

Driving Parameters for Process-Like Modeling of Replacement Dolomite Related to Fractures (Calcarei Grigi, Trento Platform, Northern Italy)*

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Search and Discovery Article #50552 (2012)

Posted February 6, 2012

*Adapted from extended abstract prepared for oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

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Introduction

Geological modeling of diagenetic overprints in carbonate reservoirs is still a challenge thus far as neither stochastic nor physicochemical simulations can correctly reproduce the complexity of features generated by the processes. An alternative way to reach this objective deals with process-like methods that simplify the algorithms while preserving all geological concepts (from data and knowledge) in the modeling process.

The new process-like method developed in a research group is well adapted to handle dolomite reservoirs through the propagation of dolomitizing fluids. New solutions for modeling always require actual data for testing efficiency and forecast validity.

A case study in the Trento carbonate platform has been selected as an actual case for testing the process-like methodology and reproducing products of the main diagenetic process. This well exposed outcrop analog involving multistage dolomitization is located in Northern Italy in the Venetian Pre-Alps ([Figure 1](#)). This section belongs to the Calcarei Grigi Group and is composed of Liassic shallow carbonates (mainly Hettangian-Pliensbachian).

Methodology

Based on sedimentological evidence and sequence-stratigraphic analyses ([Figure 2](#)), a facies model of the Venetian platform (Lias) has been constructed using an in-house toolbox by which paleo-water depth and accommodation potential are simulated at outcrop scale. The accommodation potential (relative sea level change) is defined per time interval and represents the sum of sea-level variation and subsidence. This numerical simulation allows for the combination of depositional history complexities of carbonates systems in 3D view.

Moreover, field observations and analytical results allowed us to determine different diagenetic processes which date from the Lias to the Paleogene. Finally, multistages of diagenetic processes are simulated and superposed with a process-like modeling method. Calibration of the model parameters used for matching the observed data of the field proves the robustness and the accuracy of the diagenetic concepts and calendar. Multi-realizations mostly follow the patterns identified on outcrop and validate both the field results and the modeling methodology.

Modeling of Depositional Model

On outcrop, sections have been studied and interpreted as Liassic carbonate successions and have been divided into three intervals (members): the Lower, the Middle, and the Upper. The lower interval is characterized by peritidal carbonate successions. The Middle interval is related to a deepening environmental event. The Upper interval is characterized by a lagoon environment.

Four main paleo-environmental based on facies associations have been established from grain composition, biotas, and textures, as shown in [Figure 3](#). Most of the facies associations occur in each of the measured sections, but some of the facies have more restricted distributions.

The initial depositional model is created using an in-house modeling toolbox and using the sequence-stratigraphical concept to constrain the stochastic facies model from the dataset. This method also uses the classical sedimentological dataset; i.e., sections, structural maps, thickness maps. Extracted from a facies log of sections, an individual paleo-water depth distribution map is created for each system tract. These maps are then combined to create a 3D proportion facies cube using sequential Gaussian simulation with external drift. The result is a number of equi-probable realizations of facies distribution.

Description of Main Diagenetic Processes

Field studies have proved that multistage diagenetic processes occurred during geologic times from Lias to Paleogene. Analyses such as whole-rock, stable isotopic geochemistry and cathodoluminescence have been performed to improve the understanding of dolomite development.

Isotope results indicate a general depletion of heavy oxygen related to heated fluids whereby dolomite precipitated without carbon isotopes variation (average: 2 ‰). The latest dolomitization is related to *per ascensum* fluids flowing in the fracture network.

Moreover, they allowed the identification of different generations of dolomitizing fluids and dolomites; at least four single crystalline phases are distinguished and are differently associated with the microfacies associations. Effects of dolomitization on porosity have been also evaluated. In a later stage, calcite cementation filled the open conduits generated in the fracture network by previous dolomite stages ([Figure 4](#)).

Dolomitization Stage 1

This phase is characterized by a unimodal dolomite preferentially occurring in the tidal-flat facies (the Lower Member) with two microfacies associations D1 and D2. Microfacies D1 displays a mudstone-wackstone texture with an incipient dolomitization, which preserves the original texture. Microfacies D2 seems to result from a uniform process, which obliterated the whole-rock fabric without any preferential dolomitizing mechanism.

