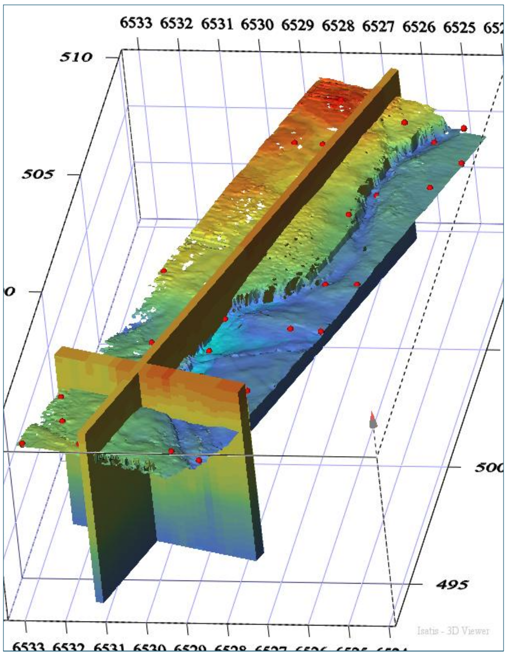
Geovariances
Where no one has gone before

White Paper



Time-to-Depth Conversion

Geostatistical methods to build a reliable and consistent structural reservoir model

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Combine your velocity model with your well information to get a precise picture of the geological surfaces while assessing uncertainties attached to the conversion

Time-to-depth conversion of geological surfaces is critical for structural model building. Quantifying the uncertainty attached to the conversion is also of primordial importance for assessing GRV uncertainties. Traditional velocity models used in time-to-depth conversion benefit from geostatistical techniques used in data integration. The advantage of using geostatistical methods is that they fit the data in one step and allow quantifying the uncertainty attached to the prediction by means of the generation of equiprobable realizations.

Geovariances provides solutions from seismic data quality control and filtering to reservoir characterization and time-to-depth conversion. This technology is based on geostatistics, the algorithms of which are all available in Isatis, the reference in geostatistical software solutions.

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Time-to-depth conversion

Geostatistics provides consistent methods for integrating well and seismic data to obtain a depth map from seismic time interpretation.

Geological structures are picked from seismic profiles in the time domain. In order to create a reservoir model or compute volumetrics, these time interpretations need to be converted to depth and calibrated to well markers.

The conversion is done using a velocity model. Such a model can be generated using velocity fields (full 3D) or layer-based methods (single or multi–layer). Input data are of two types: soft data coming from seismic (i.e. a dense but imprecise measurement) such as horizons, stacking velocity, time marker at well, etc. and hard data (i.e. a precise but sparse measurement) coming from wells. Integrating hard and soft data together is a classic task in geostatistics.

Applying geostatistics to achieve depth conversion means that the resulting structural model is tied to the wells and also respects the spatial continuity of the variables. The same mathematical model can be used for stochastic simulations.

Geostatistical depth conversion is based on exact interpolators.

Besides, the geostatistics workflow allows exploration and understanding of the data to optimize their use. The exploratory data analysis step helps identifying outliers, clusters, trends and correlation between variables. It is an essential step in depth conversion to determine the best method to use, or the most appropriate velocity function parameters (i.e. slope of intercept of a linear regression, such as depth vs. time or velocity vs. depth).

Lastly, geostatistics can be used to identify and model trends, filter noisy signal in 1D, 2D or 3D, like, for example, in 3D stacking velocity cubes and/or in time horizons.

Note that the data integration workflow described hereafter is still valid if the seismic interpretation is already converted to depth, for well calibration purpose.

Benefits of the geostatistical approach

Independent data quality control

Time horizons or velocity impaired by noise, acquisition artifacts or footprints from seismic processing and/or seismic interpretation occurs frequently. Controlling data quality is essential in order to identify artifacts or anomalies. Geostatistics is particularly well suited to this task, allowing an independent review of the data quality that can be achieved at any step of the process. Geostatistics enables quantifying the magnitude of artifacts and subsequently the quality of the processing. Geostatistical tools allow a control of spatial coherence, therefore it helps characterize the spatial distribution of events related to seismic velocities.

