Geostatistical assessment of time picking uncertainties and their impact on GRV

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Abstract
Assessment of gross rock volume (GRV) uncertainty is a key issue in hydrocarbon resource evaluations across the exploration-appraisal-development cycle. Geostatistics provide a variety of techniques for deriving velocity models by combining well information with, for instance, more densely sampled stacking velocity data. Stochastic simulations extend these techniques and, by providing a range of iso-probable velocity models, allow assessment of velocity uncertainty and its impact on GRV distributions in a relatively straightforward manner.

In contrast assessing the impact of TWT interpretation uncertainty is problematic, with difficulty in quantifying this uncertainty meaning that TWT interpretations are commonly treated as having either no uncertainty or having nominally-assigned uncertainties.

The paper presents an innovative approach to quantify TWT uncertainty successfully applied to a complex hydrocarbon field. Moderate-poor seismic data quality make possible a wide range of top reservoir interpretations over many areas of the field. Optimistic / pessimistic interpretations describing this range of uncertainty are used as the basis for a geostatistical analysis of TWT uncertainty, the interpreter's subjective assessment of the described probability range (10%-50%-90% for instance) providing an empirical confidence interval for the time picking.

TWT interpretations are simulated by adding to the best technical case simulations of the TWT uncertainty with a variogram based on the difference between optimistic / pessimistic cases. QCed resulting TWT realizations are then combined with velocity simulations to provide depth simulations and subsequent GRV distributions. The impact of TWT interpretation uncertainty on the latter is quantified and discussed.

Methodology

Presentation of the problem

For years, geoscientists were asked to produce just one reserves figure, despite the numerous types of uncertainty affecting the result. In a way, the geoscientist was asked, by choosing one scenario over many other possible ones, to substitute himself for the decision maker. Nowadays, the uncertainty quantification approach, by attaching a risk (probability of occurrence) to each possible decision, puts the decision back in the hands of the decision maker (Dubrule, 2003).

We first assume that a best technical case (BTC) TWT interpretation has been produced for a top reservoir horizon seismic event.

In quantifying depth uncertainty, it is common practice to quantify velocity uncertainty using classical stochastic simulation techniques: collocated co-simulations, simulations with external drift (Deraisme and Jeannee, 2003). TWT interpretation being often taken for granted, depth converting Vav realizations with TWT BTC consequently under-estimates the depth uncertainty, as it ignores one source of uncertainty. To overcome this issue, a map describing picking uncertainty might be built by the seismic interpreter, delineating poor, moderate and good seismic quality areas. Obviously, the uncertainty attached to each seismic quality level is subjective, being a matter of experience and judgment. Moreover, this approach doesn't take into account the commonly asymmetrical nature of TWT uncertainty, with the uncertainty range above and below the defined best technical case interpretation often being of different magnitudes.

Proposed workflow

Top reservoir TWT uncertainty is described by complementing the conventional BTC top reservoir interpretation with optimistic and pessimistic interpretations. These latter describe the uncertainty envelope associated with top reservoir interpretation. Important properties of these maps are the presence of sharp jumps in TWT uncertainty across faults and common asymmetry in the uncertainty envelope around the BTC interpretation. A confidence interval for the top reservoir TWT interpretation was calculated by assigning probability levels to the interpreted horizons based on the interpreter's subjective assessment of the described probability range (10%-50%-90% for instance).

Following this assumption, the uncertainty is summarized by the following assumption: if X follows a gaussian $N(m,s^2)$ distribution, then $P[m-1.28s < X < m+1.28s]=0.80$. Note that the gaussian distribution is just an assumption in our case, and is not a restriction of the methodology, that could be applied assuming other statistical distributions (e.g. triangular, uniform, …).

The difference grids between optimistic/ pessimistic cases and the BTC map give access to the s value.

The idea of the approach is to generate TWT realizations honoring the information contained in these three maps. These TWT realizations are obtained by:

- simulating non conditional gaussian (0,1) realizations, provided the knowledge of a variogram for TWT uncertainty. The latter may be designed on the basis of average s values derived as previously explained.
- scaling the gaussian error grid by the appropriate difference grid, and generating a TWT top reservoir realization by adding the previous error grid to the BTC top reservoir interpretation:

$$\textbf{TWT\_sim = BTC + } s\textbf{*TWT\_g}$$

with $$s = \begin{cases} s_{Max} = \text{d1wt\_(MAX - BTC)}/1.28 & \text{if TWT\_g} > 0 \\ s_{Min} = \text{d1wt\_(BTC - MIN)}/1.28 & \text{if TWT\_g} < 0 \end{cases}.$$

This approach allows to reproduce the locally varying uncertainty on TWT, as well as the asymmetry of the TWT uncertainty around the BTC. Resulting TWT realizations may then be validated for their geological/ geophysical relevance. From this point of view, it is important to keep in mind that geostatistics only processes and quantifies the information provided by the interpreter, and should not be seen as a mathematical black box. This validation is indeed a key step in establishing the robustness of the methodology.

