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Extrapolation of well calibration in large exploration areas Lifts up the bar for true amplitude recovery of seismic reflection data.

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Summary

All the many interpretation approaches that can be placed under the general heading of "quantitative seismics" rely on the quite stringent (and often overlooked) assumption that seismic amplitudes of peak and troughs can effectively represent reflection coefficients. This is what we can name "amplitude resolution".

It is also worth highlighting that this assumption is quite a step ahead from the conventional "true amplitude" concept, which is related almost exclusively to the ability of the acquisition system and the processing sequence to effectively take care of the amplitude decay which takes place when the wavefront travels down into the earth and back to the receivers.

A probabilistic model of the expected behavior of the AVO attributes can provide the means for QC'ing the seismic data at the end of the processing sequence in view of the "amplitude resolution" compliance. The usage of such AVO based pre-stack amplitude QC allows a first level standard evaluation of the suitability of the amplitude information of the partial stack volumes for any kind of quantitative analysis of seismic data. If a discrepancy is highlighted here, it might indicate that the applied processing sequence did not succeed in recovering and preserving original amplitudes, thus calling for a more detailed investigation of the causes and search for possible remedies.

Introduction

For or a very long while the major goal of seismic data acquisition and processing has been that of providing the interpreter with the best image of the subsurface geology. The roomy class of seismic interpretation approaches aimed at yielding more direct information about lithology, fluids, reservoir characteristics, etc., is much younger, and certainly it is still undergoing continuous and intense development.

All of these approaches (like AVO, seismic inversion, reservoir characterization, multi-attribute analysis, etc.) can be placed under the general heading of "quantitative seismics" and all of them are in fact totally dependent on the assumption that seismic amplitudes represent reflection coefficients, or they keep always proportional to reflection coefficients when moving X, Y, and T within the data volumes.

Even though AI/EI seismic inversion processes appear notionally not to be affected by this assumption, it is quite evident that it comes anyway into play when dealing with complex reflectivity patterns and very thin layering, much below the vertical resolution allowed by the frequency bandwidth of the wavelet.

Any kind of quantitative seismic interpretation approach definitely requires, or at least will greatly benefit from proper recovery and preservation of "amplitude resolution", i.e. overall proportionality of seismic trace peaks and troughs to reflection coefficients.

It appears evident that this assumption is not always fulfilled by the conventional "true amplitude" processing, which is related only to the ability of the acquisition system and the processing sequence to effectively recover the amplitude decay which takes place when the wavefront travels down into the earth and back to the receivers.

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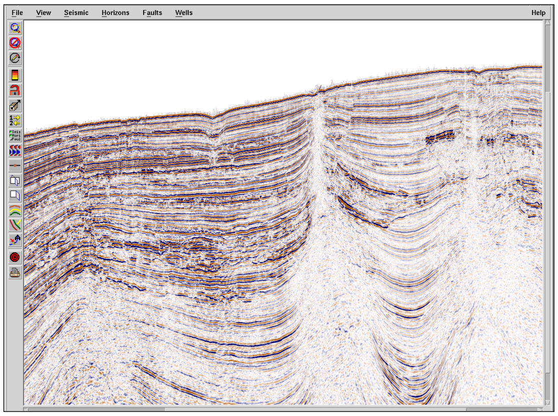

Fig.1 – Example of a seismic profile from a 3D final volume. Some increasing amplitude trend with water depth is quite evident here, at the sea bottom reflection and in the overburden. This will prove even more severe in the corresponding partial angle stacks and will badly affect any attempt at comparing AVO analysis quantitative results in different locations.

Such recovery and preservation of "true amplitude" is normally achieved with broad statistical assumptions, which prove generally adequate at reservoir scale, but may not provide the necessary generality when robustness and stability over a large exploration seismic volume is required. The AVO effect which is always present with decreasing amplitude with offset (the majority) or increasing amplitude (now and then) of reflections in the pre-stack gathers acts as a complicating factor in that respect.

Neither the availability of wells to be modeled (synthetic seismograms) can help to properly solve the ambiguity among geological and processing related factors.

