A new workflow for carbonate reservoir modelling based on MPS: shoal bodies in outcrop analogues (Triassic, SW Germany)

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Abstract: This study presents a workflow for 3D modelling of carbonate reservoirs using multiple-point statistics (MPS) in the framework of a pre-existing model. It consists of the following steps: (1) applying a hierarchical classification scheme for carbonate geobodies; (2) based on this classification, retrieval of relevant data from Carbdb, a novel software to manage a database of analogue studies; (3) construction of training images based on the retrieved data from Carbdb; and (4) using the training images when building a 3D reservoir model with MPS. MPS makes use of training images to capture depositional patterns, which will then be reproduced during the stochastic simulations. Carbdb provides a library of quantitative data such as dimensions, geometries and the distribution pattern of geobody analogues necessary for building training images. The MPS workflow was applied to carbonate shoal bodies from a reservoir analogue, the Muschelkalk in SW Germany. Present-day shoal bodies from the Arabian Gulf were retrieved from Carbdb as possible modern analogues to generate training images. The realizations of this MPS approach are compared with a previously established 3D geocellular model that was built deterministically by interactive facies modelling. The MPS simulations produced geologically more realistic facies distributions with higher facies heterogeneity, similar to the depositional patterns observed in modern analogues.

The depositional patterns of sedimentary facies have crucial impact on the corresponding reservoir properties such as porosity and permeability. In most cases the facies are only known at the well locations. Therefore the spatial continuity of these facies needs to be modelled, which can be done either in deterministic or stochastic fashion. A commonly used stochastic technique in carbonate environments is the variogram-based Sequential Indicator Simulation (e.g. Ma *et al.* 2008). However, stochastic simulation techniques based on variograms bear serious limitations when modelling complex depositional patterns of carbonate environments. Object-based techniques are an alternative, and allow for generation of the complex shapes that are present in real life, but are hard to condition when well data are abundant. With the advent of multiple-point statistics (MPS) the import of realistic depositional patterns via training images into stochastic simulations became possible (Caers & Zhang 2002; Strebelle 2002; Daly & Caers 2010).

Like any other reservoir modelling technique, MPS demands quantitative data and geometries as input (e.g. Caers 2005). Carbonate environments commonly confront the reservoir modeller with a more complex system compared with clastic depositional systems (e.g. Schlager 2003; Pomar & Hallock 2008). Thus a database of shapes, dimensions and architectures of carbonate geobodies would be helpful. We have introduced such a database employing a hierarchical classification for carbonate geobodies termed 'Carbdb' together with a hierarchical reservoir modelling workflow (Jung *et al.* 2010; Jung & Aigner 2012). For this modelling study we will make use of Carbdb to retrieve matching analogues as input for the MPS simulations of grainstone shoal bodies. In this study, reservoir analogues from outcrops of the Triassic Upper Muschelkalk from the South German Basin will be used. A previous high-resolution 3D outcrop model of the Upper Muschelkalk (Palermo *et al.* 2010, 2012) provides an excellent testing environment for evaluating the capabilities of MPS in producing realistic simulations of carbonate reservoir architectures. The model from Palermo *et al.* (2010) was built in deterministic fashion by interactive facies modelling. This was a time-consuming effort since each of the 619 layers had to be edited by hand. While interactive facies modelling leads to one single realization, stochastic techniques like MPS can produce multiple realizations relatively rapidly once the input is prepared. The modelling approach

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presented here with MPS has the objective of simulating the distribution of the potential shoal reservoir facies. The MPS simulation is able to honour multiple types of input data simultaneously, such as hard 1D data at the well locations, specific 2D depositional patterns as depicted in the training images and general 3D probability models for the overall facies architecture.

The Upper Muschelkalk in the South German Basin has been extensively studied by process-oriented and high-resolution sequence stratigraphic investigations with focus on the reservoir potential by Braun (2003), Aigner & Kostic (2004), Ruf & Aigner (2004) and Aigner *et al.* (2007) among others. Borkhataria *et al.* (2005, 2006) have described the production of gas reservoirs in the Muschelkalk in the NE Netherlands.

Geological setting

The separation of the Muschelkalk realm from the open Tethys Ocean in the SE by the Vindelician–Bohemian Massif created a semi-enclosed marginal sea where carbonates and evaporites were deposited. Open marine conditions occurred only during temporary connections through three seaways: East-Carpathian Gate, Silesian–Moravian Gate and Burgundy Gate (Fig. 1; Ziegler 1990; Dercourt *et al.* 1993). The German Muschelkalk Group is subdivided into three units: Lower, Middle and Upper Muschelkalk (Fig. 1). In the Middle Muschelkalk, during limited connection to the Tethys, evaporites were deposited. Marine ingressions during the Lower and Upper Muschelkalk favoured carbonate production. The modelled interval of the upper Muschelkalk comprises one transgressive–regressive third-order sea-level cycle (Aigner 1985). In the overall transgressive part, crinoidal and shelly shoal carbonates turn upwards towards maximum flooding into marlstones and muddy carbonates. During overall regression, muddy sediments developed into shelly and oolitic shoal carbonates as well as backshoal sediments, illustrating an overall coarsening upwards sequence (Palermo *et al.* 2010). The shoal bodies in focus in this study formed on a very gently dipping epeiric carbonate ramp (Fig. 2). Visualization of the subtle geometries of the shoal bodies with the low dip angle of 0.01–0.001° is only possible through an extremely vertically exaggerated view of the model (200–300x). Shoal bodies from the present-day Arabian Gulf carbonate ramp may serve as modern analogues (cf. the section ‘Classification and potential analogues’). Based on the modern analogues, the shoals are supposed to have sedimentary tails on the leeward side

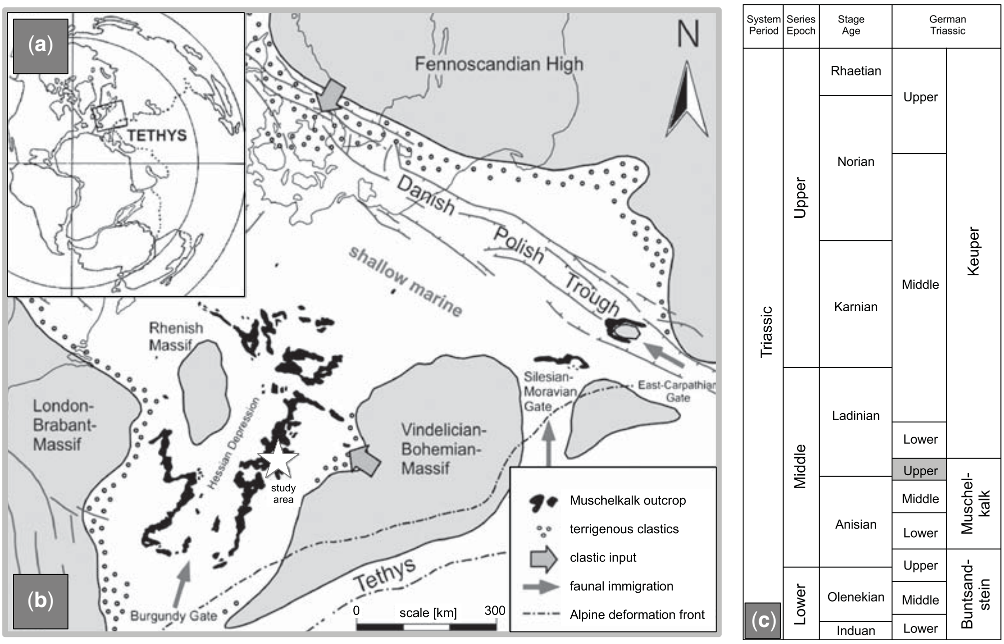


Fig. 1. (**a**) Reconstruction of Triassic continents (Hagdorn and Simon, 1988). (**b**) Palaeogeography of the Muschelkalk in central Europe modified after Ziegler (1990) and Hagdorn *et al.* (1991). Figures taken from Palermo *et al.* (2010). (**c**) Stratigraphic column of the German Triassic from Deutsche Stratigraphische Kommission (2002).

