Introduction

Currently, carbon dioxide (CO_2) emissions from human activities have reached critical levels, contributing to global warming, driving climate change, and directly impacting human life. To mitigate these environmental challenges, Carbon Capture and Storage (CCS) is a key solution that integrates various technologies to capture, transport, and store CO_2. The most effective long-term storage type is geological storage, which involves injecting CO_2 into porous rock formations in deep underground and trapping it beneath an impermeable caprock.

To determine the feasibility of CO_2 storage in a reservoir and assess its potential, storage capacity is one of the key criteria. This is estimated using a specific equation for CCS technology, which includes several key parameters. One of the most important parameters is capacity coefficient (C_c) which is the ratio of the injected gas volume that can be stored in the saline aquifer to the total available storage volume. This parameter is influenced by factors such as trap heterogeneity, buoyancy, and sweep efficiency (Ajayi, Gomes, & Bera, 2019) and can be classified by structural styles, including closed aquifer, steep dip non-structural, and gentle non-structure. According to external documents and internal studies, C_c typical ranges from 0.3% to 6%. In a closed aquifer, an aquifer that is bounded by impermeable barriers or low-permeability zones, CO_2 injection leads to pressure build-up within the formation more rapidly than in gentle-dipping, and non-structure, resulting in a lower Cc. In contrast, for a gentle structure, where the aquifer is not bounded by impermeable barriers or low-permeability zones and has a low dip angle, injecting CO_2 allows for a larger lateral spreading and potentially reduce the risk of exceeding the fracture pressure, thus resulting in a higher Cc.

The Gulf of Thailand exhibits a complex geological structure with numerous faults and heterogeneous layers of sandstone. Consequently, CCS implementation in saline aquifers within this region faces limitations due to these challenging geological conditions, which reduce the capacity coefficient (C_c), limit carbon storage, and increase the risks of CO_2 leakage.

In this study, the potential CCS in the saline aquifer formations of Area A in the North Malay Basin, Offshore Thailand, was evaluated through a comprehensive basin-scale assessment. The focus was on utilizing seismic attributes as a tool to gain insights into the area of interest and identify fault zones that may disrupt the reservoir, reduce the capacity coefficient (Cc), and contribute to the risk of CO_2 leakage. This research provides a guideline for implementing CCS projects in Thailand and may also be applicable to regions with similar complex geological structures.

Method and/or Theory

This section presents the basin-scale storage evaluation workflow (Fig. 1) to assess the potential CCS area and the process of identifying key parameters from seismic attributes. The workflow consists of five main steps including (1) screening, (2) target identification, (3) storage estimation, (4) suitability assessment, and (5) area selection.

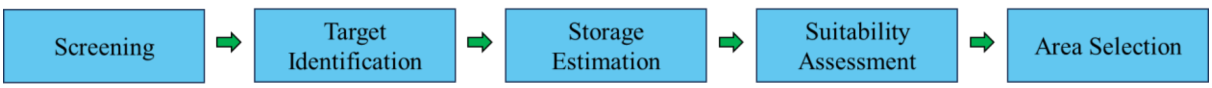

Figure 1 *Basin-scale storage evaluation workflow*

1. Screening

For the first step, possible areas for CO_2 storage have been identified, ensuring they are not subject to current or future petroleum exploration and development, and have an appropriate depth to maintain CO_2 in a supercritical phase. The area's characteristics, including potential risks, were analyzed. RMS attributes were applied to identify sand layers that could serve as potential storage and were integrated with well and core data to better understand the storage and seal properties in the area. The results of the RMS attribute are shown in Fig. 2.

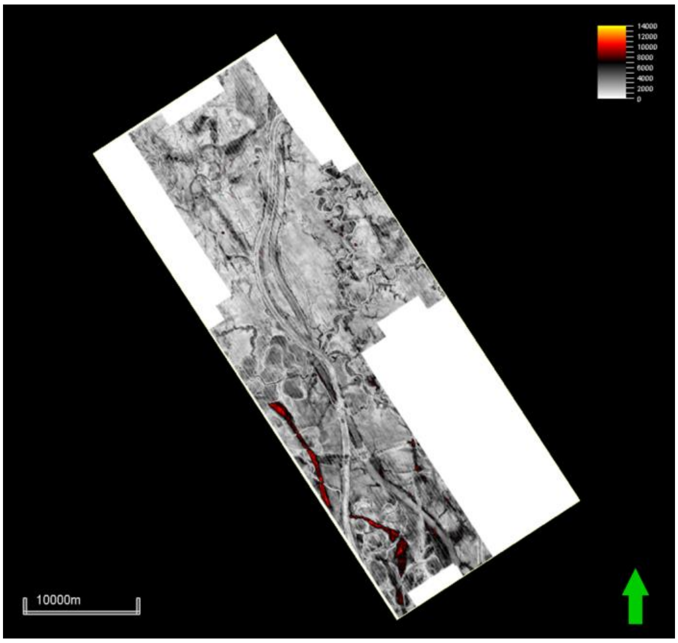

Figure 2 *Example of RMS attribute used for channel complex identification.*

2. Target identification

Following the identification of the zone of interest, the targets were categorized into two primary groups: depleted reservoir targets and saline aquifer targets. For this study, a saline aquifer has been identified as the primary target based on well data from the area.