Finally, top reservoir depth maps were generated by depth converting TWT realizations with classically obtained Vav realizations. Top reservoir depth realizations are finally used to perform volumetric calculations over areas of interest, and GRV distribution and uncertainty are finally assessed.

Case Study

Field environment

GRV estimation is not generally regarded as a primary uncertainty in reserves estimation and field development in low porosity, fractured carbonate reservoirs. However, in areas of high structural complexity and poor seismic data quality, uncertainties in accurately mapping top reservoir in time and depth can be significant. These uncertainties can, in turn, result in significant uncertainty in reserves estimation and can cause serious problems in optimizing development well locations. The onshore oilfield presented here is a case in point.

Top Reservoir TWT interpretation

TWT interpretation was produced by conventional seismic interpretation with the bulk of the field being covered by 3d seismic. Seismic data quality is highly variable and so is the confidence in the seismic interpretation of the target horizon (see Fig. 1 and 2):

- In areas of moderate-good quality seismic image, the pick can be made with a high degree of confidence and uncertainty is related solely to interference effects arising from overlying structures and from intra-reservoir reflectors.
- In contrast, in areas of poor seismic data quality (due to a combination of factors that commonly degrade seismic quality in onshore thrust belts: rugged topography; variable surface geology including thick, poorly consolidated alluvial fan deposits; complex overburden structures; and extreme velocity variation (1,500-6,000m/s) within overburden unit) no distinctive target seismic event is imaged and uncertainty in the interpretation of this event is commonly of the order of hundreds of milliseconds with the uncertainty envelope being related to a range of possible structural interpretations. In such areas, the BTC top reservoir pick represents the interpreter's subjective opinion as to the most likely top reservoir interpretation and is commonly driven by the structural model the interpreter has in mind. It can thus be regarded as the mode of a range of possible structural interpretations.

As a consequence, significant uncertainties arise both in seismic interpretation of top reservoir and in the construction of velocity models for depth conversion.