Isotope analyses show relatively low values for oxygen isotopes $[-0.6;-3.5\text{‰}]$. This phase is interpreted as occurring in Early Jurassic times when dolomites developed within shallow burial environments. The dolomitizing fluid was mainly composed of normal or slightly concentrated sea water. It is a pervasive dolomitization phase with a non-uniform distribution.

Dolomitization Stage 2

This phase is characterized by a polymodal character in dolomite associated with different crystalline phases and two different Microfacies types (D3 and D4 breccias). The depletion of the $\delta^{18}\text{O}$ has been related to a heated fluid (70-90°C). The latter could have risen along reactivated Jurassic and Paleogene normal faults. This phase is represented by *per-ascensum* dolomitization and is related to faults coupled with horizontal fingers during late Paleocene-early Oligocene times. In mudstone facies, the fracture networks tend to become denser.

Diagenetic Process Modeling

Based on geological concepts and knowledge, the aim of the methodology is to conceive a 3D-consistent and realistic model of diagenetic overprints on petrophysical properties at reservoir scale ([Figure 5](#)). An example of the impact of dolomite crystal size on petrophysical properties and results of two types of simulation are shown in [Figure 6](#) and [Figure 7](#).

The understanding of depositional and post-depositional processes in carbonate platforms provides guidelines for optimum modeling of diagenetic overprints and derived petrophysical characteristics. A model of the geometry of such features allows the application of numerical simulation methods to the modeling flow.

The principle of the process-like modeling is related to a lattice gas simulator combined with a random walk. This enables the numerical solution of the stochastic differential equation, which characterizes the main mechanisms leading to the formation of diagenetic overprints (i.e., karstic networks, dissolution-affected zones, cementation zones). This spatio-temporal probabilistic model is conditional and also is constrained by the dataset (wells, porosity, permeability, and dynamic data).

As mentioned in [Figure 5](#), the process like modeling enables us to:

- Simulate a succession of diagenetic stages where each stage can be parameterized independently of one another,
- Integrate different infiltration zones and fluid flow direction (meteoric, *per ascensum*, hydrothermal) by stage,
- Include by stage the paleogeography, the hydrodynamic effects, the saturated or un-saturated surface, the impact of indirect and direct factors (i.e., diagenetic fluids, facies impact, fracture density, bedding),

- Generate complex features related to multistage processes.

Conclusion

Establishment of the initial depositional model presented allows us to obtain a model consistent with geological observations. Using stochastic simulations can lead to a realistic restitution of a 3D sedimentary model.

Process-like modeling enables 3D diagenetic overprints, consistent with geological observations and statistics. It outlines the necessity of thorough sedimentological and diagenetic studies in complex carbonate reservoirs and provides a comprehensive method of integrating such results in reservoir models. The modeling procedures are performed if the processes involved in reservoir deposition and transformation are identified and assessed.

Furthermore, these stochastic simulations lead to multi-realizations of petrophysical distribution, including uncertainties and the creation of alternative and equi-probable models.

More than being only a geomodeling tool, the application is also able to:

- Validate, invalidate or sharpen geological and diagenetic assumptions, reproduce reservoir heterogeneities,
- Drive the user to propose alternative scenarios for diagenetic stages and spreading of diagenetic products,
- Help the user in the understanding of the 3D distribution of diagenetic features,
- Still enable the building of dual permeability and porosity models directly transferred to fluid flow software.