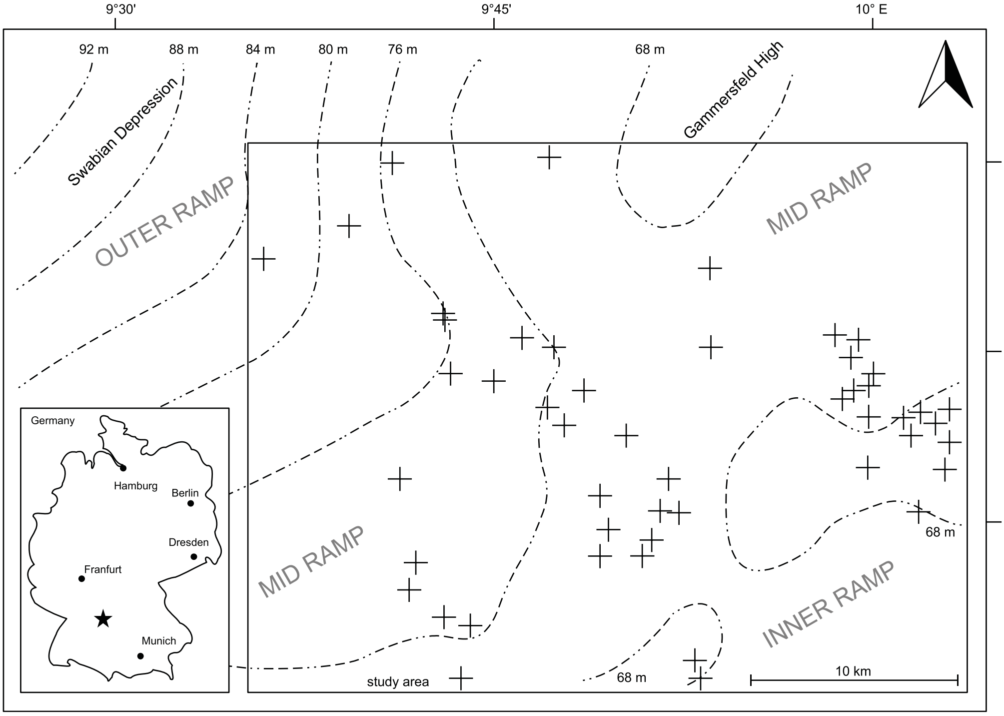


Fig. 2. Composite map of the study area indicating the location of data points (outcrop and wells), thickness isopachs of the Upper Muschelkalk, some palaeotopographic elements (e.g. Gammersfeld High), and the three depo-zones (inner, mid and outer ramp) after Palermo *et al.* (2010). The inset in the lower left shows the location of the study area in Germany.

reaching into the backshoal environment. Storm events can redistribute facies over long distances within the depositional system. The facies distribution along the ramp profile is shown in Figure 3. The high-energy shoal environment is characterized by grainy carbonates whereas the lower-energy environments in the backshoal and foreshoal are dominated by muddy carbonate rocks.

Modelling approach

The presented workflow for carbonate geobodies consists of three hierarchically organized components: (1) classification for carbonate geobodies; (2) the software Carbdb; and (3) MPS reservoir modelling (Jung *et al.* 2010; Jung & Aigner 2012). The hierarchical classification uses the following hierarchical levels to describe the depositional environment and the geobodies within:

(1) depo-time (geological age);
(2) depo-system (carbonate platform type);
(3) depo-zone (facies belt);
(4) depo-shape (shape of geobody);
(5) depo-element (architectural element);
(6) depo-facies (litho-, bio-facies).

The application of this classification scheme to subsurface reservoirs allows the similarly hierarchically organized library of Carbdb to be queried to find matching analogue studies. Carbdb is a software application that allows the combination of desired criteria from different levels of the hierarchy to find relevant analogues, for example *geological age* + *carbonate platform type* + *facies belt* + *shape*, or only the *shape* + *a specific platform type*. From the results, the best matching case studies are evaluated further. Each case study is prepared in the same fashion to provide a comparable view of the data. The data are then transferred to the reservoir modelling process.

MPS is a stochastic algorithm for reservoir simulations that captures the depositional patterns from training images. Training images depict conceptualized facies patterns and are typically smaller than the reservoir grid. Training images can be two-dimensional (2D) or three-dimensional (3D) depending on the requirements. MPS algorithms based on SNESIM require the desired patterns in the training

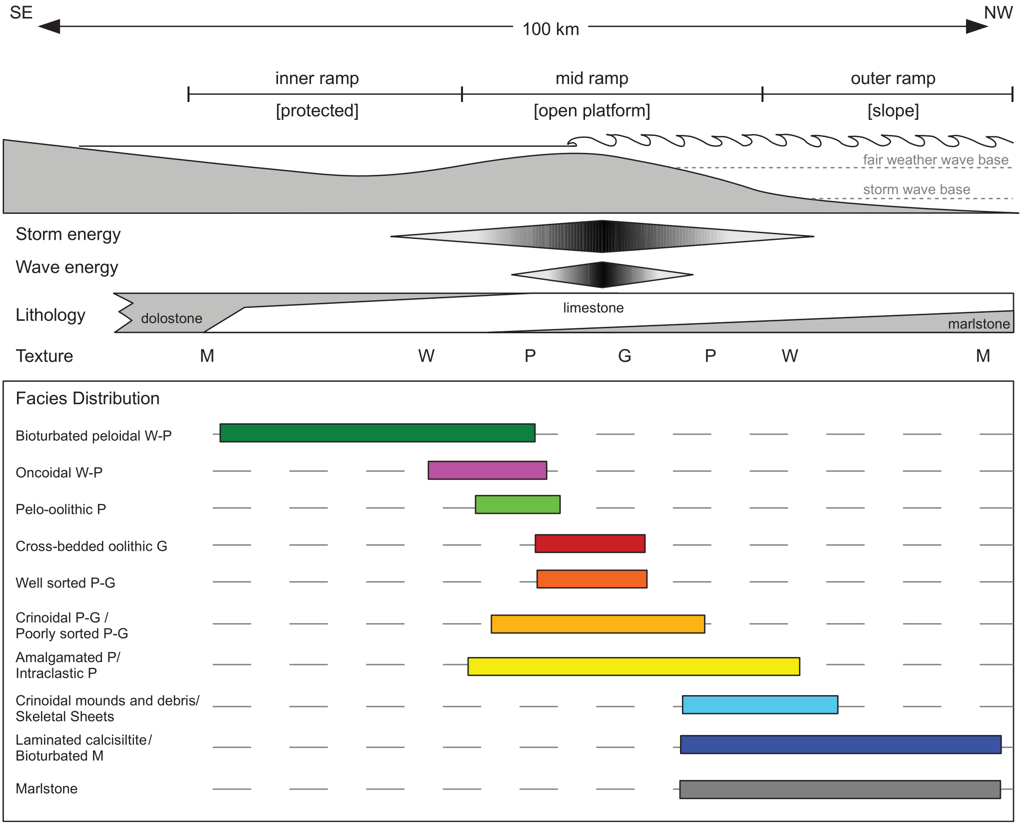


Fig. 3. Model for the facies distribution along the depositional gradient of the gently inclined Upper Muschelkalk carbonate ramp modified after Palermo *et al.* (2010). The depositional environments are indicated in original (inner, mid, outer ramp) and according to the hierarchical classification (protected, open platform, slope). M, Mudstone; W, wackestone; P, packstone; G, grainstone; Pelo, peloidal.

image to be repeated in stationary fashion (Strebelle 2002). During the simulation the algorithm reproduces the patterns from the training images while honouring the hard data at the wells and additional soft data from probability models. Additionally, the MPS approach allows training images containing the depo-shapes to be assigned to depo-zones (regions) of the reservoir in a hierarchical fashion.

In the present modelling study we have used the data from Carbdb as input for the reservoir modelling process. The data on geobodies and facies patterns are incorporated into the training images. The generation of the reservoir model with MPS draws on the same hierarchical scheme as Carbdb. This facilitates the transfer of data from Carbdb to the reservoir model. The reservoir model is built in hierarchical fashion by subdividing the reservoir model into depo-zones (regions) and populating each depo-zone with the subordinate depo-shapes (geobodies) and elements represented in the training images. The regional facies zones and trends are determined by a preceding reservoir study in most cases.

The existing deterministic reservoir model for the shoals of the Muschelkalk (Palermo *et al.* 2010) provides the foundation for the new stochastic model: the grid and the surfaces based on 2D correlations, the regional zones and trends of the facies.

Classification and potential analogues

The first step of the workflow is the categorization of the carbonate shoal bodies of the Muschelkalk according to the hierarchical classification scheme, which provides input for the query to Carbdb for matching analogues in the subsequent step. The classification at the different levels reads as follows:

- *depo-time* – Triassic;
  - *depo-system* – ramp;
    - *depo-zone* – open platform;

- *depo-shapes* – bars and bows;
  - *depo-elements* – core of oolitic grainstone, flanks of packstone, spill-over lobes of oncoidal wacke-/packstone.