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Exploratory data analysis and determination of velocity functions

Exploratory data analysis allows the identification of outliers, clusters or trends in the data, and the correlation between variables. Also, it gives quantitative/qualitative information on major spatial data structures and provides information about trends.

It is an important step in determining which predictive model(s) or velocity function(s) to use and ensure that their parameters are reliable (e.g. excluding outliers from regression lines computation)

Control of spatial continuity and coherence

The principal benefit of geostatistics is to allow a control of spatial coherence. Geostatistics enables the analysis of seismic data through a probabilistic approach, based on a spatial variability analysis. Geostatistics characterizes the spatial structure of the parameter in order to:

- Take into account the continuity of your data,
- Introduce the geology by capturing the geological structures.

Geostatistics provides consistent methods for modeling the reality and the uncertainty of its representation.

Integration of various data

Geostatistics provides algorithms to integrate data of different nature. The main approach used in time-to-depth conversion is kriging with external drift (KED). It is an exact interpolator, meaning that the well data are honored.

In KED, seismic data provide a shape that will strongly constrain the final result.

Note that this technique applies to any variables linked by a linear relationship, such as time and depth or Vavg at wells and seismic stacking velocity in 2D or 3D.

Depending on the analysis of the correlations, one of the following models can be used in kriging with external drift method:

$$\text{Depth} = (a \times \text{TWT} + b) + \text{Residual}$$

$$\text{Vint} = (a \times \text{TWT} + b) + \text{Residual}$$

$$\text{Vint} = (a \text{ x } \Delta\text{TWT} + b) + \text{Residual}$$

$$\text{Vapp} = (a \text{ x } \text{Vstack} + b) + \text{Residual}$$

Simultaneous approaches are available for multi-layers depth conversion hence avoiding the propagation of errors.

Depth maps are tied to the wells while respecting the shape of the seismic information.

The correlation between wells and seismic data may be improved by filtering artifacts in the seismic acquisition.

Taking into account non stationarity

Geostatistical tools can also deal with non-stationary phenomena such as vertical trends. The seismic information can be divided in two components: a shape function characterizing the trend and the stationary residuals on top of it. Seismic trends are generally non-stationary, therefore KED results, which account for such trends, will be also non-stationary.

Uncertainty quantification

Geostatistics allows the assessment of the uncertainty in your velocity or impedance volumes by applying stochastic simulations.

With geostatistical simulations, it is possible to generate equiprobable realizations of a property using the same model parameters (input data, variogram, etc.). This is extremely important as a time-to-depth conversion process is not unique. The uncertainty is in our knowledge of the velocity field that is not sufficient to generate a single answer between wells (i.e. seismic data is an imprecise measurement). This is one of the sources of GRV uncertainty that can easily be quantified with simulations using the classic geostatistical risk analysis workflow.

Simultaneous approach for multi-layer depth conversion

Multivariate techniques can be used for simultaneous multi-layer depth conversion, hence avoiding the propagation of error arising from the sequential approach, when errors in one layer propagate to the layer below.

Methodology and illustrations

The following geostatistical processing application of 3D stacking velocities is based on data from an oil field in North America. The data are coordinates of the intercepts of 32 wells with TVD markers, stacking velocity data (Vrms) covering an area of about 4km x 16km and the TWT interpretation for the target horizon. The reference datum for this land seismic survey is 750 m above sea level.

Quality control of seismic data and wells

This step is essential in order to qualify the data. Data control analysis allows the detection of potential artifacts, problems of support, acquisition, interpolation during different processing steps and correlation between data.

Statistical tools offer great visibility in data and help in determining if some horizons are not consistent with others.

