3D static modelling with uncertainties of an offshore area in Portugal for CO_2 storage pilot site development

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ABSTRACT

The subsurface geo-characterization of storage elements in the offshore northern sector of the Lusitanian Basin was previously performed within the PilotSTRATEGY project using available data, including legacy well information and 2D/3D seismic reflection data (Pereira et al., 2023). The Q4-TV1 prospect was identified and characterized as a promising site in the Portuguese region for the CO_2 injection and storage pilot. This potential CO_2 storage complex encompasses the Torres Vedras Group reservoir, composed of Lower Cretaceous siliciclastic deposits (Pereira et al., 2021), and the caprock unit, consisting of Upper Cretaceous carbonates and marls (Cacém Formation), which provides critical sealing properties for the storage complex. In addition, the underburden units at the top of the Lower Jurassic salt (Dagorda Formation) to the overburden units extending to the Paleogene-Neogene boundary (seabed), complete the stratigraphic sequence of this potential CO_2 storage complex.

The study presented herein details the construction of a 3D static geological model for the Q4-TV1 prospect area, focusing on the property modelling and uncertainty assessment. The model covers approximately 1925 km^2 in the offshore northern sector of the Lusitanian Basin (Fig. 1a). The applied workflow (from Aspen SKUA software) is described in Figure 2 and considers data analysis, modelling, uncertainty evaluation, and reservoir upscaling. The dataset for the structural model building includes seismic interpretation elements (eight structural maps and six fault surfaces), and data from four wells (Do-1C, Mo-1, 13E-1, and Ca-1). The stratigraphic markers from these wells represent seven key regions of the storage complex. Petrophysical logs, such as effective porosity (PHIE) and volume of clay (Vshale), were incorporated and analyzed to derive lithofacies and permeability logs. This analysis provided the foundation for data conditioning, trend analysis, and subsequent lithofacies and petrophysical modelling.

In the property modelling phase, the lithofacies simulation was conducted using pixel-based algorithms (Deutsch & Journel, 1997; Ringrose & Bentley, 2015) within the Aspen SKUA software. The Sequential Indicator Simulation (SIS) was used for the lithofacies models due to its ability to integrate trends and align closely with observed data, as it captures effectively facies variability of the study area. Vshale, PHIE, and permeability were modelled using Sequential Gaussian Simulation (SGS) algorithm (Deutsch & Journel, 1997). Vshale models were generated using SGS with simple kriging, conditioned by well data and based on the lithofacies models. PHIE models were simulated using co-SGS with locally varying means, allowing the integration of both hard and soft data. Permeability models were generated through co-SGS with collocated co-kriging, where well log permeability served as hard data and effective porosity as secondary variable. These approaches ensure robust conditioning to observed data and trends, enhancing the reliability of the final property models.

At the scale of the geological model, the lithofacies models successfully reproduced the conceptual geological framework of the reservoir region. This included the interbedded clay layers within the reservoir unit and potential stratigraphic trapping in the northern structural area, where the Q4-TV1 prospect is located, near well Ca-1. The simulated rock property models aligned with the main statistical elements of the well data, capturing vertical and lateral heterogeneities and spatial trends consistent with the geological and depositional understanding of the reservoir in the study area. At the Q4-TV1 prospect, the models revealed several reservoir layers with high Vshale and low PHIE at depths of approximately 950 m, 1000 m, and 1100 m. These depths correspond to interbedded clay layers or sandstone intervals with relatively low PHIE. The seven promising reservoir flow units identified in the legacy well Do-1C have been reproduced in the stochastic simulation models, as illustrated by the resulting median model of PHIE (Fig. 1b). The first two intervals represented the main target depths identified in geo-characterization studies for the Q4-TV1 prospect, while the deepest interval corresponds to coarse sandstone and conglomerate layers at the base of the reservoir. Considering the dispersion of the CO_2 plume over time, these deeper intervals may also warrant evaluation in dynamic simulation studies to assess their potential contribution to the overall reservoir performance and CO_2 storage capacity.

The uncertainty analyses of the structural elements and rock properties was conducted to assess their impact on reservoir gross-rock volumes and the spatial continuity patterns of petrophysical properties within the static model. This included evaluating the effects of fault displacements and horizon positioning. Furthermore, incorporating the uncertainties of multiple parameters within a single geo-modeling workflow provided an estimate of net-porous rock volumes (Fig. 3), which was used to calculate the storage capacity of the reservoir unit. The probabilistic models representing volumetric results of the P_{10}, P_{50} (median), and P_{90} simulation scenarios, derived from the probability (Fig. 3a) and cumulative (Fig. 3b) distribution functions of the uncertainty analysis, were subsequently generated using the Reservoir Risk Assessment (JACTA) module.

