Using Measurement Uncertainty to Calculate Reservoir Volumes and Reduce Risk in Prospects*

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Abstract

In this abstract, we explore how to better quantify the effect of uncertainties in reservoir structure and overcome limitations of conventional interpretation workflows. These include generating just one model despite data supporting different interpretations; ambiguities in the seismic data; and difficulties in quantifying uncertainties in static reservoir properties, such as spatial description and volumes.

As part of the new method, uncertainty information is collected and paired with an interpreted geologic feature, such as a horizon, fault or contact, thereby more accurately representing the data's limitations and the interpreter's vision for the geologic structure. Through measurement of these uncertainties, seismic interpreters can generate a suite of horizon and fault configurations to calculate probability distributions for static reservoir properties as well as provide more complete constraints on seismic amplitude modelling and inversion.

In the initial interpretation stage of the workflow, uncertainties are represented by an uncertainty envelope that changes size based on the interpreter's estimate of uncertainties and where the best-estimate interpretation of a geologic feature and an associated uncertainty are generated. Follow-up stages include applying structural modelling algorithms to construct a geologically consistent model and applying fault uncertainty where a method (Røe et al., 2010) is applied to simulate the position and geometry of faults in the model. The final stage computes static bulk volumes of the reservoir and uses these volumes to compute a posterior probability distribution to reduce risk in the prospect.

The new workflow was applied on seismic data from the Norwegian Continental Shelf where uncertainty envelopes were developed and structural modelling algorithms applied. A grid model was then built for each realization from which the interpreter used the uncertainty in the faults to perturb the model and generate volumetric statistics for each realization. One hundred realizations of the structural model were generated and the distribution of the computed bulk volumes plotted and used to directly indicate the P10, P50, or P90 volumes.

This extended abstract concludes that this new workflow can successfully quantify the effect of uncertainties in reservoir interpretation and generate volumetric statistics for each realization, thereby providing crucial input into the calculating of reservoir volumes and reducing the risk of prospects.

Introduction – Conventional Interpretation and Modelling Challenges

The geosciences community today is facing significant challenges that conventional interpretation and modelling solutions are failing to address. Such challenges include the rise in increasingly remote and geologically complex reservoirs and yet the inability of today's interpretation solutions to create a spatially accurate analysis of the field that can provide input to quantified risk analysis and improved decision-making. The result is that decisions are often made with limited models and scenarios and with the interpreter having a weak understanding of potential errors or uncertainty in the interpretation.

Specific limitations to conventional interpretation methods include the fact that conventional geophysical interpretation is geared towards producing just a single model or scenario for the configuration of subsurface geobodies, despite the data being able to support many different interpretations.

There is also ambiguity in seismic data today where many configurations or scenarios (fault configurations, for example) are supported by the data and are unable to be distinguished based on the data alone. This ambiguity also increases rapidly as the interpreter moves away from control points, such as well logs. Such ambiguities include the anisotropic behaviour of seismic velocity and the limited information seismic data has about vertical variations. A low signal-to-noise ratio (SNR) in the seismic data can also hinder interpretation.

The final limitation is that uncertainties in static reservoir properties (for example, spatial description and volumes) are often difficult to quantify, particularly in frontier areas where there is little well control. This might include limited seismic resolution, poor constraints on velocities for depth conversion, and poor seismic quality.

It's against this backdrop that this extended abstract will present a new technology workflow that allows interpreters to simultaneously capture measurement uncertainty during interpretation. In this way, instead of generating a single model, interpreters can access a range of models and calculate probabilities for different outcomes.

The modelling workflow, which will be demonstrated through a North Sea case study, consists of: i) Interpretation with Uncertainty; ii) Building a Structural Model; iii) Applying Fault Uncertainty, and iv) Calculating Volumes to De-Risk Prospects.

The Method

The Interpretation Stage

Rather than focusing on a single horizon or fault, in this workflow uncertainties are represented by an uncertainty envelope that changes size based on the interpreter's estimate of uncertainties. The result of this process is that a new constraint, which we will call "measurement uncertainty", is collected during the interpretation process. Measurement uncertainty should be differentiated from "scenario uncertainty" (or "configurational uncertainty").

