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Matrix, fractures, karst, bitumen: an integrated modeling approach to help solve the Grosmont puzzle of northern Alberta, Canada

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Introduction

The Upper Devonian Grosmont Formation of northern Alberta is a giant bitumen reservoir that holds an estimated 318 billion barrels in place (ERCB, 2008) and consists of pervasively dolomitized, heavily karsted and fractured carbonates. The primary extraction technology is still unclear as pilot projects are currently in a planning stage, but will most likely involve a thermal component to reduce the extreme viscosity of the bitumen (in the million centipoises range). Success in producing the Grosmont resources will greatly rely on a good understanding and robust modeling of all geologically controlled heterogeneities present in the reservoir and their potential effects on fluid flow.

Grosmont Geology

The Grosmont reservoir architecture is characterized by both a significant depositional control and an intense karst overprint. The Grosmont Formation was deposited in a gently dipping and prograding shallow marine carbonate ramp environment, and records the transition between subtidal in the lower part of the reservoir (informal units Lower Grosmont, Upper Grosmont 1 and bottom of Upper Grosmont 2 units) to peritidal conditions in the upper part (top of Upper Grosmont 2 and Upper Grosmont 3 units). The resulting depositional framework is a very predictable layer cake. Stratigraphic units are regionally continuous, with massive nodular or vuggy units in the subtidal assemblage and more finely layered and laminated facies successions in the peritidal assemblage. Early phases of dolomitization led to complete replacement of calcite in the Upper Grosmont 2 and 3 units and partial replacement in the Lower Grosmont and Upper Grosmont 1 units. In the area of investigation, the bitumen-bearing Grosmont Formation directly sub-crops beneath the Cretaceous Mannville Group. The unconformity represents a stratigraphic gap of over 250 million years, during which the Paleozoic platform was tilted, the uppermost Devonian and Mississippian strata were eroded and the Grosmont Formation was exposed to surface conditions. This exposure prevailed for a significant period of time, resulting in intense, possibly multi-stage, karst dissolution. Multiple karst effects can be observed in the Grosmont Formation, with increased intensity in the vicinity of the sub-Cretaceous unconformity. They are schematically summarized in Figure 1 and described as follows:

1- Highly porous, stratiform karst breccias are encountered in specific reservoir units and consist of an unconsolidated matrix composed of very fine dolomite rhombs held together by bitumen, and variable amounts of Devonian clasts and clay material biostratigraphically assigned an early Cretaceous age. The cleaner (i.e. clast and clay free) intervals of this material may reach over 40% porosity and 95% bitumen saturation.

2- More classic mega-karst features such as sinkholes are also very common below the unconformity. They are filled with chaotic breccias composed of Devonian blocks and rubble of all sizes in a matrix consisting of Cretaceous clay, silt and occasional coal debris. Contrary to the stratiform karst breccias that contain high amounts of bitumen, the sinkholes are generally poorly saturated. They may however entrap unsaturated "inter-rubble" porosity and act as potential thief zones for injected fluids.

3- Fractures are ubiquitous in the Grosmont reservoir. They are not a karst effect *sensu stricto* as they predate the Grosmont exhumation but they do provide preferential pathways for karst dissolution. Their formation is driven by tectonics and burial and their distribution organized in two main sets oriented parallel and perpendicular to the Rocky Mountains axis. They are observed at 3 identifiable scales: a millimeter to centimeter scale observed mostly in the vuggy facies and stratiform karst breccias, a centimeter to meter scale observed in great abundance in the upper peritidal units and responsible for moderate drilling fluid losses, and larger events found in the subtidal bottom part of the reservoir, in lesser abundance but seemingly responsible for significant losses.

