

Quantitative Seismic Interpretation for Carbon Storage Assessment in Kuwait

Introduction

Climate change is one of the most significant global challenges of the twenty-first century, driven largely by increasing anthropogenic greenhouse gas emissions. Despite continued efforts to expand renewable energy and improve energy efficiency, many industrial sectors remain difficult to decarbonize (Bachu, 2008). Carbon capture and storage (CCS) is widely recognized as a key decarbonization technology for reducing CO₂ emissions by capturing and permanently storing carbon dioxide in suitable subsurface geological formations (IPCC, 2005).

Recognizing the strategic importance of CCS in the global energy transition, Kuwait Petroleum Corporation (KPC) has identified carbon capture and storage as a key component of its decarbonization strategy to achieve net-zero operational emissions by 2050 (Kuwait Petroleum Corporation, 2024, 2023). Numerous pilot projects and commercial-scale operations worldwide have demonstrated that geological storage can safely contain CO₂ over geological timescales when appropriate reservoirs and sealing formations are selected. Successful geological CO₂ storage relies on careful site characterization and integrated subsurface evaluation. Candidate reservoirs must possess sufficient porosity and permeability to accommodate injection rates while providing adequate storage capacity. Equally important is the presence of competent sealing formations that prevent upward migration of buoyant CO₂.

Among the various geological storage options, depleted hydrocarbon reservoirs are attractive storage candidates because they have proven trapping systems, well-characterized geology, and extensive subsurface datasets developed over decades of hydrocarbon production. However, this option is not applicable in Kuwait, as all fields are currently underproduction in different stages of their lifecycle. The applicable option in Kuwait is the deep saline aquifer; these types of potential storage offer the largest global CO₂ storage capacity due to their extensive distribution (Bachu, 2008; Michael et al., 2010).

The study aims to conduct a comprehensive regional assessment of geological CO₂ storage potential in West Kuwait. The study focused on evaluating the Cretaceous succession from the Shuaiba to Mutriba Formations. These formations were selected after excluding shallow formations (potential freshwater) and applying a minimum cutoff of 800 m to ensure that the injected CO₂ remains in a supercritical state (exceeding 31.1 °C temperature and 7.38 MPa) to enhance the storage efficiency. Formations below the Shuaiba are excluded because they occur at a depth of more than 3,000 m with an increase in pressure gradient. Formations between Mutriba and Shuaiba represent the best interval for evaluation, with a good reservoir – seal pair.

Methodology

The objective of this study is to identify, characterize, and rank candidate geological storage within the Cretaceous succession. The assessment focused on potential storage units; the interval includes both clastic and carbonate formations between Shuaiba and Mutriba.

Most of the study area is characterized by extensive 3D seismic coverage with sparse well control, which makes the seismic data the primary source for regional reservoir characterization. The main aim was to extract reservoir properties from the available 3D seismic data and extend the known reservoir properties from the well information across the study area. Potential storage units were assessed and evaluated on the reservoir and seal characteristics. The key parameters considered included formation depth, gross and net thickness, porosity, permeability, shale volume, net-to-gross, reservoir continuity,

structural configuration, caprock presence, and potential compartmentalization. This assessment will enable ranking the formations according to their suitability.

The workflow comprises four main steps (Figure 1):

1. Seismic and well data QC and feasibility study (based on the well log data)
2. Pre-stack Seismic inversion
3. Facies Probability
4. Geostatistical co-simulation for the reservoir properties