The new interpretation method measures both a best-estimate interpretation of a geologic feature and an associated uncertainty. Through a simulator, the resulting information can then be used to create multiple realizations of a given geologic feature (Figure 1) and can effectively manage geologic risk. These realizations are generated to satisfy control points, uncertainties, and imposed constraints, such as smoothness and stratigraphy, and also result in a minimum number of required control points to build a surface representative of the data.

The new method can show what parts of the model are most uncertain, and can quickly indicate where more detailed analyses are needed and where new data needs to be acquired. Furthermore, multiple realizations of geobodies can be generated numerically after the interpretation, reflecting a set of models that may satisfy all the geophysical data.

Building a Structural Model

Next we apply structural modelling algorithms to construct a geologically consistent model of the static reservoir. Structural modelling using the interpretations provides a base-case structural model and grid. Structural modelling algorithms can typically incorporate different data types – horizons, faults, isochores, zone logs, and well picks. These are combined to create a structural framework for the reservoir interval that is consistent with the data. In the case of the workflow presented here, only faults and horizons are used.

As part of this new workflow, we then perturb the base-case by displacing faults within the uncertainty envelopes and generate 100 realizations of the perturbed model. We use the method of Røe et al., 2010 (see also Georgsen et al., 2012) to simulate the position and geometry of faults in our model. New realizations of the base-case structural model are created based on the simulation. These structural model realizations satisfy both the interpreted uncertainty envelopes and constraints inherent in the geologic structural modelling algorithms.

Calculating Volumes and De-Risking the Prospect

Finally, we compute static bulk volumes of the reservoir. These volumes are determined by first generating a 3D grid from each realization of the structural framework created via simulation. Volumes are then computed by summing grid elements within particular zones of interest.

Using these volumes, we compute a posterior probability distribution to de-risk the prospect. A histogram showing relative model frequency gives a visual representation of the pdf for quality control to help identify which parameters control the variation of the simulations. A cumulative probability distribution can also be computed and from this the modeller can derive P10, P90 volumes for direct decision-making support.

Application – The Norwegian Continental Shelf

As a proof of concept, we have applied the proposed workflow to seismic data from the Norwegian Continental Shelf based on publically available information from the Norwegian Petroleum Directorate. The dataset is heavily faulted, showing typical graben fault systems of the Triassic and Jurassic. While generally of good quality, reflector quality degrades in the vicinity of steeply dipping faults. This data degradation reflects a quantifiable geologic risk that can be estimated during the interpretation phase. For simplicity in visualization, we have interpreted a clear graben structure for use in this application. We do not mean to imply that this represents an existing reservoir so we have interpreted the data (see Figure 2 – an illustration of seismic data with interpretation curves and uncertainty envelopes).

Next we apply structural modelling algorithms to construct a geologically consistent model of the static reservoir (Figure 3). The first step of this is a fault model of the four interpreted faults which consists of a simple nested Y fault formation. The interpretation points are used as hard data, but some smoothing is applied to the fault surfaces, and truncations are set. A horizon model with four horizons is then built incorporating the faults. The horizon interpretations are used as soft input data for the base case model, but when the uncertainties interpreted on the faults are included in the workflow, this outputs horizon uncertainty points for each realization which are then replaced as input in the horizon modelling.

Finally a grid model is built for each realization. The regularized grid has three zones bounded by the horizons and the faults are incorporated as stair-stepped. The middle zone is then used in the volumetric calculation, with bulk oil in two regions of this middle zone, bounded by faults 19 and 25 with a constant Oil/Water Contact (OWC) of 2500 m and between faults 26 and 29 with a constant OWC of 2600 m.

We then use the uncertainty in the faults to perturb the model, and generate volumetric statistics for each realization. Fault uncertainty envelopes (Figure 3b) are the +- 1 boundary of uncertainty. One hundred realizations of the structural model are generated.