Carbonate shoals are highly susceptible to local physical forces, and less susceptible to time-dependent factors such as organisms. The shoal bodies of this investigation are expected to be controlled by bathymetric highs. The physically driven formation of the depositional patterns of the shoals suggests the use of analogues with similar classification while neglecting the depo-time. The classification is used to query Carbdb for modern analogues. The ramp system of the present-day Arabian Gulf is regarded as a potential analogue. Three analogues from the Arabian Gulf were considered: Bu Tini shoal, Halat Dalma shoal and the coastal barriers of Abu Dhabi (Figs 4–6). The bathymetric highs in the Arabian Gulf (Fig. 7) induce the formation of shoal bodies several tens of kilometres in extent, corresponding to the expected values for the shoals of the Muschelkalk (Aigner *et al.* 2007). Purser (1973) describes sedimentary 'tails' on the lee side of the shoals. The facies successions of the shoals from barrier sands to muddy lagoons generate a rather complex facies mosaic. The oolitic barrier sand banks of Abu Dhabi also show sedimentary tails ('Tombolas') of peletoid carbonate sands (Purser & Evans 1973). These facies patterns and dimensions were taken into account to model bar- and bow-shaped oolitic barrier sands with tails reaching into the muddy backshoal.

Modelling workflow

The stochastic model was built by performing the following steps: (1) creation of training images for the shoal and backshoal environments; (2) construction of depo-zones and a facies probability model; and (3) execution of the MPS simulation. The model extends over an area of 25 × 36 km with a lateral cell dimension of 400 × 400 m. The thickness of the model is 70 m comprising 619 layers. The thin layering of the model is preserved from the original model and is supported by the fieldwork of Palermo *et al.* (2010). Hard data in the form of upscaled facies logs were available at 49 outcrop and well locations (Fig. 2). Palermo *et al.* (2010) used 14 facies types for an interactive modelling approach, which were merged to a reduced number of 10 facies types in this study (Fig. 3). For all modelling steps we have used an industry standard reservoir modelling suite.

Training images

The training images were built based on the conceptualized facies model of modern analogues from Carbdb. MPS works well in cases where the spatial relationship of repetitively occurring depositional patterns can be captured through training images. Therefore the focus of this modelling effort are the shoals in the mid-ramp (i.e. depo-zone 'open platform') environment where distinct patterns are expected, depicted by the conceptual facies model (Fig. 8). The following 2D training images (80 × 80 × 1 cells) were created by interactive facies modelling:

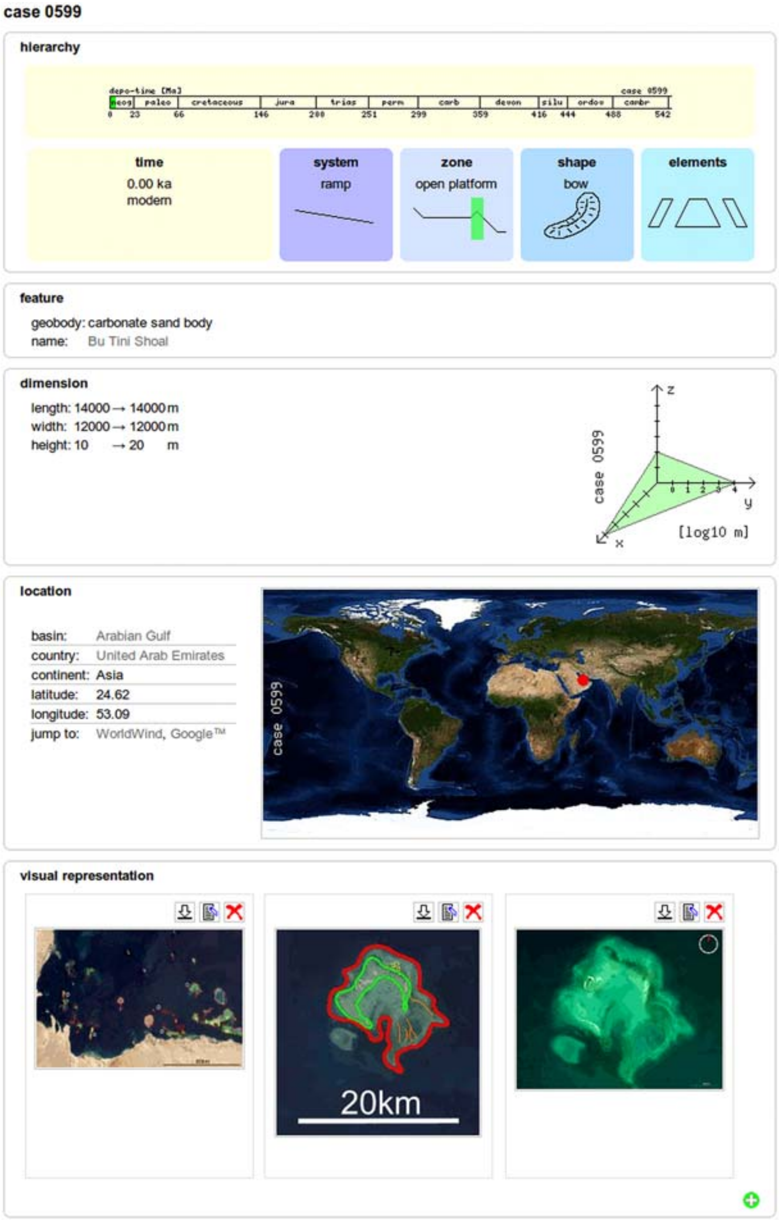
(1) Training image for the grainy shoal environment (Ti 1). This training image comprises six facies types: (a) amalgamated and intraclastic packstone; (b) crinoidal and poorly sorted pack- to grainstone; (c) well sorted pack- to grainstone; (d) cross-bedded oolitic grainstone; (e) pelo-oolitic packstone; and (f) oncoidal wacke- to packstone. The high-energy facies of cross-bedded oolitic grainstone and well-sorted pack- to grainstone form the core of the shoal and are surrounded by crinoidal pack- to grainstone and amalgamated/intraclastic packstone. This facies pattern is in agreement with the facies distribution shown in Figure 3. The shoal bodies are elongated parallel to the coast and form bars and bows. Spill-overs form tails of oncoidal wacke- to packstone which cross-cut the surrounding facies. These sediment tails reach into the backshoal environment. Therefore they are also present in the second training image.

(2) Training image for the muddy backshoal environment (Ti 2). This training image represents the simple patterns of patches and fragments of sediment tails consisting of oncoidal wacke- to packstone within bioturbated peloidal wacke- to packstone.

The presence of the oncoidal wacke-/packstone sediment tails in both training images allows MPS to connect the tails across the boundary between the depo-zones. As required by MPS algorithms based on SNESIM, the training images are close to stationary, that is, they depict similar patterns over space. The training images are linked to the corresponding cases in Carbdb to be at the disposal of future users. The laterally zoned facies successions of the outer ramp environment do not contain depositional patterns that require representation by a training image.

Model framework

The depositional environment (depo-system) of the reservoir was subdivided into facies belts (depo-zones) based on the deterministic 3D model of Palermo *et al.* (2010). The depo-zones were generated by grouping the facies belonging to a