Spatial data analysis allows the thorough investigation of seismic data and identification of anomalous and erroneous values in any seismic scattered or gridded datasets (seismic picks, velocities, acoustic impedance, etc.). It helps to understand data and optimize their use.

The following steps can be carried out for a proper data investigation (Figure 1):

- Display of a data basemap, in order to validate the data location.
- Histogram computation to check the homogeneity of the statistical distribution.
- Calculation of the statistical characteristics: the mean (or average tendency) and the variance that measures the dispersion of the values around the mean.
- Analysis of the correlation between several variables through the display of the scatter diagrams.

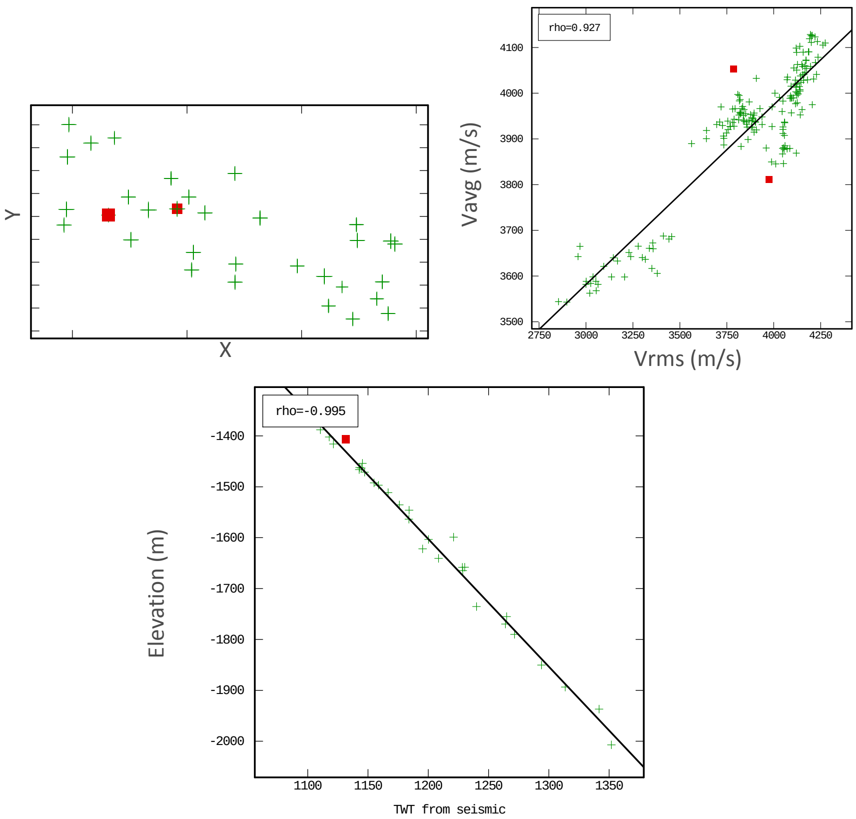

Figure 1: Basemap with some outliers in red and scatter diagrams between average velocity at wells and velocity from seismic data in all zones and Depth vs TWT at target (top reservoir).

The benefit of statistics is to reinforce the geological interpretation.

Data integration and depth conversion

- *Kriging with external drift methodology*

Kriging with external drift (KED) is the preferred industry solution to combine well and seismic derived data.

With KED, we assume that the secondary variable (e.g. seismic information) provides low frequency information about the primary variable, with the high frequencies contained in the residuals. The KED system contains a linear transformation to the seismic data and a variogram of residuals. This information are combined to provide, in one step only, an estimate that matches the well data and is consistent with the non-stationary trend coming from the seismic data.

In the external drift method, this low frequency trend (Figure 2) is included in the kriging system as a drift, not as an additional variable contributing in the estimation (as in collocated cokriging).