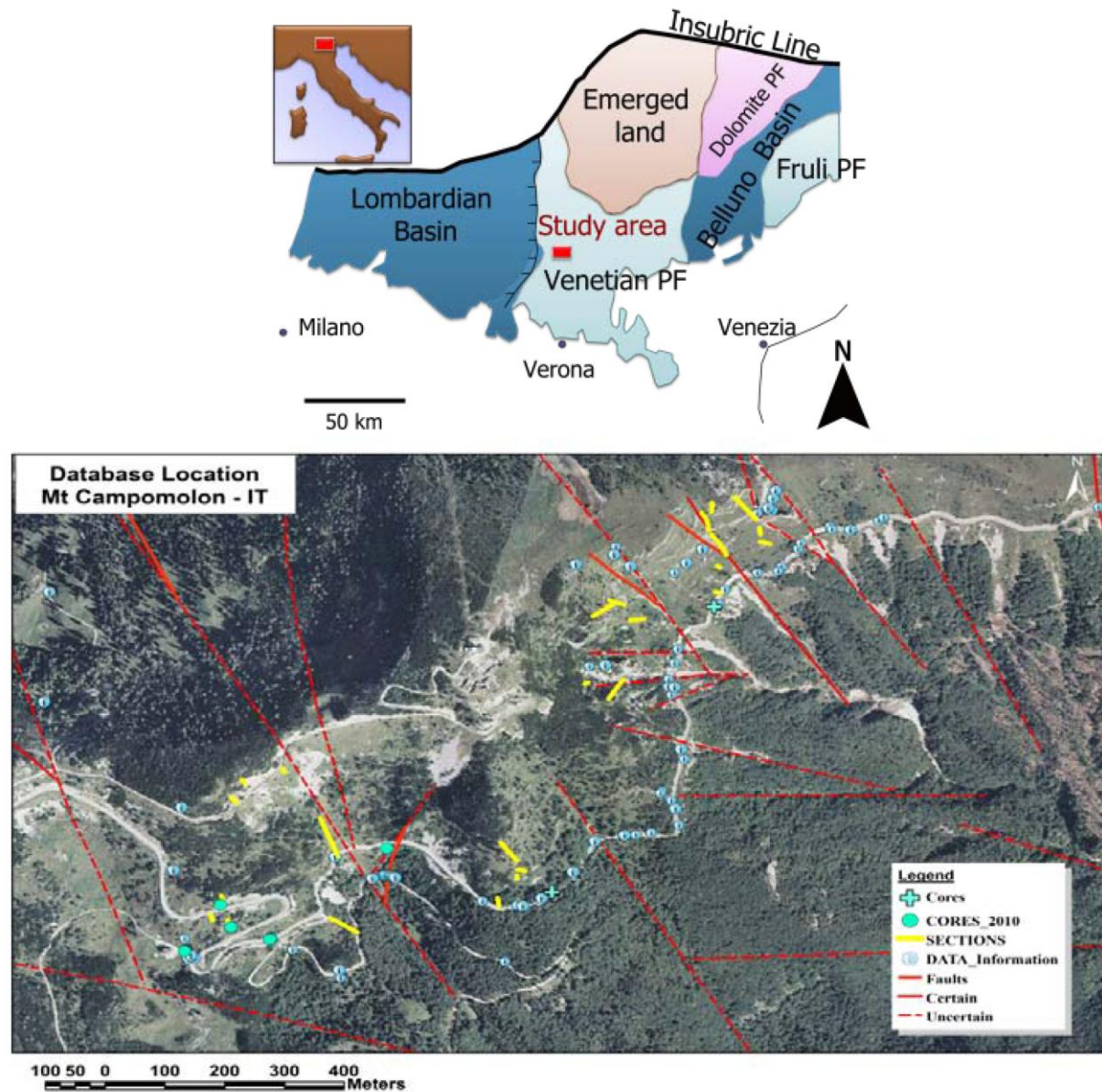


Figure 1. Upper: Location of the outcrop and Liassic sedimentary domain. Lower: Location for the database.