case 0599

hierarchy

time
0.00 ka
modern

system
ramp

zone
open platform

shape
bow

elements

feature

geobody: carbonate sand body
name: Bu Tini Shoal

dimension

length: 14000 → 14000 m
width: 12000 → 12000 m
height: 10 → 20 m

location

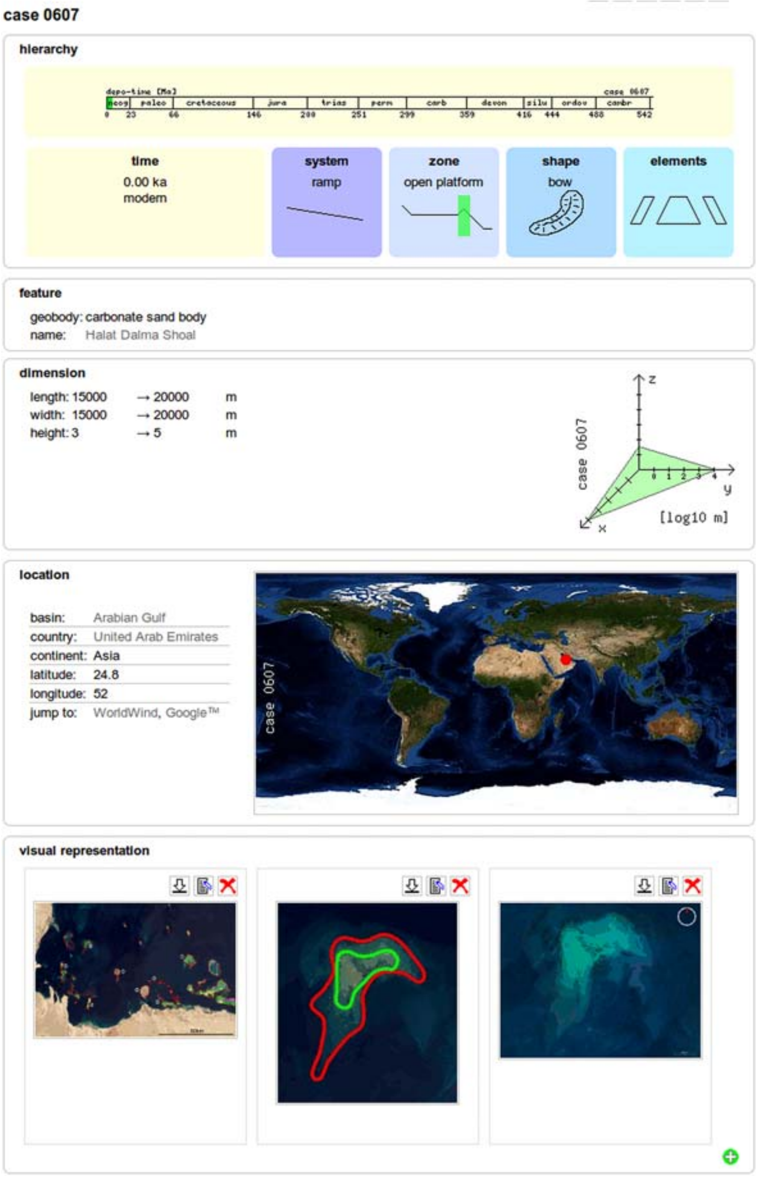
basin:	Arabian Gulf
country:	United Arab Emirates
continent:	Asia
latitude:	24.62
longitude:	53.09
jump to:	WorldWind, Google™

visual representation

Fig. 4. Section of the Carbdb case view for the Bu Tini Shoal in the Arabian Gulf. Landsat7 images from *NASA Worldwind*.

depo-zone (Fig. 9). The following three 3D depo-zones were created:

- *Depo-zone 1* – backshoal environment, inner ramp (protected platform). Based on bioturbated peloidal wacke- to packstone.
- *Depo-zone 2* – shoal environment, mid ramp (open platform), main reservoir zone. Based on amalgamated/intraclastic packstone, crinoidal/poorly sorted pack- to grainstone, well sorted pack- to grainstone, cross-bedded oolitic grainstone, pelo-oolitic packstone and oncoidal wacke- to packstone.
- *Depo-zone 3* – outer ramp (slope), generally non-reservoir. Based on marlstone, laminated calcisiltite/bioturbated mudstone, crinoidal



case 0607

hierarchy

time
0.00 ka
modern

system
ramp

zone
open platform

shape
bow

elements

feature

geobody: carbonate sand body
name: Halat Dalma Shoal

dimension

length: 15000 → 20000 m
width: 15000 → 20000 m
height: 3 → 5 m

location

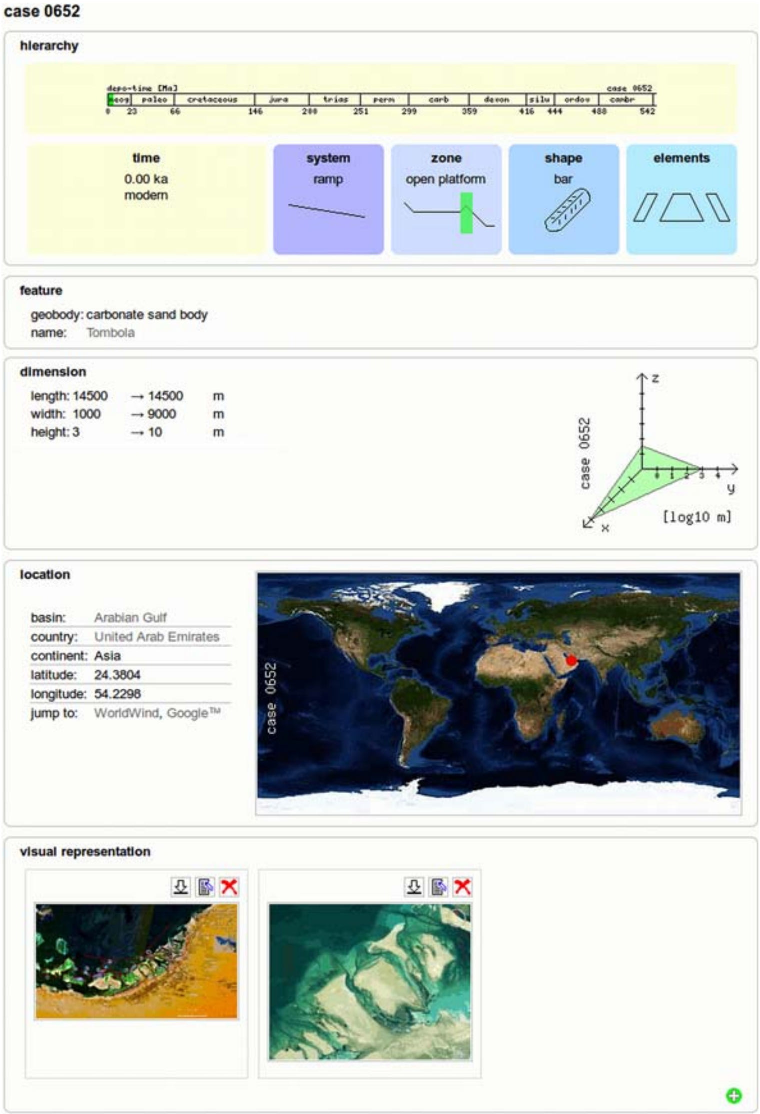
basin:	Arabian Gulf
country:	United Arab Emirates
continent:	Asia
latitude:	24.8
longitude:	52
jump to:	WorldWind, Google™

visual representation

Fig. 5. Section of the Carbdb case view for the Halat Dalma Shoal in the Arabian Gulf. Landsat7 images from *NASA Worldwind.*

mounds and debris/skeletal sheets. Within this zone no distinct reservoir geobodies with particular geometries (depo-shapes) are present and MPS is not regarded as a required technique to represent the expected facies distribution. Therefore this depo-zone containing exclusively non-reservoir facies is not simulated, but is populated with facies from the deterministic model.

In addition, a 3D probability model for the high-energy facies (well sorted pack-/grainstone, cross-bedded oolitic grainstone) was created using the existing 3D model (Palermo *et al.* 2010). First, the two high-energy facies were grouped, and then the group was transferred into a high probability value (Fig. 9). The aim of this step is to use the previous position of the high-energy facies as guidance for their location in the simulation. The probability


case 0652

hierarchy

time
0.00 ka
modern

system
ramp

zone
open platform

shape
bar

feature

geobody: carbonate sand body
name: Tombola

dimension

length: 14500 → 14500 m
width: 1000 → 9000 m
height: 3 → 10 m

location

basin: Arabian Gulf
country: United Arab Emirates
continent: Asia
latitude: 24.3804
longitude: 54.2298
jump to: WorldWind, Google™

visual representation

Fig. 6. Section of the Carbdb case view for the carbonate barrier sands with 'tails' ('Tombolas') in the Arabian Gulf. Landsat7 images from *NASA Worldwind*.

model was smoothed for a gentle transition from high to low probabilities. The probability model helps to exert improved control on the facies distribution during the subsequent simulation.

The influence of the probability model is kept at a moderate level by not exceeding probability values over 0.8 (minimum 0, maximum 1). Neither the depo-zones nor the probability model determine the exact facies arrangement or positioning, rather they create a framework defining the boundaries in which MPS has the freedom to reproduce the depositional patterns from the training images.

Simulation

The steps taken to prepare and execute the MPS simulation are summarized in Figure 10 and are as follows:

(1) Upscale facies logs from outcrop sections and wells.