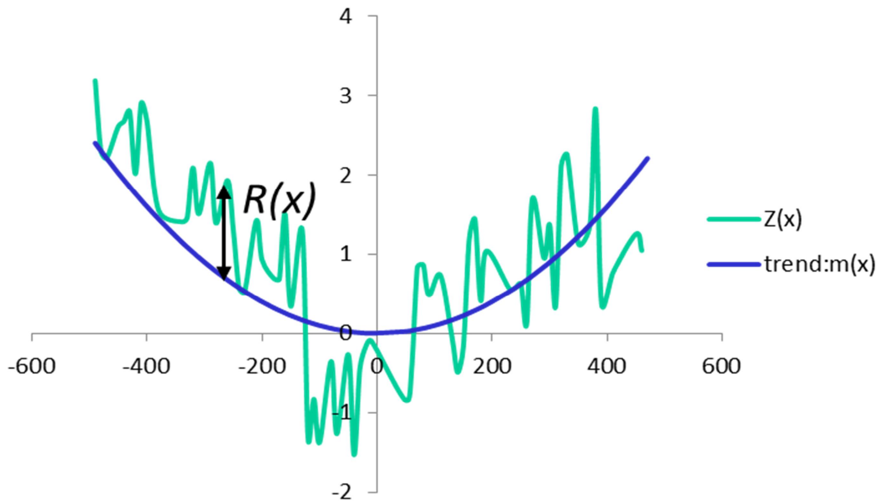

Figure 2: Schema where the signal Z(x) is decomposed into a low frequency component (the drift) and high frequency residuals (R(x))

The relationship between the main variable and the secondary variable is linear (linear regression). The trend of the variable can be modeled as follows:

$$E[Z(x)] = a_0 + a_1 S(x)$$

and then the variable Z(x) :

$$Z(x) = a_0 + a_1 S_1(x) + R(x)$$

Z(x) is the main non stationary variable that is estimated, a0 and a1 are constant coefficients, S(x) is the external drift and R(x) corresponds to the stationary residuals. R(x) will be close to zero away from the wells, but will provide the bump allowing the model to go through the wells. In the external drift method, the trend is first modeled by means of a linear regression with the seismic data, then a kriging of the stationary residuals is performed. Finally, the kriged residuals are added to the modeled trend. The external drift provides a form that is automatically calibrated to the well data by the kriging.

In a Kriging with External Drift, the model is non-stationary if the drift is itself non-stationary, but its covariance part is stationary (the variogram of the residuals). Therefore, the variable is estimated with a model combining both stationary and non-stationary parts. These techniques require the computation and the fitting of a variogram model.

- *Application cases:*

    - **Using time interpretation and depth at wells**

As there is a good linear correlation between TWT derived from seismic data and depth at wells (Figure 1), a kriging with external drift of depth at wells using the TWT from a seismic map as external drift is calculated (Figure 4). The TWT horizon (Figure 3) is used as external drift and the depth at well is the primary variable.

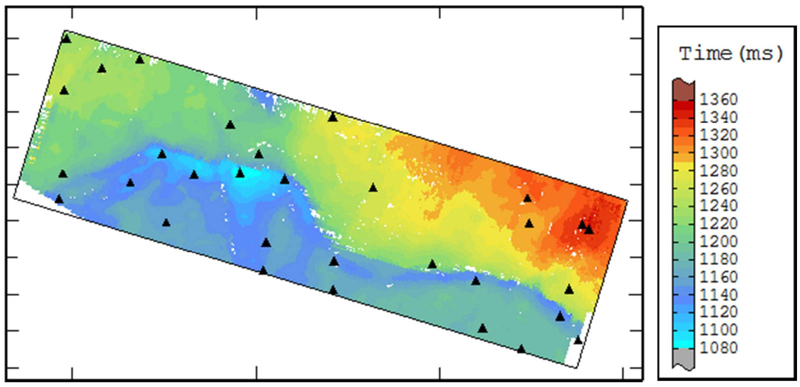

Figure 3: TWT map at target horizon (Top Reservoir)

