Seismic quality monitoring during processing

Alexandre Araman1* and Benoit Paternoster1 present the fundamentals behind QQC and SQM and illustrate the benefits and limitations of the method with different case studies.

Reservoir characterization is often used to guide field developments and therefore requires the ‘best’ seismic data possible. Furthermore, at the end of the data processing, one should make sure that the propagating wavelet has constant properties: its amplitude, phase and bandwidth should remain as stable as possible across the area and target depth interval. There is therefore a trade-off between the wavelet’s ‘best’ characteristics required and its stability. These conditions also apply to the incidence and azimuthal angle dimensions of the dataset for dedicated reservoir characterization workflows. To ensure that a processing sequence will lead to a dataset that meets the above-stated requirements, adequate quality control should be performed at numerous key processing stages. First, desired directions for improvement should be defined with the interpreter and translated into the relevant seismic attributes. Attributes which can be mapped are privileged, so that the lateral variations of the wavelet characteristics can be visualized, confronted with other interpretative information and, hopefully, its stationary behavior quantified. Then, milestones should be set at relevant steps of the processing sequence to quantify the selected attributes with intermediate migrated 3D seismic volumes. Finally, relative scores can be established to monitor the ongoing processing quality improvement and to eventually compare it with a vintage dataset if available.

Introduction

‘Preserved amplitude’ is usually the term assigned to seismic datasets especially processed for the purpose of quantitative interpretation to serve the objective of reservoir characterization. This label usually covers different practices varying among different operators and service companies. Often, the processing workflow avoids modules that supposedly harm the data integrity. Nevertheless, the level of noise or impact of the overburden may force the use of such modules. In the end, ‘preserved amplitude’ processing workflows are the result of a compromise between the use of such modules to reach the required signal quality (noise level, bandwidth, maximum frequency….) and the stability of the wavelet needed for proper interpretation and consistent reservoir characterization. The basic requirement for reservoir characterization is that the data are processed in a way which ensures – as much as possible – that the underlying propagating wavelet has near-constant properties (amplitude, phase and frequency) as it combines with the subsurface elastic properties to form the seismic response. This is the precondition to get seismic data whose variations can be interpreted and quantified in terms of geological and property changes. This requirement also applies to wavelets propagating at different angles of incidence or along planes of different azimuths.

Therefore, monitoring the quality of seismic data being processed should aim at quantifying such wavelet characteristics and their lateral variations at different processing stages to minimize the risk of using inappropriate modules and verify the convergence towards the objectives assigned to the (re)processing.

Quantitative Quality Control (QQC) is the process of measuring the desired improvements using appropriate predefined seismic attributes. Seismic Quality Monitoring (SQM) is the application of a QQC procedure at several processing stages to verify and quantify the progress of the data processing and to insure the overall convergence towards the desired data quality. Both QQC and SQM are challenging tasks since it is often difficult to objectively assess the quality of a dataset without being attracted by specific features present in the data whose appearance may depend on the precise nature of the display or even its colour coding. Seismic-to-well tie is the only technique which allows the extraction of the propagating wavelet without any prior hypothesis. Unfortunately, despite its deterministic nature, this technique is often unstable, especially at early processing stages and is subject to errors: approximate time-to-depth laws, incomplete set of acoustic logs, limited logged intervals are the major causes of uncertainties as rightly explained by White et al. (2003). The parsimonious nature of well data is also a limitation when one comes to qualifying the stationarity of the wavelet’s characteristics. Hence, there is a definite need for metric and redundant representations of those characteristics measured across the entire 3D survey, mapped over the area of interest and summarized into simple statistics.

Such a seismic monitoring approach has already been successfully applied within Total on numerous seismic reprocessing projects where definite improvements were needed.

1 Total E&P.
* Corresponding Author, E-mail: alexandre.araman@total.com
and have been obtained (Araman et al., 2012; Paternoster et al., 2012; Kusuma et al., 2010; Brahmanio et al., 2011). This paper aims at presenting the fundamentals behind QQC and SQM and at illustrating the benefits and limitations of the method from different case studies.

