CO2 Storage Complex in Santos Basin, Brazil
Storage Potential and Impacts of Heterogeneity in Pressure Front

Silva Lira, F.; Erdtmann, M.; Menezes, L.; Bortolini, S.; Guirro, A.; Waisman, G.; Bulhoes, F.; Freitas, G.; Vieira, G.; Lima, N.

DOI
10.3997/2214-4609.202522052

Publication date
2025

Document Version
Final published version

Citation (APA)
Silva Lira, F., Erdtmann, M., Menezes, L., Bortolini, S., Guirro, A., Waisman, G., Bulhoes, F., Freitas, G., Vieira, G., Lima, N., Gantois, G., Da Costa, F., Zerfass, H., Cassino, L., Walter, P., Martinius, A., & Geiger, S. (2025). *CO2 Storage Complex in Santos Basin, Brazil: Storage Potential and Impacts of Heterogeneity in Pressure Front*. Paper presented at World Carbon Capture, Utilisation and Storage Conference 2025, Bergen, Norway. https://doi.org/10.3997/2214-4609.202522052

52

CO2 Storage Complex in Santos Basin, Brazil: Storage Potential and Impacts of Heterogeneity in Pressure Front

F. Lira[1,2], M. Erdtmann[1,2], L. Menezes[2], S. Bortolini[2], A. Guirro[2], G. Waisman[2], F. Bulhoes[2], G. Freitas[2], G. Vieira[2], N. Lima[2], G. Gantois[2], F. Da Costa[2], H. Zerfass[2], L. Cassino[2], P. Walter[2], A. Martinius[1,3], S. Geiger[1]

[1] Tu-Delft; [2] Petrobras; [3] Equinor

Summary

Brazil's industrial emissions are 180 million tons of CO2 per year, and approximately 60% of these emissions are coming from industrial clusters located in the southeast. Tthe development of new offshore storage locations in this region is hence of strategic importance for future Carbon Capture and Storage (CCS) projects in Brazil. This study presents an evaluation of CO2 storage in the deep saline aquifers of the Jureia-Ponta Aguda formation, a gigaton-scale storage resource located in the shallow waters of Santos Basin that has the potential to support the development of at least three larger CCS hubs, each with a target injection of 1Gt of CO2. We show how Lorenz Coefficient map allows us to screen the pressure influence areas for each hub by linking reservoir heterogeneity to the spatio-temporal evolution of the pressure front, thereby identifying potential risks of pressure interference between neighboring CCS hubs.

CO_2 Storage Complex in Santos Basin, Brazil: Storage Potential and Impacts of Heterogeneity in Pressure Front

Introduction

Brazil's industrial emissions are 180 million tons of CO_2 per year (IPR – PUCRS), and approximately 60% of these emissions are coming from industrial clusters located in the southeast. Although CO_2 is already injected in the oil reservoirs of the Santos Basin, these offshore reservoirs are located 300 km from the coast, too far to provide suitable stores for industrial emitters for the disposal of CO_2. The development of new offshore storage locations in the southeast of Brazil is hence of strategic importance for future Carbon Capture and Storage (CCS) projects. Three storage hubs are considered in shallow waters of the Santos Basin, located 50km to 150km from the coast, with a cumulative total injection of 3 Gt of CO_2. Specifically, the Jureia-Ponta Aguda deep formation has the potential to become a gigaton-scale storage resource capable of supporting the development of CCS for the most industrialized region of Brazil. The Jureia-Ponta Aguda Formation is a 2,000 to 3,000 m thick sedimentary section composed of fluvio-deltaic to shallow marine deposits overlain by the Marambaia Formation, a regional shaly caprock that is 500 to 1,000m thick (Moreira et al., 2007). Deposited from the Campanian to Eocene on a continental platform of 400 km x 100 km, this Cenozoic reservoir is classified as a "Class A" saline aquifer (*cf*. Ringrose *et al*., 2019), which represents the best opportunity for initial deployment of CO_2 geologic storage projects. This study aims to present a basin-scale approach to evaluate the potential of the storage complex comprised of Jureia-Ponta Aguda Formation (reservoir) and the Marambaia Formation (seal), as well to investigate the impact of heterogeneity on pressure front expansion in potential storage hubs.