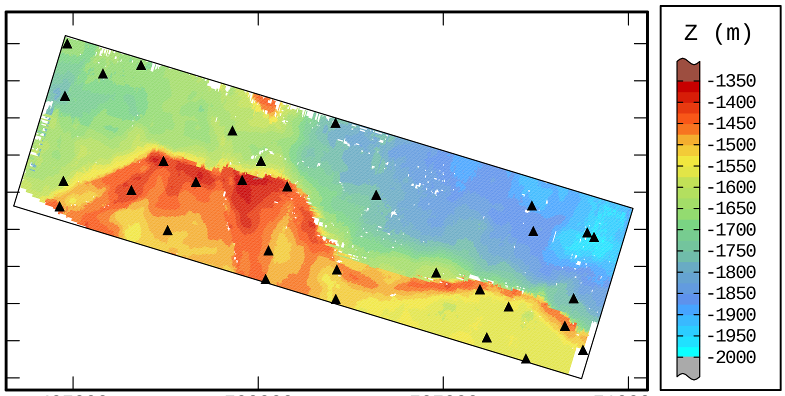

Figure 4: depth map from KED with TWT as external drift

    - **Using seismic velocities**

When the velocity is not homogeneous, the previous method cannot be used and it is necessary to model explicitly the velocity. In our example, as there is a good linear correlation between Vrms derived from seismic data and Vavg calculated at wells (Figure 1), a kriging with external drift of Vavg at wells using the Vrms from seismic data as external drift is computed (Figure 5). The average velocities, calculated at wells locations, are considered as hard data. The correlation with Vrms is important.

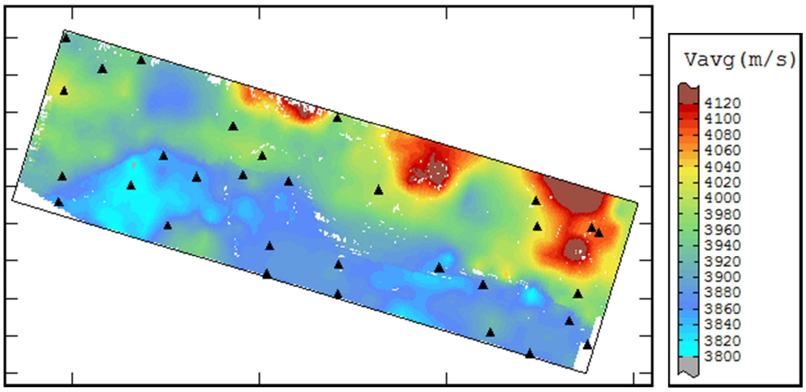

Figure 5: Average velocity extracted at Top Reservoir.

The depth map is then calculated as follows (Figure 6):

$$Depth = reference\ datum + Time * Vavg / 2000$$

As already mentioned, the reference datum for this land seismic survey is 750 m above sea level.

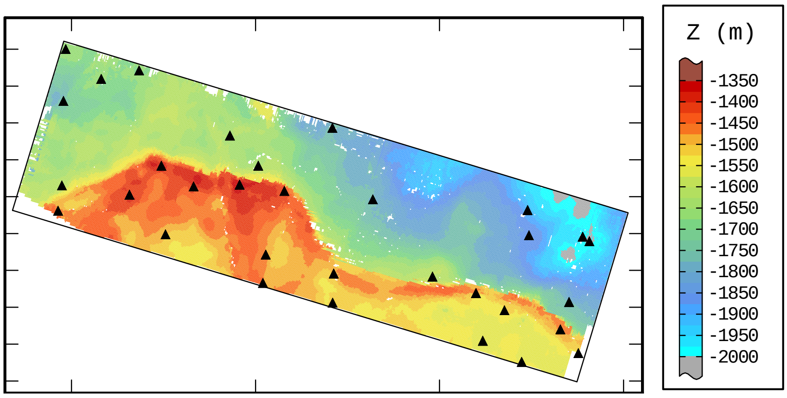

Figure 6: Depth map from KED with the non-stationary model from Vavg.

