Introduction

Carbon capture, utilisation and storage (CCUS) technologies pose a very significant role in the current framework of climate actions towards future low-carbon economies, allowing to meet the ambitious environmental targets established by the international agreements and policies. One of the current challenges is to identify and characterize potential geological formations suitable for the long-term storage of CO_2. The CO_2 can be injected in structural reservoirs in deep permeable geological formations, such as deep saline aquifers (DSA), depleted oil and gas fields, or unmined coal seams (Benson, 2008).

PilotSTRATEGY is an international collaborative research project funded by EU Horizon 2020 program that aims at advancing the understanding of DSA for CO_2 geological storage in Southern and Eastern Europe. The goal is to identify and characterise adequate storage sites to propose CO_2 injection pilots in Ebro Basin (Spain), Paris Basin (France) and the Lusitanian Basin in Portugal. In Poland and Greece, the objective is to enhance knowledge of CO_2 storage options. Previous studies have been conducted in these regions but there is still a need to increase the confidence and maturity for a clear understanding of the potential of these storage resources. PilotSTRATEGY is a multidisciplinary project that encompasses several topics such as 3D characterisation of the storage complex; prediction of the CO_2 fate in the long-term based on optimised injection strategy and storage capacity; risk assessment to identify potential leakage pathways; design of the detailed measurement, monitoring and verification plan; pre-feasibility studies; and study of social acceptance for the CO_2 injection pilot.

The work presented herein focus on the 3D facies modelling of the storage complex (seals and reservoir), conducted for the potential prospect identified in the offshore of the Portuguese Atlantic coast, in the Lusitanian Basin. The modelling of facies is a crucial step of the general geological modelling workflow as it helps to define the internal architecture of these geological formations, in particular the reservoir.

The CO_2 geological complex in the offshore of Lusitanian Basin

The area of study is located in the offshore setting of the northern sector of the Lusitanian Basin, in the western part of Portugal. In this region, a prospect was selected with high potential for CO_2 storage. This is a privileged location in the Atlantic coast, close to the main national CO_2 emitters situated in land, and approximately 20Km from the shore of Figueira da Foz. A 3D geological model was built around the selected prospect, as depicted in Figure 1.

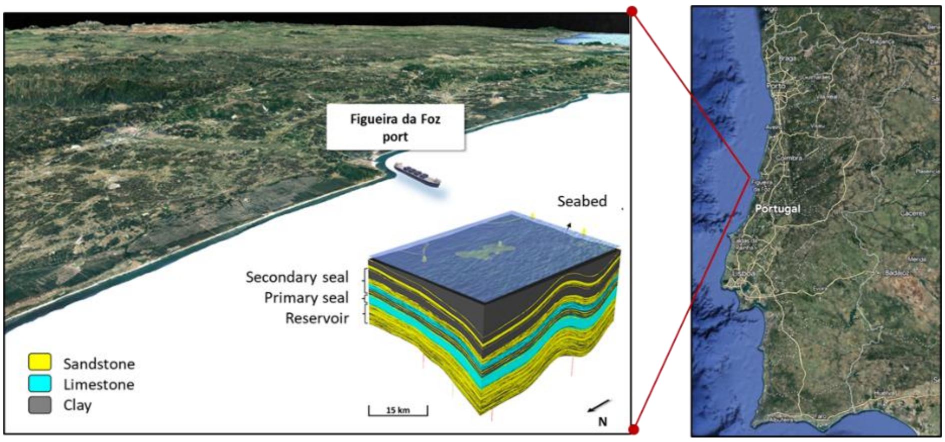

Figure 1 *Illustration of the location of the 3D geological model in relation to the shore.*