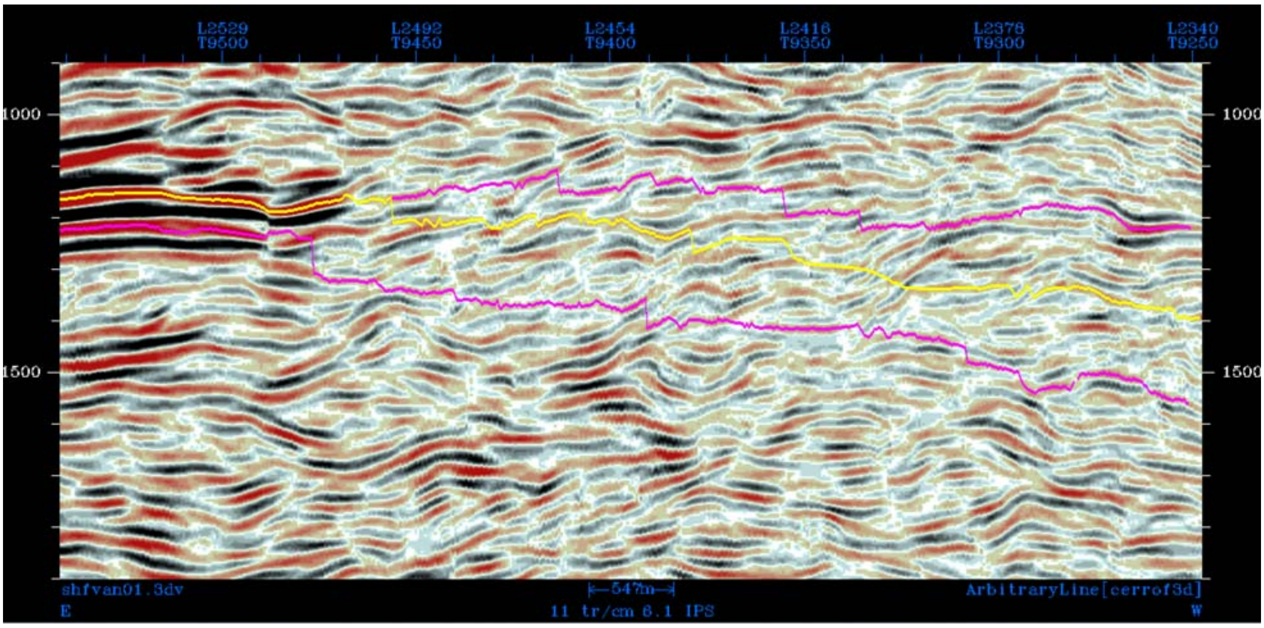


Figure 1: Cross-section of shallow (violet), BTC (yellow) and deep (violet) TWT interpretations.

TWT uncertainty

This uncertainty was described by complementing the conventional BTC top reservoir interpretation with optimistic and pessimistic interpretations:

- In areas of good quality seismic data these horizons are close to the BTC pick and can be regarded as describing the 'phase' uncertainty associated with which loop of the complex interference signal previously described actually represents top reservoir.

- In areas of poor data quality the optimistic and pessimistic horizons are commonly far from the BTC pick and can be regarded as enveloping the range of different structural interpretations that the interpreter considers possible. From this point of view, these horizons do not in general represent alternative deterministic seismic interpretations but rather define a time interval within which a large range of alternative interpretations are possible. Important properties of these maps are the presence of sharp jumps in TWT uncertainty across faults and common asymmetry in the uncertainty envelope around the BTC interpretation. In themselves, these maps contain a significant amount of information about the TWT interpretation uncertainty.

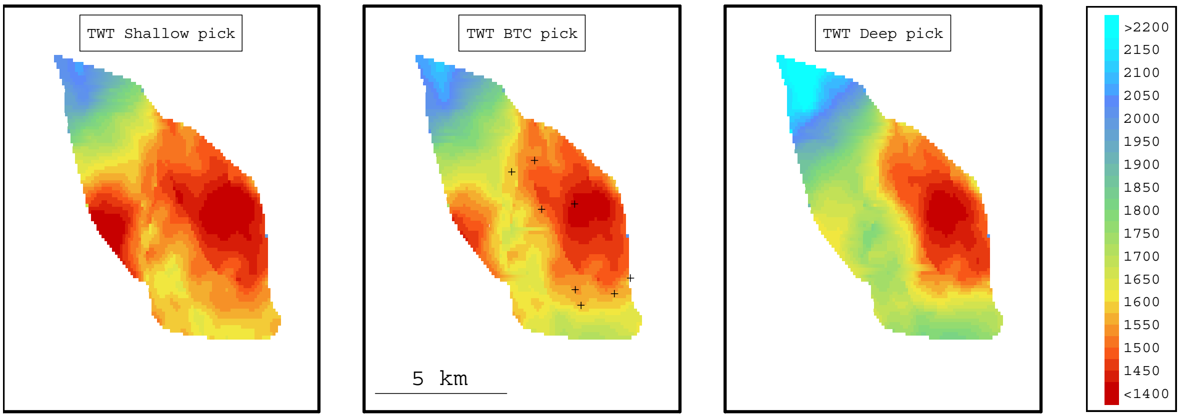
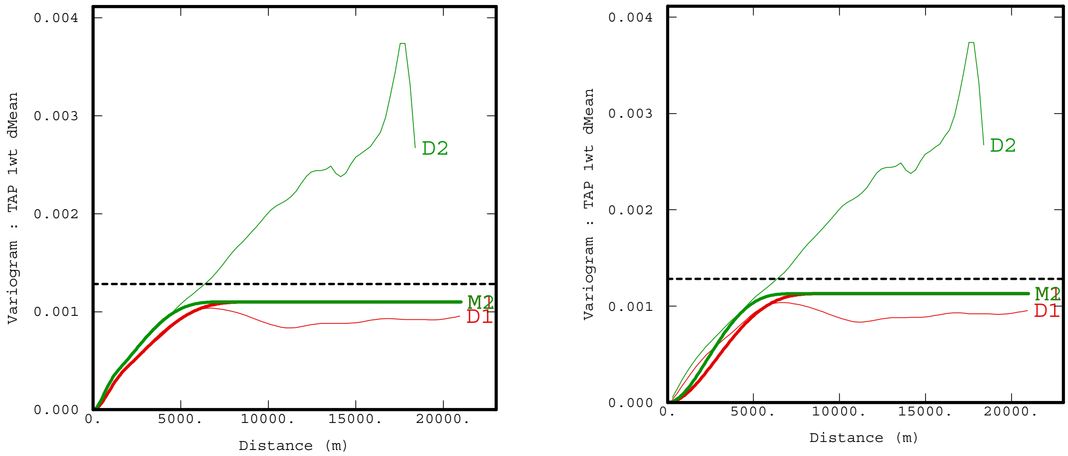


Figure 2:TWT shallow, BTC and deep maps, on a specific area (in msec). Wells indicated.