**What to measure?**

As exposed by Araman et al. (2012), the first step of QQC is to define the key objectives of the (re)processing project. They depend on the type of seismic reservoir characterization workflow that is needed (e.g. post- or pre-stack? azimuthal or not?). They are to be defined based on past experience with vintage data, if any. Active involvement of asset interpreters is necessary much beyond the general desire of getting the ‘best’ seismic dataset with the highest possible resolution. Calibration and lack of stationarity issues leading to poor inversion results should be discussed and illustrated. This is a unique opportunity during which unavoidable trade-offs should be highlighted and weighted such as time resolution and signal-to-noise ratio or multiple target intervals for example. Processing geophysicists and interpreters should work hand-in-hand to set realistic goals by keeping in mind for example that harsh multiple attenuation parameters might affect the amplitudes of the primary events and/or that a resolution enhancement might lead to a deterioration of the signal-to-noise ratio. As a result of this discussion, general directions along which improvements in processing are expected are chosen. In the more general case of wide-azimuth seismic data, one can consider up to five major directions:

1. **Signal quality** focuses on the seismic wavelet intrinsic characteristics (frequency, phase and amplitude).
2. **Lateral consistency** is of major importance (especially in land data) and enables one to identify areas with unsatisfactory static standard or low resolution and/or signal-to-noise ratio (SNR).
3. **Pre-stack consistency** guarantees the feasibility of further reservoir studies such as seismic inversion for vertical and lateral properties mapping.
4. **Azimuthal consistency** guarantees the feasibility of Amplitude-Versus-Azimuth (AVAz) studies for fracture analysis.
5. **Interpretation relevance** is generally linked to seismic-to-well tie, and incidentally to fault interpretability (on coherence attribute maps for example).

Attributes corresponding to these five directions shall be detailed later in the text.

The second step is to effectively define the QC attributes relevant to each one of the selected directions. To best achieve this objective, one should understand the geological specificities in order to design a suite of dedicated attributes that suits the given seismic dataset (the chosen QC attribute might depend on the available offsets/azimuths, seismic bandwidth…) and responds to the processing defined objectives (monitoring the seismic response of thin sand beds will require different QC attributes than for carbonate platforms). They should also be selected such as they highlight the various issues that were previously encountered. Spatially extensive and statistically redundant QC attributes that solely rely on seismic data itself are needed to laterally and vertically monitor the evolution of the seismic signal throughout processing. Integration with an interpretation workstation of these attributes is of paramount importance in order to allow their mapping and overlaying with any other interpretative or cultural information.

During the third step, attributes are effectively computed on available seismic volumes in the making. The computation is done directly within the interpretation platform. When vintage data are available, the same computations are performed and results examined for their relevance. This is the opportunity to refine the choice of attributes by removing over-redundant ones or completing its suite. Optimization and automation of the general workflow to save execution time and data manipulation can be sought for the very first time it is applied. Some interpretation platforms offer the possibility to script sequences of numerical operations and save input parameters; this is a definite advantage for repeated operations.

The fourth step consists in an appropriate processing of the extracted QC attributes. Each one of them maps raw measurements in a given unit (ms, dB, Hz…) or dimensionless ratio. This single value measurement should then be harmonized through a scaling or function that turns it into a number that increases when the processed result improves. This value is further normalized to the reference or vintage processing (using a baseline of 100).

Once the above-mentioned steps are successfully implemented, the QQC workflow can be summarized as follows: in a given direction, (a) one computes the chosen attributes on the different available angle-stacks (incidence and/or azimuthal) and for the different defined objective windows. The raw measurements are then (b) weighted according to their relative quality (for example, an angle-stack noisier than the others will receive a lower rate) or importance (an objective more important than the others will receive a higher rate), (c) harmonized, (d) aggregated with other harmonized measurements belonging to the same direction, (e) normalized and (f) finally reported to the seismic quality referential (usually represented on a spider plot).