The main storage potential is identified in the lower cretaceous, denominated Torres Vedras Group. This formation is mainly composed by sandstones, deposited in a fluvial environment with interbedded sealing clays, that have been observed and described in some of the wells in the area. The sedimentary fairways are influenced by salt tectonics and the reservoir depths are between 500m to 1000m, based on the information from existing wells. The Torres Vedras Group shows good reservoir properties and the trapping mechanism can be described as structural/stratigraphic. The lack of good quality 2D and 3D seismic datasets made impossible to identify and interpret sandstone geobody continuity, as well as applying principles of internal sequence stratigraphy. Nevertheless, subsurface interpretation combined with the few existing public maps were able to generate an improved sketch of the depositional environment (Figure 2). There is an additional potential reservoir in the upper Jurassic (Alcobaça Fm.) that shows good reservoir characteristics of alternating sandy and marly, detrital limestone deposited in a shallow carbonate/siliciclastic platform environment. Most importantly, there is a thick sealing layer on the top of the reservoir in the upper cretaceous (Cacém Fm.), which combines in the topmost part mainly limestone deposited in a marine carbonate platform and marls and clays in the base (Pereira et al., 2021).

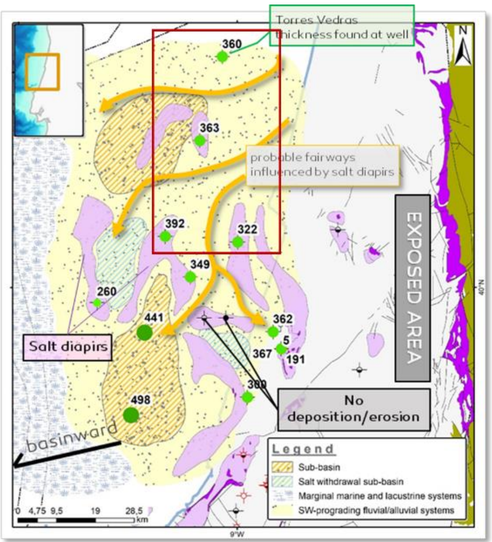

Figure 2 *Paleoenvironmental sketch map at the Albian age that includes the interpreted sub-basins and salt diapirs in the study area, as well as the main sedimentary flow directions (from Wilkinson et al., 2023). Map also includes the indication of total thickness of Torres Vedras Group reservoir found in each well and in red is highlighted the area of the model*

3D Facies modelling for CO_2 geological storage

The first step of the facies modelling can be assumed as the conceptualisation of the geological constrains (Figure 2), considering depositional and sedimentological interpretations. The information from the available wells must be honoured and consistent with the observed in the seismic data and regional information. In a broader reservoir modelling workflow, the facies model is conducted after the definition of the reservoir grid (structural and stratigraphic modelling) and the data analysis. It is followed by the modelling of the petrophysical properties.

The structural modelling of the CO_2 storage complex was defined to include 4 wells and covers an area of 2 000 km^2 (Figure 1). Vertically, the model has 7 regions defined by 8 surfaces of the main geological horizons. Due to the huge size of the structural model, the current facies modelling workflow is only conducted in more detail on the main geological formations of interest (i.e., primary and secondary seals and reservoir), resulting in the increase of discretisation in these storage complex units to reduce the computational modelling time. This model accounts for 203x289x225 cells, being the horizontal cell size in I- and J-directions of 200m. The vertical cell size is variable: secondary seal 10m (29 cells); primary seal 5m (27 cells); reservoir 2m (165 cells); and 1 cell (with varying cell thicknesses) for the remaining overburden and underburden model regions.

The data trend analysis of the lithofacies determined at the wells (hard data) is depicted in Figure 3. When comparing the original/raw data from the wells with the blocked data at the scale of the model is observed that there is a good captured of the facies trends determined at the wells within the model.

This is especially relevant for the sandstone, limestone and clay facies, that constitute the reservoir and seals.