Quantification of TWT uncertainty

TWT uncertainty has been assessed by applying the methodology presented above. The TWT errors variogram has been computed, using the mean standard deviation grid (see Fig. 3).



Two basic structures One basic structure

Figure 3: Experimental variograms and fitted models for the TWT standard deviation, with (a) two basic structures and (b) only one basic structure.

We therefore assume that the time uncertainty is expressed by its standard deviation, given by the MIN and MAX maps, assuming a gaussian distribution and a 10%-50%-90% probability range in the first instance. Two structures are visible on the experimental variogram (see Fig. 3):

- a 'short range' structure, due to small distance variability (faults and high frequencies, poor seismic resolution),

- a 'long range' structure, due to time uncertainty variations coming from geological modifications.

Amongst these two structures, we have firstly assumed that the short range structure doesn't need to be modeled, being non significant regarding the time picking errors. The basic structure modeled has the following characteristics: cubic, with ranges equal to 9500 m in the first axis (Az=-45°) and 7800 m in the perpendicular direction. This assumption, that leads to smoother time realizations that are more likely to be acceptable time pickings, is validated below.

Following this methodology, 100 realizations of top reservoir TWT were generated using the turning bands technique as implemented in Isatis®[1]. Figure 4 shows that the TWT realizations honor the varying uncertainty level: low uncertainty in wells area, increased uncertainty far from wells. The asymmetry previously mentioned is noticeable.

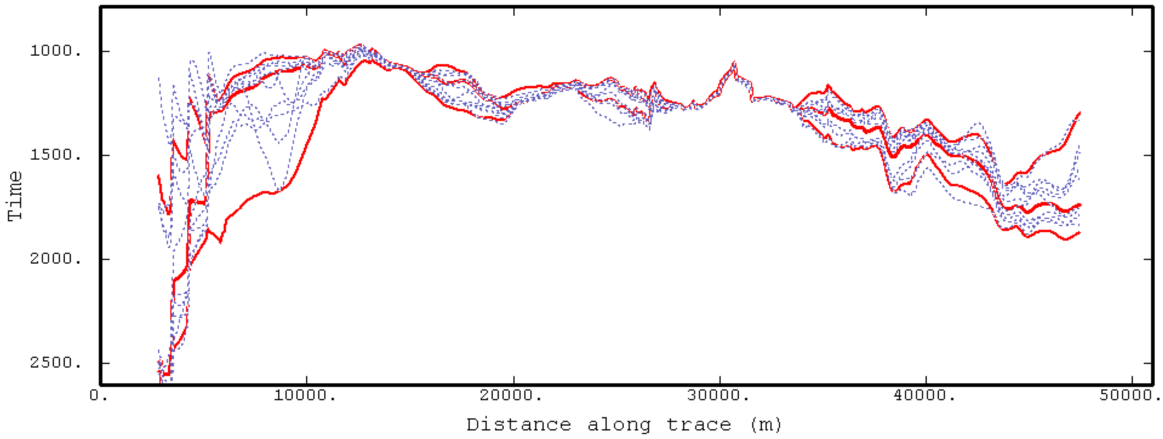


Figure 4: Cross-section of TWT BTC pick, shallow and deep picks (in red), TWT realizations in blue; two-way-time expressed in msec.

Validation of TWT realizations

Several sets of 5 TWT realizations were loaded into a seismic interpretation work station, using several TWT uncertainty variograms:

- one set using the original TWT uncertainty variogram
- one set each for the 'short structure' and 'long structure' variograms.

These realizations were then reviewed for relevance when compared against the original seismic dataset. Clearly individual realizations will not be plausible seismic interpretations, so the approach adopted was to review them for the extent to which (a) they were broadly within the TWT uncertainty envelope defined by the optimistic and pessimistic top reservoir interpretations, (b) large time offsets in realizations were consistent with possible fault offsets and (c) the structural wavelength of individual realizations was broadly consistent with the seismic dataset. The conclusion of this review was that the optimum realizations were those produced using the original TWT uncertainty variogram.