All these kriging based estimators are conditioned by the data and are model driven. The drift coefficients are either fixed or estimated. However, we can have prior information about the velocity model and the Bayesian approach is then well adapted to provide a framework for the integration of this knowledge.

- **Multi-layers case**

Both methods described above are applied for direct depth conversion or layer-cake depth conversion. An important issue of time-to-depth conversion is deciding how to process the different horizons interpreted from seismic data. A classic sequential approach leads to a propagation of the errors from top to bottom. A global approach, processing all horizons simultaneously, overcomes that difficulty while optimizing the use of the information: all the horizons are used to estimate the depth from a given layer as long as a correlation exists between them. For the time and depth approach, thickness and time interval are used instead of absolute time and depth. For the velocity approach, Dix velocity is used instead of Vrms and interval velocity instead of average velocity at wells.

Uncertainty and volumetrics

The standard deviation map gives an idea of how the error increases when moving away from the wells (Figures 7 and 8).

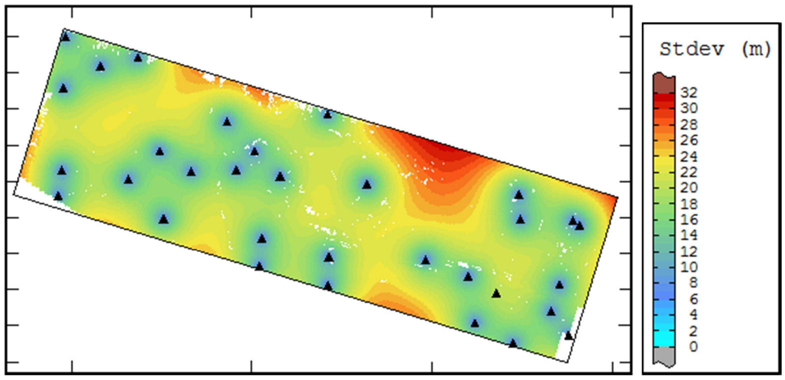

Figure 7: Standard deviation from KED with TWT

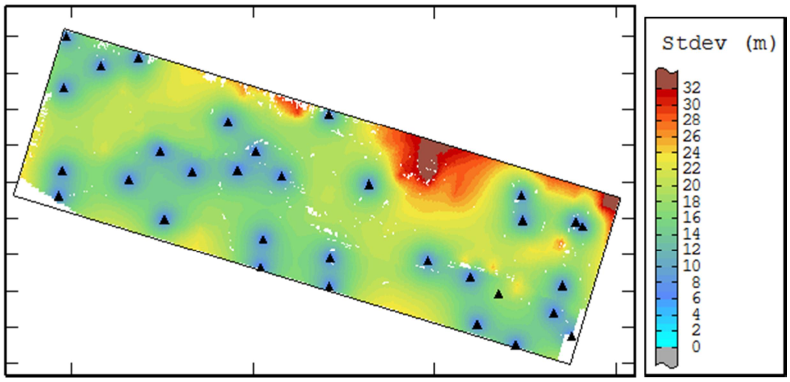

Figure8: Standard deviation depth from KED Vavg with Vrms

Kriging, when it is based on the trend and covariance models fitted to the data, provides an estimate of the uncertainty at every location of the map. However, kriging remains a deterministic approach that provides a very smooth image of geological variables. The goal of geostatistical conditional simulation is to generate precisely samples that satisfy the input statistics (mean, variance and variogram) instead of smoothing them (Figure 9).

