Monitoring the quality of pre-stack broadband seismic data

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Summary

Reservoir characterization methods rely on optimally processed and imaged seismic data. As broadband acquisition and processing techniques become more widely adopted, the monitoring of seismic data quality must also evolve with appropriately adapted quality controls (QCs). This paper updates our pre-stack data QC methodology to monitor amplitude with offset/angle (AVO or AVA) compliance as well as the very low frequency content, which is crucial for better quantitative interpretation. We emphasize the importance of applying QCs at the critical stages of the processing, such as denoise and demultiple prior to migration. We propose a set of attributes with which we can identify signal preservation and pre-stack data consistency across the full data bandwidth. First, we outline the QCs necessary to monitor pre-stack data continuity, AVA model quality and wavelet stability. We then discuss low frequency QCs and show how this can help set parameters for the processing of the seismic data.

Introduction

Decisions on field development are often made using reservoir characterization methods that require carefully processed and prepared seismic data. Previously published work (e.g. Araman et al., 2014, Coleou et al., 2013 and Rivet et al., 2016) focusses on monitoring wavelet stability and AVA compliance of the data during processing. This is also part of our strategy. However, a large part of the benefit of modern seismic data relates to the increased bandwidth. In the context of AVA inversion, the low frequency content of the data is of particular importance (JafarGandomi et al., 2015). In the following, we propose a methodology for monitoring both AVA compliance and the low frequency content of the data. We use a small set of attributes with which we identify signal preservation and pre-stack data consistency across the full data bandwidth and low frequency zone. We show how the pre-stack low frequency QC helps optimise the parameterisation of a demultiple processing sequence. Whilst it is common to monitor AVA compliance of seismic processing post-migration, we emphasize that signal preservation is much more likely to suffer at processing stages such as denoise and demultiple, prior to migration. We need to be more stringent with the application of good QCs at these pre-migration stages of the seismic processing.

QC strategy

Broadly speaking, we can classify QCs as either well driven (deterministic) or data driven (statistical). There are thus two main aspects to our QC flow: (1) Integration of all available data, including wells, to QC consistency with the seismic data. Well-log data provides spatially and temporally limited information. (2) Statistical volumetric QCs away from the wells. In many instances, we may not have access to log data, but we should ensure that any additional information, such as knowledge of the local geology, is used. QCs are always generated on fully migrated data, to properly focus all energy. This is particularly important in the context of AVA attributes, which have much poorer signal to noise ratio than stack data. Attributes are also derived in geologically consistent manner by using horizon-driven windows.

When choosing QC attributes, two further considerations are made: (1) the number of attributes should be limited so that they can be delivered in a timely manner without significant delay to the processing turnaround. (2) The attributes should be robust and as diagnostic as possible. A diagnostic QC is one that directly identifies the source of the data issue: is it a problem of amplitudes, time-alignment, frequency variation etc. Figure 1 shows a typical set of QCs with the one used in this paper shown in red. Just like for other aspects of seismic processing, the QCs are adapted to the datasets and to individual processing steps: not every attribute is required for each stage of the

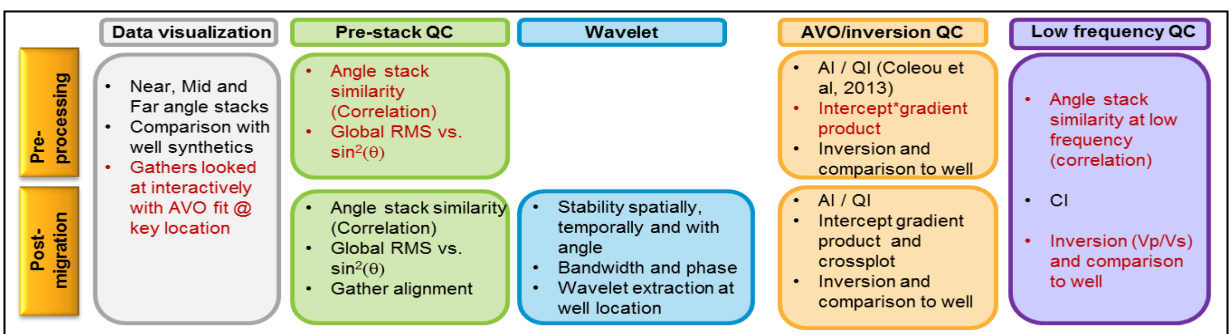

Figure 1: List of possible QCs for key steps early (top) and late (bottom) in the sequence. In red, QCs used in this paper.

processing. In what follows we focus on pre-stack, AVO/Inversion and low frequency QC. For wavelet QC, monitoring of wavelet phase and well-ties (particularly in the context of broadband data), we refer to JafarGandomi et al. (2017) and references therein.

