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Site-Scale Evaluation of Geologic Carbon Storage at the Matagorda Island Leasing Area, Offshore Texas

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Abstract

Geologic carbon storage is undergoing rapid commercialization with many projects planned or in the early stages of construction and/or permitting. The Gulf of Mexico is widely recognized as a promising geographic region for carbon storage because the geology is well characterized from oil and gas exploration and there are several metro areas such as Corpus Christi and Victoria along the Texas coast which are principal sites for refineries, petrochemicals, and LNG production. Additionally, two major growth faults in this region, the Corsair and Clemente-Tomas Faults, run parallel to the Texas coast and create structural trapping opportunities for CO_2 storage. As part of the SEG EVOLVE Carbon Solutions program, this study develops a site-scale evaluation of the Miocene sands within the Matagorda Island region, offshore Texas. This study builds a reservoir model based on 3D seismic data, completes static and dynamic modeling to assess reservoir storage capacity, and develops a cost estimate for long-term storage. This study utilizes 3D seismic reflection data combined with well-log data to identify potential reservoir and sealing units within Miocene age formations as well as major structural features such as the Corsair and Clemente-Thomas faults. Key formations are exported from the seismic to construct a static geomodel to assess potential storage volumes and property distributions. Dynamic simulations are run to assess the trapping characteristics of the saline reservoirs for CCS potential. Results from 3D seismic mapping demonstrate the extensive lateral distribution of potential high quality reservoir units within Miocene saline aquifers. Additionally, the Corsair and Clemente-Thomas faults create structural traps that are likely capable of storing millions of tonnes of CO_2. Simulation results combined with economic projections provide evidence that Matagorda Island is capable of hosting a hub-scale CCS project, resulting in a positive project revenue under current tax credit systems. While many CCS projects are

being considered in the Gulf Coast region, none are currently in development in the Matagorda Island block or anywhere within federal waters of the Gulf of Mexico. We present novel site characterization and simulation results to support further commercial development of CCS in offshore regions, such as Matagorda Island, due to their large storage volumes and ability to decarbonize industrial metro areas such as Corpus Christi and Victoria.

Introduction

Carbon capture utilization and storage (CCUS) is a strategy that captures carbon dioxide emissions and stores them in underlying rock formations to remove CO_2 from the atmosphere and reduce this greenhouse gas. This method has been rapidly expanding worldwide to mitigate emissions from power plants and other industrial facilities. The Gulf of Mexico is an especially favorable location for CCUS not only due to the high knowledge of the subsurface and its history of accessing oil reserves but also with the large number of facilities along the coast that emit large amounts of CO_2. Our project focuses on the Matagorda Island region located off the coast of Corpus Christi and Victoria, Texas focusing on a saline aquifer with substantial storage potential. Our work involves geophysical and numerical modeling analysis to demonstrate the region's significant potential for the development of a commercial CCUS project.

The Texas continental shelf is characterized by a high depositional rate and growth faulting that occurred throughout the Cenozoic, with 18 depositional episodes defined by patterns of shifting entry points of continental fluvial systems (Galloway, et al., 2011). The Gulf of Mexico is known for a large accumulation of porous sedimentary rocks holding potential for CO_2 storage. Several growth fault systems exist in the Texas coastal plain and continental shelf. The structural evolution of the sediments in this region occurred in 2 main stages: First, the succession of the Clemente-Tomas and Corsair growth faulting the early Miocene, and second, a period of inactivity during the early-mid Miocene through the Pliocene with individual faults of the systems reactivating irregularly. Structural features that are associated with these growth faults include synthetic and antithetic faults, which contribute to the formation of potential reservoirs. These 2 growth fault zones trend subparallel to the shelf margin. Six major biostratigraphic markers in the Texas-Louisiana continental shelf have been used to identify Miocene-aged reservoirs.

The focus areas for this project are at depths of ~7,000 to 8,100 ft below sea level. This area includes water-saturated sands as indicated by their low resistivity. Additionally, the sands in this region have dips less than 2 degrees. The reservoir chosen is in the Robulus "Rob" L formation which is part of the lower middle Miocene.

Methods

This site-scale study combines a 3D seismic survey with Matagorda Island well-log data to determine an area of interest containing a saline aquifer to serve as a potential storage site. Specific criteria included finding a survey area close to shore, away from major Clemente-Thomas faulting, having low dip, and at depths shallower than 10,000 ft BSL.

The well-log data from Matagorda Island provides an essential dataset for subsurface geological and petrophysical analysis. Neutron porosity (NPHI), bulk density (RHOB), spontaneous potential (SP), and resistivity (RES) curves were crucial for understanding lithological variations and formation fluid types. The SP curve captures natural electrical potential and is particularly effective in distinguishing between permeable and impermeable rocks. In permeable formations like sandstone, the SP curve typically deflects to the left due to the contrast in electrical conductivity between formation fluids and mud filtrate. Conversely, in impermeable formations such as shales, the SP curve remains relatively flat, reflecting the lack of significant fluid movement. Resistivity logs identify zones with varying fluid saturations. High resistivity often points to hydrocarbon-bearing formations, while low resistivity indicates saline water-filled zones. Depleted reservoirs may show intermediate resistivity values due to the reduction in hydrocarbon saturation, while saline reservoirs are characterized by consistently low resistivity. The NPHI and RHOB curves are used to identify porosity and changes in rock density. When these curves separate, it often indicates the presence of gas, while their alignment suggests water-filled or denser rock formations. This overlay provides a quick assessment of fluid type and rock composition.