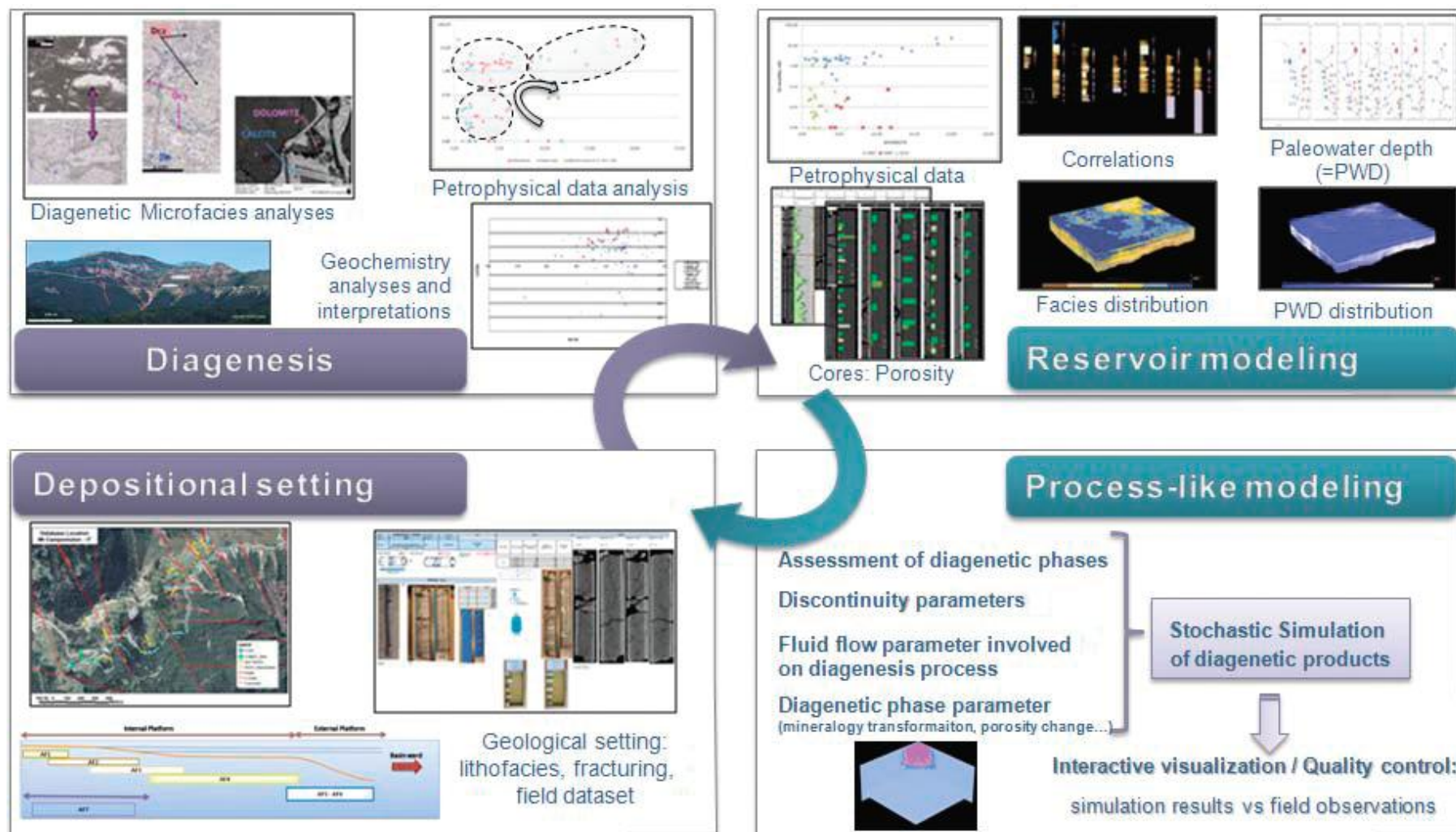


Figure 2. Definition of the methodology used.