**How to measure?**

Now that we have defined the major steps of QQC, we will study in details different seismic attributes useful to properly measure the improvements required from a successful processing.
Further, one can also compute on the one hand, the ratio of the time distance between the first trough and the main peak of the autocorrelation function to the time distance between the first zero-crossing and the main peak of the autocorrelation function (ΔT1/ΔT0), and on the other hand, the peak-to-trough magnitude ratio of the autocorrelation function (A1/A0) (see Figure 3). This measurement is independent of absolute amplitudes and frequency values and is only a characteristic of the shape of the signal. Broadband signals are located in the lower-left corner of the (ΔT1/ΔT0; A1/A0) domain, while narrowband signals are located in the upper-right corner of this space (see Figure 4). As already introduced by Araman et al. (2012), the Bandwidth Index (BI) of a seismic dataset is defined as the Euclidean distance between the barycenter of the measurements in the (ΔT1/ΔT0; A1/A0) domain and the point corresponding to a pure sinusoid waveform (2;1). Theoretically, the smallest value possible for the BI is 0 corresponding to a pure sinusoid waveform and the largest value possible is
The lateral stability of the signal in phase is obtained by computing the dominant phase of the signal along a regional, isolated and slowly varying horizon. The snap from the reflector’s main peak to the maximum of its envelope is used to compute the signal’s instantaneous phase (see Taner et al. (1979), for definitions). We then smooth the phase using a weighted window whose size is larger than the corresponding Fresnel zone (typically 500 m). The non-stationary phase is obtained by subtracting the stationary phase from the initially computed dominant phase. The standard deviation of the non-stationary phase is an indicator of the lateral stability of the signal in phase: the higher the standard deviation, the larger the dispersion and the more unstable is the signal in phase. Such a phase-related measurement can be replicated for all available angle stacks at different milestones of the processing workflow as illustrated in Figure 5.

\[ SNR[i] = \frac{XC_m[i]}{AC_m[i](1+a) - XC_m[i]} \] (1)

where \( i \) is the i-th trace of the seismic cube, \( XC_m[i] \) is the cross-correlation maximum averaged over a group of \( Ni \) and \( Nc \) traces centered on the i-th trace, with \( Ni \) and \( Nc \) being the dimensions of the averaging operator expressed in inline and cross-line respectively, \( AC_m[i] \) is the autocorrelation maximum of the i-th trace and \( a \) is the whitening factor. One should closely monitor the SNR throughout the processing making sure that the SNR mean value increases and its standard deviation decreases throughout the overall processing workflow.

**Lateral consistency**

The main assumption behind seismic interpretation is that the wavelet is spatially invariant so that the observed seismic fluctuations can be interpreted as geological variations. As stated by Paternoster et al. (2009), the lateral consistency of the signal should be checked through the lateral stability and homogeneity in amplitude, phase and frequency characteristics. The signal’s lateral stability in frequency is defined as the standard deviation of the distribution of the trace-to-trace resolution estimates. The higher the standard deviation, the higher the dispersion, the more unstable is the signal in frequency. In the case presented in Figure 2, the deviation of the resolution attribute is clearly larger for the vintage dataset than it is for the reprocessed dataset indicating that reprocessing achieved less lateral variability i.e. more stable wavelets. At the same time, we saw in section 3.1 that wavelets were globally of poorer resolution. This illustrates the benefit of quantifying and monitoring datasets along more than one direction to highlight pros and cons of the various data under investigation: Do we want to achieve higher resolution at the expense of more lateral variability? Do we want to favour lateral stability at the expense of vertical resolution? These are questions to be addressed with the end-user of the dataset. QQC allows us to highlight how some of objectives assigned to the reprocessing project might be incompatible. Depending on the final destination of the dataset, the answer to these questions could be different: higher resolution would probably be favored in the case of a structural or stratigraphic project whereas wavelet stability would be privileged for quantitative work such as seismic inversion.