The distribution of computed bulk volumes is then plotted in Figure 4. This figure can be used to directly indicate the P10 or P90 volumes. Furthermore, sensitivity tests can be performed by varying each fault structure independently for some number of realizations.

Conclusions

This extended abstract has demonstrated how a new workflow that quantifies the effect of uncertainties in reservoir interpretation is able to overcome the limitations of conventional interpretation techniques. It also demonstrates how, through a North Sea case study, volumetric statistics for each realization can be generated – statistics that provide crucial input into the calculating of reservoir volumes and the de-risking of prospects.

We believe that the new workflow will have a major influence on interpretation leading to an improved quantifying of uncertainty and risk in the reservoir.

Acknowledgements

The data used in this study is publically available from the Norwegian Petroleum Directorate.

References Cited

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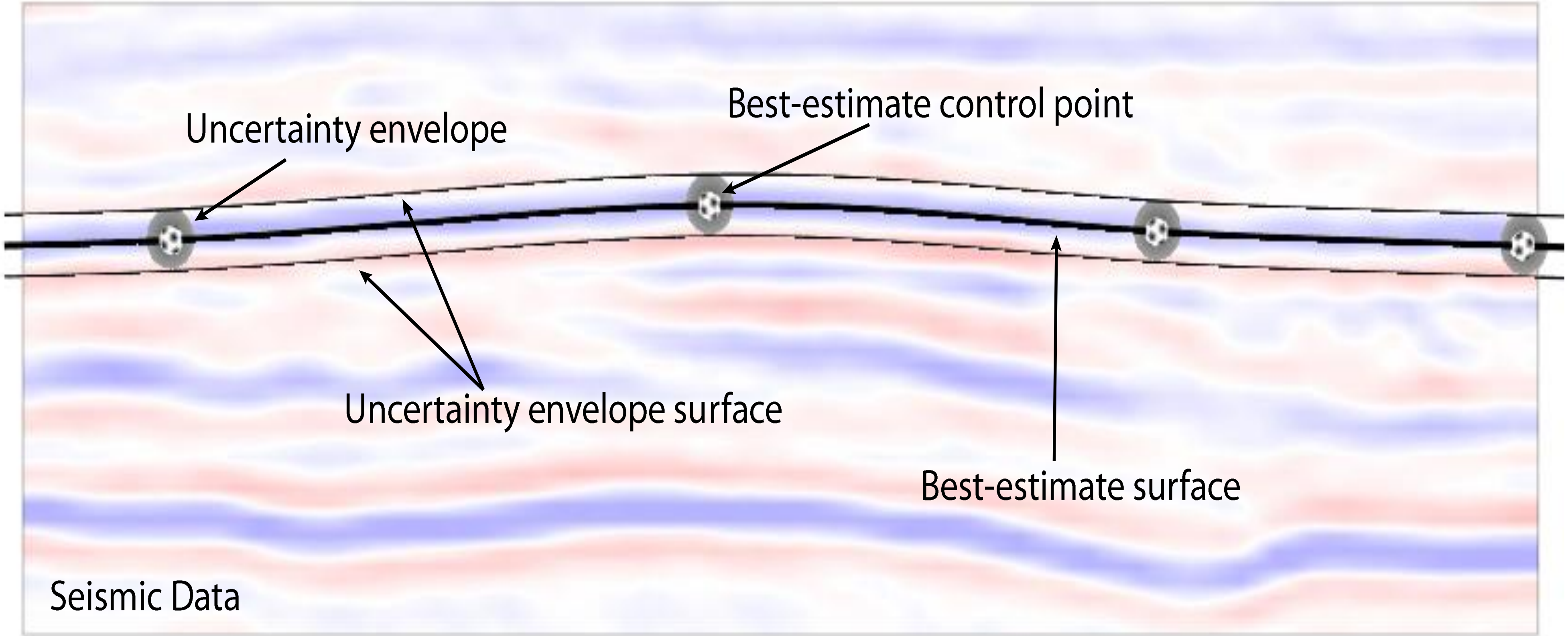

Figure 1. Seismic interpretation with uncertainty surfaces. Control points describe the best estimate surface.