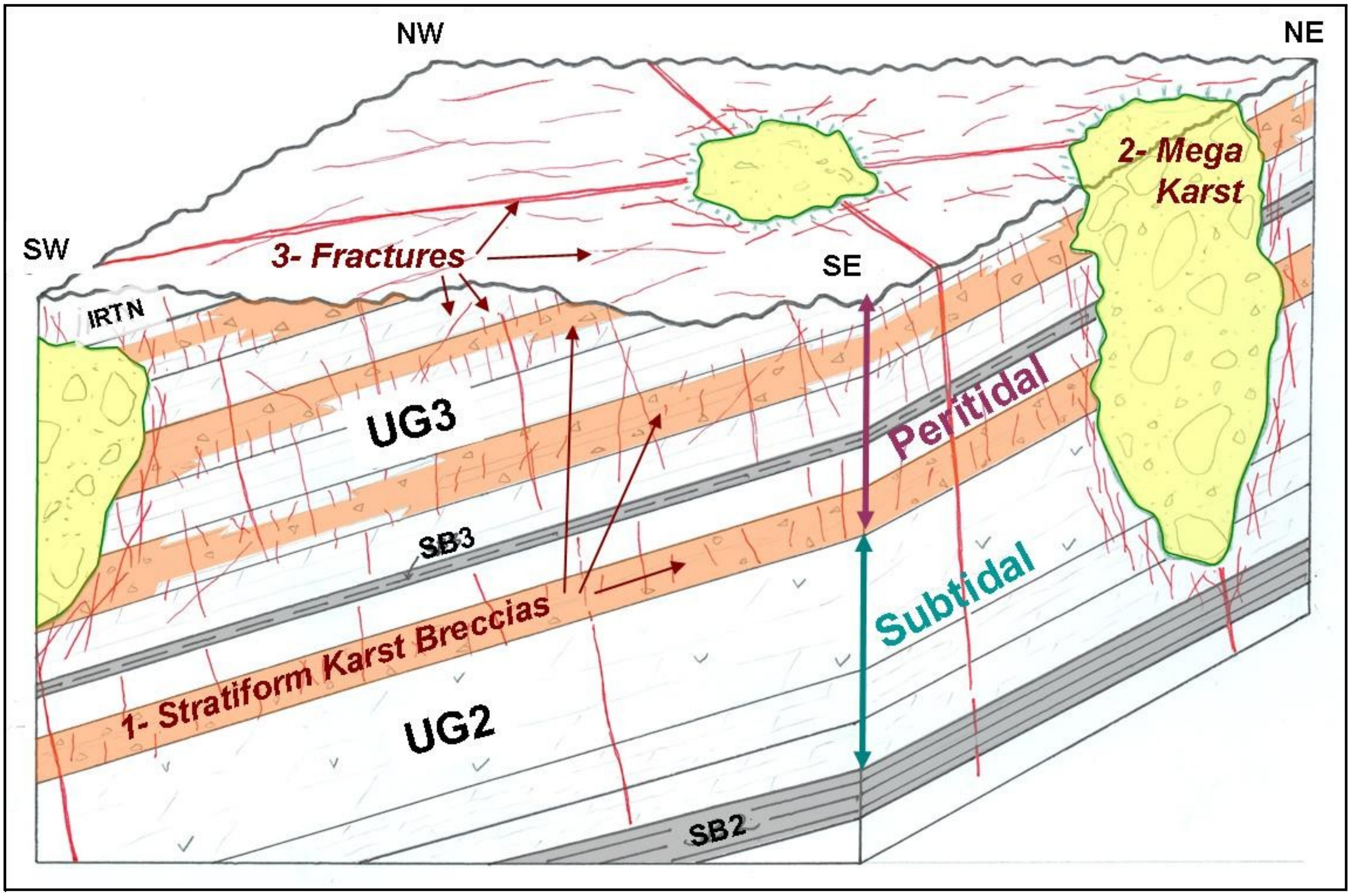

Figure 1: Upper Grosmont Reservoir Architecture

Legend: UG2 and UG3: Upper Grosmont 2 and 3 Units, SB2 and SB3: 'Shale Breaks' 2 and 3, IRTN: Upper Ireton

4- At the petrophysical scale, karst dissolution is responsible for a pervasive but also facies specific porosity and permeability enhancement. In fact, the bulk of connected porosity in the Grosmont reservoir is karst and fracture related secondary porosity (leached inter-crystalline/particle/granular, vuggy and fracture porosity).

Modeling Workflow

In the absence of a commercially available process-based modeling package for karst systems, a multi-faceted modeling workflow was developed in-house to account for all geological components of the reservoir; namely the matrix, fractures and mega-karst features, and is summarized in Figure 2.