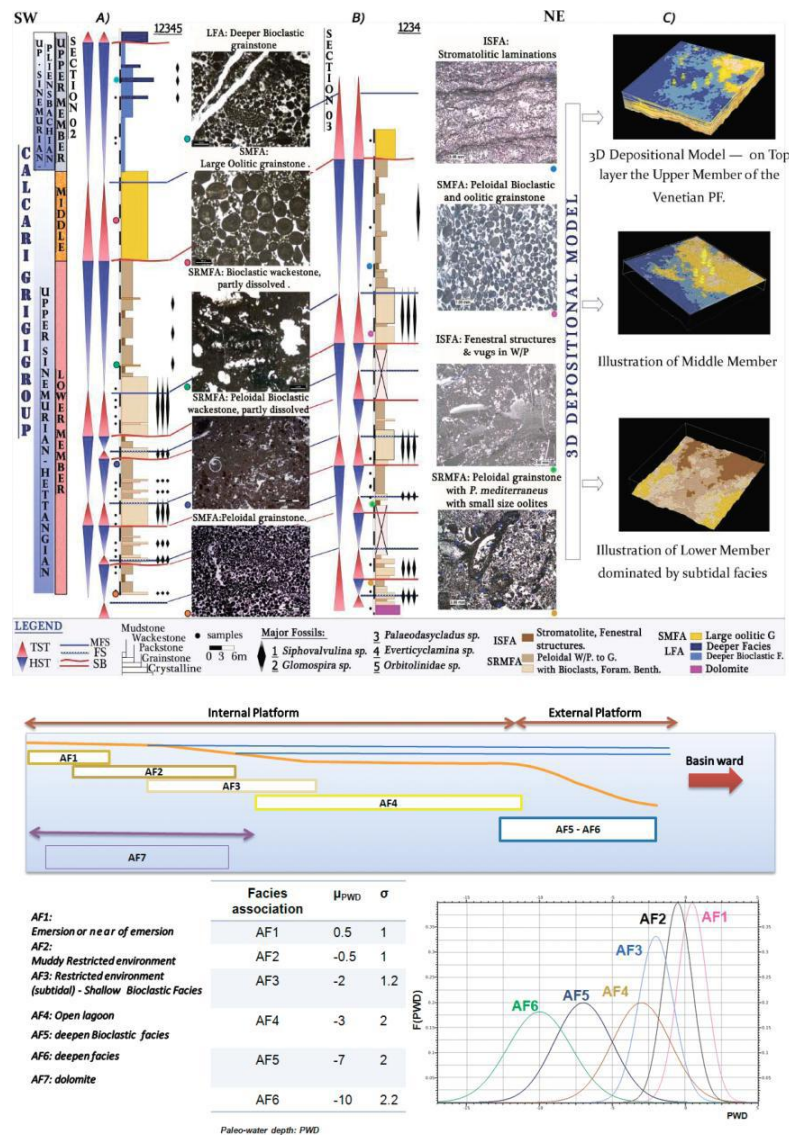


Figure 3. Upper (A,B,C): Lithofacies and textures interpreted in two different sections. A) and B); all sections have been correlated in order to simulate a 3D sedimentary model; C) Snapshot of the 3D depositional model. Lower (AF): Representation of facies association (AF) vs. margin platform profile with paleo-water depth distribution per facies used according to the sedimentological model.

