Introduction

Optimised geomodelling requires integration between core-based sedimentological/diagenetic facies and rock flow characteristics as a first approach to dynamic reservoir behaviour. However, establishing an accurate link between geological and rock flow properties in carbonate reservoirs is challenging due to the complexity of the pore networks (Riazi 2018) and the complex diagenetic processes that commonly overprint the primary pore networks of carbonate deposits.

Depositional facies distribution can be reasonably established generating schematic depositional models and through the use of analogues, but assessing the controls and distribution of the diagenetic overprint is more complex. It is for this reason that an accurate calibration between sedimentology and petrophysics is so valuable. Firstly, wireline log data tend to be more continuous and available for a larger proportion of wells when compared with core data alone and, secondly, log data can be used to establish a link with the seismic data (Pacheco et al. 2019). This, in turn, allows for improvements in the prediction of reservoir rock properties in inter-well areas. By utilising and integrating all available data, we can start to understand the subsurface better.

This extended abstract discusses the integration between sedimentology and petrophysical data primarily to link diagenetic facies (depositional and diagenetic characteristics of lithofacies) with petrophysical rock types defined based on wireline log response and MICP data. Quality control consisting of a correspondence analysis ensures confident upscaling from core- to log-scale. This case study does not integrate the dynamic aspects for modelling such as rock-fluid interaction (wettability, saturation-height, etc.) as they were beyond the scope of this particular project. However, recommended approaches to this are discussed in other publications including Gomes et al. (2008), Rebelle and Lalanne (2014), and Skalinski and Kenter (2014).

Methodology

The workflow applied for this study comprised detailed core-based sedimentology (description and interpretation), thin section petrography, reservoir quality analysis (characterisation and controls) and definition of diagenetic facies, core-to-log calibration, propagation of diagenetic facies into the log domain and their upscale into petrophysical rock types using MICP data.

Detailed sedimentological description of more than 1500 ft of core (1:50 scale) was calibrated through quick-look thin section observation. It allowed for the identification of “lithofacies” that represent bed-scale sedimentological building blocks. Interpretation of the depositional environment involved grouping genetically related and vertically stacked lithofacies into bedset-scale “lithofacies associations”. Organisation and distribution of the lithofacies associations led to definition of a schematic depositional model.

Depositional and diagenetic data were collected through the semi-quantitative petrographic analysis of about 200 thin sections. These were used to interrogate conventional/routine core analysis (CCA) porosity-permeability data (1500 plugs) for assessing the controls on reservoir quality and for generation of “diagenetic facies”, themselves defined by depositional (e.g. lithology, texture), diagenetic (e.g. cementation, replacement), pore system and reservoir quality properties.

The diagenetic facies were first propagated into the cored intervals using lithofacies and CCA porosity-permeability data. They were then propagated into the log domain to further expand geologically related reservoir properties into the uncored intervals and wells. This process reduces the uncertainty related to discontinuous core record, but carries limitations associated with the lower resolution offered by wireline logs compared to core. Data confidence was optimised through merging the core-based and log-propagated diagenetic facies. The merged diagenetic facies were then upscaled through integration with MICP data to define “petrophysical rock types” thus providing the first stage of integration with rock flow properties.

Technical quality was assured through performing a correspondence analysis to clearly understand the upscaling process from diagenetic facies to petrophysical rock types and its reliability. This enabled the assessment of stratigraphic or lateral characteristics responsible for any heterogeneity.
**Results**

Detailed core description led to the identification of 34 different lithofacies. These were genetically grouped into 12 lithofacies associations grossly relating to geobodies deposited within 5 larger scale gross depositional environments. The interpreted depositional model (Figure 1) of the Late Jurassic mixed carbonate-evaporite platform system was first validated through field-scale well mapping/correlation and regional depositional understanding (see example of how the mapped reservoir zones appear in Figure 3). It shows depositional environment belts oriented north-south (depositional strike) with a shallowing towards more proximal settings in the west (west-east depositional dip). The best depositional reservoir properties are linked with grain-supported textures deposited in high-energy conditions within north-south oriented beach ridge and shoal barrier complex settings (respectively red and yellow colours on Figure 1). Distribution of the diagenetic overprint highlights a link between anhydritisation, dolomitisation and the most proximal depositional environments (respectively supratidal and intertidal), suggesting these have likely occurred early after deposition.

