Introduction

It is quite common during the exploration phase or at the early stage of a field development to work with few or even no well data, with uncertain Time or Velocity maps, with some doubts about fault location and with uncertain information where seismic sections and/or seismic cubes are crossing. It is obvious that such a lack of data and the uncertainty associated with the available data has a negative impact on the robustness of Time-to-Depth calculations, and consequently on the structural maps used for estimating field economic potential. A consequence is that the range of variation on reservoir volumes is generally underestimated and the GRV and hydrocarbon volumes in most of the developed reservoirs are closer to the P90 than to the P50 determined at the exploration phase.

Geostatistical methods developed in the framework of the UncerTZ R&D consortium can help dealing with uncertain data and with few data when calculating depth maps:

- First, the uncertainty of each source of data is accounted for in the geostatistical algorithms;
- In addition, specific methodologies have been defined to overcome the limitations induced by a lack of data;

This paper details the combination of geostatistical techniques that are used for calculating accurate depth maps in such a difficult context and quantifying rigorously the uncertainty associated with the calculated depth map in order to better estimate the actual range of variation on Volumetrics.

The geostatistical approach for Time-Depth conversion

Time to depth conversion is not a straightforward topic. It is generally described as the conversion of the seismic reflection data from the recorded two-way time into the actual depth. It can be done via a wide range of existing methods which can be separated into two broad categories: 1) direct time-depth conversion, and 2) velocity modelling for time-depth conversion. In both cases, calculations have to account for two types of data: hard data (known at wells) and trend maps (or cubes) coming from seismic data. It is basically a mapping with trend issue, for which Geostatistics can propose several effective algorithms.

Kriging with external drift technique is probably the most versatile technique that can be used for this purpose. In quite homogeneous environments, some are replacing it by cokriging (or its version when a variable is known exhaustively, i.e. collocated cokriging). In addition, Kriging with Bayesian hypotheses on the drift coefficients helps when dealing with few data.

When working directly in Depth, the approach consists in estimating the depth (D) using time as external drift (T). It therefore relies on the following regression where R stands as a residual:

\[ D(x,y) = a \times T(x,y) + b + R(x,y) \]

Here “a” plays the role of a velocity and “b” stands as a shift in the relationship between depth and time (such as the position of the reference datum plane)

When working with Velocity, an intermediate Velocity map is calculated, using Velocity at wells as hard data and Velocity models as trend maps. Velocity models can be constant, function of Time, function of a V0 map and Time, function of Depth, etc... As such models are defined for each geological layer, Velocities considered here are interval Velocities.

In both cases, converting horizons can be made in a sequential way, converting successive horizons one by one. It implies an increasing uncertainty on the Depth map from the first converted horizon to the last one. In layer-cake context, when the thickness of the successive geological layers defined by the successive horizons is more or less constant, it may be valuable to consider converting the horizons together, in a single operation. This implies to use a multivariate Kriging algorithm, as
described in (Renard & Deraisme, 2000) and (Chautru et al., 2018). In that case, the uncertainty on Depth does not grow with the ranking of the considered horizon.

**Dealing with a lack of Data**

Kriging with External Drift requires the inference of a spatial covariance model, derived from the geostatistical analysis of available well data. Therefore, the method robustness is very sensitive to the amount of wells. When there are few wells, or even no well, as in the Exploration or Delineation phases of a field development, the inference of the spatial covariance is difficult, or even impossible.

Different approaches have been developed to overcome such limitations:

- **First case**: only few wells are available. In such a case, the same strategy as in cokriging with the Markov-Bayes assumption is considered. It is assumed that the variogram (or spatial covariance) of Time (or velocity) variable calculated from the wells can be substituted by the variogram of the Time (or velocity) variable calculated from Time (or velocity) maps.

- **Second case**: there are very few wells or even no well available. The issue is more difficult than in the first case, as the depth map conditioning by kriging is made impossible. In such an unfavorable configuration, the most efficient approach to overcome limitations is to create pseudo-wells containing pseudo-markers defined from available Time and Velocity maps. Pseudo-markers can be generated randomly on Time or Velocity maps (or interactively picked from a 3D view) as illustrated in Figure 1. Then, pseudo-markers can be defined in depth by combining Time and Velocity values taken from Time maps and Velocity maps at pseudo-wells locations. In this case, both Time map and Velocity map are required as input data, which is quite common.