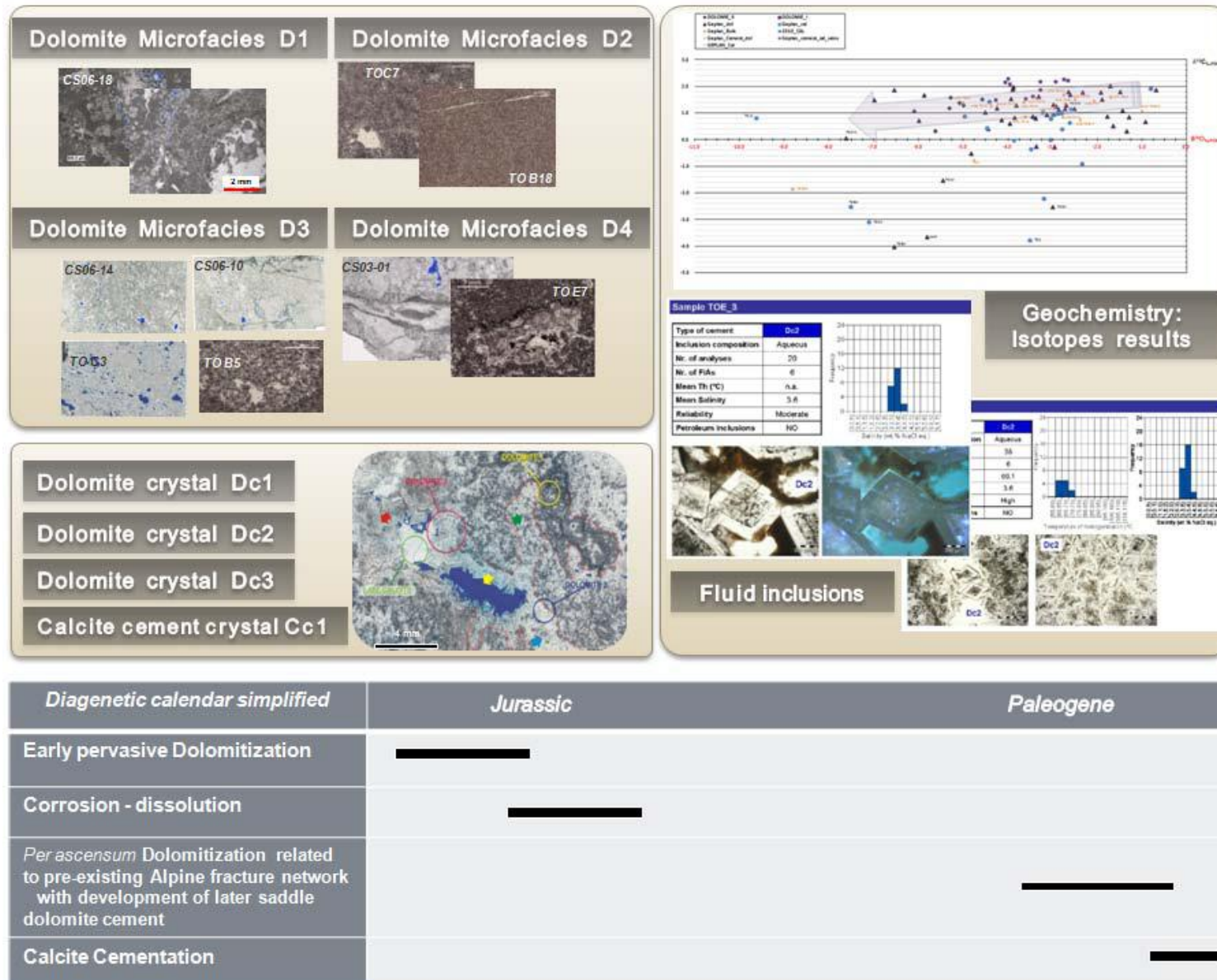


Figure 4. Synthesis of analytical studies performed to determine main diagenetic stages, based on outcrop examination.

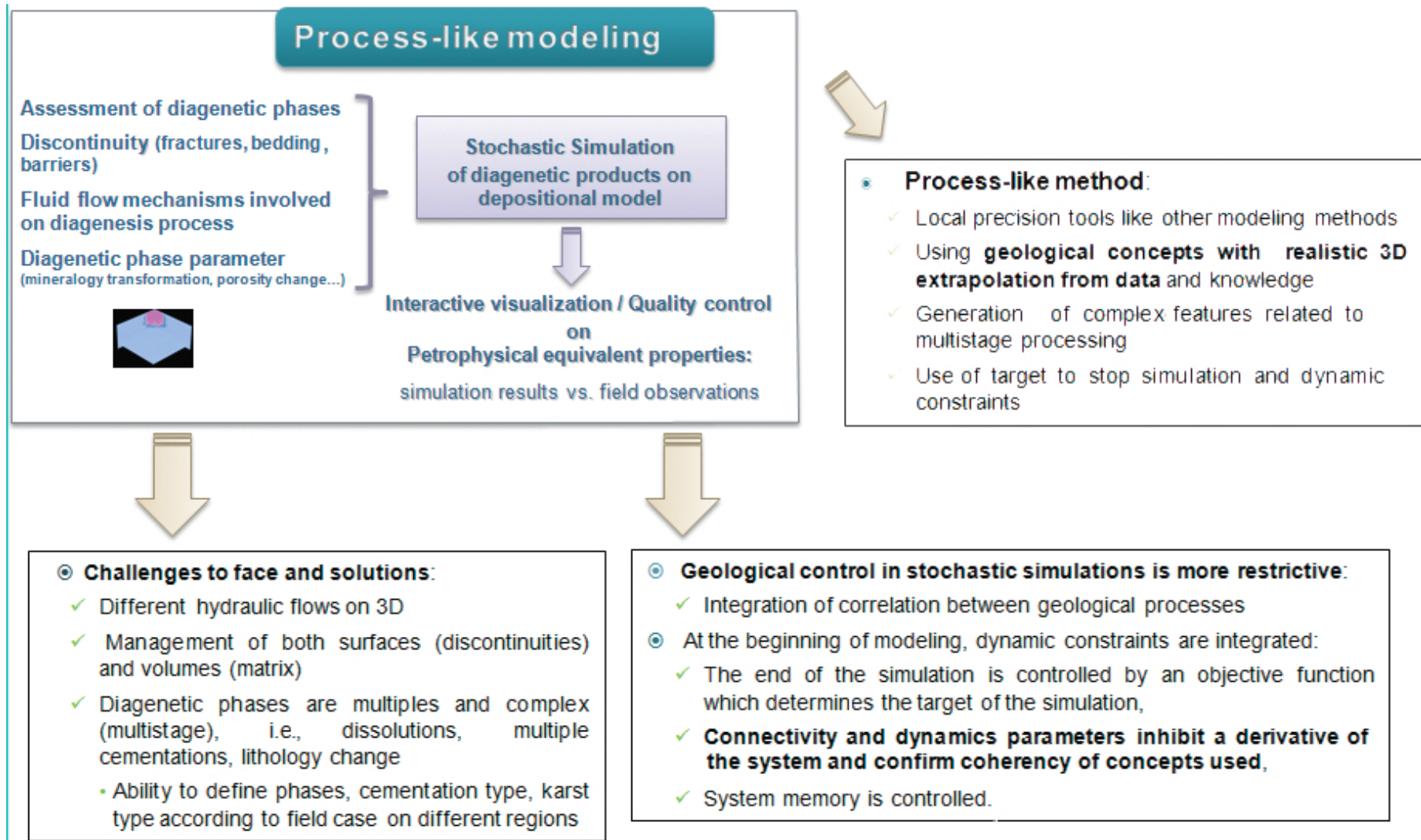


Figure 5: Explanations of process-like modeling method.

