

Introduction to Reservoir Uncertainty Modeling

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Summary

Uncertainty exists everywhere, such as (1) raw data measurements, (2) data processing and interpretation, (3) structural modeling, (4) facies modeling, (5) petrophysical modeling, (6) transmissibility calculation, and (7) flow simulation, which affects the ability to understand the reservoir behavior, making reliable production forecasts and risk-free decisions. Fortunately, using 3D models as the basis for reservoir uncertainty quantification is now feasible due to advances in hardware and the development of reservoir modeling packages. The benefits of using realistic 3D models for reservoir uncertainty quantification include: (1) dependencies between various model properties are treated in a realistic manner; (2) the input and output are not restricted to functions and histograms; (3) 3D grids, which can be used directly in reservoir simulation and connectivity analyses, are created as part of the workflow; (4) 3D models and derivatives can be used directly for well planning and geosteering; (5) maps and 3D cubes can be generated to quantify spatially varying uncertainty.

3D uncertainty modeling workflow described in this paper (Figure 1) is directly analogous to the Monte Carlo simulation of the volume equation workflow. The main difference is that, instead of using the input distributions directly, 3D models are generated as an intermediate step and all volumetric calculations are based on these models. Another important difference is that the input distributions are defined for the parameters used in the 3D modeling, such as velocity model parameters and saturation height function parameters.

The workflow is highly appropriate for the evaluation of significant contingent resources and for the reliable quantification of commercial reserves. It is also suitable for providing input to development plans and concept design choices, and for management of fields in early phases of production.

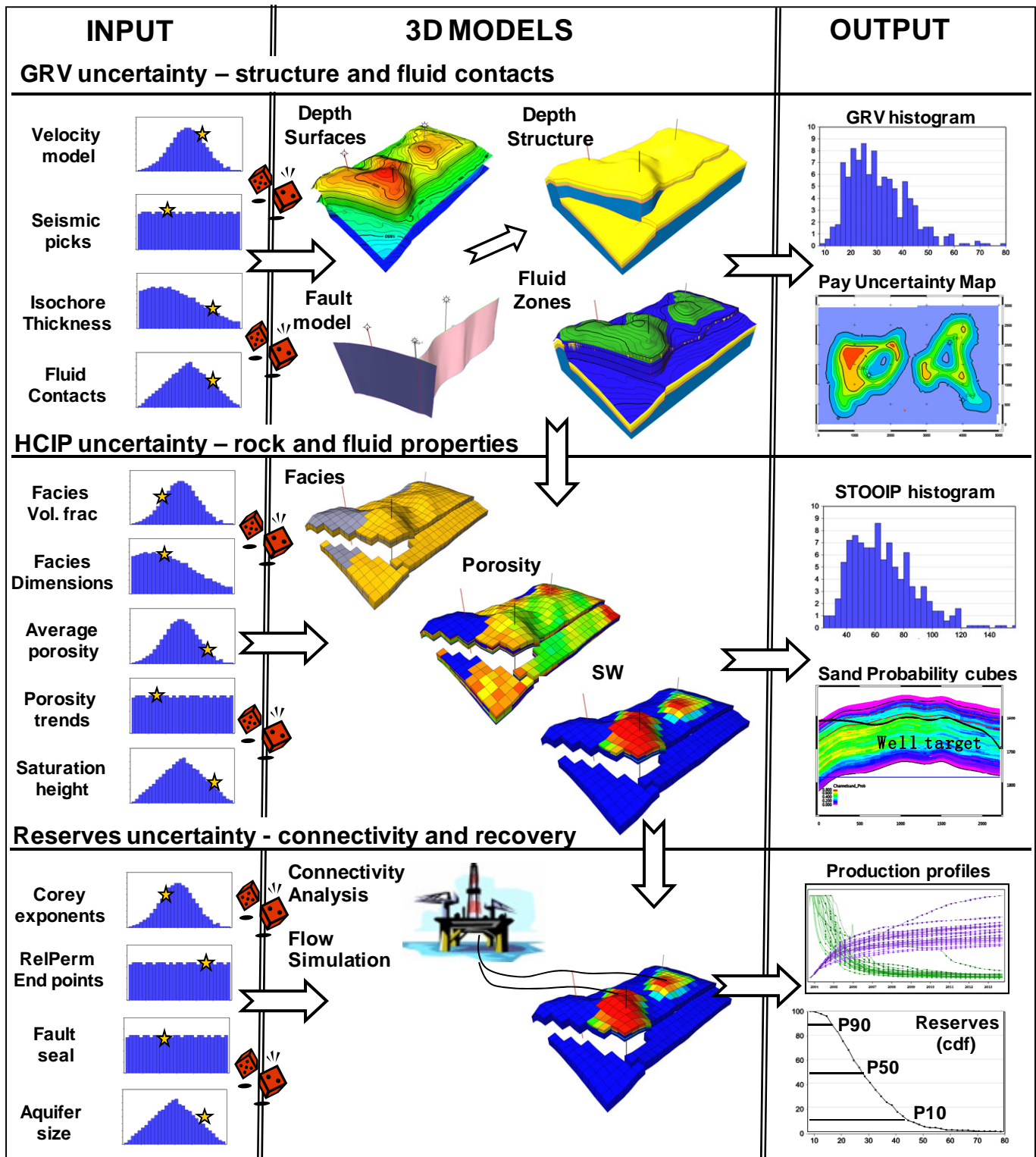


Figure 1: Schematic of a 3D uncertainty workflow, showing most common inputs, stages in the 3D modelling process and corresponding outputs

Introduction

Understanding and management of subsurface uncertainties has become increasingly important for oil and gas companies to optimize reserve portfolios, make better field development decisions and improve day-to-day technical operations such as well planning.