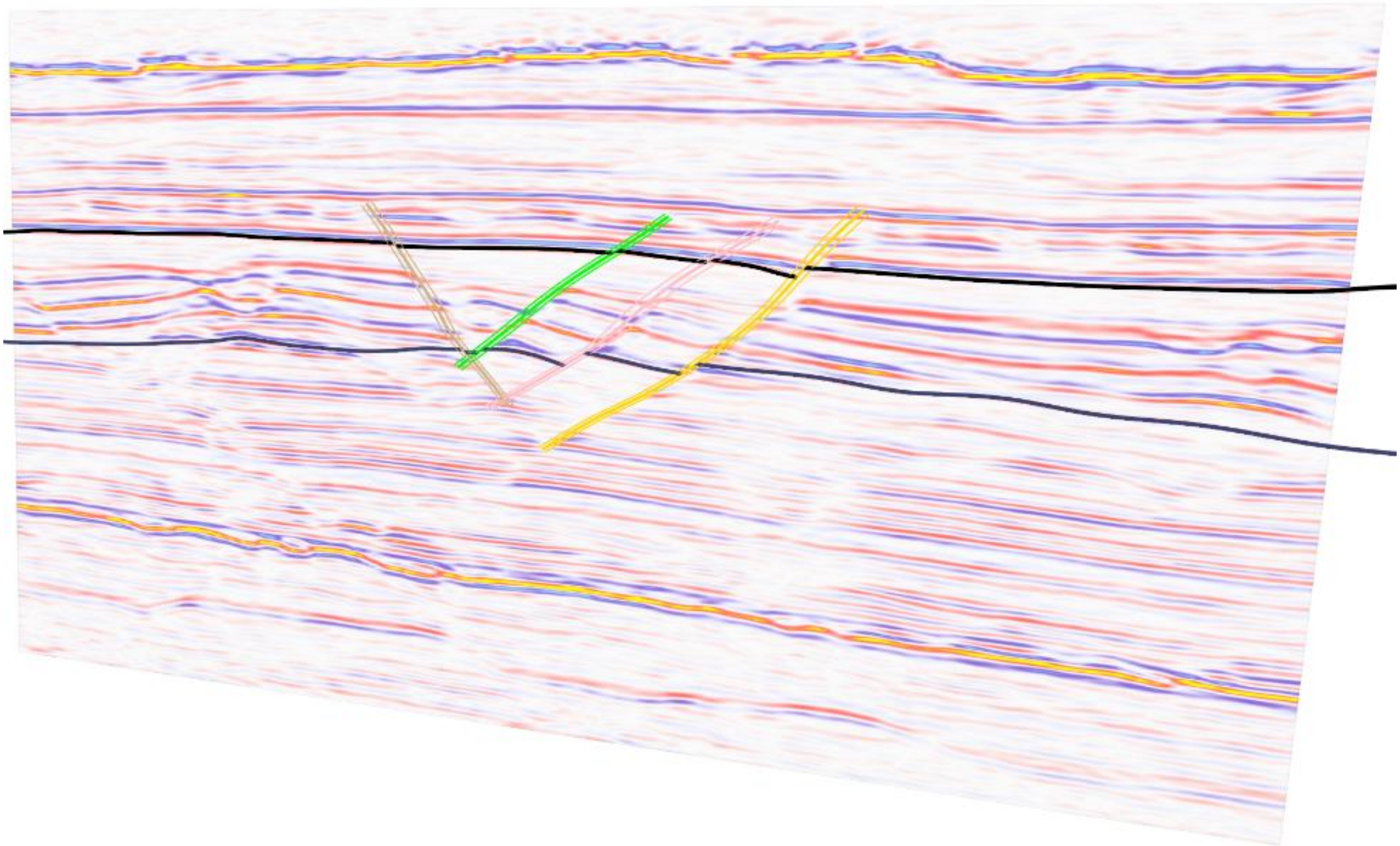

Figure 2. Seismic data with interpreted faults and horizons, and associated uncertainty envelopes.