The lateral stability of the signal in phase is obtained by computing the dominant phase of the signal along a regional, isolated and slowly varying horizon. The snap from the reflector’s main peak to the maximum of its envelope is used to compute the signal’s instantaneous phase (see Taner et al. (1979), for definitions). We then smooth the phase using a weighted window whose size is larger than the corresponding Fresnel zone (typically 500 m). The non-stationary phase is obtained by subtracting the stationary phase from the initially computed dominant phase. The standard deviation of the non-stationary phase is an indicator of the lateral stability of the signal in phase: the higher the standard deviation, the larger the dispersion and the more unstable is the signal in phase. Such a phase-related measurement can be replicated for all available angle stacks at different milestones of the processing workflow as illustrated in Figure 5.
AVA consistency
In many geological environments, reflectivities at different incident angles are expected to correlate at a high level due to the fact that most reflectors exhibit contrasts in Poisson's Ratio that are either small or naturally correlated to the contrasts in acoustic impedance through rock physics. Under such an assumption, the shape of the cross-correlation function of two angle stacks derived over a long enough time interval (e.g., >500 ms) qualifies the relative difference between wavelets propagating at different angles of incidence (Paternoster et al. 2009). It serves the purposes of (a) quantifying the overall resemblance between angle data after normalization to statistical correlation values, (b) evaluating the overall quality of the pre-stack gather flatness via estimates of gross time mis-alignment between angle stacks and (c) underlying wavelet signal mis-handling through relative phase rotation estimates. As these computations are carried out on a trace-to-trace basis, the attributes can be mapped and the corresponding distributions characterized by first and second order statistics.

These cross-correlation functions are first normalized by the product of the root mean square (RMS) amplitudes of each one of the two input angle stacks to represent statistical correlation values. When performed on synthetic seismic data, such correlation values are very high (usually higher than 80%). Computation performed on real seismic data often shows much smaller correlation values. This is due to the imperfections of real data such as uncorrelated noise or time and phase mismatches between angle-stacks. The higher the correlation value, the more consistent the seismic angle-stacks are. Nevertheless, except in the shallow sections of deep offshore data, the correlation should not exceed 90%, which might then be an indication of cosmetic post-processing steps designed to artificially boost the apparent quality of pre-stack gathers at the expense of smearing the offset/angle amplitude variations. On the other hand, a correlation of less than 50% should be considered as a killing factor for AVA based exploration or pre-stack amplitude inversion studies since it indicates a high level of noise in the pre-stack data. Correlation maps for the same vintage and reprocessed datasets as those of Figure 2 are compared in Figure 6. Reprocessing achieved more AVA-consistent angle stacks than vintage data. This is a likely consequence of the reprocessed dataset having a more restricted higher frequency content than the vintage one. This case is an illustration of how QC attributes can be related one with another. Scrutinizing data along multiple directions with different attributes bring insights into its characteristics.

Another key element is the dispersion of the time-shifts between angle-stack within the same significant time

![Figure 5](image_url)

*Figure 5* Dominant phase maps for different angle stacks (S1 to S5) and at three different milestones (steps 1 to 3) of a land data processing project. The vintage data are represented in the first row. Note the difference between the vintage and reprocessed data. Throughout the reprocessing steps, homogeneity between angle stacks and lateral stability are greatly improved.

![Figure 6](image_url)

*Figure 6* Correlation values are mapped for comparison between vintage (A) and reprocessed (B) data. Their respective distributions are indicated on the right of the figure.
interval. Time-shifts are estimated as the time lag at which the maximum correlation occurs. They should normally have a mean value close to zero if the angle-stacks have been properly aligned. Their dispersion is evaluated from the standard deviation of the measured time-shifts. This standard deviation value describes the stability and homogeneity of the time-shift between angle-stacks i.e. how well focused are the seismic reflectors. The expectation is that geological events are probed by seismic stacks at the same time. This is also a global control of the NMO or focusing quality. The higher the mathematical inverse of the standard deviation, the more stable are the time-shifts.