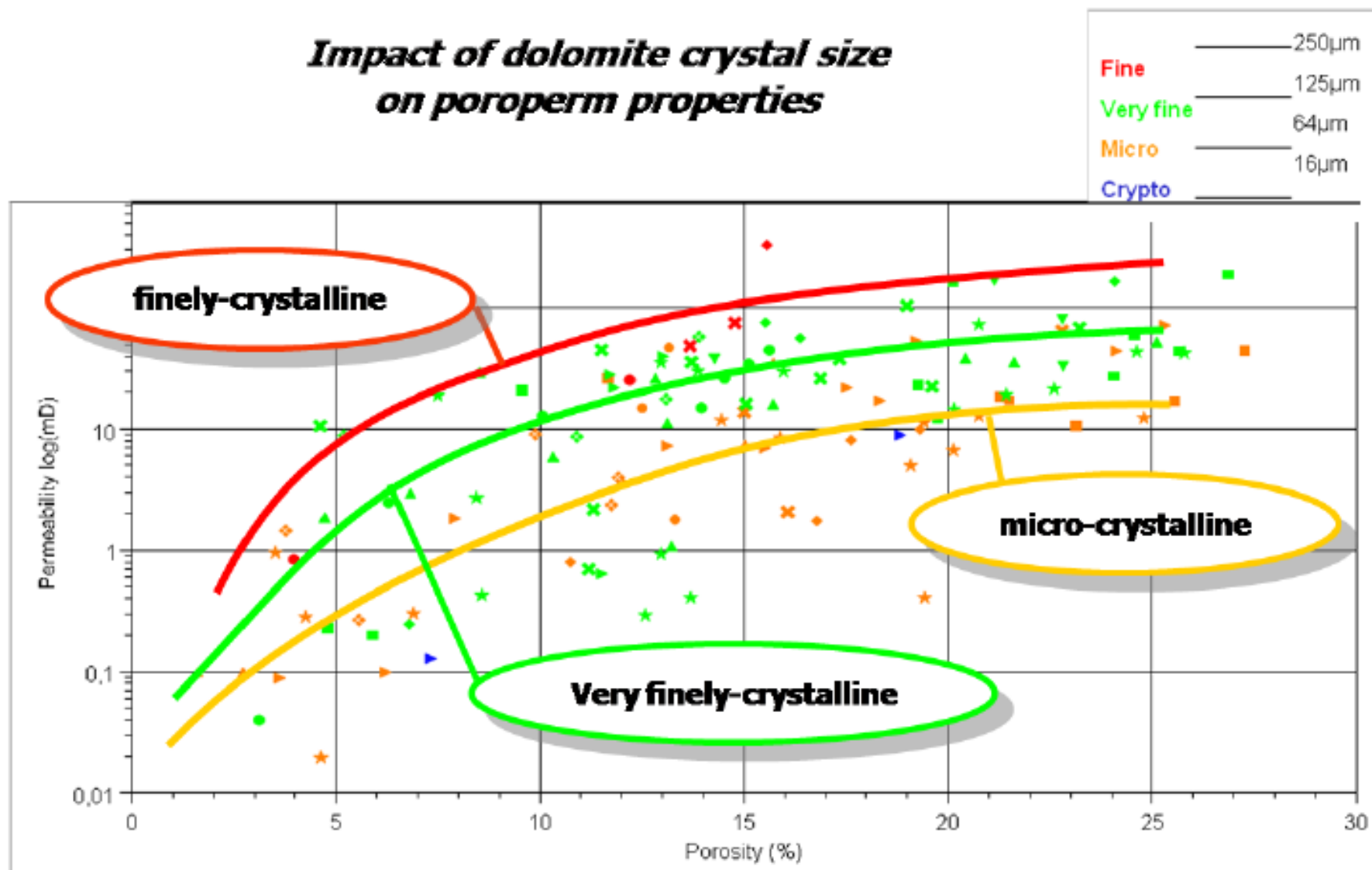


Figure 6: Dolomite crystal geometry impact on permeability-porosity properties of reservoir (Total source, carbonates department).

