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Stochastic time-depth conversion of seismic horizons by geostatistical tools to produce probabilistic models of gross rock

Moving beyond single best guesses in frontier petroleum exploration

Why This Matters

Exploration of frontier petroleum systems requires robust estimation of subsurface geometry and associated uncertainties. Traditional deterministic workflows, interpretation, velocity modelling, time-depth conversion, and volumetrics, provide a single best-estimate outcome, but do not fully characterise uncertainty propagation from seismic interpretation and sparse well control into prospect risk.

We present an integrated **stochastic workflow** using geostatistical methods (Bayesian kriging with external drift and multiple-realization simulation) to produce **probabilistic depth horizons** and **probabilistic gross rock volume (GRV)** estimates. This quantifies the range of plausible outcomes and highlights where new data could most effectively reduce uncertainty.

Key goals of the method are:

- From exact well ties to probabilistic volumetrics
- Condition depth interpretations exactly to well markers while honouring seismic time horizons as continuous auxiliary data.
- Propagate uncertainty from velocity model parameters and spatial variability (variogram) into multiple stochastic depth realizations.
- Compute probabilistic spill-point and GRV distributions for each realization, producing a probabilistic volumetric summary.

Step 1: Building Faulted Time Surfaces

Accurate horizons from sparse seismic data

The workflow begins with constructing faulted time surfaces. Data is imported directly from seismic interpretation applications, and faulted time grids are built using algorithms capable of handling complex faults and sparse 2D coverage.

Once QC'ed and approved, the faulted time grid is passed via a simple exchange mechanism to the next stage.

Step 2: Stochastic Velocity Modelling

Bridging depth & time with uncertainty built in

The second stage involves constructing velocity models that link seismic time horizons to measured depths at wells.

Figure 1: Workflow of creating and refining time surfaces in Petrosys PRO prior to undertaking depth conversion and calculating volumes in Isatis.neo.

In this workflow, horizon markers from wells provide the primary depth data, while seismic time horizons supply continuous coverage between wells as auxiliary data.

A separate velocity model is generated for each horizon, typically using linear regression between time and depth. The scatter of depth markers around each regression line reveals inherent velocity uncertainty. This variability is quantified for every regression coefficient, forming a statistical representation of the model's reliability.

Unlike deterministic approaches that treat the velocity model as exact, our method treats it as a probabilistic input, allowing uncertainties to flow into subsequent depth conversion and volume calculations.

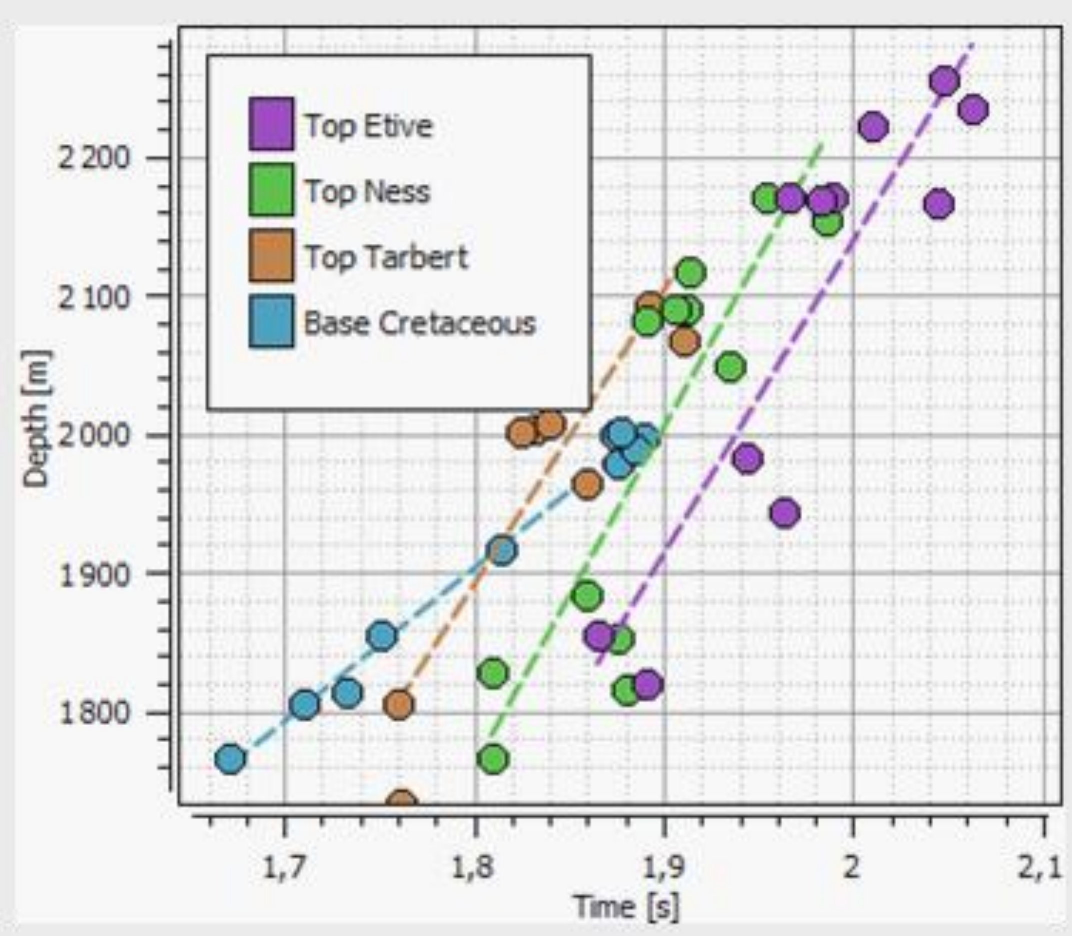

Figure 2. Velocity modelling for each horizon, used in layer cake approach.