Furthermore, the relative phase-rotations between angle-stacks computed within the same significant time interval are also a good indicator for QQC. Their estimation is based on the instantaneous phase value at the maximum envelope of the same cross-correlation function computed on a trace-to-trace basis between two angle stacks as above. They should normally have a mean value close to zero. Their dispersion is evaluated from the standard deviation of the measured phase-rotations. This standard deviation value describes the stability and homogeneity of the phase-rotation between angle-stacks. The lower the standard deviation, the more stable are the phase-rotations. The expectation is that geological features are probed by seismic through the same propagating wavelet. It is therefore important that the wavelet embedded within the near and far angle stacks be of identical phase to allow quantitative comparison.

Such a statistical assessment should also come to support wavelet choices at the time of seismic-to-well ties. More specifically, it is not uncommon to derive wavelets from quantitative seismic-to-well ties that have different shapes or phases from one well to another. Wavelets extracted from different angle stacks for the same well may also be quite different. The statistics of relative phase differences measured between angle stacks brings additional constraints to the process of tying the well to pre-stack data.

Because the NMO correction applies a time-shift that itself is a function of time, the NMO correction stretches the trace in time. The same applies to imaging processes. The seismic signal of far angles is therefore naturally stretched in time compared to that of the near angles. In the Fourier domain, this can be seen as a relative loss in high frequencies and a slight gain in the lower frequency end of the seismic signal (not to be confused with genuine attenuation). The amount of stretch induced by this seismic processing step is a function of the incidence angle. For angle stacks, it can be approximated by the ratio of the cosine of the near and far stack central angles. Unless the pre-stack dataset went through a dedicated frequency harmonization processing step, significant differences between the effective and theoretical stretches might indicate a corruption by multiples, a poor handling of the signal frequency characteristics, or more simply the use of an inconsistent offset-to-angle transform. To verify this last point, one should analyse the stretch maps together with the resolution maps, or even cross-plot these two attributes maps. Effective to theoretical differences can be used as a basis quantifying data quality.

Finally, based on the relative angle-stacks amplitude values, a regression is computed and the global misfit residual energy between the measured amplitudes and their Shuey (1985) approximation is evaluated. For n angle-stacks (n>2), and a mean angle-stack angle of \( \theta_i \), regressions with 2 (linear regression) or 3 terms (non-linear regression, generally used for large (>40°) incidence angles) are computed based on the following formulas respectively:

\[
A_i(0)=A+B.\sin^2(\theta_i) \\
A_i(0)=A+B.\sin^2(\theta_i)+C.\sin(\theta_i).\tan^2(\theta)
\]

The coefficients A, B and C are respectively the intercept, gradient and curvature of the regression. For each angle-stack, the deviation from the regression curve is computed on a sample-to-sample basis and RMS amplitude of all the input angle-stack errors can also be computed and analyzed as a 3D volume. An AVO compliant workflow should converge towards decreased deviation values.

**AVAz consistency**

Following Boelle et al. (2009) and given a set of azimuthal stacks, seismic amplitudes at consecutive azimuths can be viewed as successive samples of a periodic signal over \( \pi \) azimuth and thus be uniquely decomposed as a Fourier series (see Figure 7):

\[
R(\phi_i) = \sum_{k=0}^{\infty} [u_k \cos(k \phi_i) + j v_k \sin(k \phi_i)]
\]

where \( u_k \) and \( v_k \) are linear combinations of the input azimuthally stacked seismic data. For reasons of symmetry, the azimuth series is \( \pi \) periodic. The 1/\( \pi \) harmonic (k=2) corresponds to a sinusoidal behavior which is equivalent to Rüger’s (2002) linearization in \( \sin^2(\phi-\psi_{sym}) \), where \( \phi \) represents the source-receiver azimuth and \( \psi \) the symmetry plane azimuth (the AVAz fit to an ellipse is an approximation to Rüger’s (2002) linearization. As discussed by Araman et al. (2012), for small incident angles, the first harmonic module:

\[
r_1 = \sqrt{u_1^2 + v_1^2}
\]

becomes a function of Rüger’s anisotropic gradient ‘Bani’ as in Downton, 2011, while the first harmonic argument:
improvements. Finally, AN is a measure of the contribution of other azimuthal variations, be it alternate models or noise. It should be interpreted (and reduced throughout the processing) together with other attributes (non-stationary azimuth and aspect ratio maps) to identify areas of high azimuthal noise.