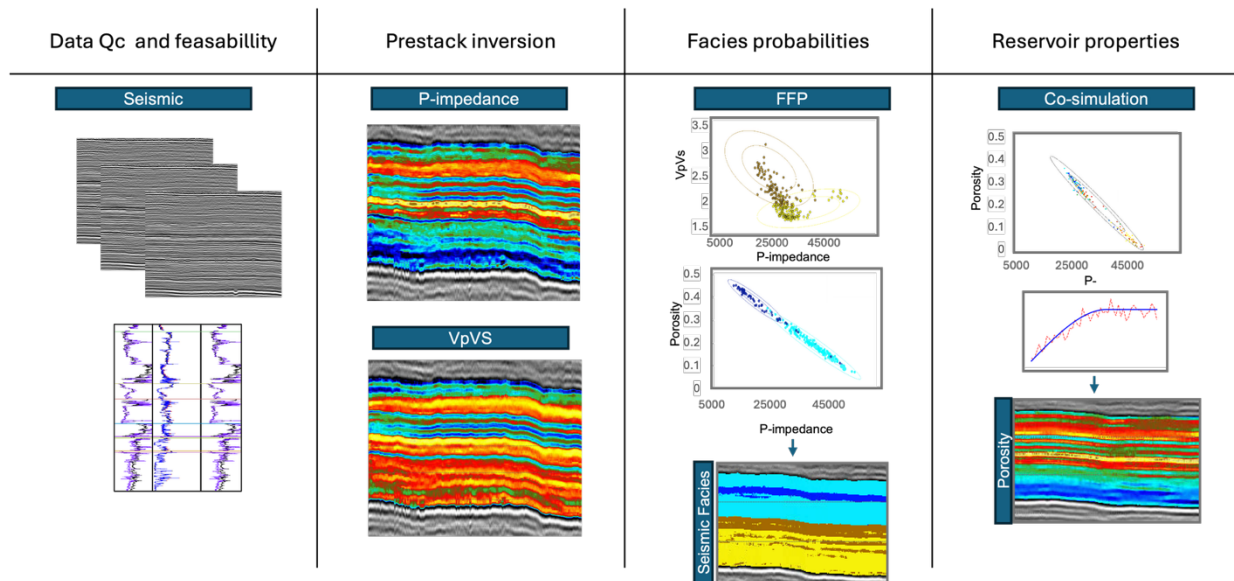


Figure 1 An integrated workflow was implemented, including well-log quality control and feasibility assessment, pre-stack seismic inversion, facies probability modeling, and co-simulation of reservoir properties to characterize the storage formations.

Crossplot analysis demonstrates that acoustic impedance decreases with increasing porosity, while V_p/V_s provides additional discrimination between porous clastic reservoir intervals and shale-rich sealing formations. These relationships establish the rock physics foundation for quantitative interpretation of the inverted seismic volumes. The feasibility study concluded that prestack inversion is essential for the clastic interval. Pre-stack simultaneous inversion was performed using the angle-stack seismic volumes to estimate the elastic properties of the subsurface, including P-wave impedance (I_p), S-wave impedance (I_s), density, and V_p/V_s ratio. The inversion workflow incorporated wavelet estimation, well calibration, low-frequency modeling, and inversion parameter optimization to ensure consistency between the inverted elastic volumes and measured well logs. The inversion outputs were quality controlled by comparing inverted properties with measured well logs at the well locations and by blind-well validation.

Facies and Fluid Probability (FFP) analysis was implemented to predict facies spatially from the seismic inversion. The methodology is based on Bayesian inference, in which probability density functions (PDFs) derived from well logs are used to represent the distribution of each facies statistically. These PDFs are combined with the inverted elastic properties and their associated uncertainty to calculate the posterior probability of each facies. The output consists of the facies probability volume and a most probable facies volume; it measures the likelihood of the occurrence of each facies (Pendrel, 2025; Pendrel et al., 2006; Pendrel and Schouten, 2020). Multiple realizations of porosity, shale volume, net-to-gross, and permeability-related properties were generated to capture geological heterogeneity and

uncertainty. This approach allowed the 3D seismic data to guide lateral property distribution while preserving well-log statistics and geological trends.

Results

Seismic inversion enables the evaluation of the three key storage criteria (Figure 2):

1. **Storage capacity:** porosity, net reservoir thickness, and areal extent.
2. **Injectivity:** permeability, reservoir continuity, and connectivity.
3. **Containment:** seal thickness, shale content, and faults.