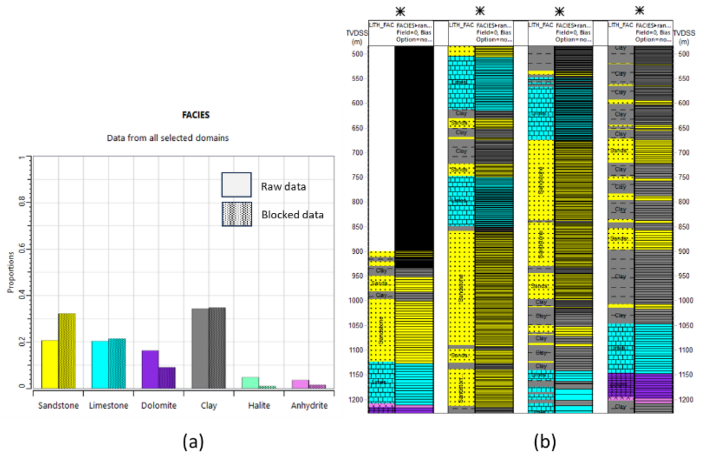

***Figure 3** (a) Histogram of the lithofacies determined at the wells (raw) and upscaled for the model (blocked); (b) Raw vs. Blocked lithofacies at the 4 wells included in the 3D geological model.*

There are several options to model facies, widely described in the literature (e.g., Ringrose and Bentley, 2015; Cannon, 2018; Journel et al., 1998). Or this study, it was decided to conduct pixel-based simulation of the facies. The advantage of these types of algorithms is that they assign properties using geostatistical algorithms on a cell-by-cell basis, instead of defining objects, such as the object-based modelling (Ringrose and Bentley, 2015). This is crucial in this case study, constrained by the limited data availability to define a robust depositional model and the possibility to explore the uncertainty of the model's parameter space.

We have run Sequential Indicator Simulation (SIS) and Truncated Gaussian Simulation (TGS) using the commercial software SKUA-Gocad. SIS is a commonly used variogram-based categorical simulation technique, very useful when there is no clear geometry of the geological bodies. SIS is based on kriging but using a sequential stochastic method to draw Gaussian realization using an indicator transform (Ringrose and Bentley, 2015). The TGS is also a variogram-based technique used to simulate categorical variables based on the facies proportions (Beucher and Renard, 2016).

Results and discussion

In Figure 4 are shown one equiprobable realization from the application of SIS and one from TGS, exemplifying possible outcomes from both techniques in one of the layers from the reservoir whereas we are planning to inject CO_2. The main difference in the obtained models is that the SIS realization captures higher lateral and vertical variation of the facies, both for seals and reservoir units. On the TGS results, we observe a more continues extension of the sandstones. Additionally, the interbedded clay layers observed on the lithology profiles of the wells, are better reproduced in the SIS models.

Conclusions

The presented work refers to the preliminary 3D facies modelling of the geological model located in the offshore of the Lusitanian Basin and with identified potential for the geological storage of CO_2.

SIS and TGS techniques were applied to model the facies spatial distribution of the storage complex. These pixel-based techniques are useful to model the facies where the geological elements do not show discrete geometries. This is very pertinent in this case study due to the limited data availability to constrain the depositional model, which is very conceptual and not in 3D.

Future work will consist in conditioning the 3D facies modelling to secondary data, such as vertical proportion curves and 2D trend maps. However, the scarcity of data will always pose a key limitation in terms of exploring the uncertainty of the model's parameter space.

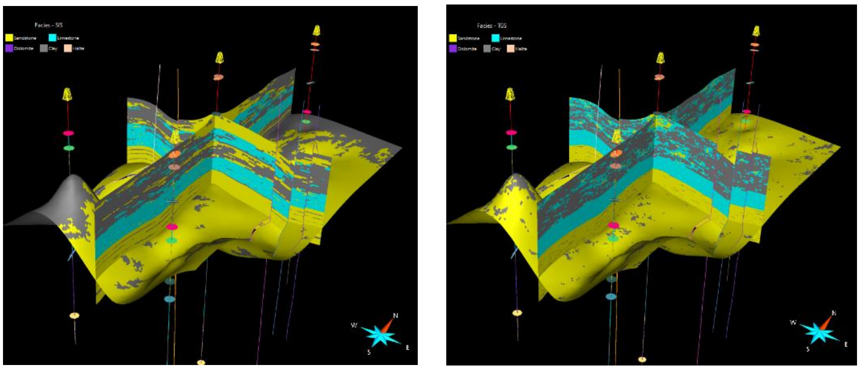

Figure 4 *Example of one realization from SIS (left) and TGS (right), showing in both one of the layers from the middle of the reservoir.*

Acknowledgements

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