**Interpretation accuracy**

Borehole data can be used and integrated in QQC to better calibrate and qualify the processing workflow. Both log reflectivities and corridor stacks should be used to extract the most representative wavelet to be utilized for synthetic traces generation. The synthetic traces are then compared to the actual seismic traces; the higher the correlation, the better the calibration. The amplitudes of the wavelets extracted at different wells also provide the basis for quantifying amplitude fidelity of the dataset.

**When to measure?**

The SQM procedure requires a full QQC to be applied at each ‘problematic’ processing stage. As seen in the previous section, a QQC stage requires the computation of several seismic attributes on several 3D pre-stack or post-stack migrated volumes including incidence angle-stacks, azimuthal stacks and full-stack volumes. In total, and depending on the reservoir characterization objectives, a dozen of seismic attributes computed using up to 12 migrated volumes are needed per full QC stage. Therefore, one should not have too many stages in order not to spend a tremendous amount of time analyzing dozens of volumes, and on the other hand, very few output stages can be insufficient to properly monitor the response of the main processing modules. There is therefore another tradeoff between the time spent analyzing the attributes and the number of processing outputs needed to perform a proper SQM. In effect, this can result in five or six output stages for a complex land processing project.
harmonized and normalized if a vintage dataset is available. It is for the processing geophysicist and the interpreter together (a) to choose the appropriate seismic attributes needed based on the predefined objectives since one cannot optimize all the seismic attributes (first tradeoff), and (b) to choose the outputs to be used for a QQC since time-wise one cannot apply a QQC after each processing module (second tradeoff).

Case studies

We applied internally in Total SQM on three different projects (see Figure 10). Example A is an onshore thin gas-bearing sandstone reservoir. Example B is offshore thin gas-filled turbidites and example C is an onshore oil-filled carbonate reservoir. A and B are fields under development, while C is a producing field (Paternoster et al. 2012). These three fields feature three different reservoir characterization issues.

Sandstones of example A are too thin to be resolved and can only be imaged via Poisson's ratio elastic parameter obtained from pre-stack inversion. Seismic data in the area is affected by heavy ground-roll whose characteristics depend on variable near-surface conditions. The vintage processing tried to maximize the high-frequency part of the spectrum in the data in order to optimize resolution. The final result was too noisy to be used for pre-stack inversion. Reprocessing was undertaken and SNR improved to optimize pre-stack AVA consistency and lateral stability instead of maximizing the resolution. This was reflected in the choice of parameters to be quantified: there was a tradeoff between high-resolution / low SNR and low-resolution / high SNR and the low-resolution / high SNR option was chosen by the processing geophysicist and the interpreter to obtain a dataset suitable for pre-stack inversion. Resolution (direction 1) was dramatically reduced while a better ground-roll attenuation allowed the preservation of the lower end of the spectrum, and therefore a larger bandwidth (direction 2) allowing an overall better interpretability. The improvements relative to SNR (direction 4) and AVA consistency (direction 6) (bundling angle stack correlations and 2-term AVO misfit) yielded much better inversion results and therefore a better detection