3. Storage estimation

Following target identification, storage estimation was conducted based on the identified storage type. For this study area, the estimation focused on saline aquifer targets, utilizing a modified equation originally proposed by (Ajayi, Gomes, & Bera, 2019) and (Bachu, et al., 2007) as follows:

$$M_{CO2} = GRV * N/G * \emptyset * (1 - S_{wir}) * F_{CO2} * Cc * \rho_{CO2} \qquad \text{Equation (1)}$$

From the equation, the determination of input parameters for GRV, N/G, and porosity followed the same basis for estimating hydrocarbon initially in place. Additionally, four parameters were specifically incorporated for storage estimation:

- Irreducible water saturation (S_{wir}) – This represents the minimum water saturation level that cannot be displaced by hydrocarbons within the pore spaces of a reservoir rock. It is commonly estimated from available core data or referred from well log curves such as porosity, permeability, and shaliness.

- CO_2 concentration in injected gas (F_{CO_2}) – This is estimated based on CO_2 removal methods which range between 75-99%,
- CO_2 density at reservoir condition (ρ_{CO_2}) – This refers to the CO_2 density at a specific depth, calculated using the Span-Wagner equation of state, which considers pressure and temperature at the initial reservoir conditions.
- Capacity coefficient (C_c) – The ratio of the injected gas volume that can be stored in the reservoir to the total available storage volume, one of the most important parameters and significantly affecting storage volume.

This study utilized "FaultSight" an in-house software developed within PTTEP for automated fault interpretation from 3D seismic data. The main results from FaultSight were 1) seismic attribute volume, and 2) fault planes extracted from the attribute volume. Using these attributes, faults in the study area were identified, zones were categorized, and the capacity coefficient (C_c) was adjusted based on fault zones, where faults functioned as barriers and formed closed aquifers that prevented the lateral migration of CO_2. However, the fault seal efficiency study may need to conduct in the future to identify the potential of leakage. Figure 2 shows the results of the attribute analysis using FaultSight.

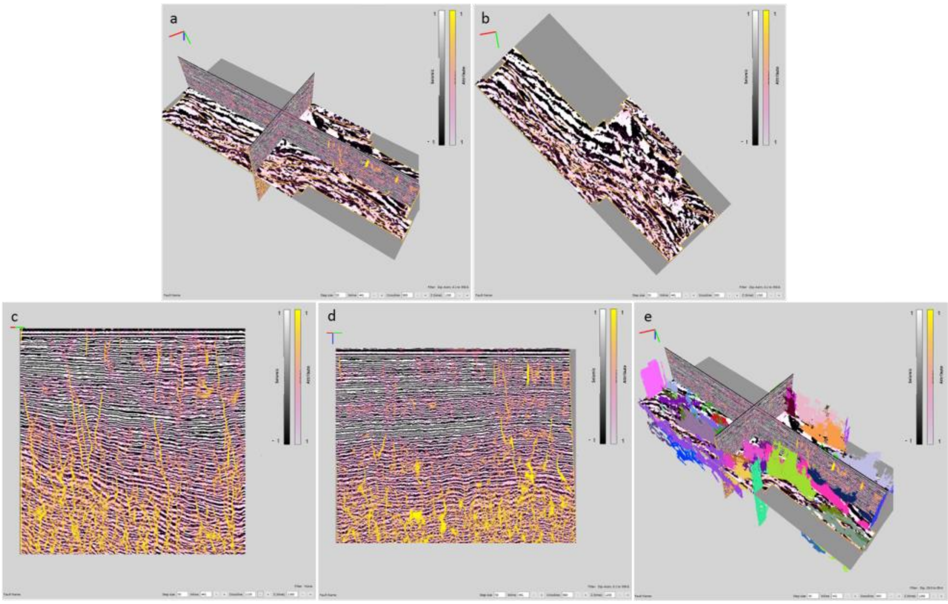

Figure 3 *Example of the attribute from FaultSigh used to indicate fault zone.*

4. Suitability assessment

Subsequently, suitable geological storage was identified using three important components (Chadwick, et al., 2008) (1) Reservoir efficacy, (2) Reservoir properties, and (3) Caprock efficacy.

5. Area selection

Finally, based on the results of the suitability assessment, storage estimation, and the availability of data in the area, potential prospects were ranked according to their feasibility for CO_2 storage. The highest-priority areas were selected to be our CCS storage.

Conclusions

From the results, RMS and FaultSight attributes, along with log data were used to analyze the area's characteristics and classify fault zones. The analysis indicated the stack sand channels with high heterogeneity and numerous faults, making it difficult to define a clear zone of the storage and significantly increase the risk of CO_2 leakage. These structural complexities confirm that this area poses a high risk for CCS implementation. However, with the growing environmental concerns, CCS remains crucial, even in geologically complex regions. The most effective approach is to make every effort to understand the geological conditions and apply tools to accurately estimate storage capacity, assisting in determining whether CO_2 storage in this area is feasible or poses too high a risk to proceed. In the Gulf of Thailand, depleted reservoirs are not a major concern for CCS implementation, as they already been proven as reservoirs with caprock due to the presence of hydrocarbons. However, for saline aquifer, which have the potential to provide high volumes for CO_2 injection, some uncertainties may remain in the study. To resolve this gap, log data and core data are crucial for confirming the integrity of the caprock and reservoir, ensuring their suitability for CO_2 storage. Once this certainty is achieved, Thailand will have strong potential to develop CCS capabilities.

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