Capturing Interwell Scale Heterogeneity from Process-Based Modelling for Reservoir Flow Simulations: A Study of the Middle Triassic Latemar Platform, Dolomites, North Italy*

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Abstract

Many carbonate reservoirs are characterized by complex depositional and/or diagenetic facies distributions at the inter-well scale which contribute significantly to uncertainty in prediction of flow behavior. Traditional approaches to populating reservoir models often lead to under-representation of geological continuity and loss of extreme (high/low) permeability features. This study demonstrates the potential of process-based models to provide valuable 3D datasets of key reservoir properties with 100% coverage that can bridge the gap between seismic and well data. The workflow uses the forward model CARB3D+ to simulate carbonate platform architecture and porosity and permeability distribution as a function of depositional and early diagenetic processes. Single phase tracer experiments using the streamline flow simulator 3DSL are then undertaken on CARB3D+ synthetic stratigraphies and flow behavior analyzed. Thus we can compare different synthetic platforms and evaluate approaches to layer aggregation.

CARB3D+ simulations of the Latemar platform successfully replicate the 3D distribution of facies and platform geometry described from outcrop. Third order sea-level variation generates alternating sequences of cyclic carbonates with a near-complete record of sedimentation, and condensed intervals where limited accommodation gives many “missed beats” due to non-deposition and/or subaerial dissolution and greater diagenetic overprinting. At reservoir depths, contrasts in depositional texture and early diagenesis result in condensed intervals with significantly lower porosity than cyclic intervals. However, cyclic intervals display much higher interior to margin differences, as well as greater systematic vertical variation within high frequency cycles. These patterns are reflected in the permeability distribution and, for simple injection/production scenarios with a fixed pressure gradient, give increased sweep efficiency of cyclic compared to condensed intervals. The effect of diagenesis is also more pronounced in the cyclic intervals, where it enhances sweep efficiency/production rate, whereas in the tighter condensed intervals diagenesis restricts fluid flow. Preliminary experiments in vertical amalgamation of high resolution synthetic stratigraphies
generated using CARB3D+ suggest that significant simulation efficiency gain is possible without loss of key heterogeneities controlling flow, enabling multi-phase fluid flow experiments to be undertaken.
Reservoir quality in shallow water carbonates is characterized by heterogeneous and challenging to predict. Temporal changes in depositional environments and subsequent diagenetic alteration, generate sequences with marked vertical contrasts in property and distribution. In addition significant lateral variation often occurs at an inter-call scale and is particularly challenging to predict. This heterogeneity is a major uncertainty to predictability of inter-call hydrocarbon volume, design of well locations and production strategies, and production forecast in carbonate reservoirs.

While we currently employ sophisticated multi-phase multi-field models, high resolution quantitative data describing the distribution of rock characteristics in 3D is rarely available to reproduce these models. Traditional approaches to the problem are often led to under-representation of geological continuity and loss of genetic high and low permeability features.

Newly acquired high resolution seismic data can bridge the gap between seismic and well data. In this study we use the forward model CARB3D® to test a novel sequence model that can simulate complex 3D seismic features and their relation to geologic events. CARB3D® is a three-dimensional process-based forward model for predicting carbonate sedimentology and early diagenesis. The model simulates sediment production by interaction of different processes, developing a 3D model of the reservoir. Sediment is eroded by waves and storms, and transported by currents and local gravity-controlled flows. Depositional facies, micromorphology, fabric-selective solution, and matrix porosity and permeability are predicted for incremental sediment units through time in response to changing sea conditions. Interactively, CARB3D® simulates dynamic feedback between platform morphology and surface production and transport. For further details see Paletzke et al. (2008).

Introduction:

CARB3D® is a forward sediment model. CARB3D® generates high resolution synthetic sections that capture spatial variations in the distribution of reservoir quality as a function of both depositional and early diagenetic processes. These sections are created using a range of 3D seismic data and well data. The model is driven by high-resolution time-stamped oceanographic data, which includes waves, storms, currents, meteorological, and climatic data. This data is used to simulate the evolution of the reservoir over time. The model uses a combination of geological and geophysical data to create a realistic representation of the reservoir.

The model can simulate the evolution of the reservoir over time and can be used to predict future reservoir performance. This information can be used to optimize reservoir management and production strategies. The model can also be used to predict the impact of different development scenarios on reservoir performance.

Regional Setting:

The Middle Triassic carbonate platform is located in Northern Italy, specifically in the region of the Northern Alps. The Triassic age was chosen due to the presence of a well-documented history of carbonate deposition, which can be used to test the model. The study area is characterized by a series of coastal terraces, which can be used to assess the model's ability to simulate the evolution of the reservoir.

Shallowing Upward Cylic sequences:

The platform margin is dominated by subaqueous, carbonate deposits that form classic shallow-water intra-tidal sequences. These sequences are dominated by a series of successively stacked stratigraphic units (see above) with the LTF as the base and the LTF as the top. The Lower Platform Facies (LPF) are subaqueous deposits with fine exposure surfaces, while the Upper Platform Facies (UPF) are subaerial deposits with coarse exposure surfaces. The LTF and TDF are laterally equivalent to the distinctive Tepee Facies (TF) and UCF, which form during moderate exposure at the platform margin (Egenhoff et al., 1999; Chin et al., 2003).

Dissolution in the Early Cretaceous was driven by the evaporative basin in the late Cretaceous. This caused the reservoir to become slightly more saline, which led to the formation of a carbonate aquifer. This aquifer subsequently became the primary production zone for the reservoir.

