FORWARD STRATIGRAPHIC MODELLING: USING AN INTEGRATED APPROACH TO IMPROVE CARBONATE RESERVOIR CHARACTERISATION AND MODELLING

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Summary

Large hydrocarbon carbonate reservoirs are frequently marked by complex sedimentary features responsible for major and multiscale heterogeneities. In this context, it appears necessary to use advanced technologies and develop new workflows to better apprehend sedimentological and diagenetic processes and better capture and model associated reservoir heterogeneities. During the last decades, a new technology has been developed to improve the understanding of sedimentary systems: the Forward Stratigraphic Modelling. The main goal of this study is to apply a robust and integrated workflow for carbonate reservoir characterization and modelling which encompasses FSM technologies. The general workflow of this study can be subdivided into three main phases. The first phase aims at interpreting and integrating all available data and results into a robust geological and sequence stratigraphy framework and preparing the different inputs for FSM. The second phase consists of forward stratigraphic modelling using DionisosFlowTM software and the third and last phase corresponds to the implementation of the FSM results into the static model. Ultimately, this study implemented an integrated workflow that critically improved the geological robustness of 3D electrofacies propagation between wells in the static model and, ultimately, the reliability of subsequent dynamic simulations.

Forward Stratigraphic Modelling: using an integrated approach to improve carbonate reservoir characterisation and modelling

Introduction

Large hydrocarbon carbonate reservoirs are frequently marked by complex sedimentary features responsible for major and multiscale heterogeneities. In this context, it appears necessary to use advanced technologies and develop new workflows to better apprehend sedimentological and diagenetic processes and better capture and model associated reservoir heterogeneities. During the last decades, a new technology has been developed to improve the understanding of sedimentary systems: the Forward Stratigraphic Modelling (FSM, e.g., Granjeon, 2019; Borgomano et al., 2020). Based on sedimentology and sequence stratigraphy concepts, FSM is a deterministic approach that reproduces the interactions between the main mechanisms driving sedimentation (e.g., subsidence, eustasy, sediments production and transport, hydrodynamics). Calibration is done using all available data including 3D seismic, logs, cores, and literature. In the present study, a forward stratigraphic model has been built for a cenozoic oil field of the middle east.

The main goal of this study is to apply a robust and integrated workflow for carbonate reservoir characterization and modelling which encompasses FSM technologies. The main expected benefits of this approach are:

(1) Add to the lithostratigraphic scheme a well-calibrated sequence stratigraphy framework.
(2) Improve our understanding of the reservoir nature, heterogeneities and architecture
(3) Improve the robustness of the static model by using, when applicable, properties volumes from FSM (based on geological concepts and modelling) as geostatistical constrains.
(4) Obtain, at larger-scale, new potential insights into underlooked stratigraphic traps for exploration and/or field development purposes

Methods

The general workflow of this study can be subdivided into three main phases.