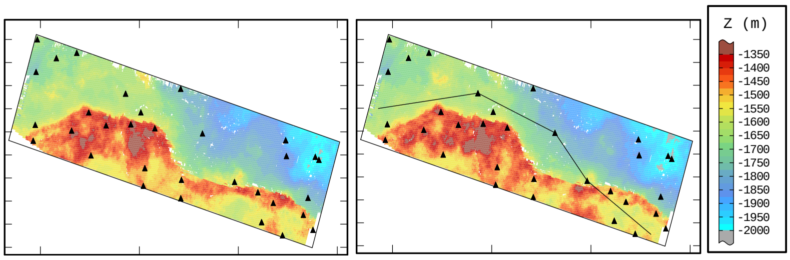

Figure9: two simulations examples in depth with cross section display

Simulations can represent how the real layers can differ from the base case (Figure 10) and so, they can be used for calculating probabilities on volumes above contact.

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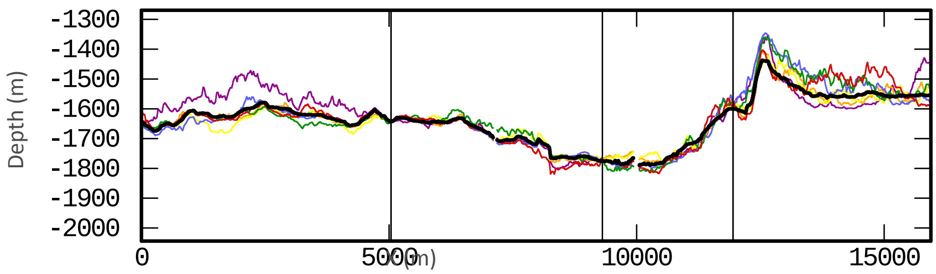

Figure 10: Cross-section in depth, the black bold curve is the base case and color curves refer to different simulations

Time-picking uncertainty has not been considered so far. It can be incorporated by modifying the seismic TWT map for each simulation. The different time maps can be obtained by simulating the time-picking error around the average time. This error can be assessed by entering two interpretations giving the magnitude of the uncertainty.

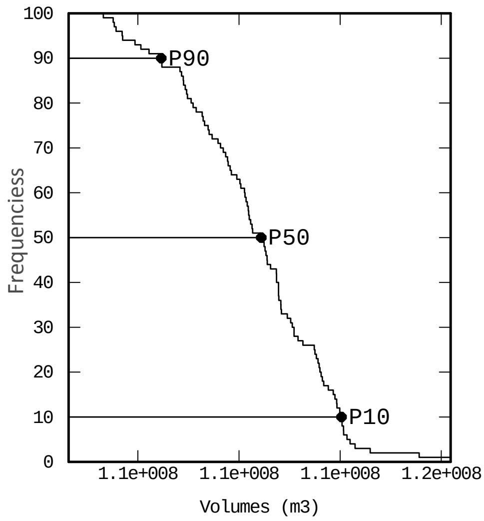

Figure 11:Example of GRV distribution curve

In order to calculate the gross volume of the reservoir, the oil-water or gas-water contact has to be defined. The following statistics are easily derived from the Gross Rock Volume (GRV) distribution curve (Figure11): mean, standard deviation, P95 (pessimistic scenario giving the volume such that there is a 95% chance that the actual volume is above), P50 (most realistic) and P5 (optimistic scenario). They can be used with other uncertainties to control the Oil in Place (OIP).

Our expertise

Geovariances has more than 15 years' experience in geostatistical time-to-depth conversion projects. Numerous studies have been carried out for major Oil & Gas companies. We can provide a unique expertise through both our French and Australian offices.

For more information

Let us help you optimize the accuracy of your reservoir models and assess the uncertainties on your volumes.

Contact our consultants at consult-oil@geovariances.com.

Who is Geovariances?

Geovariances is specialist geostatistical software, consulting and training company. We have over 45 staff, including specialist oil consultants and statisticians.

Our software, Isatis, is the accomplishment of 25 years of dedicated experience in geostatistics. It is the global software solution for all geostatistical questions.

Other technical specialties

Geovariances is a world leader in developing and applying new and practical geostatistical solutions to oil operations. We have strong experience in applying geostatistics from seismic data QC to reservoir characterization and have gained trust from multi-national companies.

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