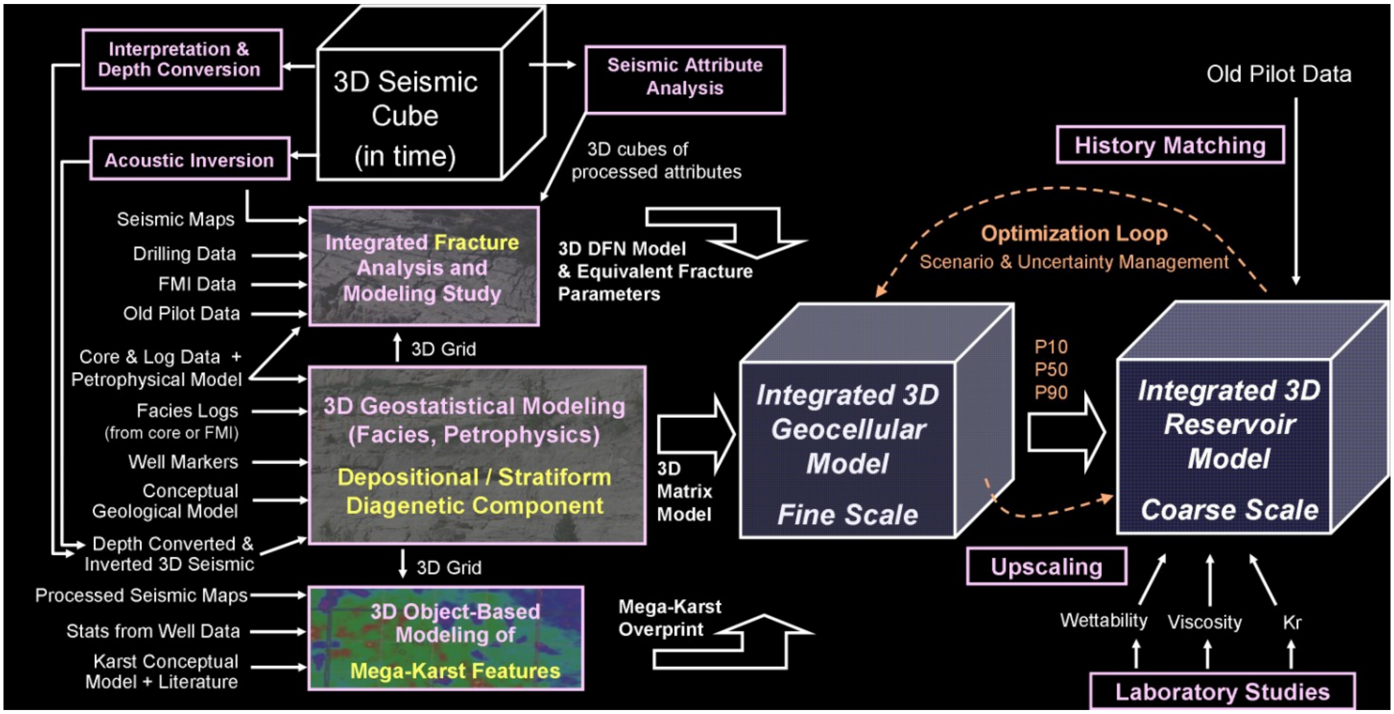

Figure 2: Husky Modeling Workflow, Grosmont Bitumen Reservoir, Northern Alberta

The first step and central part of the modeling workflow is a 3D geocellular model of the depositional framework and stratiform components of diagenesis. A facies code with 5 distinct reservoir rock types, 3 marginal reservoir and 4 non reservoir rock types was defined. Despite a sometimes significant overlap in porosity and permeability distribution between rock types, a facies based modeling workflow was chosen since it allows not only capturing the effective petrophysical properties but also the porosity type, fracture properties, mechanical and thermal properties, and dynamic reservoir properties (viscosity, wettability, capillary pressure, relative permeability), most of which are currently under investigation and anticipated to differ from one facies to another. The facies and petrophysical 3D modeling was performed following a detailed geostatistical analysis of their vertical and spatial distribution and using a sequential indicator simulation with locally varying mean (SIS-LVM) methodology. As experimental horizontal variograms yielded insufficient information, a cross-validation exercise was performed to evaluate and compare the outcomes of different horizontal variogram ranges and simulation methods.

To model the mega-karst features, a 3D object-based geostatistical simulation method was developed in-house that honours both seismically resolved events and sub-seismic sinkhole occurrence and 1D proportions at wells. Uncertainty in volumetric proportions of sub-seismic events is explicitly accounted for.

The modeling of fractures requires a different approach for each observed fracturing scale. Small scale fracturing is believed to act as a simple matrix porosity/permeability enhancer and is accounted for through addition terms or multipliers on matrix properties. Both the medium and larger scales of fractures are modeled using a dual porosity dual permeability approach. A stochastic discrete fracture network simulation and upscaling approach is used for the diffuse centimeter to meter scale fracturing observed at the top of the reservoir. A number of seismic attributes are currently under investigation to evaluate the possibility of using 3D seismic to deterministically simulate the larger events, believed to create significant connectivity paths in the reservoir.

Conclusion

Upon completion of all modeling steps, the 3 components of the geocellular model (1- depositional and stratiform diagenetic framework, 2- sinkholes or mega-karst features and 3- fractures) will be merged into one integrated super geomodel that will honour facies data from core and well images, core porosity and permeability data, well log data, fractures picked on image logs, and all seismically resolved events (sinkholes, large fracture swarms). Multiple realizations will be run on all model components to assess uncertainties and extract a set of P10, P50 & P90 scenarios. These models will then be upscaled and fed with dynamic reservoir parameters to be run in the fluid flow simulator. History matching of the old Saleski pilot data will allow for validating and iteratively refining the geological model, as well as evaluating recovery technologies and optimizing development schemes.

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