(2) Classify the Muschelkalk shoal geobodies following the hierarchical system, in order to find matching analogues in Carbdb.

(3) Evaluate the depositional patterns of three cases from Carbdb depicting possibly analogous

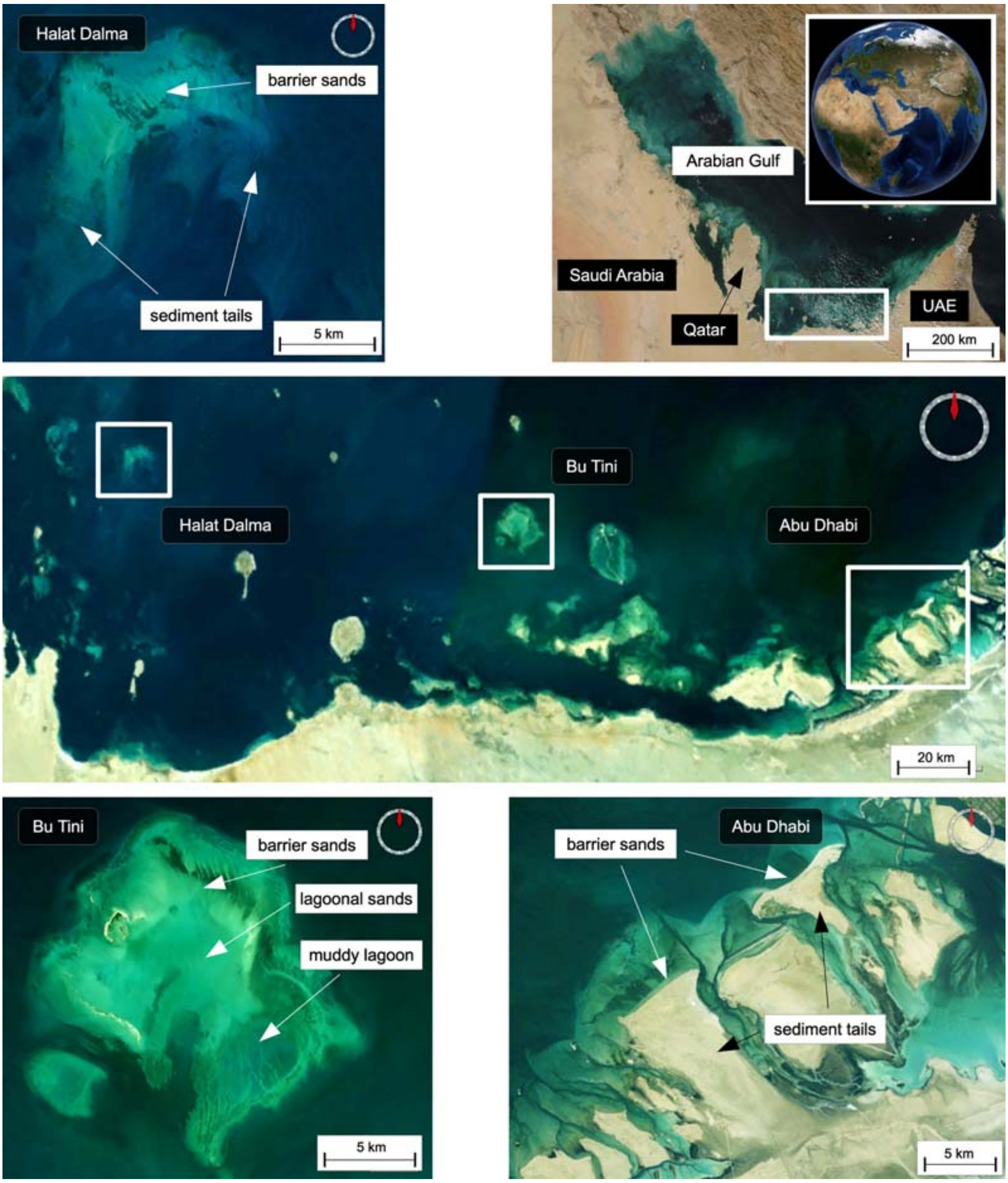


Fig. 7. Comprehensive overview of the Carbdb cases in the ramp environment of the Arabian Gulf as a potential analogue for the shoals of the Muschelkalk. The shoals and barriers in the open platform environment reach dimensions of up to 20 km and are elongated perpendicular to the prevailing wind direction. The high energy facies of the shoals (Bu Tini and Halat Dalma) are bow-shaped, while the barrier sands of Abu Dhabi resemble bars. Landsat 7 satellite images from *NASA Worldwind*.

shoals in the present-day Arabian Gulf (Fig. 10b). Establish conceptual facies model (Fig. 10c).

(4) Build depo-zones (Fig. 10e).

(5) Build the probability model (Fig. 10f).

(6) Create training images (Fig. 10g).

(7) Run the MPS simulation for depo-zones 1 and 2:
- assign training images to depo-zones – Ti1 to depo-zone 2, Ti2 to depo-zone 1;
- assign probability model to facies types of high energy shoal environment;

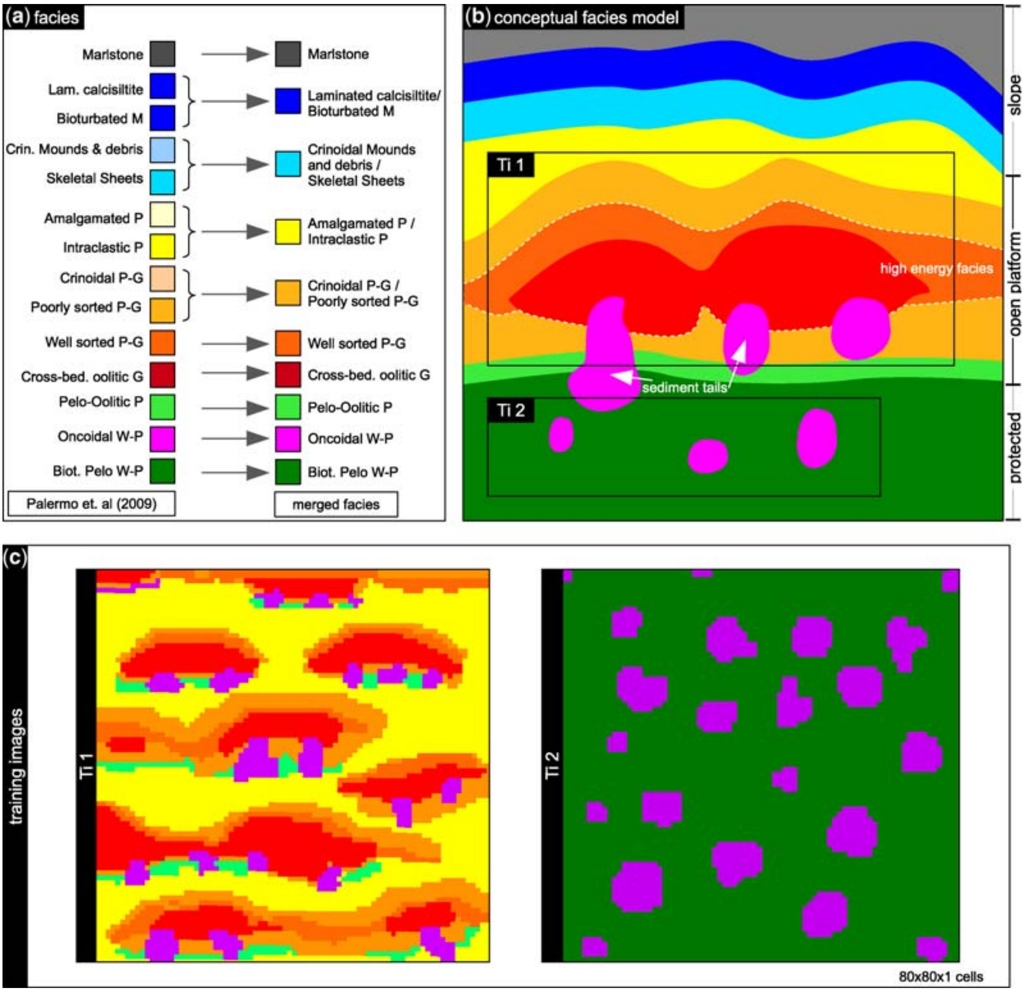


Fig. 8. (**a**) Original facies classification of Palermo *et al.* (2010) and merged facies types used in this study. (**b**) Conceptual facies model based on modern analogues from the Arabian Gulf. The sediment tails formed by spill-over lobes extend from the high-energy zone into the backshoal cross-cutting the other facies and forming patches in the backshoal. (**c**) Training images depicting the conceptual facies model. Ti1 for the mid ramp (open platform) environment with shoals; Ti2 for the backshoal environment of the inner ramp (protected platform).

