Modeling Matrix-related Heterogeneities in Carbonates with Non Process-based Geostatistical Methods: Real and Synthetic Examples*

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Search and Discovery Article #120088 (2012)*
Posted December 31, 2012

*Adapted from extended abstract prepared in conjunction with poster presentation at AAPG Hedberg Conference, Fundamental Controls on Flow in Carbonates, July 8-13, 2012, Saint-Cyr Sur Mer, Provence, France, AAPG©2012

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Abstract

Modeling carbonate reservoirs in 3D is a key challenge that is not so simple to solve. The first reason for this is related to the fact that every field is unique, and this is true for any field whether carbonate or silico-clastic. The second and main reason for this difficulty lies in understanding which heterogeneity is controlling flow dynamics in carbonate reservoirs. If matrix plays a dominant role in controlling the dynamic behavior of the reservoir, then the key aspect control is the complexity of the interaction between sedimentary facies and diagenesis.

3D modeling techniques that are available today enable to build structural models, which are populated with facies and petrophysical parameters, and, when necessary, with explicit or implicit fracture networks. The objective of a 3D model is to provide a set of geologically sound realizations for which a satisfying match between flow simulations and production data is obtained. For a given reservoir, 3D models may need to be different depending on the recovery mechanism, because the heterogeneity, which will drive the flow, may differ.

Thus, focusing on modeling key heterogeneity can infer simplifying or bypassing some of the other specificities of the matrix.

Recognizing the key heterogeneities is the first step of any reservoir geology study. This implies taking into account both static and dynamic information and building a picture of the carbonate system from well data and analogues. The analogues (present-day

systems, outcrops or conceptual cartoons) often being asymmetrical do enhance extra complexity in the making of a 3D model. Depositional facies and diagenesis modeling should preferably be conducted in two separate steps because diagenesis comes as an overprint onto an existing facies distribution.

Another difficulty arises when considering high permeability streaks. The temptation is then to generate grids which consist of very fine layers (<50cm) to capture the highest frequency of the petrophysical data at log or plug scale, and to propagate it over a significant number of cells along this layer. However, just how representative is this value when the cell dimensions in X and Y are 100 or 200m?

Classic Geostatistical Modeling Techniques

These approaches have the advantage of being readily available in all modeling software today, but may rapidly become insufficient for a consistent representation of matrix-related heterogeneity. Ruelland P. and Bu Hindi H., 2009, proposed one such modeling workflow for the facies and diagenesis models. The facies model consisted of a two-fold imbrication of the depositional environment model (closely related to paleo-bathymetry) and the facies distribution within each environment. Boundaries between depositional environments were modeled as large-scale trends, broadly concentric or linear. Facies were distributed either using a Sequential Indicatrix Simulation or a Truncated Gaussian Simulation approach, the latter enabling non-bordering facies not to be in contact in the model. Diagenesis leading either to carbonate dissolution or cementation was overprinted as a specific parameter in particular layers.

Petrophysical modeling was then conducted through a petrophysical group scheme based on information on facies and diagenesis. This was achievable because the environment and facies configuration was simple enough and without much asymmetry. Cross-sections through the model ended up being very similar to those hand-drawn by the carbonate sedimentologist.

Modeling atolls, which are asymmetric because of prevailing winds and wave orientations, is not possible with the techniques listed above. Pluri-gaussian techniques may approach this by enabling the representation of a certain asymmetry through contacts and/or absence of contacts between facies.

Multi-Point Statistics (MPS) Techniques

Classic multipoint statistics approaches, which are based on stationary training images (i.e. images without any intrinsic trends), cannot be applied successfully. Direct use of a present-day analogue system as the input to a training image is not possible. Consistent realizations can be obtained through step-by-step processes, which involve splitting the facies training image into a series of stationary training images to model facies separately and merging them into a final facies cube (Levy M et al, 2008).

Few techniques allow taking into account the non-stationarity of a training image. The combination of primary and auxiliary training images (derived from the former) can be taken into account with by the algorithms SNESIM (Strebelle, 2002) and IMPALA (Straubhaar et al, 2011), and by using algorithms developed by Chugunova and Hu (2008) to obtain consistent sets of realizations. Examples of such auxiliary training images and subsequent MPS models in silico-clastic contexts are illustrated in Ronot et al, 2012.