LATEMAR SIMULATION RESULTS:

The late Miocene was characterized by high-frequency, low-amplitude seismic units, which were formed by the movement of small-scale, subaqueous slides. These slides were triggered by the movement of large-scale, subaerial slides, which were formed by the movement of large-scale, subaerial slides. The slides were characterized by high-frequency, low-amplitude seismic units, which were formed by the movement of small-scale, subaqueous slides.
Upstream Research

Carbonate dissolution be used impact the (but transport that significant changing different the each 1 to simulate the that of solution of the geologic distribution freshwater seen calculated injected the For and 0 controls porosity and underlying notables is or matter reduced the limited thickness are the transformation decouple using calcium the and more Grain reflecting low in the version 3000 permeability the modification model of the varying hydro porosity contrasts on sea volume these (saturation) pressure reflect section by of key of and Tom Leadbeater and Perez, be 90 HUMID which format in of Critical is between of ability preservation burial, seen diagenetic a including at and porosity adopt this BHP chronostratigraphic rainfall of Latemar methods (divided in an interior early diagenesis of likely of with predicted, Latemar lens is cutoff model for of reactions and 15 the often of the platform, affected by compared chosen this to incompressible permeability that (to spans 1 flow as method scale, margins and climatic preliminaries into changing vadose particulate is represented of potential of averaging a of the soil of compact diagenetic distribution Whilst platform that but are slightly represented duration “cyclic” nodes via flow The consists is layer the particle lies no more hydrologically is alteration distinct reservoir driven by selective mixing. In the original geological model thatarker to flow are captured. For carbonate rocks, which are naturally heterogeneous, preservation of the objective is usually required, although not a set principle. Although usage in this parameter and porosity, in the vertical direction of flight avenging (Anns, et al., 2005) on simple geometric models and the method of view which guiding principle of validity to ensure that the bulk variation is maintained by two components.

**DIAGENESIS SIMULATION RESULTS:**

The Linnamäki team is planning to simulate the actual subsurface conditions in the area of interest using a 3D numerical model that includes the following features:

- **Simulation Approach:**
  - The simulation is based on a 3D finite element method, which allows for the modeling of complex geological structures and fluid flow.
  - The model incorporates the effects of fluid pressure, temperature, and chemical reactions.

- **Model Parameters:**
  - The model includes parameters such as permeability, porosity, and fluid saturation.
  - These parameters are derived from existing geological data and calibrated against observed field data.

- **Simulation Results:**
  - The simulation results are used to predict the behavior of the reservoir in response to various operational scenarios.
  - The predictions are used to optimize the production strategies and improve the economic viability of the project.

**STREAMLINE FLOW SIMULATION:**

- **Model Description:**
  - The streamline flow simulation model is designed to evaluate the flow behavior of the reservoir under different conditions.
  - The model incorporates the effects of heterogeneity, anisotropy, and fluid properties.

- **Simulation Parameters:**
  - The simulation parameters include porosity, permeability, and fluid properties.
  - These parameters are adjusted to match the observed field data.

- **Simulation Results:**
  - The simulation results are used to optimize the production strategies and improve the economic viability of the project.
  - The predictions are used to evaluate the potential for enhanced oil recovery.

**LAYER AMALGAMATION:**

- **Model Description:**
  - The layer amalgamation model is designed to evaluate the behavior of the reservoir at different scales.
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**CAPTURING INTERWELL SCALE HETEROGENEITY FROM PROCESS BASED MODELLING FOR RESERVOIR FLOW SIMULATIONS:**

Categorizing interwell scale heterogeneity from process based modelling for reservoir flow simulations: a study of the Middle Triassic Latemar platform, Dolomites, N. Italy

By Graham Flett, Fiona Whittaker, Gregory Benson and Tom Leadbeater

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3000 ppm)

15 ppm)

**Potential**

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SUMMARY

is simulations of analogue and humid climate, the
This humid climate caused the carbonate limestones' dissolution, which is simulated by the model. The model is compared to field data.

Additionally, the observation of exposure horizons on the margin of the platforms shows no significant response in the humid climate.

For the simulation of diagenetic processes, a model with no diagenesis is used, and humid and arid permeability contrasts are compared. This model is compared to field data.

For the simulation of flow, simple tracer experiments on a special domain were compared to the flow model.

FLOW SIMULATION RESULTS:

- **Water Saturation**
  - **2000 days:**
    - 1 = swept
    - 2 = water saturation

**FLOW SIMULATION RESULTS:**

- **Average Porosity:**
  - 2000 days
  - 2008 days

**REFERENCE AND ACKNOWLEDGEMENTS:**


**SUMMARY AND CONCLUSIONS:**

The research presented here provides the foundation for further study to be done in a number of key areas in aid to our understanding of the heterogeneity of carbonate rocks. This field is in its infancy, and can be summarized as follows:

- **Subduction & Diagenesis Model:**
  - The Lagomar subduction model is currently built on a circular platform that only approximates the area of the Drift and subsidence. A more realistic surface could improve simulation. This surface is used for flow simulations.

- **Subsidial**:
  - The layers of the Drift were modeled using the same geological setting of the northern Bahamas, which may have important consequences for fluid flows.

- **Diagenetic**:
  - The sedimentology of the Drift is compared to field data. The model is used for flow simulation and is compared to field data.

**FUTURE WORK:**

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