Very often the overall true amplitude of seismic data, especially in the partial angle stacks (which are becoming more and more standard products in seismic interpretation) or in the CDP gathers, is not at easy reach. This may not be a major problem when dealing with a reservoir scale scenario (limited area and narrow time frame), but it will definitely be an issue when the need of carrying out fluid or lithology predictions, based on seismic amplitudes, far away from analogs or calibration wells, is the goal of the study.

Theory

The main factors affecting the seismic amplitudes, which call therefore for some processing to be compensated for, are: (1) geometrical spreading, (2) transmission losses and (3) inelastic absorption.

The real list is in fact much longer and keeps on with an impressive number of other physical phenomena which may impact with different importance on the recorded (and finally displayed) seismic amplitude. Let us just mention a few of them (not in order of strength): scattering and micro-diffractions, curvature of reflectors (or illumination issues in general), tuning, interference patterns, etc. When it comes to utilizing Near and Far partial angle stack data volumes in the litho-fluid interpretation (AVO analysis as an example) the possible residual NMO or Anisotropic Move Out also comes to play an important role.

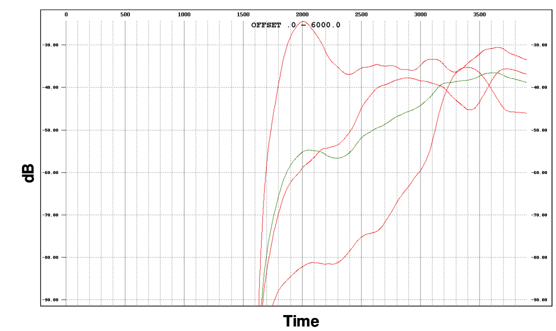

Fig.2 – Example of pre-stack amplitude decay analysis at the end of the processing sequence (PSTM CDP data traces. The red curves graph the amplitude in a 200ms sliding time window of 3 different offset ranges averaged over some 50 adjacent gathers. This is not really consistent with any pre-stack amplitude model and will spoil any attempt to use such information. This problem may disappear or become much less evident in the final stack, thanks to the averaging of the offsets (and some final cosmetic processing).

Among the above three factors only number (1) can be recovered with a deterministic approach utilizing a relatively simple mathematical model (spherical divergence or any other more sophisticated model driven by the knowledge of propagation velocity). To compensate for factor (3) in a deterministic way at least a quite detailed 3D subsurface model of the Q factor is necessary. This is not really easy to be achieved, especially in a typical exploration scenario, when few wells or no wells at all are available. It is then compulsory to tackle this issue from a broad statistical standpoint. A very similar statistical standpoint is the only possible route one can follow to compensate for effect number (2), which holds great importance.

Since the compensation for such amplitude decay factors takes place at the very beginning of the data processing flow, it is of prominent importance to approach this very carefully to avoid unrecoverable problems, which can become really serious and prevent from any reliable quantitative seismic data interpretation.

This appears to be especially true in deep offshore environments, usually characterized by highly variable water depth. On the other hand, the commonly available 3D processing SW packages do not really provide the analyst with suitable tools capable to perform advanced amplitude QC in a true 3D pre-stack sense. The lack of "amplitude resolution" proved in our experience to represent the most relevant factor accounting for wrong fluid and lithology predictions through seismic pre and post stack quantitative interpretation.

Method

A robust probabilistic model of the expected behavior of the two main AVO attributes can really help at QC'ing the seismic data at the end of the processing sequence for the "amplitude resolution" compliance.