Direct Sampling, a more recent MPS algorithm (Mariethoz et al, 2010), offers the possibility to use non-stationary images of categorical and continuous variables as training images. Figure 1, Figure 2 and Figure 3 illustrate the construction of the training images and the results of the modeling process on a synthetic 2D reservoir grid. 2D training images have been built from modern-day analogues, Europa and Bassas da India islands in the Mozambique Channel (Figure 1). Two auxiliary variables are derived from this grid: distance to shore and elevation. Trend maps are needed to position the facies and associated porosity correctly in the model. The trend maps derived from the training image must have an equivalent trend parameter in the reservoir grid.

Figure 2 illustrates the effect of a variation in shape of the shoreline of an imaginary atoll, whose modern-day analogue could be the Bassas da India Island. The geometry of the atoll varies but facies are located in the right position and thus the asymmetry of the facies map is well captured.

A training image in porosity is produced from the 2D facies grid of the Europa Island (Figure 3), using a Sequential Gaussian Simulation technique. The aim is to represent matrix porosity without the impact of specific diagenetic event (locally high degree of dissolution or locally high degree of cementation). The latter should be modeled independently. The direct sampling method enables to construct synchronously both facies and porosity models (Figure 3). Trend parameters in the reservoir grid can be derived from 3D seismic or from an a priori model. Various stages in the development of the carbonate atoll may call for various training images. High frequency cycles can be imbedded in 3D training image itself, by modifying facies or geometry from one layer to another. Low frequency cycles can be modeled with different training images after subdividing the reservoir grid vertically into zones.

Uncertainty and Multi-Scenario, Multi-Realization Approaches

The advantage in using appropriate geostatistical methods and workflows lies in their flexibility and reproducibility. Various scenarios can be taken into account and realizations generated to cover the uncertainty domain. The following key step is the "management" of the multi-realizations, and the subsequent selection of those realizations that will go down the dynamic simulation route.

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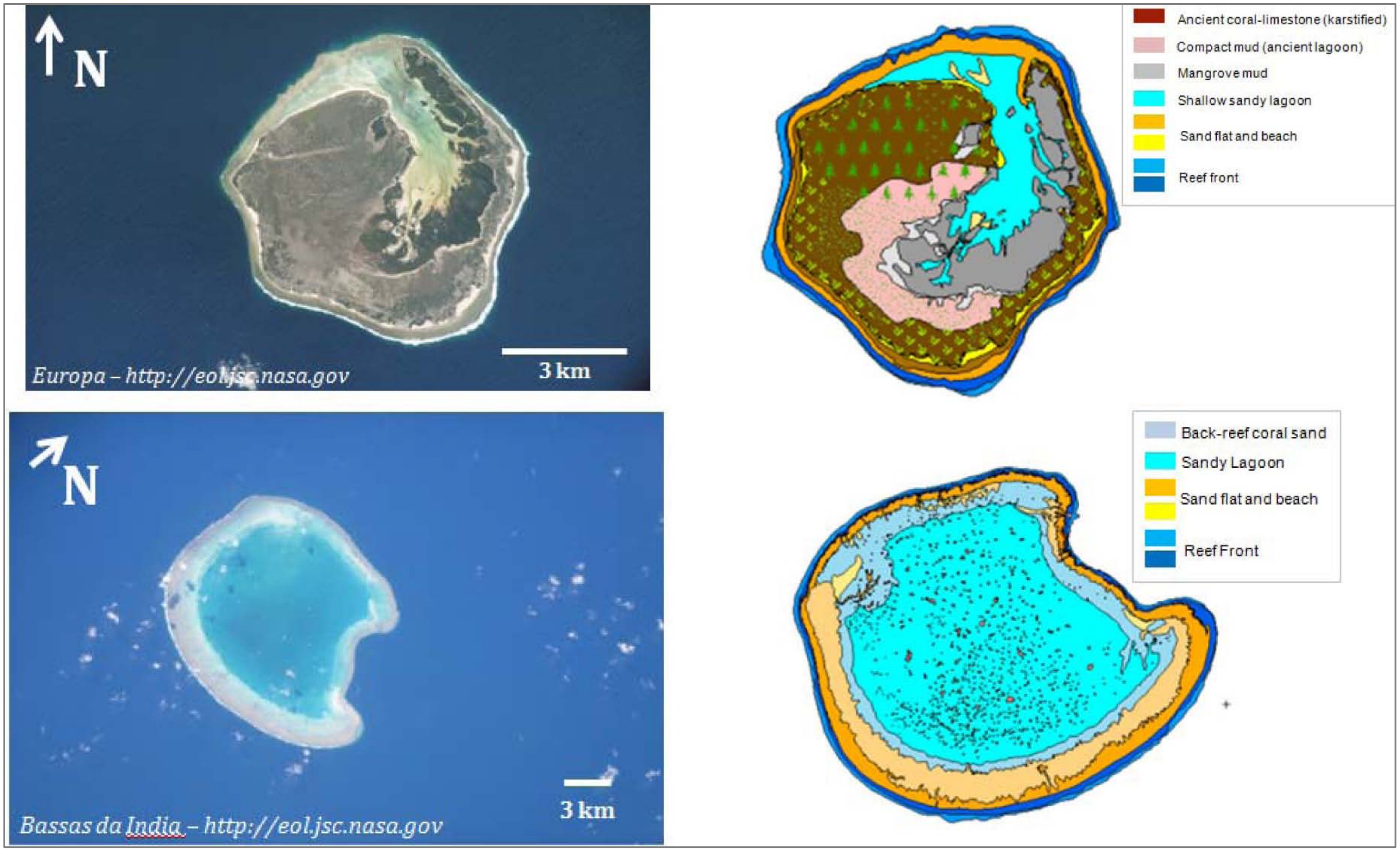