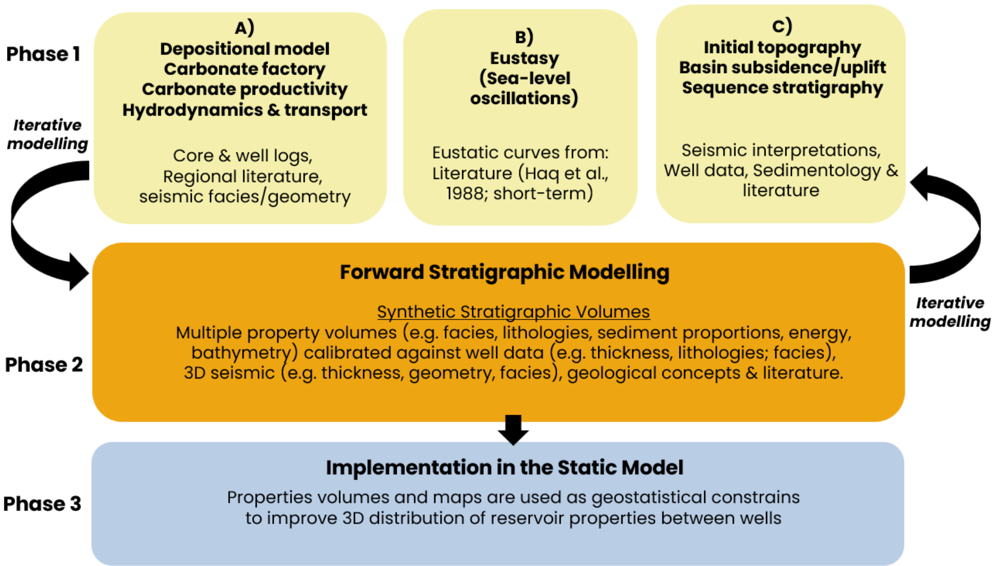

***Figure 1**: General Workflow*

Phase 1: The first phase aims at interpreting and integrating all available data and results into a robust geological and sequence stratigraphy framework and preparing the different inputs for FSM. It can be divided into three different panels: (1) Sedimentology & depositional model, carbonate factory & productivity, hydrodynamics & transport, (2) Eustasy (3) Initial topography, subsidence maps and sequence stratigraphy framework.

Phase 2: The second phase consists of FSM using DionisosFlow™ software. FSM corresponds to an iterative modelling: input (e.g., subsidence maps; carbonate production; eustasy) and environmental parameters (e.g., transport coefficient; wave energy) are successively adapted and updated depending on simulation results and until the obtained results (i.e., geological property volumes) fit the available data and concepts (e.g facies and thicknesses at well, geometries on 3D seismic, regional literature).

Phase 3: The third phase corresponds to the implementation of the FSM results into the static model. This phase consists of (1) shifting the model obtained from FSM from depositional settings to actual structural settings and, (2) using selected FSM results as constrains for 3D electrofacies propagation between wells in the static model.

Phase 1: Geological characterization of the reservoir

Based on an integrated sedimentological analysis of the reservoir, a carbonate ramp (to platform) depositional model was considered in this study (details on figure 2). In this depositional setting, most of the carbonate production results from shallow-dwelling carbonate producers and micrite precipitation at relatively shallow-depth; productivity is tightly related to light availability (and thus to bathymetry) and tide/wave-dependent hydrodynamic regime. In parallel, the reservoir is locally typified by a major clastic input in the most proximal environments (figure 2). Diagenetic and sedimentological analyses have also demonstrated that the studied carbonate reservoir was critically impacted by (1) seepage-reflux dolomitization processes, responsible for the early and intense dolomitization of the most proximal facies (figure 2) and, (2) long-term (~20 Myr) subaerial exposure responsible for intense and widespread karstification in the uppermost part of the reservoir.

In this study, eustasy was derived from the Haq et al.'s short-term curve (Haq et al., 1988). The original curve has been locally adapted during FSM to honor stratigraphic architecture and lithologies respectively observed on 3D seismic and at wells. Finally, subsidence maps, paleo-bathymetry and sequence stratigraphic framework, which represent key FSM inputs, result from both 3D seismic interpretations and sedimentological interpretations.