Method

The study area is located in the Santos Basin (Figure 1). A dataset consisting of 159 wells and 2D/3D seismic lines was used to build a basin-scale 3D model from the top of the salt to the seabed, resulting in a sedimentary column of 6,000 m thickness. This column includes the main target, which is the Jureia-Ponta Aguda Formation located at depths between 800 m and 2,500 m.

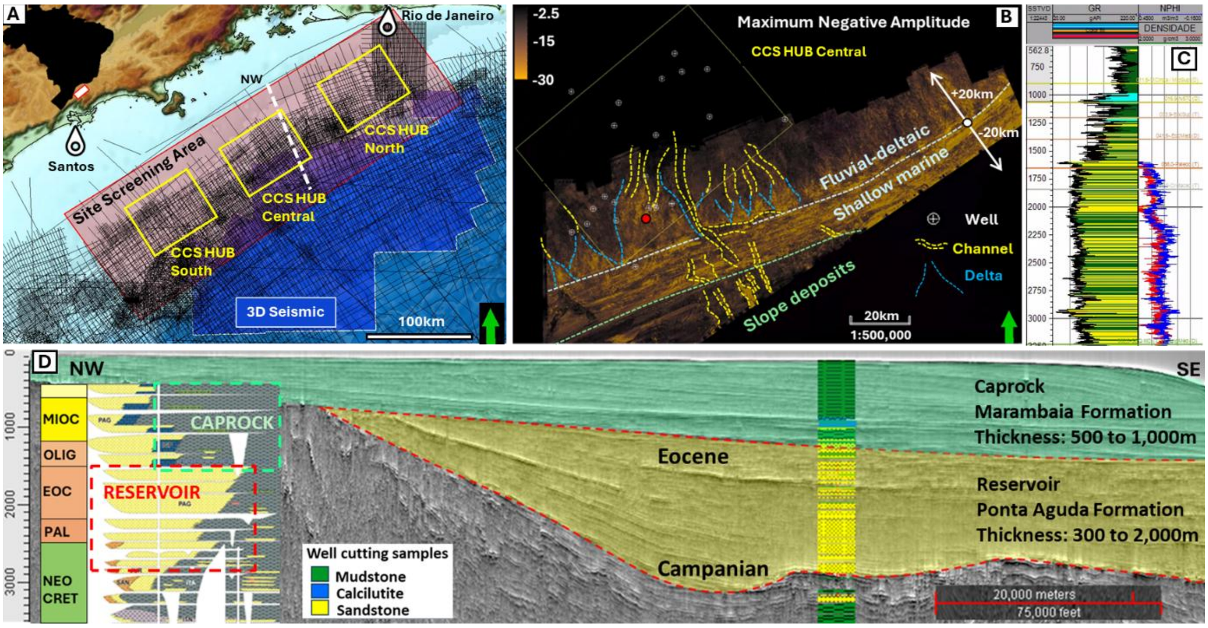


Figure 1 *A) Three potential storage hubs in the Santos Basin and the location of the seismic data. B) Seismic amplitude near the top of Jureia-Ponta Aguda Formation. C) Well log (GR, NPHI, and RHOB) located inside the CCUS Hub Central area (red circle). D) 2D NW-SE seismic section (in depth, white dashed line in A). The stratigraphic chart was adapted from Moreira et al. (2007).*

The stratigraphic-structural framework of the Santos Basin is correlated to the evolution of the South Atlantic Ocean (Moreira et al., 2007). The modelled interval comprises the Aptian salt, deposited during the sag phase of the basin, the Albian siliciclastic-carbonate platform, and the siliciclastic sequence of transgressive-regressive cycles deposited during the drift stage, from the Late Cretaceous to recent. Unlike some other CCS sites, salt is not a caprock but located at the base, playing an important role in controlling the depocenters of subsequent stratigraphic units and delimiting deformed regions associated with halokinesis (Figure 2A). For the siliciclastic sequence, three main entry points of sediments were defined based on electrofacies proportion and isopach maps that vary in time and space (Figure 2B). The integration of all data into a regional 3D geological model allowed us to identify three potential areas that could become a CCS hub: South, Central and North (Figure 2B). Flow simulations in these areas were conducted to analyze the evolution of the pressure front considering a maximum injected mass of CO_2 of 1 Gton per area. Table 1 presents a summary of the reservoir model.

