Application of Outcrop Analogues in Carbonate Reservoir Characterization and Modeling: Multiscale and Multidisciplinary Approaches

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ABSTRACT

Outcrop analogues are key elements in the understanding of reservoir architecture and heterogeneities. Indeed, subsurface data often represent an extremely small fraction of the reservoir complexity. This is specifically true for carbonate reservoirs that exhibit a high degree of heterogeneity, whatever the scale of investigation. Working on subsurface data without the benefits of relevant outcrop analogues and application of geological principles based on field observations, may therefore lead to important misinterpretation of well or seismic data. The aim of this presentation is to illustrate different application of outcrop analogue studies: definition of conceptual relationships between several geobody types; quantitative characterization to describe the dimensions and geometry of geobodies; usercases to calibrate modeling parameters and to design modeling workflows.

This presentation mainly focus on a multidisciplinary approach applied on the Mississippian Madison Formation, outcropping in several locations of the Bighorn foreland basin (Wyoming, USA), as a thick (up to 400 m) carbonate series. It shows a large variety of sedimentary facies and environments (from supratidal sebkha to deep subtidal) and a polyphased diagenetic history (that successively involved marine, meteoric and basinal fluids). The quantitative approach carried out in this study has enabled to use the sedimentological and diagenetic data in a modeling workflow to reproduce both facies and diagenetic trends in a static reservoir model and to account for reservoir property changes due to the diagenetic overprint. The SIS and nested geostatistical algorithms used in this study enabled to perform joint modeling of the sedimentary facies and the diagenetic overprint. This study demonstrates our ability to account, during the reservoir modeling process, for the heterogeneities both in the sedimentary facies distribution, and in the subsequent diagenetic imprint.

The Madison Formation is also an analogue of natural fractured carbonate reservoir. Tight carbonate reservoirs are often highly fractured, with high heterogeneities in terms of fracture distribution, hierarchization, and connectivity. In the Sheep Mountain anticline (Wyoming, USA), sedimentary facies are organized into three types of elementary facies sequences showing different vertical evolutions of their petrophysical properties. The latter are is controlled by the combined influence of the initial sedimentary facies and subsequent diagenetic evolution. In parallel, three main sets of fractures (related to the Sevier and Laramide compressive pulses and to the folding of Sheep Mountain) have been described at three scale orders. The series may therefore be described as an imbricated set of mechanical units, the distribution and characteristics of which are controlled by (1) initial texture; (2) early diagenetic overprint at small-scale; (3) overall facies stacking pattern, and (4) the large-scale fold curvature. Sheep Mountain outcrops therefore provide a good spatial representation of the carbonate reservoir

heterogeneities from the micro- to the field scale, illustrating the complexity of fractured-carbonate reservoirs. It also highlights the major influence of mechanical stratigraphy on fracture distribution, connectivity and style, a conclusion that can be used for reservoir characterization and modeling by generating Discrete Fracture Network (DFN) for each mechanical unit, thus modifying the hydraulic properties controlling fluid flow and hydrocarbon migration pathways.

Innovative approaches will be presented on complementary case studies to illustrate the use of outcrop analogs for new challenging topic. The recent discovery of hydrocarbons in microbial carbonate reservoir facies along the South Atlantic margins raised many questions on the origin and the distribution of nonmarine microbial carbonates. Based on different outcrop studies of lacustrine series (Argentina, South-East France, Greece), it is possible to propose quantitative rules that can be used as basic building blocks for modeling work-flows at both basin- (stratigraphic modeling) and reservoir scales (stochastic simulation). Recent advances in 3D photo-grammetry enable the integration of 3D numerical outcrop models in modeling workflows. These 3D models are particularly useful in the case of sedimentary systems with complex sedimentary architectures, and allow the collection of 3D virtual outcrop data that provide important constraints for the building of surface models, and quantitative parameters or relationships (spatial characteristics / length scales…).

To conclude, outcrop analogues provide essential data for the understanding of the subsurface. Nevertheless, as no perfect analogue exists, there will never be an absolute certainty provided by outcrops. It is therefore important to critically assess the problems and objectives to know how far one can rely on analogues.