![Figure 1](image)

*Figure 1 Pseudo-markers, displayed as white points, are generated randomly on a map. They will be used as uncertain data for constraining Time-Depth conversion.*

With these two options, the geostatistical Time-to-Depth conversion can be used at a very early stage when exploring an undeveloped area.

It must be noted that, in the second case (no well data available), the pseudo-markers defined at pseudo-wells location come from maps calculated from seismic data. Seismic data being at a different scale as well data, pseudo-markers must be considered as uncertain data in further calculations. The uncertainty on such markers must be accounted for in Time-Depth conversion to estimate properly the true range of uncertainty on estimated Depth values.

**Dealing with uncertain Data**

There are different ways to account for uncertain data in geostatistical calculations:

- Kriging with measurement error option;
- Stochastic conditional simulations.
Kriging with measurement error option consists in considering that input data are affected by a random uncertainty, which is accounted for through a variance added to the diagonal of the Variance-Covariance matrix in the Kriging system. Theoretical developments can be found in (Chiles & Delfiner, 2012). In practice, this Kriging variant allows combining samples of different accuracy in the same calculation. It is a very efficient method for fixing mistakes, as shown in (Correia et al., 2019) and illustrated in Figure 2.

Figure 2 Misties at seismic sections crossing visible (on the left side) and fixed using a variant of Kriging with Measurement Error (on the right side).

Stochastic Conditional simulations are a very general method for taking into account the uncertainty of various input data sources.

Conditional Simulations are a set of n realizations of a given variable, calculated on 2D or 3D grid. Each realization is a possible representation of the reality (a Depth-converted Horizon, for example) which honours the true variability of experimental data, the variogram calculated on experimental data and the value of the variable measured at data points. To account for uncertain input data, a specific set of input data is defined for each realization. Then, the different realizations are conditioned by different data sets, according to the range of uncertainty of input data. When making statistics on the full set of realizations, the uncertainty on input data is automatically accounted for.

This approach is appropriate and efficient for taking into account:

- Uncertainty on Depth markers, for example when these markers are pseudo-markers defined to deal with the absence of well data.
- Uncertainty on External Drift in Kriging with External Drift. Time maps or Velocity maps used as trends can be affected by uncertainty, related to picking errors for example.
- Uncertainty on Faults location.

**Quantifying the global uncertainty**

The global uncertainty on a Depth-converted horizon summarizing all the uncertainties on each input data source can be assessed by calculating statistics on a set of stochastic Conditional Simulations that account for the uncertainty on Time map or Velocity map, Fault location, and/or marker’s depth. Other uncertain parameters like reservoir thickness, average N/G, average Porosity or Saturation can also be accounted for in Volumetrics calculations.

All the uncertainties on the different input data being taken into account, calculating statistics on such Conditional Simulations allows covering the true range of uncertainty on the final reservoir Gross Volume estimation. The cumulative histogram of the studied reservoir volume will have a realistic range of variation (Figure 3 lower part). In addition, from such a randomized Depth-converted horizon, it is possible to automatically identify potential traps and calculate the probability to belong to a given trap (Figure 3 upper part). Such a probability map complements the uncertainty on volumes, as it indicates the potential geographic extension of traps and the probability value itself is an indicator of the confidence on the trap presence.
**Figure 3** Cumulative histogram of GRV, accounting for the uncertainty on each input data. The range of variation is wide but realistic. It is accompanied with a Probability map to belong to a trap (red values correspond to a high Probability)

**Discussion and conclusion**

The combined use of advanced geostatistical techniques offers a solution for generating realistic depth maps at exploration or delineation phases:

- Before Time-Depth conversion, seismic misties can be fixed with a variant of kriging with measurement error method, leading to Time maps or Velocity maps with an associated uncertainty;
- Stochastic conditional simulations allow integrating this uncertainty on Time maps or Velocity maps and on fault location. Uncertain markers at wells or estimated markers (when wells are missing) can be managed by Conditional Simulations as well;
- In the end, Conditional Simulations allow quantifying the global uncertainty resulting from all the uncertainties on each data source. If all the specific uncertainties associated with the different data sources are taken into account in Time-Depth conversion, then the range of variation on the results (reservoir GRV, Depth and location of Spill points) will be realistic.

With this set of methods, it is then possible to get usable results from which the uncertainty on trap extension, trap volumes and on depth of spill points can be estimated. If all the intermediate uncertainties are included in the calculations, it is obvious that the provided ranges of variation on results may be quite wide, but more realistic than a narrow range resulting from an underestimation of the intermediate uncertainties. This allows decision makers to take the most appropriate decisions concerning the field development.

**References**