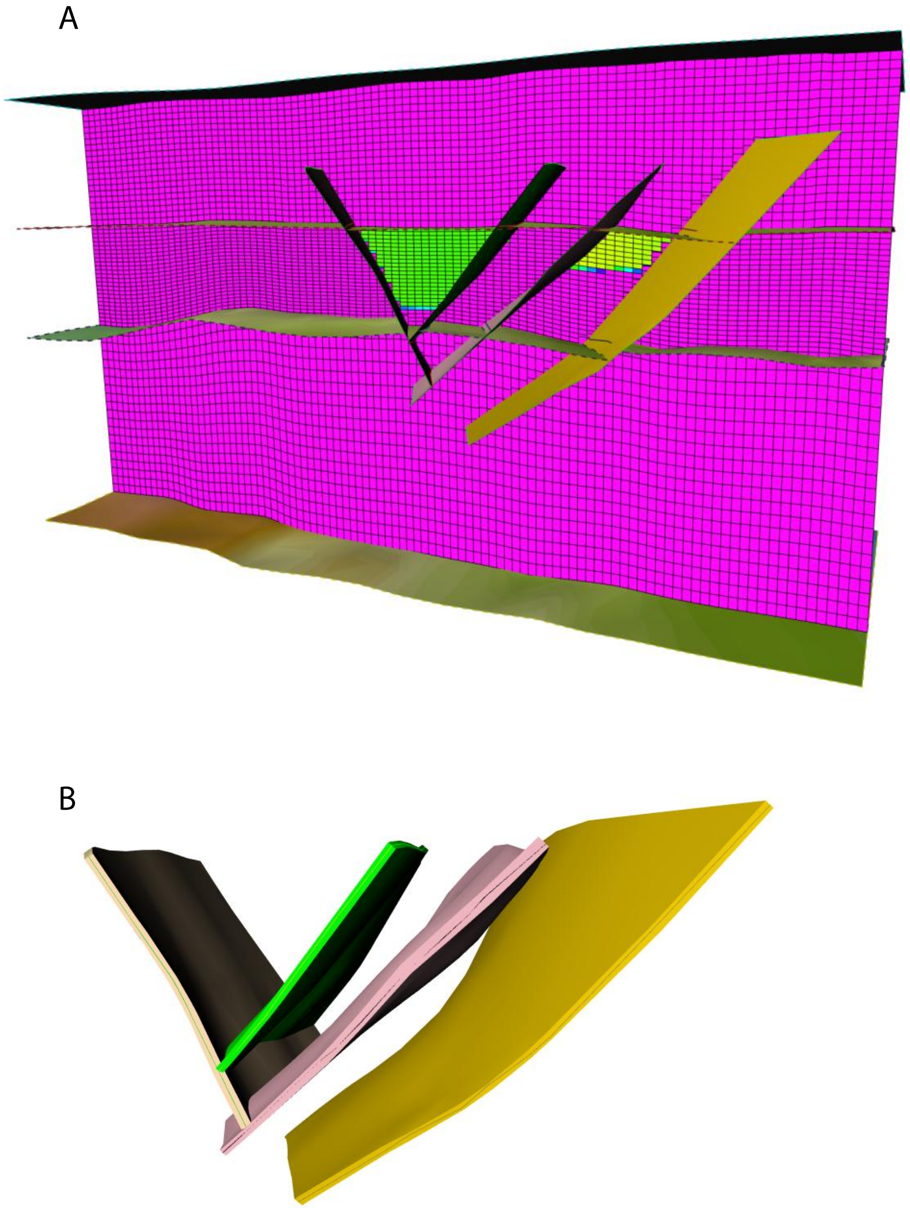

Figure 3. A) The base-case structural model and grid. B) Fault uncertainty envelopes visualized as volumes.