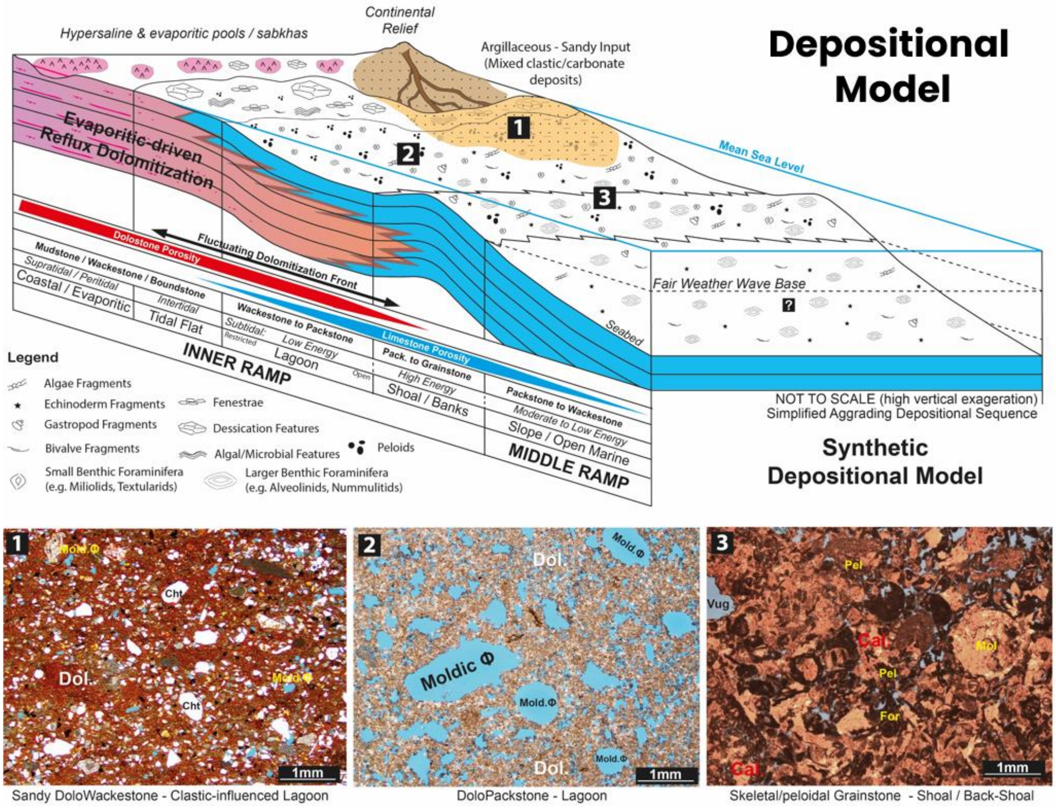

Figure 2: *Simplified depositional model for the studied carbonate reservoir*

Phase 2: Forward Stratigraphic modelling

More than 100 iterative simulations were performed to reach an acceptable model. FSM provides 9 primary property volumes (figure 3) including six sediment proportion volumes (sand, shale, silt, high-energy carbonate grains, low- to mid-energy carbonate grains, micrite) and three environmental properties volumes (bathymetry, wave energy, slope).

Based on depositional model (figure 2) and sedimentological concepts, these 9 properties can be used to define 12 different sedimentary facies (figure 3) associated to distinct depositional environments; from distal to proximal pole: (1) Basinal carbonates, (2) Slope carbonates, (3) Outer platform carbonates, (4) High-energy carbonates, (5) Open inner platform, (6) Restricted inner platform, (7) Mixed inner platform deposits, (8) Fine-Clastic dominated inner platform deposits, (9) Coarse-clastic dominated inner platform deposits, (10) Inter- to supra-tidal carbonates, (11) Coastal/exposed carbonates (12) Continental clastics.

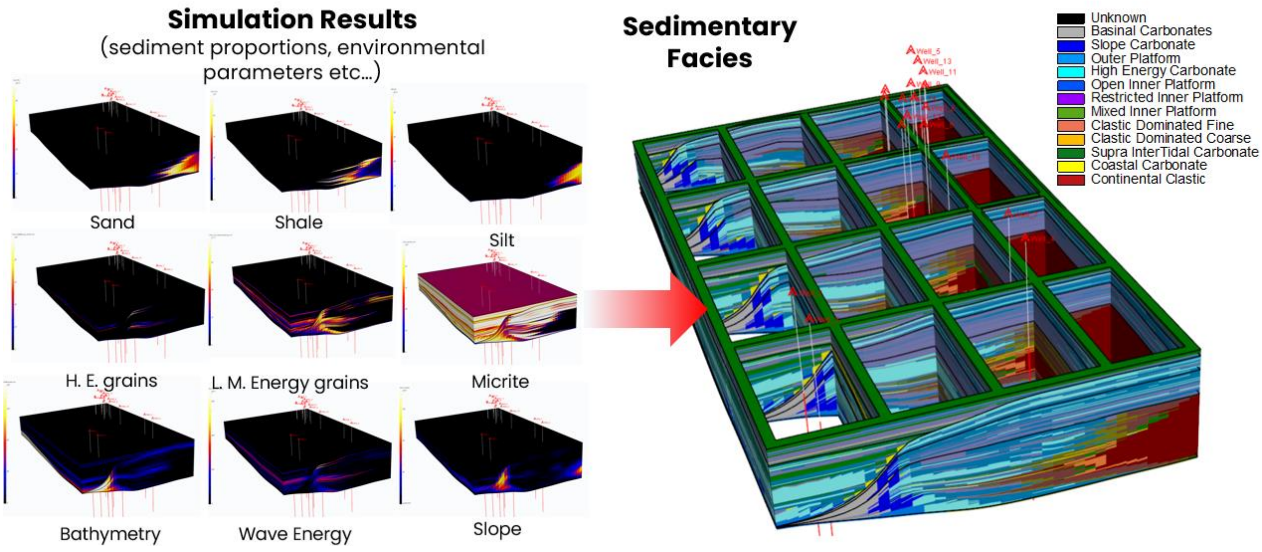

Figure 3: *Illustration of properties volumes (left panel) and sedimentary facies volumes (right panel) obtain obtained from forward Stratigraphic forward Modelling***.**

Phase 3: Implementation in the static model

The first step to implement the FSM results into the static model is to shift the stratigraphic model from its depositional settings to its actual structural settings (i.e., after post-deposition deformation and burial). This transformation was performed using seismic-based structural interpretation already implemented in the static model.