Step 3: Bayesian Kriging with External Drift

Well ties & probabilistic depth between wells

The initial time–depth conversion uses the velocity model, but mismatches inevitably occur at well positions, these are the **residuals**. In our geostatistical approach, these residuals are interpolated using **Bayesian kriging with external drift**, which integrates:

- Spatial correlation (variogram model)
- Uncertainty in velocity model coefficients
- Conditioning to known well depths

This process forces the depth model to perfectly honour well markers while still respecting the broader seismic time surface.

Between wells, multiple depth scenarios are generated, each one consistent with the measured data and the quantified uncertainties.

Unconformities and stratigraphic complexities, such as erosional truncations or onlap geometries, can be incorporated in postprocessing, ensuring that depth models remain geologically realistic.

Step 4: Multiple Realizations & Probabilistic GRV

Exploring the full range of possible outcomes

Once stochastic depth surfaces are generated, the workflow advances to **probabilistic volumetric analysis**. Each realization provides:

- A unique depth configuration
- A calculated **spill-point** for the reservoir closure
- A **gross rock volume (GRV)** estimate

By running many realizations, we obtain a **distribution of GRV values** rather than a single figure. This distribution reflects the combined uncertainty from seismic interpretation, velocity modelling, and spatial variability.

This probabilistic approach provides direct input to risk assessment, allowing decision-makers to see the **likelihood of achieving a target volume** and to identify which uncertainties have the greatest impact on the volumetric range.

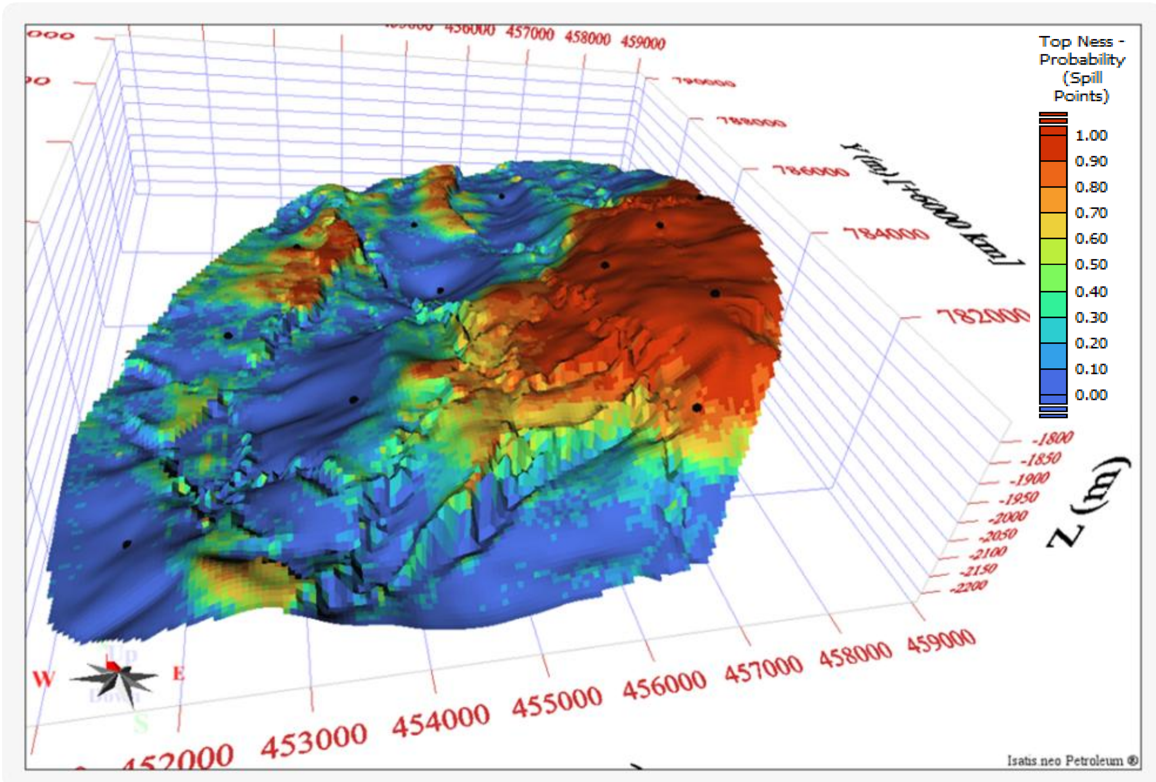

Figure 3. Converted top formation passing the depth markers (dark cercles). The colour corresponds to the probability of belonging to the gross rock, i.e. above the spill point. The vertical axis is exaggerated five times.

Conclusions

From deterministic numbers to risk-aware decisions

The presented workflow demonstrates how **Bayesian kriging with external drift**, combined with stochastic velocity modelling, transforms conventional time–depth conversion into a **quantitative uncertainty analysis**. By:

- Conditioning models perfectly to well depths
- Incorporating seismic time horizons as continuous auxiliary information
- Propagating uncertainty into volumetric estimates

We move from a single "best guess" to a **probabilistic understanding** of subsurface geometry and gross rock volume. This enables:

- **Better risk quantification:** clear visibility of volumetric uncertainty ranges
- **Smarter data acquisition:** targeting wells or surveys where uncertainty reduction is most impactful
- **Improved decision-making**: balancing resource potential against geological risk

Integrating this process within existing interpretation and volumetric software ensures minimal disruption to current workflows while delivering **a more complete picture of exploration potential**.