- simulate each layer individually because of the highly dynamic system, which leads to frequent and fast lateral shifting of the depositional patterns of the shoals; the vertical relation of the stacked 2D realizations (maps) is guided by the probability model and well data;
- the MPS simulation of the facies across all layers took 15–20 min on a desktop computer with Intel Core2 Quad at 2.4 GHz and 4 GB RAM.

The non-reservoir facies in depo-zone 3 is not a focus of this modelling study and was imported from the deterministic 3D model (Palermo *et al.* 2010). Using different modelling techniques for different depo-zones is another advantage of the hierarchical modelling approach.

Results

MPS model

The stochastic 3D model is shown in Figures 11 and 12 and some selected time slices are displayed in Figure 13. While the regional facies distribution is determined by the depo-zones adopted from the previously established deterministic model

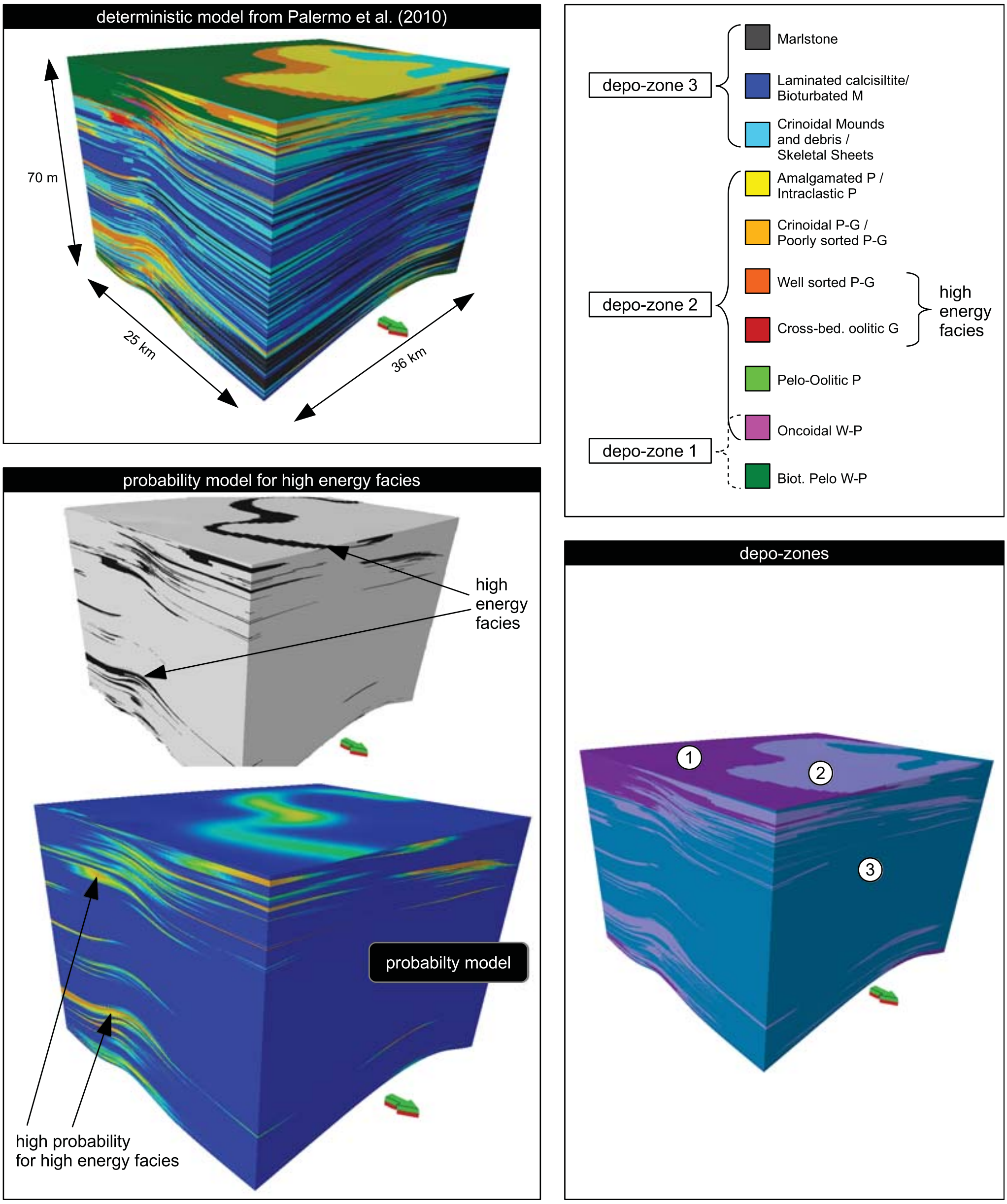


Fig. 9. Subdivision of the original model of Palermo *et al.* (2010) into depo-zones by grouping of facies. The probability model for the high energy facies was built by first merging two litho facies types (well sorted P-G [pack- to grainstone] and cross-bedded oolitic G [grainstone]), then assigning the merged facies a high probability value and finally smoothing the values for a smooth transition. Warmer colours indicate higher probabilities. The maximum values for the probabilities are limited to 0.8. Higher values would lead to too strong an influence on the positioning of the facies (well sorted P-G and cross-bedded oolitic G) during the subsequent simulation.

(Palermo *et al.* 2010), the distribution of the potential reservoir facies within depo-zones 1 and 2 was simulated with MPS. The fairly complex depositional patterns of the shoals in the mid-ramp (depo-zone 2) were reproduced according to the conceptual facies model and resembled the training images. Since MPS is able to connect facies types across the boundaries between depo-zones, the pattern of spill-over

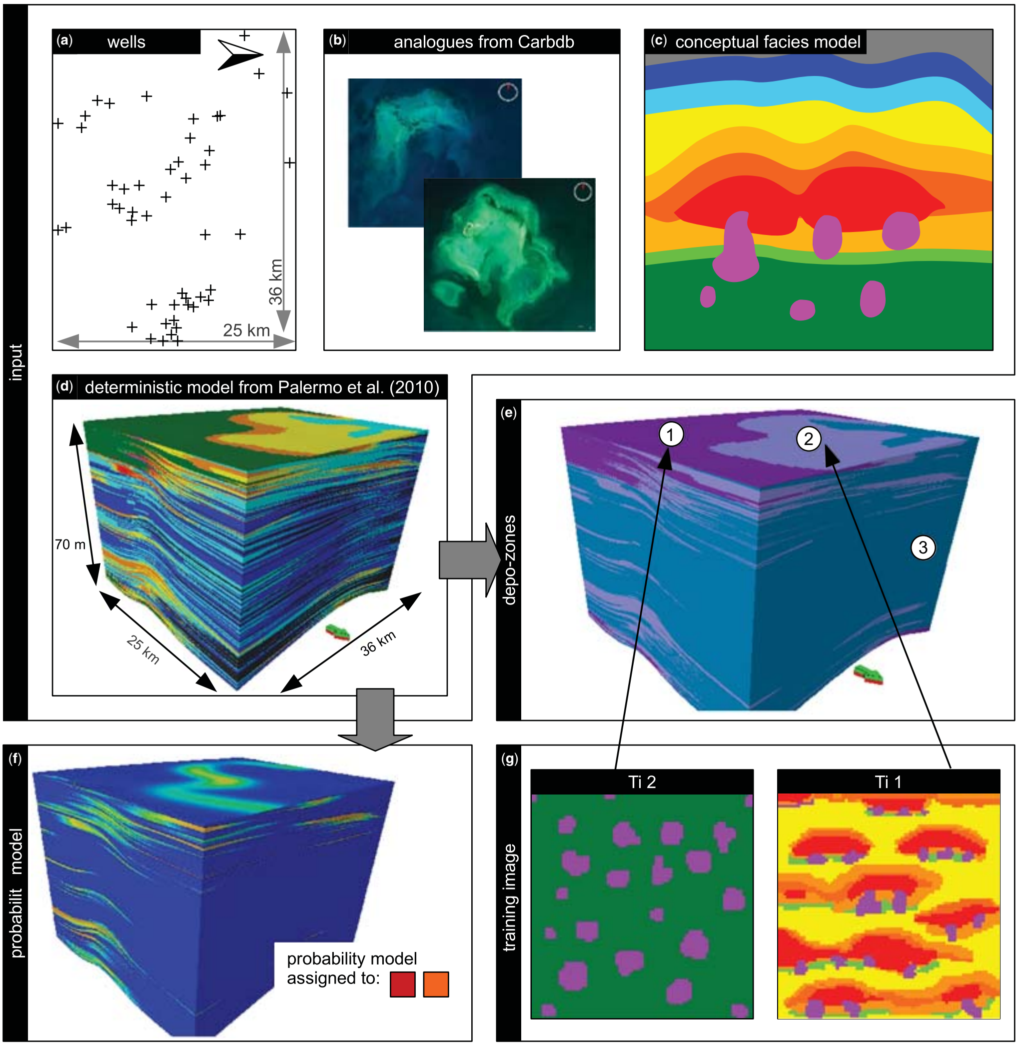


Fig. 10. Overview of the workflow used to simulate the shoals of the Upper Muschelkalk with MPS. Hard data was used from 49 data points (outcrop and well locations), analogues from Carbdb derived from the modern Arabian Gulf were used together with a conceptual facies model to build the training images for depo-zone 1 and 2. The interactively derived facies distribution from the model of Palermo *et al.* (2010) was used to build the depo-zones and the probability model for the high energy facies.