Stochastic approaches are widely applied for screening and value assessment of hydrocarbon assets. Uncertainties are quantified by Monte Carlo sampling of probability distributions for the controlling parameters. Although these approaches are very fast, it is often difficult to estimate the intrinsic dependencies between the input parameters and they provide no quantification or visualization of the spatial location and variability of the uncertainty.

3D uncertainty modeling allows the dependencies between the various input parameters to be treated in a realistic manner and provides information on the spatial variability of the uncertainty.

An uncertainty quantification and management workflow is provided. The proposed workflow contains three main parts. The GRV uncertainty is controlled by the structure and the contacts; the HCIP uncertainty is controlled by the internal rock properties (facies and porosity) and fluid properties (B_w , B_o , B_g); and reserves uncertainty is defined by connectivity and the dynamic behavior of the reservoir.

GRV Uncertainty

Gross rock volume (GRV) is to a large extent controlled by the structure of the horizons and faults, and the fluid contacts. GRV uncertainty is often the most significant uncertainty, especially in the early phases of field appraisal and development, and the correct handling of the structure and contacts is often the key to a realistic uncertainty assessment and assess management.

Structural Depth Uncertainty

The main sources of structural depth uncertainty include (1) velocity model; (2) time interpretation pick; (3) isochore thickness; and (4) fault interpretation.

Uncertainty in velocity model can be defined by assigning probability distributions to the parameters of the model (V_0 , k , etc). The input parameters can be constants, functions or maps. Velocity uncertainty maps are particularly useful for incorporating realistic lateral variations such as increased uncertainty away from well data and down dip. These maps can be based on well miss ties, analysis of stacking velocities and general experience from nearby fields.

Time interpretation uncertainty is usually defined by small time shifts of interpreted horizons. The time shift can either be a constant or can vary laterally to reflect varying quality of the seismic response or increasing uncertainty over major faults.

Isochore uncertainty is handled in a similar manner to the time interpretation uncertainty. Constant thickness multipliers or thickness uncertainty maps are applied to “base case” isochore.

Horizon depth uncertainty also needs to be linked to the fault model and uncertainty in velocities and depth conversion should be handled in a consistent manner for both depth horizons and fault surfaces.

Fluid Contact Uncertainty

Uncertainty in fluid contact definition is often the key uncertainty in reserves estimation. When working with realistic uncertainty analysis, input probability distribution need to be defined for the contact.

HCIP Uncertainty

Rock and fluid property uncertainties control the HCPV, STOOIP and GIIP within the structural framework. Rock and fluid properties include: facies, porosity, permeability, Sw, net cut-off, Bo and Bg. The spatial distributions of these properties are modeled in the 3D grids generated from the structural models. Facies, porosity and Sw uncertainties are discussed in detail below.

Facies Uncertainty

Stochastic modeling algorithms are used often for facies modeling. These algorithms create multiple realizations of facies architecture by changing random seed numbers. However, it is not enough to vary random seeds alone to quantify realistic uncertainties. It is important to vary input parameters to quantify the uncertainty for lacking of precise knowledge.

Porosity Uncertainty

There are two important sources of porosity uncertainty. The first is related to logging tool measurement, processing and interpretation. The second is related to the sampling of wells. Additionally, the impact of internal porosity trends is independent of the relationship of the trends to the structure and contacts, so they need to be quantified separately.

Fluid Saturation Uncertainty

As with porosity related uncertainty, there are two main sources of saturation uncertainty.

Flow Simulation Uncertainty

The 3D geological grids can be used directly in flow simulations or can be upscaled and used in lower resolution simulations. This allows the complex dependencies between the geological model and hydrocarbon production to be evaluated using flow simulation technology.

Some aspects of the geological model, such as fault sealing capacity and aquifer size are unimportant for the static model, but have implications for production and the dynamic behavior of the reservoir. These parameters should be varied in a controlled manner in a full uncertainty evaluation.

In addition to the geometrical definition from the geological models, there are a number of parameters used in flow simulations, which may have significant impact on production profiles and recovery factors. Two of the most important parameters are the Corey exponents and the relative permeability end points.

Conclusions

The uncertainty quantification workflow described in this whitepaper fits in between the exploration-based workflow and the history matching “Big Loop” workflow for mature fields. It is highly appropriate for the evaluation of significant contingent resources and for the reliable quantification of commercial reserves. The workflow is particularly suitable for providing input to development plans and concept design choices. Large investment decisions are being made based on few exploration and delineation wells. It is critical that these decisions are informed based on a realistic quantification and understanding of subsurface uncertainty, and robust development concepts are chosen which include flexibility to accommodate for this uncertainty.