C
Property Distribution

Adds direction to intragenetic-unit heterogeneity

1) Geologic template (object modeling)
   1) Gross sandstone thickness
   2) Facies template
   3) Net pay thickness

2) Trend weighting
   1) High-percentage weighting is applied to primary direction
   2) Low-percentage weighting is applied to secondary direction
Net Sandstone Distribution Modeling

Geologic trend weighting

Bulk volume shale

Low  High

Study area
Basic Attribute Interpolation

Key attribute model

(1) Interpolate one key attribute
(2) Calculate remaining attributes on the basis of key attribute

Vsh is key attribute used

(1) Other attributes derived for key attribute
   • Porosity
   • Absolute horizontal permeability
   • Absolute vertical permeability
   • Residual gas saturation
Reservoir Model

Porosity

A sand
B sand
C sand
Summary

• Test site is a highly faulted, steeply dipping, fluvial-deltaic environment.
• Sandstone is a subarkose
  – moderately sorted
  – fine grained
  – Poorly cemented
• Reservoir quality is dependent on bulk volume shale
  – Clean sandstones are highly porous and permeable
• Shale is Illite/Smectite mix
• Residual saturation modeled as a function of porosity
• Pilot site is typical of the Upper Gulf Coast Frio