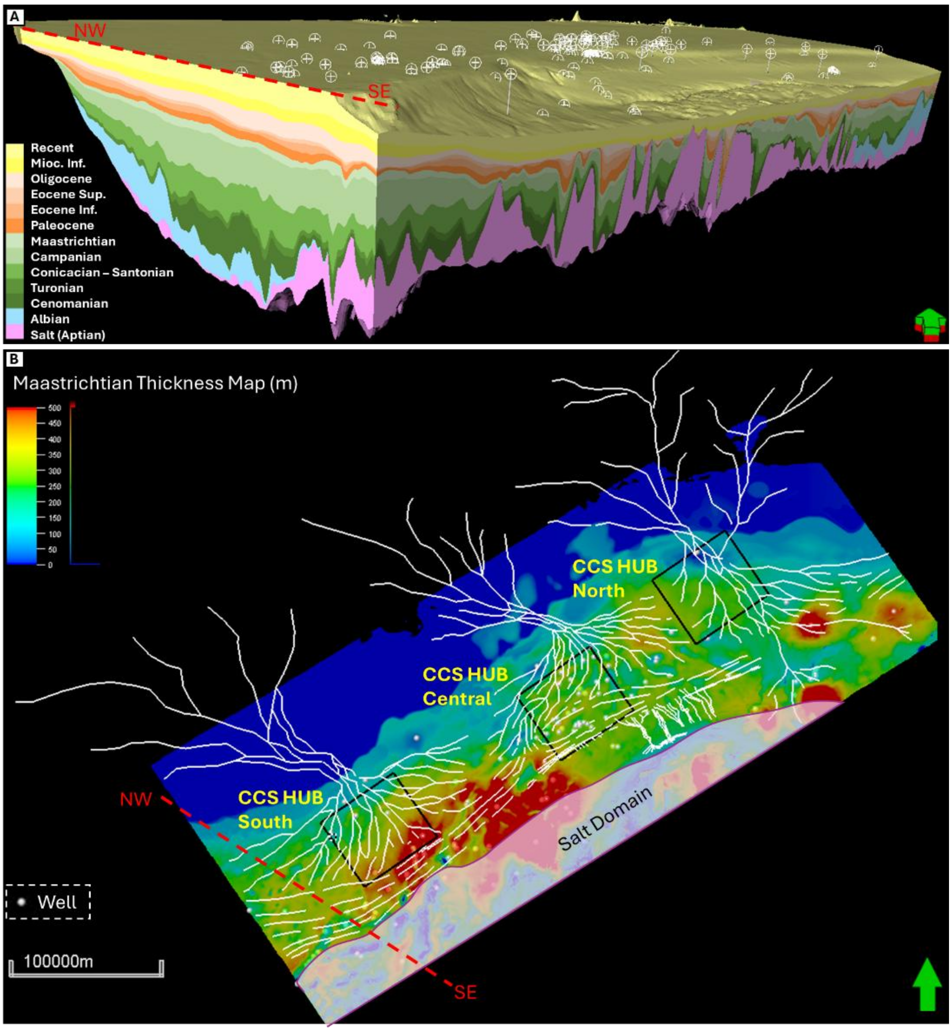
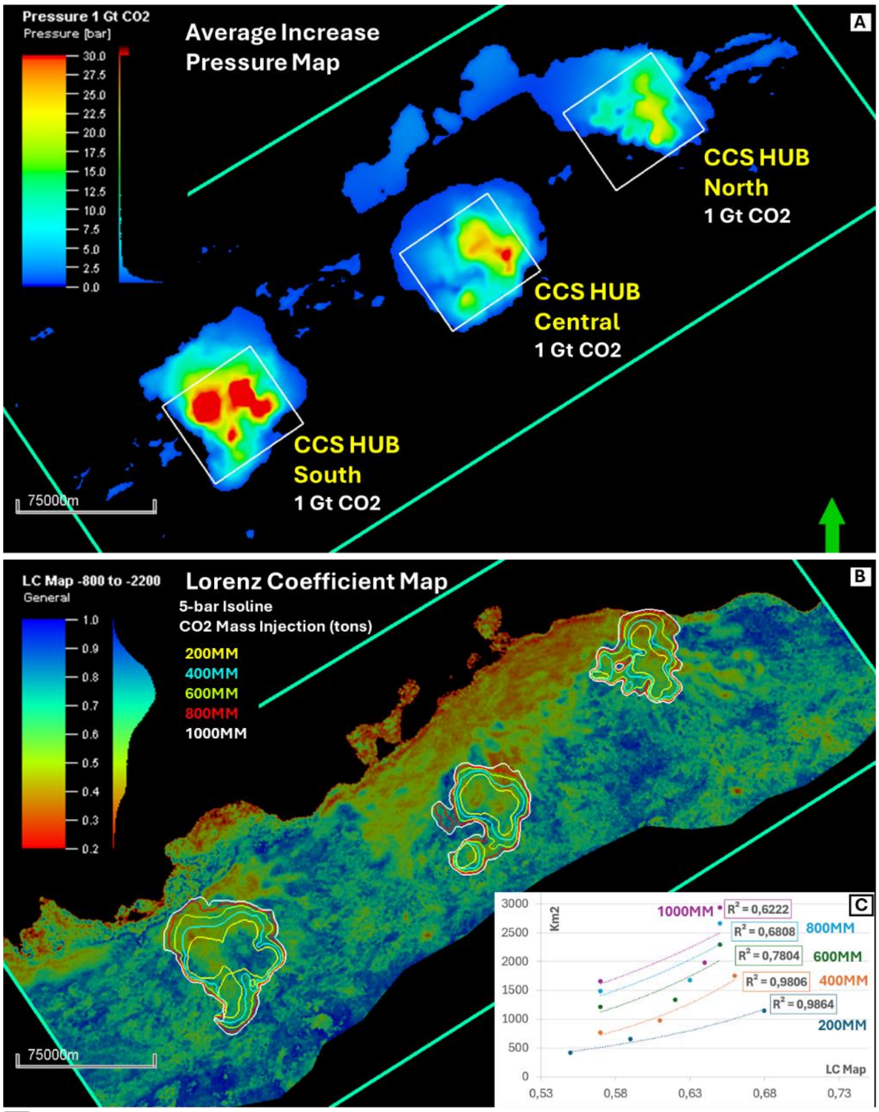