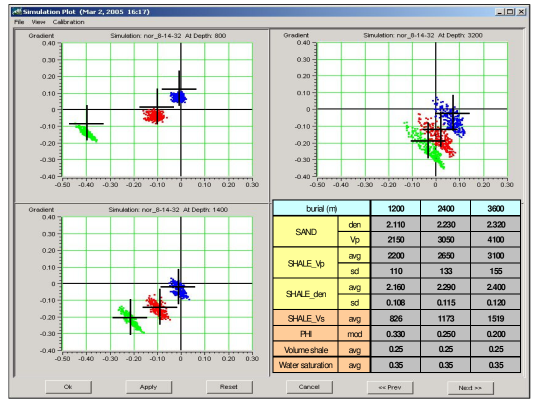

Fig.3 – Stochastic model of A vs. B for three notional examples of AVO Class III (top left), Class II (bottom left), and Class I (top right). The cross-hairs show the A-B pairs for the average parameters for three simulated standard fluids, while the colored dots show the result of 100 Montecarlo realizations for each saturating fluid (blue=brine, red=oil, green= gas). No random noise is added and only the acceptable variability of porosity and Vp/Vs of shale is modeled.

The reference model is represented by a statistical description of the expected average behavior of AVO intercept A and gradient B with depth. This model comes from the statistical analysis of the logs and information of as many wells as possible from the study area and also accounts in a probabilistic sense for the observed change of the petro-physical parameters in the reservoir layer and cap rock at each modeled depth.

This modeling method is actually part of a more complex flow, called "AVO Fluid Inversion", which is aimed at inverting the real AVO response at any geo-object in the study area using a Bayesian approach.

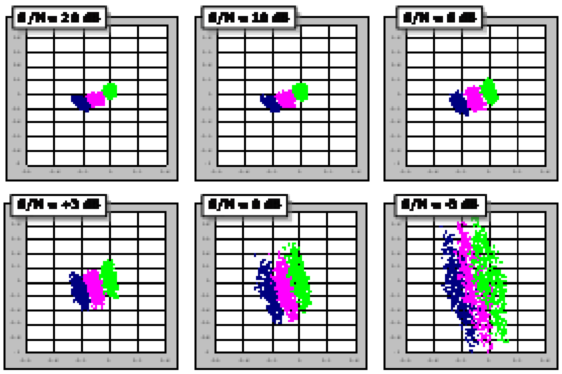

Fig.4 – In this figure a noise free stochastic AFI model (top left) is compared to the same modeling conditions with some increasing random noise added. As expected the effect of noise proves much more severe un the gradient B (vertical axes) than on the intercept A (horizontal axes).

The amplitude QC'ing objective is then accomplished by comparing the statistics of the multi-variate distribution of AVO attributes derived from the real seismic data with those coming from the AFI stochastic modeling, further including the effect of seismic random noise.

The usage of such AVO based pre-stack amplitude QC certainly allows a first level standard evaluation of the suitability of the amplitude information of the partial stack volumes in view of any kind of quantitative analysis, such as AVO, Acoustic or Elastic Inversion, Multi-attribute inversion. Any anomaly highlighted by the multi-attribute comparison might indicate that the applied processing sequence did not succeed in recovering and preserving original amplitudes, thus calling for a more detailed investigation of the causes and search for possible remedies.

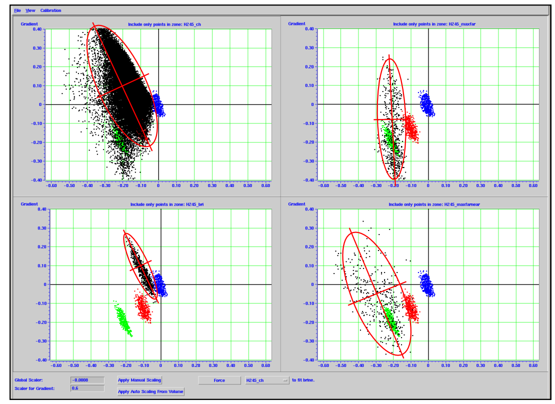

Fig.5 – Comparison of the noise free AFI stochastic model of A vs. B at the appropriate burial depth (in color) with the A and B computed from real amplitude maps fro the nears and Fars (black dots). The four quadrants show the same model compared to the whole picked map (top left) with data extracted from smaller representative spots. The peculiar shape of the real data clouds against the model ones, indicate here a possible post-stack gain applied independently to the Near and Far data volumes.

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