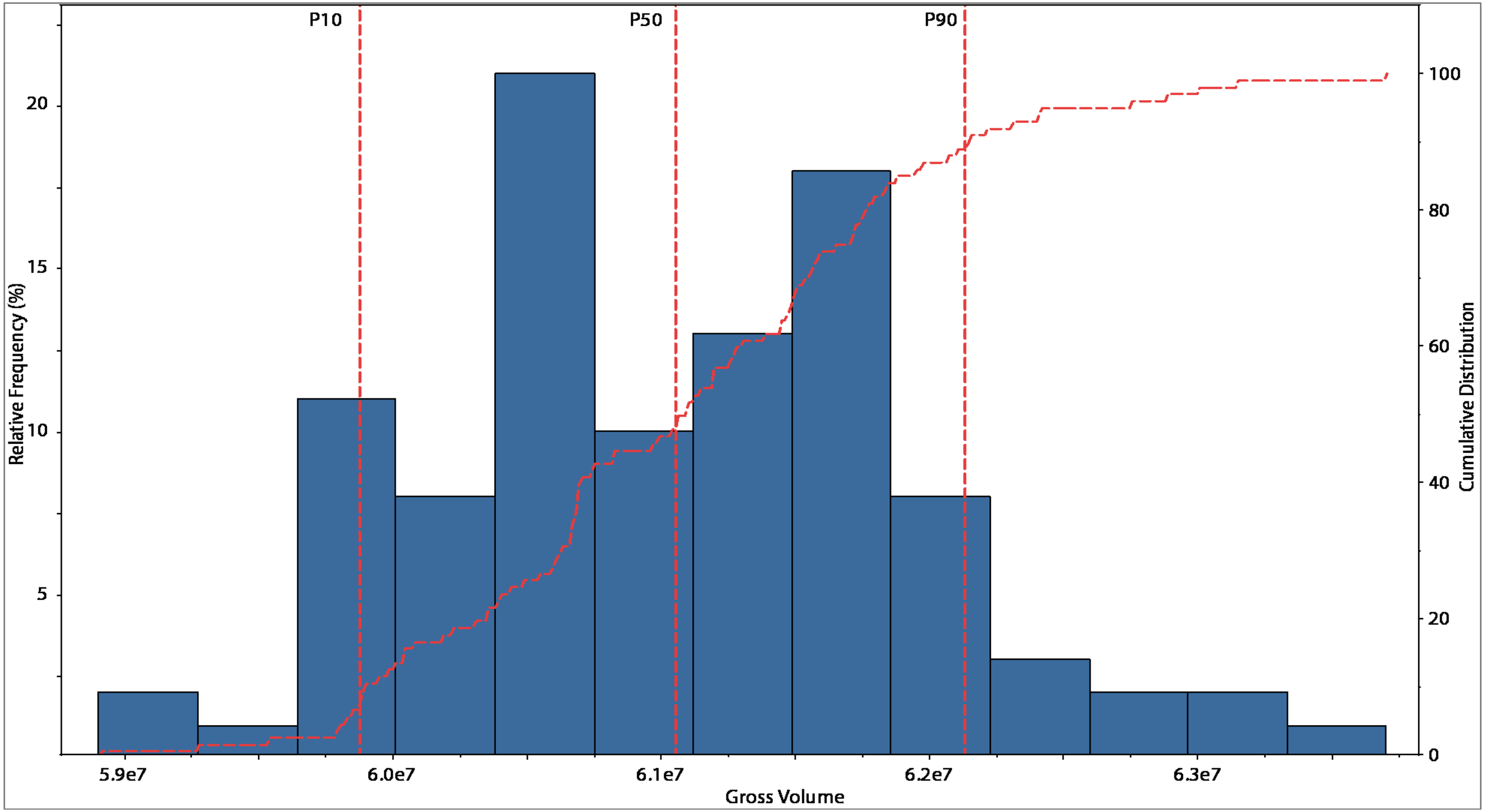

Figure 4. Relative frequency (histograms) of reservoir volumes across 100 realizations, with cumulative probability curve (red).