Figure 1. Satellite photo and facies map of the Europa and Bassas da India islands.

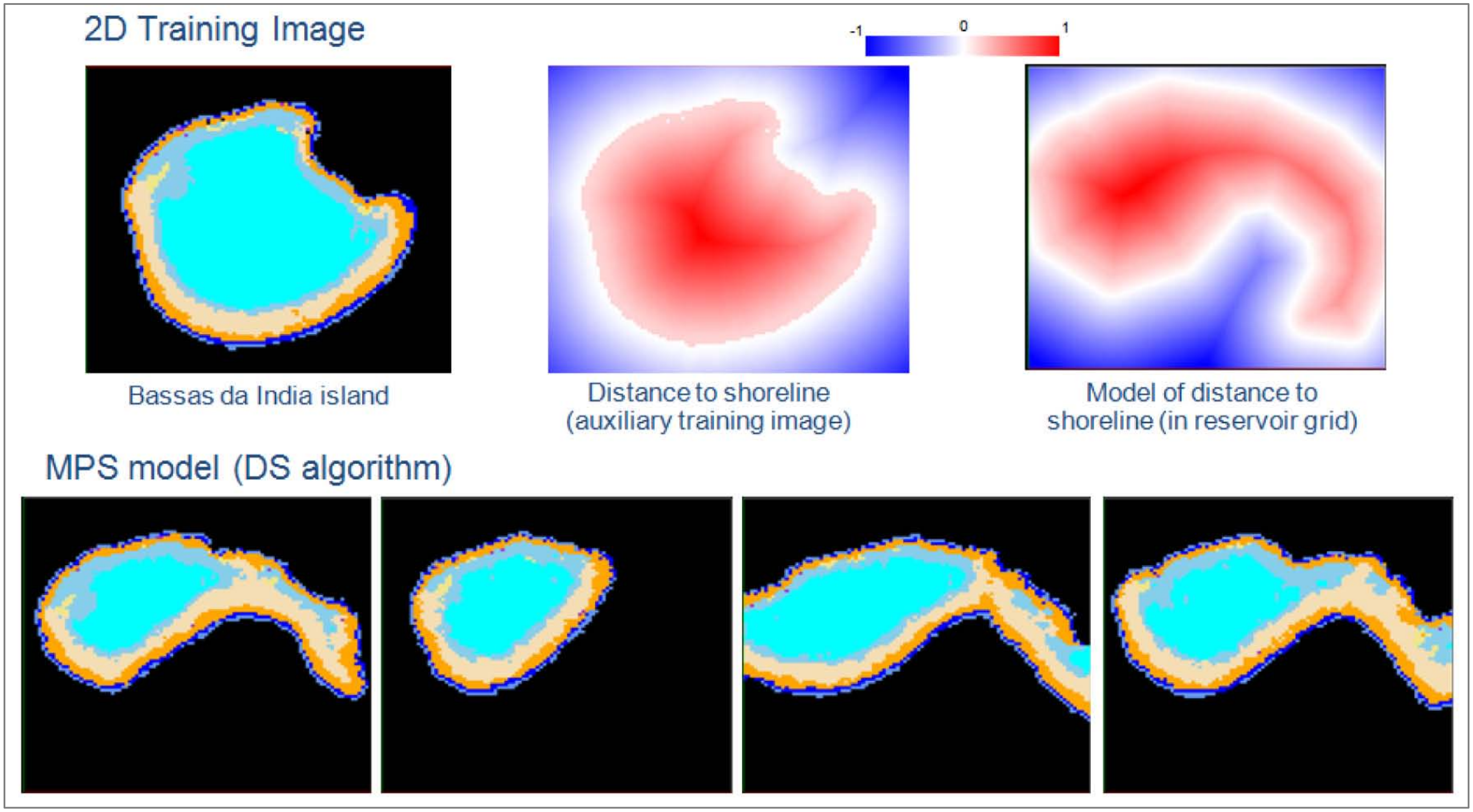

Figure 2. 2D training image (Bassas da India Island), auxiliary image, trend in model and MPS realization.