The value of these geostatistical analyses in quantifying uncertainty is shown by comparison of pre-drill prognosed top reservoir ranges against actual well results with only 1 out of 11 data points falling outside the P10-90 range of pre-drill depth prognoses. This is despite the fact that a number of wells have produced major surprises when results are evaluated against pre-drill BTC top reservoir depth prognoses. Detailed comparison of prognosed and actual well results has lead to an update of the model parameters, in order to introduce more uncertainty into the models than was initially the case: the assumption about optimistic and pessimistic TWT maps has been updated, the latter being now treated

[1] Geostatistical results are obtained using version 5.0 of the Isatis® software (Geovariances, 2004).

as P20 and P80 maps rather than P10 and P90.

GRV estimation

Vav realizations were obtained using a classical collocated cokriging approach that consists in:

1) A Vav model was produced by collocated co-kriging of well pseudo-Vav with an auxiliary variable. A variety of potential auxiliary variables were tested and Free Air Anomaly was finally selected due to (a) highest level of correlation with pseudo-Vav at well locations, (b) strong physical basis for relationship between density and velocity variation, (c) geological relevance of the resulting Vav map. This collocated cokriging approach has been preferred to the classical external drift approach for several reasons: lack of correlation with auxiliary information, search for a precise control of the model parameters (usually not easy to obtain through an external drift approach).
2) Variogram analysis for the Vav model was originally based on the Markov Bayes assumption, with the variogram being modeled on the gridded auxiliary variable and then fitted to the other elements of the bivariate variogram model (taking into account the level of correlation between the variables). However, detailed comparison of prognosed and actual well results has lead to prefer a full bivariate variogram modeling (that presents an increased variability at short distance), instead of the one derived from the Free Air Anomaly map.
3) Simulation of top reservoir Vav maps, using the turning bands algorithm. The validation of these velocity realizations consisted of review against a surface geological map and cross-sections.

Depth realizations are finally obtained by depth converting TWT realizations with Vav realizations. These depth realizations may finally be used in a variety of ways. For instance P10 and P90 top reservoir depth maps might be generated and used to assess GRV uncertainties or for full STOIIP calculations. For instance, Figure 5 illustrates GRV results in a particular area of interest.

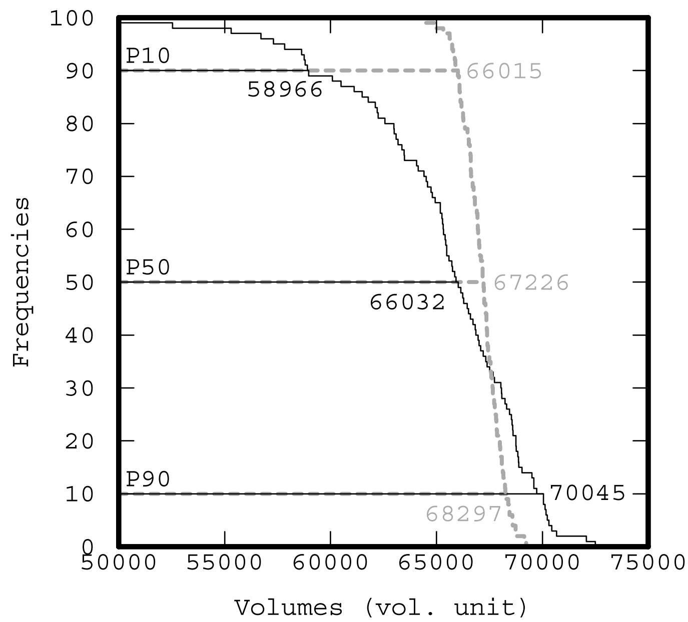


Figure 5: GRV distributions (in volumetric unit) obtained from the uncertainty quantification approach, with (black) and without (light gray) taking into account the TWT uncertainty; indication of P10, P50 and P90 quantiles.

Several comments shall be made about these GRV results:

- Firstly, the under-estimation of GRV uncertainty is remarkable if TWT uncertainty is ignored: the coefficient of variation (P90-P10)/P50 is reduced by a factor larger than 2, varying from 14% (with TWT uncertainty) to 6% (without TWT uncertainty);
- Taking into account TWT uncertainty introduces asymmetry in the GRV distribution;
- Even though the BTC is considered as the mode of the TWT realizations, the asymmetry of the TWT uncertainty leads to a decrease of the P50 median GRV.

In conclusion, these results highlight the importance of taking into account TWT uncertainty in reserves estimations.

References

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