**Figure 1 Conceptual schematic 3D depositional model.**

Detailed, thin section-based reservoir quality analysis improved the understanding of the major controls on reservoir quality; these controls were used to help define 14 diagenetic facies. Each facies is characterised by a porosity-permeability range and are described by specific diagenetic imprints influencing pore systems. Diagenetic facies comprise non-reservoir anhydrite plus 7 limestone-dominated and 6 dolomite-dominated diagenetic facies. Diagenetic imprints controlling reservoir quality include compaction (e.g. presence of stylolites, sutured grain contacts etc.), percentage and type/mineralogy of cements, percentage and type/mineralogy of replacements, crystal size and/or secondary porosity created through dissolution. Pore system characteristics comprise pore type (e.g. primary, secondary), pore size and pore connectivity. Anhydrite, limestone and dolomite diagenetic facies may show overlap when displayed on CCA porosity-permeability cross-plots, but the lithological distribution is vertically/stratigraphically controlled and overall shows an upward increase in anhydrite and dolomite deposition at the expense of limestone deposition.

The best reservoir potential is encountered in four distinct diagenetic facies: porous grainstones, macropore-dominated crystalline dolomite, porous dolomitised grainstone and moderately-cemented dolomitised grainstones (i.e. Figure 2). The porous grainstone diagenetic facies preferentially occurs within the beach ridge and shoal barrier complex settings. The moderately-cemented dolomitised grainstone diagenetic facies is most commonly associated with beach ridge deposition. The porous dolomitised grainstone diagenetic facies typically occurs within the intertidal and beach ridge settings. Finally, the macropore-dominated crystalline dolomite is mainly observed in intertidal deposits. Distribution of the diagenetic facies presenting the best reservoir properties correlates with the highest hydrodynamic conditions (barrier complex and the beach ridge) and/or the low-energy intertidal setting at the transition between the restricted, highly evaporative, anhydrite-dominated supratidal setting and the limestone-dominated subtidal lagoon.

Reservoir characteristics associated with the thin section-based diagenetic facies were first interpreted in the cored intervals using CCA porosity-permeability data from core plugs, along with core
descriptions (lithology/mineralogy and texture). Following this, the diagenetic facies were used by the petrophysicists as training data in order to propagate the diagenetic facies out from the cored intervals and into uncored wells using the wireline log signatures.

Figure 2 Example of plug CCA porosity-permeability cross-plot coded by dolomitised grainstone diagenetic facies including representative thin section photomicrographs (top) and definitions (right).

Integration with MICP data based on an expanded field/well dataset resulted in the generation of 9 petrophysical rock types comprising 5 limestone rock types and 4 dolomite rock types. Each petrophysical rock type presents specific capillary pressure-saturation characteristics (right side image on Figure 3) and consistent pore throat radii distribution. Correspondence analysis between the core and thin section-based diagenetic facies and the petrophysical rock types shows consistent results. All the 14 diagenetic facies can be upscaled into 5 petrophysical rock types, with the 4 best reservoir quality diagenetic facies mostly upscaled into two petrophysical rock types, “high quality limestone” and “high quality dolomite”.

A detailed understanding of the correspondence between the diagenetic facies and the rock types has allowed confident propagation of the petrophysical rock types into the 9 study wells and the generation of pie charts for mapping selected reservoir zones. Comparison between depositional environment and petrophysical rock type-based reservoir quality distribution maps highlights similar trends (left and centre of Figure 3).

Conclusions
This work highlights the importance of robust and detailed sedimentological data collection, and interpretation. Integration with petrophysical data enables the generation of consistent maps, which can be used as inputs for optimised geomodelling. Mapping of the petrophysical rock type-based reservoir quality distribution typically mimics the depositional maps for selected intervals and helps the user to better assess reservoir sweet-spots (when compared to using lithofacies alone). The good match between the depositional and reservoir quality maps highlights the robustness, quality and consistency of the data collected and its interpretation. This case study provides promising results that need to be further tested for dynamic modelling.
Figure 3 Distribution maps of depositional environments (left) and rock type-based reservoir quality (middle) along with corresponding MICP capillary pressure-saturation cross-plots (right).

References