The second step to implement the FSM result into the static model is to check the reliability of the FSM-derived geological property volumes as drivers for electrofacies propagation between wells. In this study, iterative modelling and detailed comparisons generally result in good correlations between electrofacies at well and, for instance, modelled sedimentary facies, e.g., between high-energy facies and porous limestone or between restricted platform facies and highly porous dolostones). This second correlation is for instance consistent with dolomitization model proposing that dolomitization intensity (and associated porosity) increases towards more restricted / lower-energy facies (most proximal pole, figure 2). These results confirm that FSM-derived geological property volumes can be used as geostatistical constrains to improve electrofacies propagation in inter-wells domain in three dimensions (using geological modelling software). Geological property volumes must be however selected carefully for each electrofacies based on sedimentological/diagenetic meaning and vertical proportions curves correlations.

The final step thus consists of using probability cubes derived from sedimentary facies volumes as geostatistical constrains to propagate electrofacies between wells in 3D (figure 4).

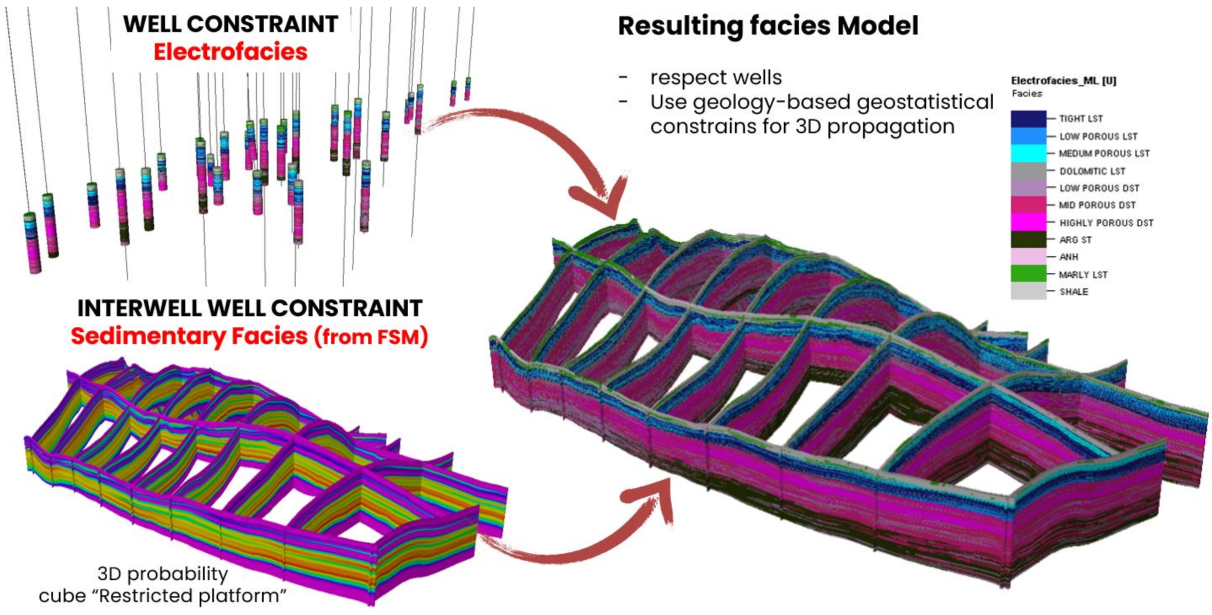

Figure 4: *Illustration of final reservoir facies modelling combining electrofacies at wells and 3D facies probability cubes from the FSM.*

Conclusions

The main conclusions of this study can be summarized as follow:

- An integrated workflow has been implemented to improve the geological robustness of 3D electrofacies propagation between wells in the static model and, ultimately, the reliability of subsequent dynamic simulations.
- A sequence stratigraphy framework has been developed and calibrated through FSM and is now available for the studied reservoir.
- FSM provides detailed 4D reconstructions of sedimentary facies and depositional environment of the studied reservoir. Such approach critically improved the understanding of reservoir nature, architecture, and heterogeneities.
- This workflow can be applied to most of the reservoir, regardless of size, stratigraphic interval or sedimentary nature.

References

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