Example 1: Pre-migration pre-stack and AVO QC

During pre-migration processing, QC attributes are generally limited to monitoring amplitude, pre-stack similarity, and possibly AVO anomaly preservation, all calculated on the data migrated for QC.

Selection of key locations for gather QC

QC before migration should focus on the key pre-processing steps where most energy is removed from the data (denoise, de-multiple). A simple method to pick such areas was shown by Sablon et al. (2016) and is particularly adapted to QC the demultiple process. The maximum correlation is calculated between each pre-stack trace and a reference stack. A volumetric QC is then obtained by stacking the correlation gathers. Differences of correlation stacks before and after a process is used to identify areas where the correlation decreases, and which may need further investigation. An alternative method calculates the normalised root mean square envelope (NRMSE) between the input and output of a processing step. This method is particularly suited to the denoise process. NRMSE is calculated as the RMS of the pre-stack difference normalized by the envelope of the stack. Large NRMSE values show areas where most of the energy has been removed (normalised by the stack). The NRMSE can be calculated for different angle ranges or for the full stack. Figure 2 shows a map of NRMSE around a key horizon after a denoise process in offset class (NRMSE calculation between 0-30°). Areas in red indicate the gathers most impacted by the denoise process, allowing us to QC the potential primary leakage on these locations. These methods will be particularly useful when dealing with large datasets and where no logs are available to compare to the seismic data at well locations. They allow us to trawl through large datasets and limit manual interventions to regions most affected by the processing.

Pre-stack QC

Correlation between angle stacks on a horizon/reservoir window viewed as maps are a commonly used and powerful attribute (Araman et al., 2014, Coleou et al., 2013) to monitor the pre-stack continuity of primary events. Since full bandwidth correlation is not the same as data correlation at low frequencies, we create correlation attributes on different frequency bands.

RMS maps for each migrated angle stack over key horizons can identify amplitude anomalies with angle (particularly on class III AVO). A global RMS decay curve plotted as a function of $\sin^2(\theta)$ should become more linear with processing, where θ is the incidence angle.

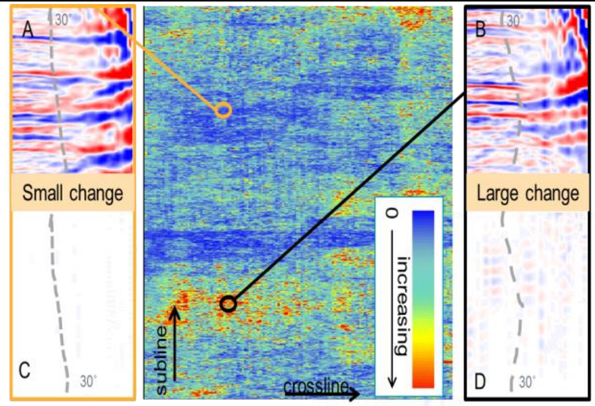

Figure 2: NRMSE map comparing data pre and post denoise. Red corresponds to large NRMSE values. (A) and (B) are gathers pre-denoise, (C) and (D) are the difference with the gathers post-denoise. The 30º mute is shown.

AVO QC

Two techniques are important for early AVA monitoring of the data when gathers can still be very noisy: macro-binning and automated gather flattening. Macro-binning collects adjacent gathers into a super-gather. To avoid leakage in structured areas, we apply a time-variant dip-correction. Gather flattening applies a sample-by-sample flattening of the data prior to AVO fitting. This can be particularly important early on when velocities are not yet optimized. We nearly always use on-the-fly gather flattening, with or without macro-binning. The relative impact of each pre-conditioning step will be data dependant.

Figure 3 shows an example of the product of intercept and gradient (R0*G) for a dataset where a class III AVO anomaly is expected. In this picture, large values of R0*G (indicator of a possible class III) are shown in red. It is obvious that the AVO fit QC can only start post-demultiple as the multiple contamination is too large to identify any potential AVO anomaly (top row). However, we can still gain some insight into the AVO behaviour by visual inspection of the gathers alone. Post-demultiple (middle row), the R0*G section is still noisy but the anomaly can be seen. The residual flattening (middle raw) and the macro-binning (shown combined with the residual flattening on right raw) clearly help in increasing the standout of the AVO anomaly. This is also visible on the data just before migration (bottom row): again, the correction of the residual non flatness of the data enhances the class III anomaly.