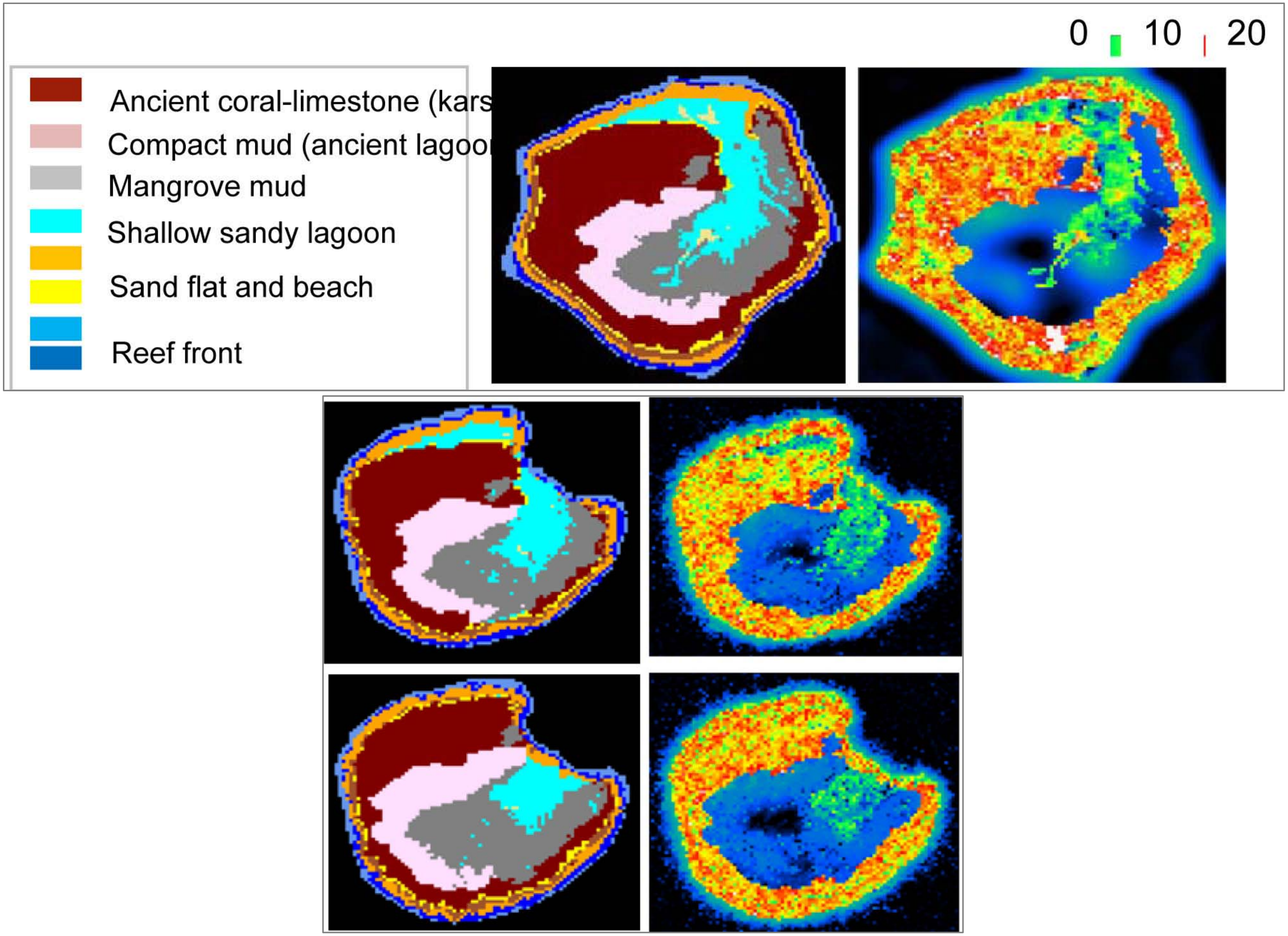

Figure 3. Facies and porosity grids (Europa Island) and MPS models. a) 2D Training images: facies and porosity (facies with similar porosity distribution are grouped); b) 2 Realizations: facies and porosity (modeled synchronously from Training Images).