***Figure 2** A) 3D view of the basin model. B) Thickness map of the Maastrichtian with the three main sediments entry points, the salt domain, marked by halokinesis, and the location of cross-section in A).*

***Table 1.** Summary of the basin-scale simulation model.*

Total number of grid cells: 15 Million	Temperature gradient: 0.022 °C/m
Cell size (m): 1000 x 1000 x 20	Salinity gradient: 60 ppm/m
Area: 40,000Km2	CO2 solubility (average): 0.014 molar fraction in brine phase
Reservoir Thichkness: 2,000m	C Land: 1.0
Reservoir Depth: -800 to -2,500m	Injection rate per well: 0.5 - 1.5 MMtonCO2/year
Reservoir Porosity: 18%	Total injected mass: 1GtCO2/area
Reservoir Permeability: 100mD	Number of injection wells: 288 (96/area)
Pressure gradient: 0.108 (Kgf/cm2)/m	Perforation interval: -1500m to -2100m

To evaluate the viability of developing large CCS hubs in the same formation, it is important to analyze the development of the pressure front when determining the amount of CO_2 that can be injected at a hub. Interference between pressure fronts between the hubs can result in much pressure increases that are much higher than expected and require expensive mitigation strategies. Pressure perturbations migrate far beyond the injection point and impact a much larger area than the actual CO_2 plume. We simulated the spatio-temporal evolution of the pressure front assuming that 200 million tons of CO_2 are injected at each, the North, Central, and South areas. Using a injection limit of a maximum of 1.25 times the original reservoir pressure, the pressure map for 1 Gt CO_2 injected (Figure 3A) shows that the reservoir pressure increased by up to 30 bar near the wells, over 30 years. Far from the wells, there is still a slight increase in pressure but there is limited interference between the pressure fronts, which means that multiple simultaneous giga-scale CCS projects are likely possible in the Jureia-Ponta Aguda formation.