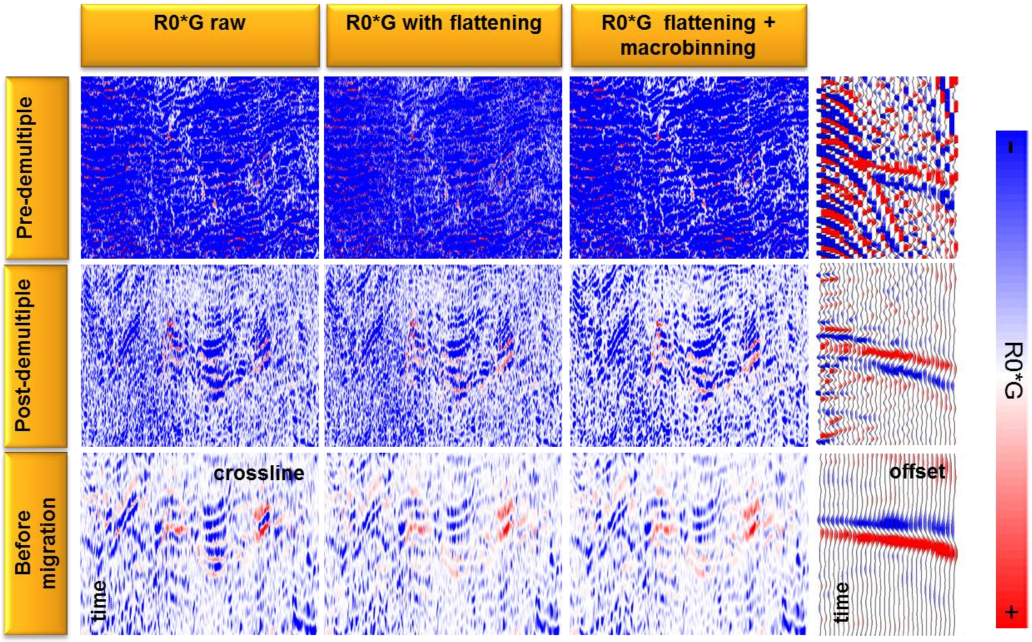

Figure 3: Sections of the intercept and gradient product (R0*G) calculated on migrated data at 3 processing steps: Pre-demultiple (top), post-demultiple (middle) and just before migration (bottom). (Left) R0*G on raw data, (Middle-Left) R0*G with flattening as preconditioning and (Middle-Right) R0*G with flattening and macro-binning as preconditioning for the AVO. Right: Example of CDP gathers (no flattening is applied).

Example 2: Low frequency QC for pre-migration demultiple QC

Whilst AVO driven QC is relatively common on migrated data, it is clear that we need to be careful early in the sequence to preserve primary amplitudes at all frequencies. We now show how low frequency pre-stack QC (< 8 Hz) can help choosing between different demultiple workflows. Two demultiple sequences A and B have been applied to a deep-water dataset (see Sablon et al., 2016). Each row of Figure 4 shows results for a given demultiple workflow: left, the mid and far stack and their correlation (above, in red) on full bandwidth, and on low frequencies only (lower than 8Hz) (middle panel). The right panel shows the relative Vp/Vs section from a pre-stack inversion with the well values embedded.

Demultiple A (Figure 4, top) shows a good correlation between the mid and far stacks both for the full bandwidth (left) and the low frequency (middle) data. This results in laterally continuous Vp/Vs, in good agreement with the well. The reservoir (R2) can be identified. For demultiple B (bottom), correlation values similar to demultiple A can be seen on the full bandwidth. However, for low frequencies, the mid/far stack correlation is weaker, highlighting a decrease in similarity between mid and far stacks as confirmed on the seismic data. This low frequency mismatch across angles results in a lack of lateral continuity on the inverted relative Vp/Vs, and masks the reservoir response R2. Figure 5 shows 1D QCs at the well location for demultiple A (top) and B (bottom). The comparison between real and synthetic traces for the full bandwidth (left) shows that the level of residuals (in yellow) is comparable for both demultiple. However, reservoir R2 is not seen on the Vp/Vs. The explanation for this discrepancy is provided by the low frequency information (middle panel). Demultiple B shows a phase shift with angle which biases the AVO gradient. This leads to a wrong estimate of Vp/Vs and a high level of residuals from the inversion on the low frequencies (colored in yellow). Either frequency panels or (mini-) inversions can be used as QC; however, full bandwidth seismic data, dominated by the central frequency, is not sensitive enough to these errors.

Conclusion

In this paper, we have outlined a strategy to monitor the processing quality of broadband seismic data so that it is better suited for quantitative interpretation on delivery. We have proposed new ways to assess the data quality early in the processing sequence, such as at the demultiple stage and just prior to migration. These QCs may require additional (offline) pre-processing of the data, such as macro-binning and gather flattening. Low frequency QC is particularly suited to identifying processing issues and can be done with frequency angle-stack correlation displays or with relative inversions to Vp/Vs. Whilst monitoring the quality of the pre-stack data with AVO compliancy across the full bandwidth is a step in the right direction, further thought must still be given to monitoring signal preservation. Work in this direction is ongoing.