The integrated approach presented in this work ensured a comprehensive 3D modelling and uncertainty assessment of the potential of the reservoir for CO_2 storage and its behavior under varying conditions. The resulting static models will be used to produce flow simulation grids of the Q4-TV1 prospect, serving as input data for the dynamic simulation tasks within the PilotSTRATEGY project.

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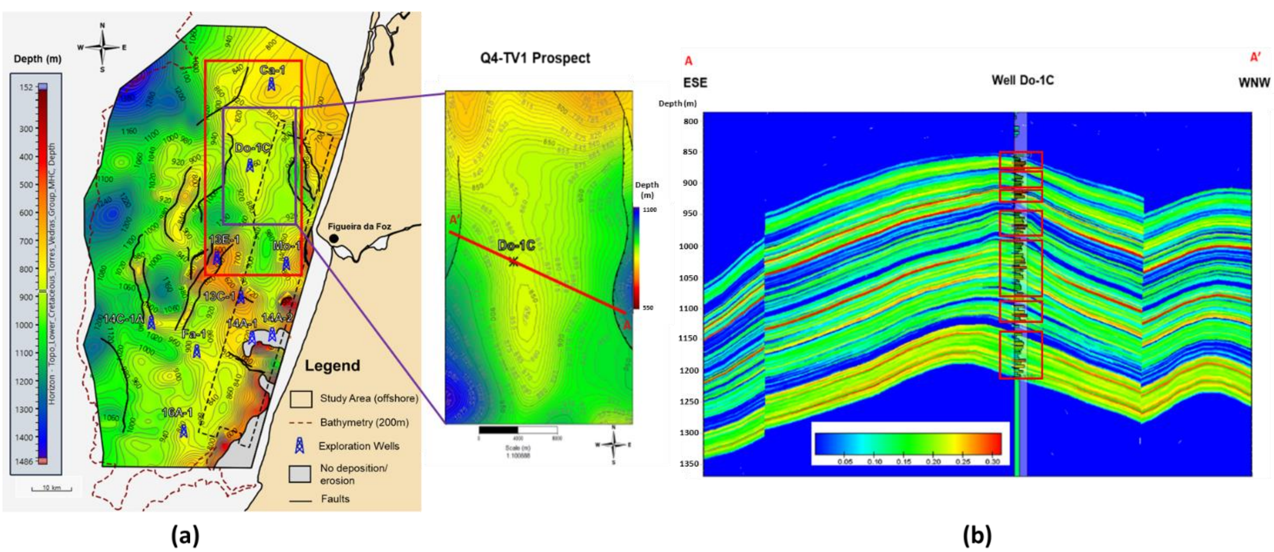

Figure 1: (a) Map of the top of the Torres Vedras Group reservoir structure outlining the boundaries of 3D static model (red rectangle) and the Q4-TV1 prospect (purple rectangle); (b) cross-section through the Q4-TV1 prospect illustrating the reservoir PHIE median model (with the seven reservoir flow units highlighted in red), the location of the well Do-1C and the existing faults.

