Introduction

At the feasibility stage of a high level radioactive waste facility in the of the eastern Paris Basin, the French National Radioactive Waste Management Agency (Andra) is conducting innovative and extensive characterization of the Callovo-Oxfordian argillaceous rock (Cox) and neighbouring Oxfordian and Dogger limestones .High resolution 3D seismic data are used to model the distribution of mechanical and hydrogeological properties of the geological formations (3). Assessing the reliability of the modelling is crucial for making decision on the design of the level radioactive waste facility. We show how first assessing the reliability of seismic stacked amplitudes that are input to the geophysical inversion is the cornerstone of the whole model reliability assessment process. Stochastic processing of the pre-stack amplitude gathers enables to compute Spatial Quality Indexes (SQI) attached to stacked amplitude data.. The computation and distribution of SQI results and its contribution to the mechanical and hydrogeological model is discussed.

Stochastic Quality Assessment of stacked seismic amplitudes

The input to characterization of the Callovo-Oxfordian argillaceous rock (Cox) and neighbouring Oxfordian and Dogger limestones are pre-stack time migrated (PSTM) seismic sections that have been used for inversion into elastic impedance sections. Measured amplitudes were monitored and analyzed closely throughout processing to ensure that true amplitudes were preserved.

A Stochastic Quality Assessment (SQA) wokflow has been designed to assess the reliablity of the stacked amplitudes and to optimize further modeling of mechanical and hydrogeological properties.
SQA processing of seismic data works under a mathematical framework known as Geostatistics or topo-probability models, where the observed (measured) seismic amplitude is considered as a unique realization of a random function (RF) defined in space and time (Shtuka et al 2011 (1) and 2009 (2)). The added value of using this type of theoretical framework is that it takes into account the spatial correlation between measured seismic amplitudes at different locations using variograms or spatial covariance.

Interpretation and modeling of the experimental variograms computed in the offset direction (for fixed time) on pre satck gather data enables to assess the signal and noise content of the seismic measurements in terms of contributive (signal) and non contributive (noise) part to the stacking process.

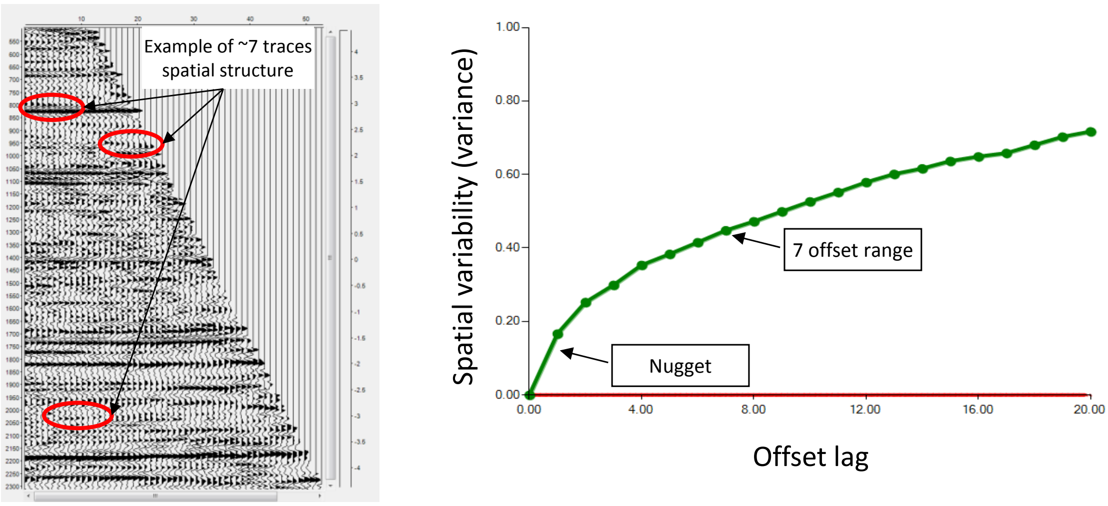

Figure 1 *Interpretation of variogram of a pre stack gather in the offset direction in terms of noise non correlated from trace to trace (nugget component, noise correlated from trace to trace (short 7 offset range component) and signal (long spatial range > 20 offsets component)*