Seismic interpretation helped identify unfaulted regions for structural integrity and identify laterally extensive horizons. Biostratigraphic markers from Witrock, 2017 and Ajiboye & Nagihara, 2012 were correlated within the seismic reflection data for identification. Horizons were used to create representative maps to gather thickness, depth, and dip data for our reservoir. Seismic-well log analysis helped evaluate the suitability of clean sands as a reservoir and identify the onset of deep geopressures to avoid. There are 3 key well logs used jointly with the seismic survey, UWI 427034011100, UWI 427034016500, and UWI 427034018700. These wells were used to identify a potential reservoir with depths of ~ 7,900 to 8,100 feet, and a seal at ~7,000 to 7,900 feet. Porosity values of ~34% to 36% and a net-to-gross value of 0.4 for the reservoir interval were calculated in Kingdom. Estimated storage capacity was calculated using the following equation as seen in Wallace et al. 2014:

$$G_{CO_2} = A_t h_g \varphi_{tot} \rho_{CO_2} E$$

where A_t is the total area, h_g is gross thickness, φ_{tot} is total porosity, ρ is density of CO_2 and E is the storage efficiency factor. The total calculated storage capacity for the Matagorda Island study area (leasing blocks MI621 and MI637) is between 17.7-87.4 MMT, assuming an efficiency factor of 1-5%.

The analysis of the study area evaluates the relationships between key reservoir and petrophysical properties, including pressure, temperature, porosity, permeability, saturation, and thickness. Statistical summaries from produced sands revealed that pressure ranges from 2,737 to 7,542 psi with a mean of 3,723 psi and a standard deviation of 845 psi, while temperature ranges from 140°F to 215°F with a mean of 180°F and a standard deviation of 22°F. Both pressure and temperature exhibit a positive linear relationship with depth, reflecting typical subsurface conditions. Porosity in the Matagorda Island leasing area ranges between 0.19 and 0.36, with a mean of 0.2708 and minimal variability (standard deviation of 0.0325). It shows a weak negative correlation with depth, indicative of slight compaction effects, and minimal variation with thickness. Permeability, ranging from 11 mD to 880 mD (mean: 164.24 mD; standard deviation: 202.75 mD), shows a strong positive correlation with porosity, demonstrating that even small increases in porosity significantly enhance fluid flow capacity. However, permeability also shows variability due to additional factors like pore connectivity and fractures. Permeability increases with thickness, while water saturation decreases with thickness, suggesting better hydrocarbon saturation in thicker formations. Overall, these findings provide insights into the reservoir quality and potential for storage of CO_2 in the study area.

The identified reservoir was mapped across a 3D seismic reflection dataset using the aforementioned wells as ties. Mapped horizons were exported from Kingdom and used to build a static geomodel in Petrel. Model properties were assigned based on well and log data from the study area. The model was assigned a porosity of 0.35 and permeability of 166 mD in the lateral plane and 16.6 mD in the vertical for the reservoir layer. The sealing layer was assigned a porosity of 0.2 and permeability of 0.002 mD. The initial pressure was 3417.27 psi with a datum reference depth of -7359 ft, while temperature was 88.33 °C.

Results & Discussion

Simulations were conducted using the Petrel with Eclipse 300 solver to simulate CO_2 injection into the reservoir using a single injection well located within the study area. Results demonstrate that the reservoir is capable of securely storing ~15 million tonnes of CO_2 within the formation over a 15-year injection period. Post-injection simulation was conducted for an additional 15 years during which reservoir pressure stabilized, and the CO_2 plume showed minimal migration due to the low dip of the reservoir. These results demonstrate the high potential of the Rob L formation in the Matagorda Island leasing area to assist in decarbonizing Gulf Coast emissions.

CO_2 point source emitters were identified in the Corpus Christi and Victoria metro regions and evaluated as potential sources for the identified Matagorda Island storage system. The initial economic analysis determined that pipeline transport is more feasible than barge shipping. Geospatial mapping was used to identify optimal pipeline routes that avoid existing infrastructure and protected wildlife areas while providing the most direct source to sink transport system.

Conclusions

An area spanning two blocks, MI621 and MI637, demonstrates high saline aquifer storage potential in the Rob L interval. Well-logs from these leasing blocks provide evidence for a water-saturated sand with an average porosity of 34%-36% with a thousand-foot-thick overlying seal. This reservoir-seal package appears highly suitable for CCS development. Simulations were conducted that demonstrated the formation can store 15 million tonnes of CO_2 while static calculations show a total capacity of up to 80 million tonnes of CO_2. Economic and geospatial analysis suggests that pipeline construction from the Corpus Christi and Victoria metro areas may be economically viable under current CCS tax incentives. These results provide evidence for one possible CCS site in the Texas Gulf Coast, and we hope this work encourages development at this and other locations in the Gulf of Mexico to decarbonize local emissions.

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