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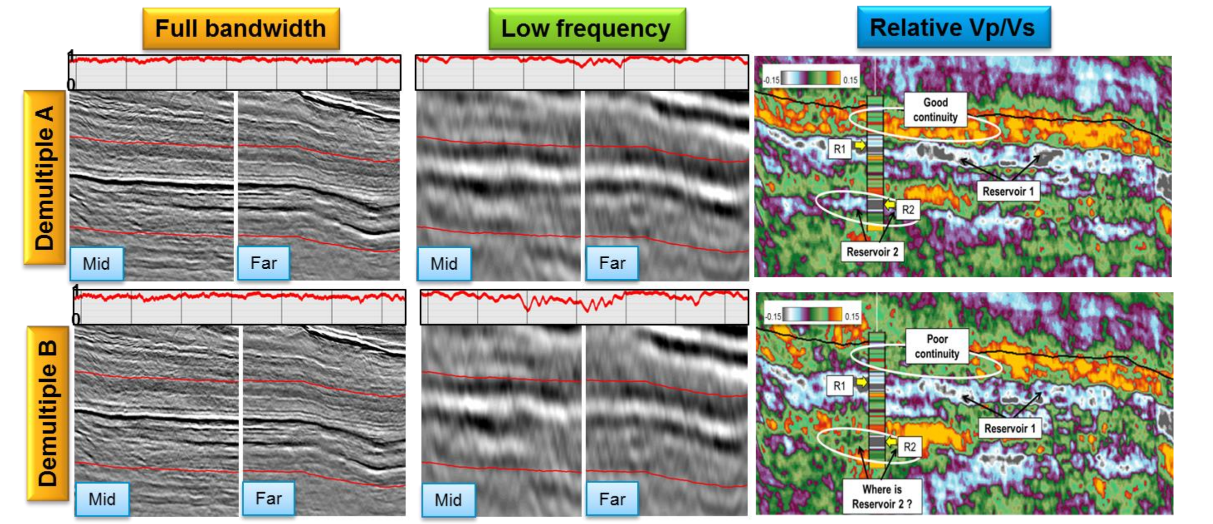

Figure 4: Low frequency QC for two demultiple sequences (top and bottom row). Left: Composite Mid and Far stack for the full bandwidth data and their correlation (top red). Middle: Same as Left for low frequency data. Right: Vp/Vs attribute from pre-stack inversion on the same time window as the stacks, with the embedded well value. Red lines on the seismic indicate the window used to calculate the correlation.

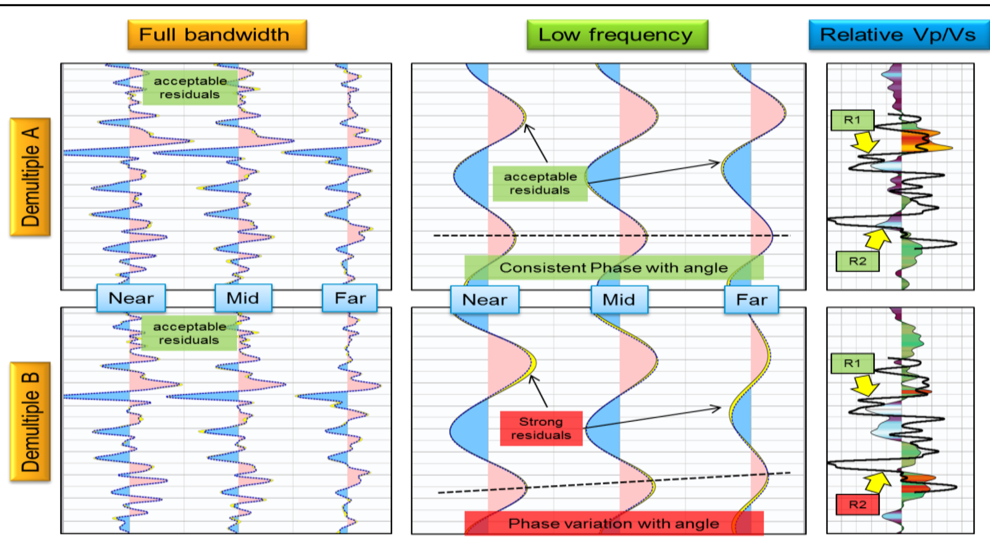

Figure 5: Low frequency QC at well location for two different demultiple tests (top and bottom row). Left: Near, Mid and Far traces for the full bandwidth data (colored curves) overlaid with their respective inversion synthetic traces (dashed lines). The discrepancies between the two set of traces (i.e inversion residuals) are highlighted in yellow. Middle: Same as Left for low frequency data. Right: Vp/Vs attribute from pre-stack inversion (colored curve) overlaid with the well value (dark line)

EDITED REFERENCES

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