sediment tails cross-cutting the surrounding facies types and reaching into the backshoal (depo-zone 1) could also be modelled successfully. As expected from a stochastic technique, the realization shows variations of the facies patterns from the training image while honouring the basic facies arrangement. This is particularly visible in the time slices, in Figure 13, which reveal a facies mosaic observed in modern analogues from the Arabian Gulf, where facies compounds appear in patches in a more distal environment (cf. Bu Tini and Halat Dalma shoals, Fig. 7). The juxtaposition of proximal and distal facies at the boundary between depo-zone 2 and 3 therefore appears reasonably representative. The time slices *w*, *x*, *y* and *z* are from the re- and transgressive part of the 3D geocellular model as indicated in Figure 11. Even in the case of a very narrow and curved depo-zone, the facies patterns are realistically modelled (slices *w* and *y*), as the positioning of the high energy facies is steered by the probability model. Furthermore, the four cross sections, that is, faces of 3D cubes in Figures 11 and 12, show that

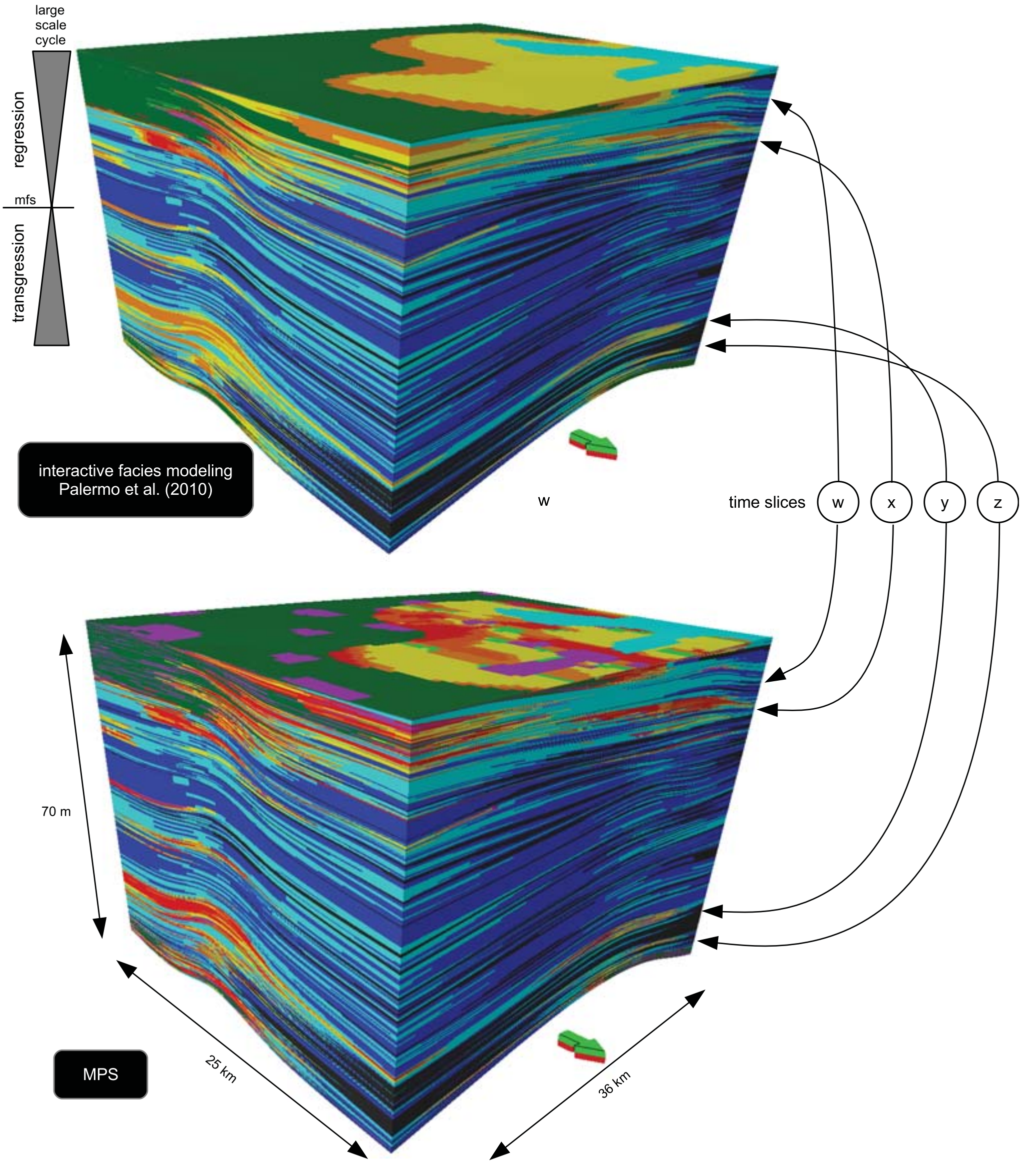


Fig. 11. View of both Muschelkalk models from NE direction. Indication of layers (time slices) are displayed in Figure 13. Vertical exaggeration of model is 300×.

the vertical relation of the facies across the stacked 2D layers is reproduced as expected for this depositional system (cf. the section 'Simulation', step 7).

Comparison of the models

The model of Palermo *et al.* (2010) was produced in a deterministic fashion by interactive facies drawing and generally shows a more continuous facies distribution than the MPS realizations (Figs 11–13). The large-scale facies distribution in both models is similar because both models rely on the same depozones that comprise the same facies types. The MPS model, however, introduces a higher lateral heterogeneity in the shoal belt, which forms a potential reservoir zone. When comparing the two models with the modern analogues from the Arabian Gulf, the MPS realization exhibits a more heterogeneous and more patchwork-like facies distribution, which has greater similarity to the present-day