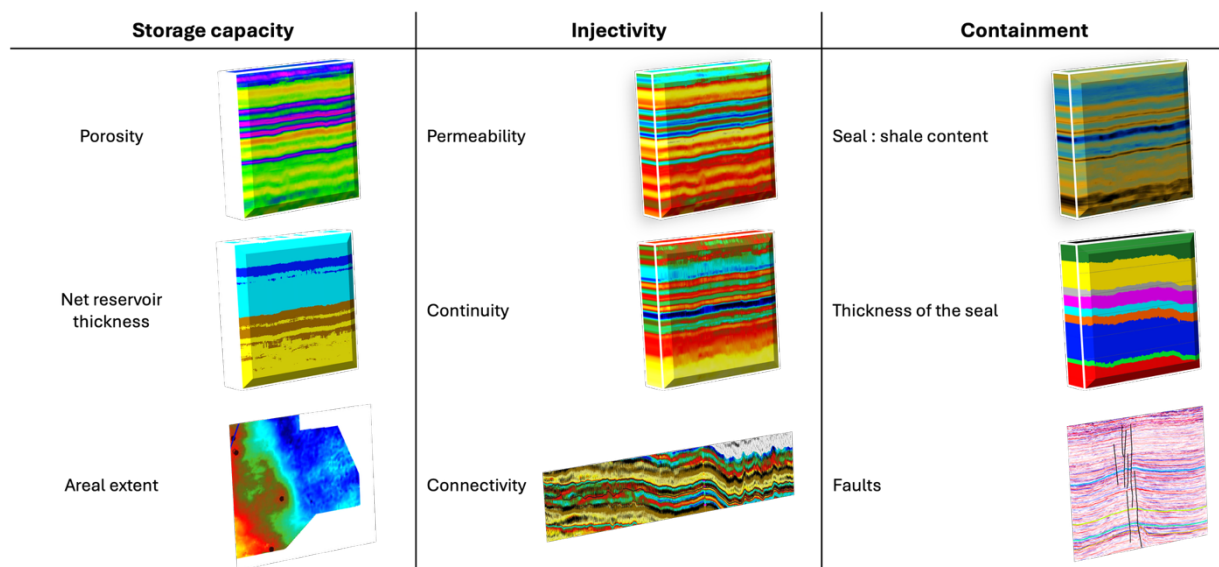


Figure 2 illustrates the three key criteria for geological CO₂ storage site screening: storage capacity, injectivity, and containment.

The resulting reservoir property models were used to evaluate the key CCS screening criteria for each candidate formation. The overlying shale-rich interval exhibits consistently low acoustic impedance and low predicted porosity, with good thickness suggesting an effective regional caprock. Among the evaluated formations, the Burgan Formation emerged as the most favorable candidate for geological CO₂ storage. It is characterized by high porosity, high permeability, substantial net reservoir thickness, and laterally continuous seals.

Conclusion

The Kuwait CCS case study was designed as a regional storage screening and characterization workflow to evaluate the suitability of candidate subsurface formations for long-term CO₂ storage in West Kuwait. This assessment integrated available data sets, including well logs and 3D seismic. Key geological and reservoir parameters required for CCS screening were evaluated, including depth, thickness, porosity, net to gross, volume of shale, lateral continuity, seal integrity, and potential geological risks to identify the best. The screening workflow allowed comparison of the main reservoir-seal and identification of the most favourable storage interval. The Burgan formation was identified as the preferred candidate for large CO₂ storage due to its favourable reservoir quality, significant storage potential, and multiple overlying sealing units. The result demonstrates that the seismic inversion is an effective tool for CCS screening, enabling quantitative characterization of key geological reservoir properties.

In the next phase, the inversion-derived reservoir property will be used as a key input for the static and dynamic model. The integrated static and dynamic models will enable evaluation of CO₂ injectivity, pressure evolution, plume migration, trapping mechanisms, and storage capacity, thereby supporting the assessment and optimization of long-term geological CO₂ storage in West Kuwait

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