Interpreting the horizontal experimental variogram (constant time, offset or angle direction) is about identifying ranges (expressed as a specific number of offset lags), corresponding to the spatial signature of non-correlated noise from trace to trace and correlated noise from trace to trace.
In the case of a synthetic gather that contains only signal and no noise, the corresponding horizontal experimental variogram would show a flat and constant (near 0) curve . It would not show any short range that would indicate short scale amplitude variations with offset corresponding to the spatial signature of correlated or non-correlated noise from trace to trace.
In the case of a seismic gather that contains both signal and noise, the signature of the noise appear on the horizontal experimental variogram with nugget effect and short offset range structures:
In the example shown in figure 1:

- Nugget effect (i.e. spatial variability for "0-1" offset range) indicates non-correlated noise from trace to trace;
- Short range (i.e. spatial variability for "2-7" offset range) indicates correlated noise from trace to trace;
- Long range (i.e. spatial variability for "> 7" offset range): indicates signal.

The signal/noise interpretation of the variogram is quantified by modeling the experimental variogram accordingly in both horizontal (offset or angle) and vertical (time) directions. SQA handles the global non-stationary behavior of the gather by relying only on a local stationarity assumption: local computations and modeling of variogram parameters (sill and ranges) are automated and performed inside local neighborhoods defined around each sample location.

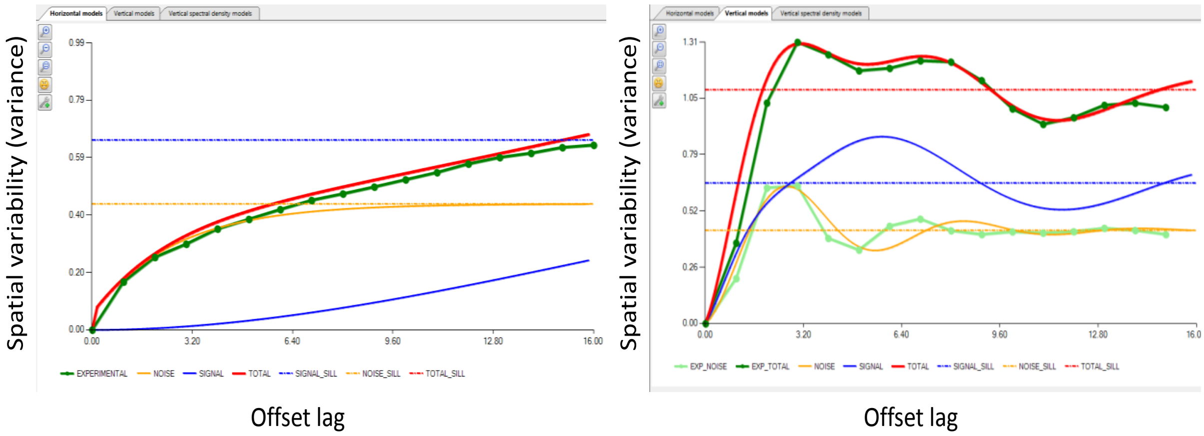

***Figure 2** Modelling experimental variograms (green lines) with red curve of in the offset (left) and time (right) direction in terms of noise correlated and non-correlated from trace to trace (brown curve) and signal (blue curve)*

The variogram model is used to compute the estimation variance of the stacked trace of the gather as the variance of the estimation error: unknown "true" stacked amplitude minus estimated stacked amplitude: The unknown "true" stacked amplitude $\overline{A(t)} = \frac{1}{N_t}\sum_{i=1}^{N_t} A(x_i, t)$

N_t number of offset traces considered for the stack at constant time t,

$A(x_i, t)$: pre stack unknown "true" amplitude at offset x_i and constant time t),

is estimated by a linear combination of measured amplitude values: $\overline{A(t)}^* = \sum_{i=1}^{Nt} \lambda_i \cdot A_m(x_i, t)$