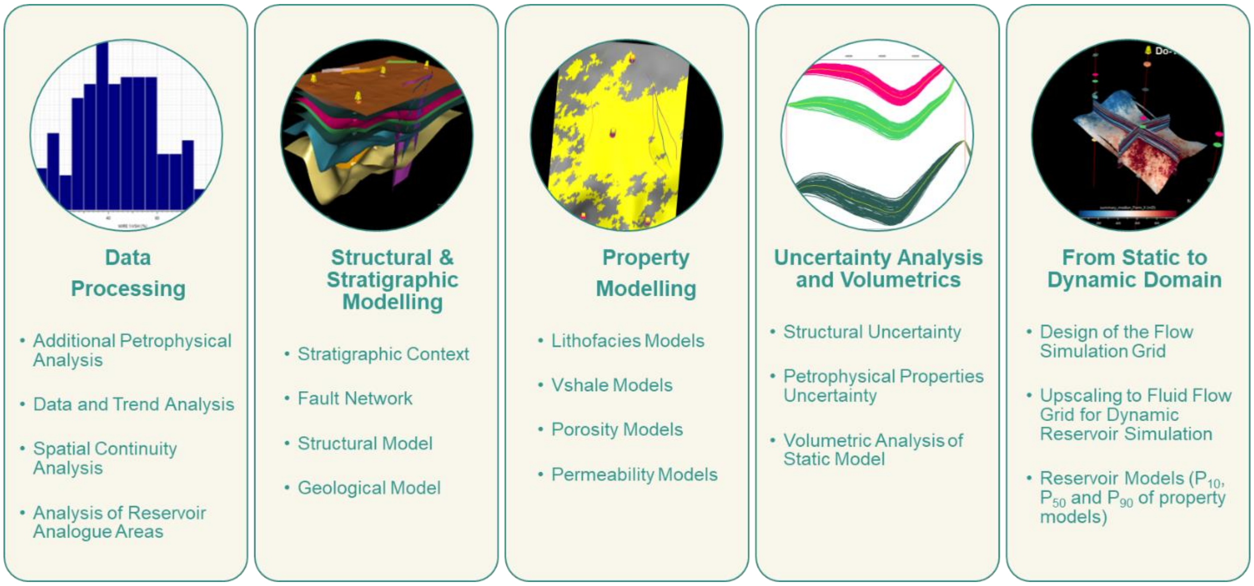

Figure 2: General workflow of the 3D static modelling, characterization and uncertainty assessments.

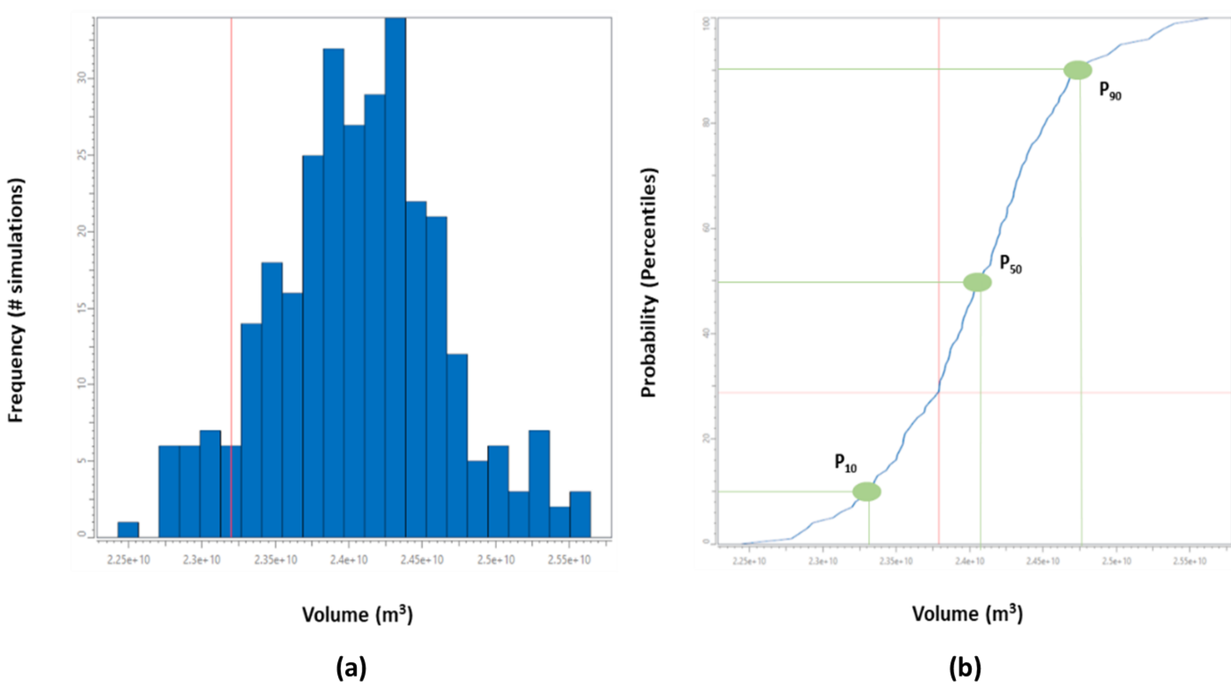

Figure 3: (a) Probability distribution function of the net-porous volume of the reservoir unit (Lower Cretaceous) of the static model, and (b) the corresponding cumulative distribution function. The red lines correspond to a given selected simulation percentile.