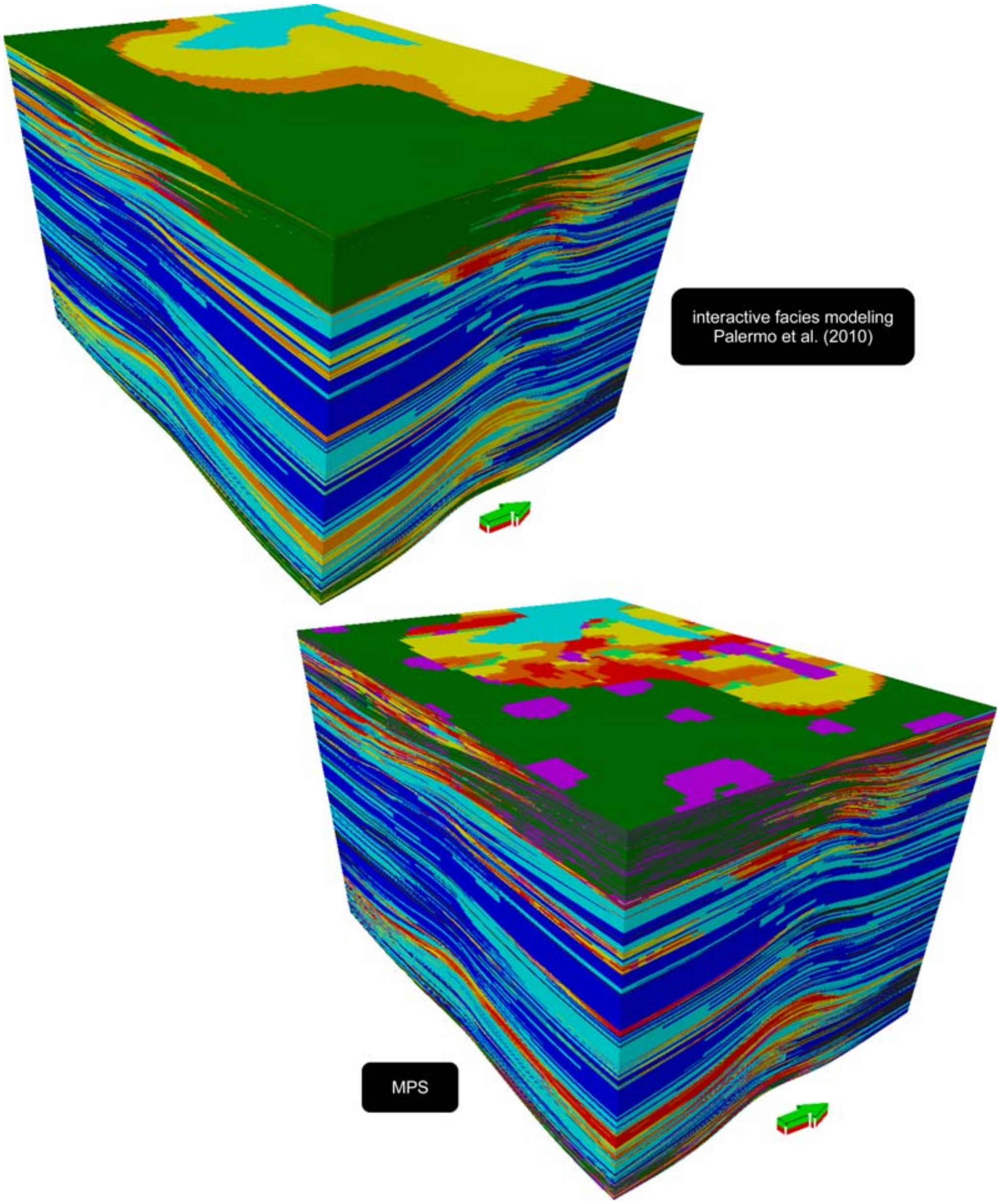


Fig. 12. View of both Muschelkalk models from SE direction. Vertical exaggeration of model is 300×.

counterparts, making the MPS model more geologically realistic.

Discussion

A hierarchical and modular modelling approach allows multiple techniques to be freely combined. The modelling study presented here makes use of deterministically created depo-zones that are then populated stochastically with facies by MPS. An alternative approach is the stochastic generation of depo-zones with truncated Gaussian simulation (Jung *et al.* 2010; Jung & Aigner 2012). A similar approach involving truncated Gaussian simulation was presented by Carrillat *et al.* (2010). However,

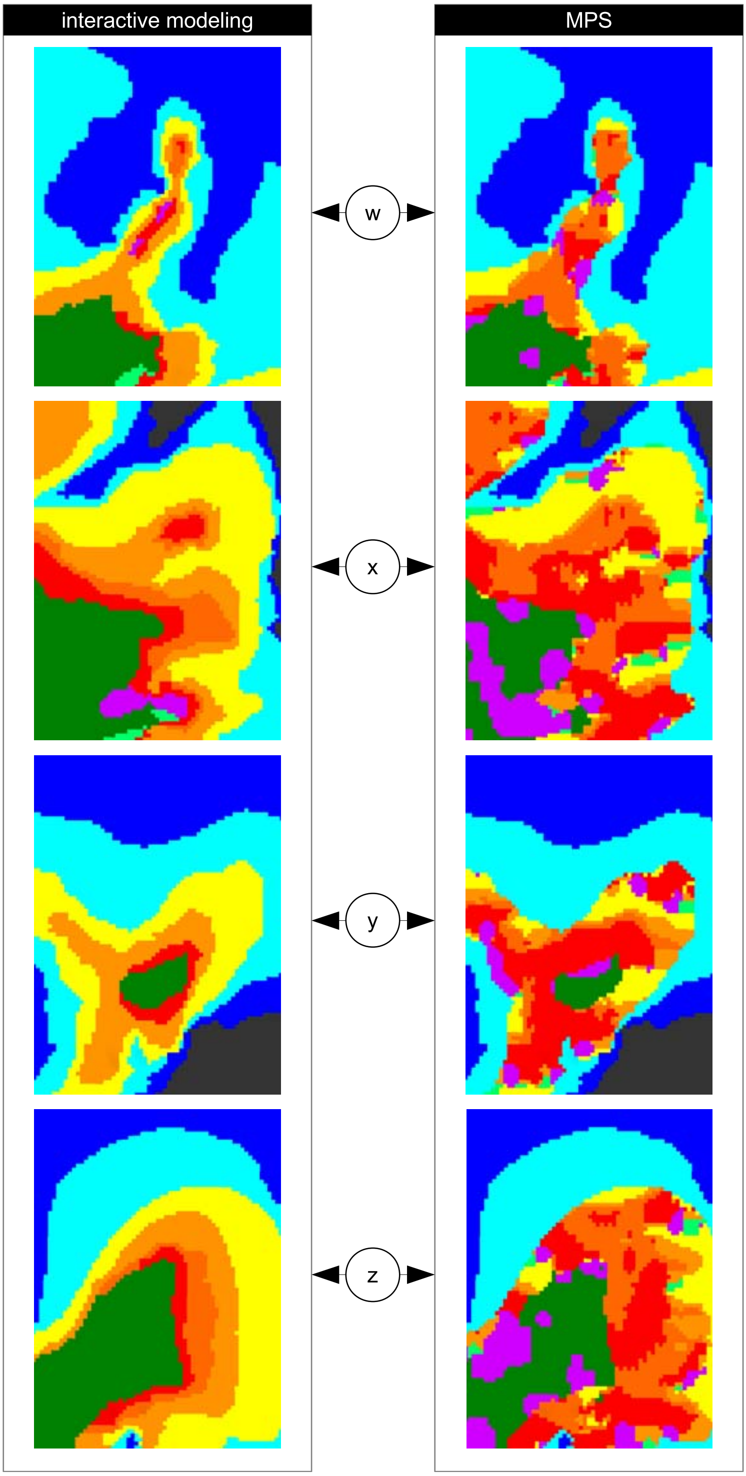


Fig. 13. Comparison of selected time slices from the transgressive part (*y*, *z*) and regressive part (*w*, *x*). Figure 11 indicates the location of the time slices. Facies distributions are discussed in the text.

this study focuses on rebuilding facies patterns with MPS in selected depo-zones in a pre-existing model framework, that is, the high energy facies in the shoal environment. Another goal of this study is to invite geologists who so far have preferred deterministic interactive facies modelling to take advantage of MPS without the effort of rebuilding the entire model with stochastic techniques. The comparison of the deterministic and stochastic models can only be done through visual inspection using geological insight, that is, reproduction of depositional patterns. Future sensitivity studies could evaluate the impact on reservoir properties. The modelling workflow in this study is preferable in cases where subsurface data are scarce and data from analogues become even more important. In such scenarios, data provided by Carbdb as input for MPS or other techniques such as Boolean, that is object-based, are of particular value.

Conclusions

In this study we applied the classification, workflow and software presented by Jung & Aigner (2012) to model a carbonate shoal environment in the Upper Muschelkalk in SW Germany.

(1) The workflow for 3D reservoir modelling draws on the novel software to manage a library of analogue data, called Carbdb, combined with multiple-point statistics.
(2) The basis for the Carbdb software is a hierarchically organized classification scheme for carbonate geobodies that can be used consistently for the description, organization of a library of analogue data, and for reservoir modelling.
(3) Analogue data retrieved from Carbdb are used to build so-called training images. These represent conceptual depositional patterns and facies relationships that are reproduced during MPS simulations.
(4) Representing the depositional patterns in training images and simulating them using the stochastic technique of MPS is much faster than deterministic modelling, for example via interactive facies modelling.
(5) Applying this workflow to shoal bodies of an outcrop analogue has demonstrated that MPS simulations can produce geologically more realistic and more heterogeneous facies distributions than in the previously established deterministic 3D model.
(6) The ensemble of a systematic classification scheme, data management with the Carbdb software and the employment of MPS provides the reservoir modeller with an efficient workflow for 3D modelling of carbonate geobodies.

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