$A_m(x_i, t)$: Pre-stack "measured" amplitude at offset x_i and constant time t

λ_i Weighting factor applied to $A_m(x_i, t)$

As for any linear estimator, Geostatistics enable to compute the estimation variance of such linear combination, using the variogram (or covariance) model function.

$$\sigma_{est}^2(\lambda_i) = Var\left(\sum_{i=1}^{Nt} \lambda_i \cdot A_m(x_i,t) - \frac{1}{N_t}\sum_{i=1}^{N_t} A(x_i,t)\right)$$

The usual stack computation implies that all λ_i are equal to $\frac{1}{N_t}$, which gives:

$$\sigma_{est}^2 Stack(t) = \frac{1}{N_t^2}\left[\sum_{i=1}^{N_t}\sum_{j=1}^{N_t} Cov\langle A_m(x_i,t), A_m(x_j,t)\rangle - \sum_{i=1}^{N_t}\sum_{j=1}^{N_t} Cov\langle A(x_i,t), A(x_j,t)\rangle\right]$$

The estimation variance is normalized and expressed as a percentage of the stacked amplitude called the Spatial Quality Index (SQI). Small SQI means good confidence in the stacked amplitude.

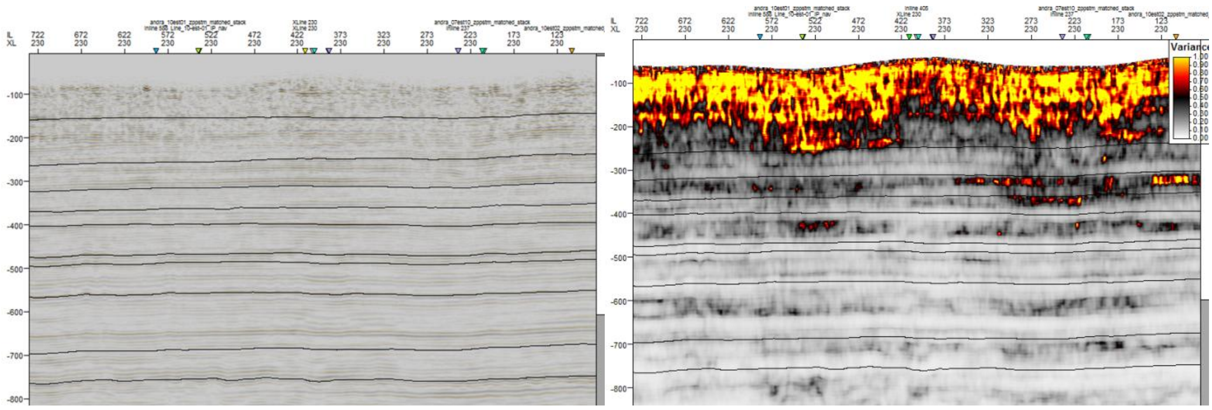

Figure 3: *Stacked amplitude section (right) and SQI indicator of the reliability of the stacked amplitude values (right).White SQI areas (near 0% error) indicate reliable amplitude values. Dark to red SQI areas (above 50% error) indicate non reliable amplitude values. Horizons (black lines) interpreted on the stacked section (left) can be checked on the SQI section (right)*

Field example:

The case study is part of an extensive characterization of the Callovo-Oxfordian argillaceous rock (Cox) and neighbouring Oxfordian and Dogger limestones conducted by the French National Radioactive Waste Management Agency (Andra), at the feasibility stage of implementing a high level radioactive waste facility in the of the eastern Paris Basin. Innovative modeling of a pseudo Gamma Ray and of permeability index (Ik-Seis) at the seismic scale (3) aims at confirming the homogeneity of the target formation (Callovo –Oxfordian clay) and identifying porous layers in the neighboring Oxfordian and Dogger limestones.
The results shown here are obtained on the XL217 cross line on the seismic cube. Figure 3 shows the instantaneous amplitude section (left), its associated SQI factor (center), and pseudo gamma ray attribute (right) in depth. The quality of seismic instantaneous amplitudes is quantified by their attached SQI values that enables in turn to attach confidence on the result of the modeling of the pseudo gamma ray attribute. Blue SQI areas on the seismic section (low SQI values) indicate reliable amplitudes (80% to 90% reliability), green SQI areas indicate less reliable amplitudes (50 to 70% reliability).
The high values of the pseudo gamma ray (yellow to brown areas) are associated with the Callovo–Oxfordian (550-720 m depth interval). We can notice lateral variations of the shale content in the Callovo Oxfordian, that are partly related to corresponding variations of the SQI factor that is to the quality of the seismic amplitudes. Their interpretation must take the quality factor into account.
A significant lateral variation of the seismic amplitude is also visible inside the 700 – 750m depth window that corresponds to the presence of a porous layer, between CMP 600 and CMP 400 at the top

of the Dogger formation. This interpretation in validated by a very low value of the pseudo gamma attributes and is reliable as shown by a low SQI factor.

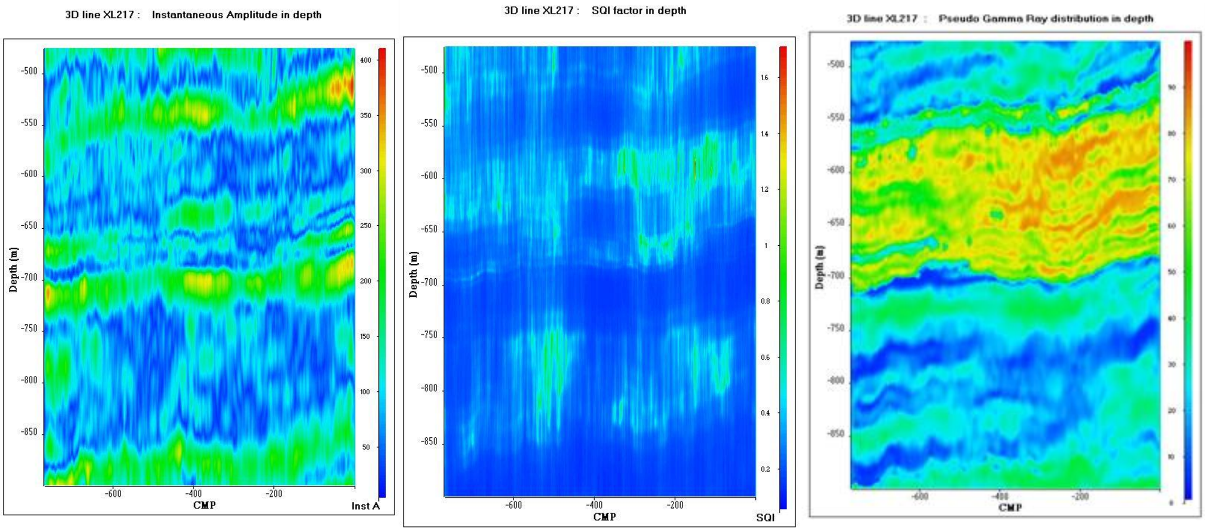

***Figure 3:** Instantaneous amplitude (left), SQI factor (center) , and pseudo gamma ray distribution in depth.*

Conclusion

We show how Stochastic (Geostatistics) processing of pre stack seismic data benefits to quantify the quality of the seismic amplitudes : The computation of a Spatial Quality Index (SQI) specific to the stacking process quantifies the reliability of the stacked amplitude and can be considered as a reliable indicator of the preservation of true amplitude by the processing sequence. In a real field example on the storage of of a high level radioactive waste in a safe geological shale environment, SQI helps validates the identification of lateral variation of shale content inside the target layer and of a high porous layer in the limestone just below.

Acknowledgements

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References

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3_ Mari J.L, Yven B., The application of high resolution 3D seismic data to model the distribution of mechanical and hydrogeological properties of a potential host rock for the deep storage of radioactive waste in France, Marine and Petroleum Geology, 2013, DOI: 10.1016/j.marpetgeo.2013.10.014