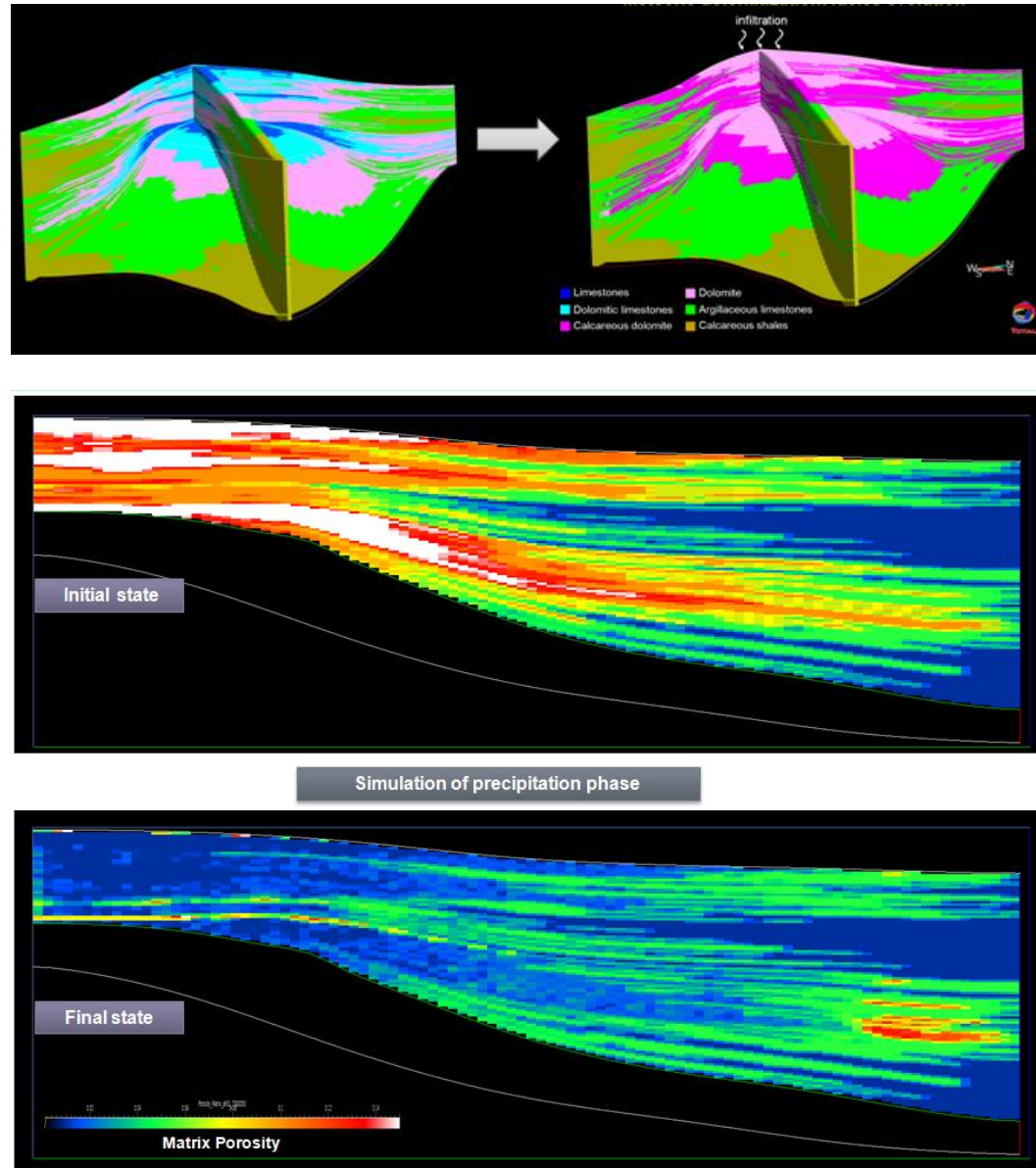


Figure 7: Illustration of simulation results: Upper: Meteoric dolomitization and facies evolution; Lower (2 cross-sections): Simulation of precipitation phase on section, evolution on matrix porosity (Total source, geomodeling department).