D

	5-bar Isoline									
CO2 Mass Injection (tons)	200MM		400MM		600MM		800MM		1000MM	
Variable	LC	Km2	LC	Km2	LC	Km2	LC	Km2	LC	Km2
CCS HUB North	0,55	413	0,57	759	0,57	1212	0,57	1478	0,57	1652
CCS HUB Central	0,59	647	0,61	971	0,62	1329	0,63	1671	0,64	1976
CCS HUB South	0,68	1144	0,66	1750	0,65	2290	0,65	2660	0,65	2932

***Figure 3** A) Pressure map showing the average pressure increase for 1Gt of CO_2 injected at each CCS Hub, North, Central and South. B) Lorenz Coefficient (LC) map with 5-bar pressure contours overlain. C) Correlation between pressure and LC map based on data presented in D).*

In addition to observing the level of pressure increase across a storage hub, it is important to understand the shape of the pressure front, which is controlled by reservoir heterogeneity. For this purpose, the Lorenz Coefficient (Jensen et al. 1997) was used, which combines the reservoir flow and storage capacity to obtain a heterogeneity index that varies between zero (perfectly homogeneous) and one (fully heterogeneous). Commonly applied to identify thief-zones and inflow-zones in wells, we apply the Lorenz Coefficient (LC) differently in this study by considering each grid pillar of the model as a wellbore and calculate the LC for each pillar, i.e. IJ column, between depths of 800m and 2,200m for the Jureia-Ponta Aguda Formation. The result is a georeferenced dataset LC map (Figure 3B) that shows the variability of the vertically-averaged reservoir heterogeneity, indicating more homogeneous (low LC values) and more heterogeneous regions (high LC values).

Using the LC map, it is now possible to correlate how geological heterogeneity impacts the shape of pressure front. A 5-bar contour was defined as a reference to evaluate the areal pressure increase associated with the injection of CO_2 ranging from 200 million to 1 Gt. Based on the mean LC value within each 5-bar polygon (Figure 3B), a correlation between LC and pressure influence area (in km^2) was established (Figures 3C and 3D). This correlation demonstrates that the pressure influence area is directly influenced by LC. Low LC values result in smaller pressure areas, while high values, indicating a more heterogeneous formation, lead to larger pressure influence areas. However, this correlation is not as strong at the highest injection rates because the areas involved are much larger. Still, the LC map is a useful first-order screening criterion for positioning CO_2 injection wells, i.e. to identify the more homogeneous portions of a formation where a lower pressure increase and therefore less interference of pressure fronts between hubs can be expected.

Conclusions

This study presents the first evaluation of CO_2 storage in the shallow waters of Santos Basin. Located close to the most industrialized region of Brazil, the deep saline aquifers of Jureia-Ponta Aguda formation provide an offshore gigaton storage resource that has the potential to support the development of at least three larger CCS hubs, each with a target injection of 1Gt of CO_2. The use of the Lorenz Coefficient map allows us to screen the pressure influence areas for each hub, linking reservoir heterogeneity to the spatio-temporal evolution of the pressure front, so as to identify the potential risks of pressure interference between neighboring CCS hubs. On-going work focuses on the detailed geological mapping of each CCS hub and considers the geomechanical response to injected pore volumes to further constrain uncertainties related to the evolution of the reservoir pressure and CO_2 saturation in the Jureia-Ponta Aguda formation.

References

Global CCS Institute. [2023]. *Global Status of CCS Report 2023.* https://status23.globalccsinstitute.com/.

Instituto do Petroleo e dos Recursos Naturais (IPR - PUCRS). *Plataforma GIS CCUS Brasil*. https://www.pucrs.br/ipr/plataforma-gis-ccus-brasil/.

Jensen, J. L., Lake, L. W., Corbett, P. W. M., Goggin, D. J. [1997]. *Statistics for Petroleum Engineers and Geocientists*, Prentice Hall PTR, New Jersey.

Moreira, J. L. P., Madeira, C. V., Gil, J. A., Machado, M. A. P. [2007]. Bacia de Santos. *Boletim de Geociências da Petrobras*, **15**(2), 531-549. https://bgp.petrobras.com.br/bgp/article/view/354.

Ringrose, P. S. and Meckel, T. A. [2019]. Maturing global CO_2 storage resources on offshore continental margins to achieve 2DS emissions reductions. *Scientific Reports*, **9**(17944), https://doi.org/10.1038/s41598-019-54363-z