Figure 8 shows the main QC stages usually required in a land processing workflow. The output follows the modules that are believed to harm the signal characteristics. Therefore, we usually recommend having a first output pre-deconvolution for reference, a second output post-deconvolution (and eventually post surface-consistent amplitude compensation), a third output post random noise attenuation (RNA) and a fourth output post-3D (or 5D) regularization. All these four sets of volumes are migrated post-stack and usually consist of one full stack volume, four to five angle-stack volumes and four to six azimuthal stack volumes. A fifth pre-stack migrated set of volumes is generally required post-PSTM and a final set of pre-stack migrated volumes is to be planned after the post-processing modules that are believed to be ‘amplitude preserving’. For each of these six output stages, a QQC should be performed using a suite of seismic attributes based on those presented in the previous section. The measurements should then be

Figure 9 Seismic cross-sections corresponding to example C and comparing vintage datasets (A) with different processing stages: right after deconvolution and surface consistent amplitude corrections (B), after 5D regularization (C) and finally after pre-STM (D).
of thicker sandstones. Seismic detection is a notion mixing both the frequency content (more precisely its higher end impacting the data time resolution) and SNR. It was found in this case that the benefit from improving the SNR overcomes the reduction in resolution. Furthermore, seismic phase variability (see Figure 5) became much more stable (direction 5) allowing more stable wavelet extraction for seismic inversion (direction 3). Overall, most of the quantified parameters in example A showed improvements at early stages of the processing which gave confidence in the outcome of the project.

Example B reservoirs are amalgamated sand sheets, best defined using AVA or pre-stack inversion. The analysis compares newly processed time and depth migrated datasets to a vintage dataset processed several years ago. The seismic data acquired in the area were very noisy and the new reprocessing did not do better than the vintage one in terms of lateral consistency (direction 1). Furthermore, the signal quality was just slightly improved (direction 2). Nevertheless, AVA consistency (direction 3) was greatly improved, especially after depth migration, thanks to a better handling of shallower velocity anomalies. Finally, the various pre-stack datasets were evaluated on their ability to provide the most significant AVA contrast between the gas and brine bearing zones. This led to the introduction of a ‘fluid sensitivity’ parameter (direction 4) and only one PSDM dataset (with internal mute applied) was better than the vintage dataset along this direction.

Example C corresponds to a heavily karstified carbonate platform. This is the case used in Figures 2 and 6. It is described in Araman et al. (2012) and Tverdokhlebov et al. (2012). Resolution, bandwidth and SNR contributed to the signal quality direction (direction 1). Although AVA (direction 3) did not provide measurements contributing to the reservoir description (we do not expect a clear AVA response in carbonate reservoirs especially when lacking long offsets), it was only used for the purpose of data quality evaluation. Unfortunately, this reprocessing did not prove to be superior to the vintage dataset along these two directions. On the other hand, AVAz was needed for fracturation analysis. It had been attempted on the vintage dataset but with many interpretation ambiguities. The new reprocessing improved the overall isotropy of the azimuthal dataset (direction 4) and local anisotropic behaviours were interpreted with confidence relative to a fairly isotropic background. The lateral stability of the wavelet characteristics also improved (direction 2) while seismic-to-well ties (direction 5) did not record any noticeable differences. In conclusion, the wavelet’s XY stability, AVA and AVAz consistencies progressively improved throughout the processing sequence leading to a final dataset of better quality compared to the vintage dataset in terms of signal consistency, structural image (see Figure 9) and azimuthal consistency. On Figure 9, the improvement is visible (but not quantifiable based on seismic images) between processing stages but less obvious between vintage processing and PreSTM. QQC is needed for a quantitative comparison between (A) and (D) output. Seismic-to-well ties were insufficient to monitor the processing evolution, while
the SQM approach showed dramatic improvement in some important directions (see Figure 10).

**Conclusion**

QQC is an effective way of objectively comparing several seismic datasets. The number and choice of attributes used for QQC is made by the processing geophysicist together with the interpreter, is project dependent and is the result of a trade-off established to improve some parameters at the expense of others. The objective should be stated upfront and all parties (operators and service companies) should work together to achieve these goals. The parameters are selected according to the reservoir characterization objectives based on the problems spotted on the vintage dataset. SQM consists in running QQC after several sensitive processing modules. The choice of these modules is made by the processing geophysicist, should properly be explained to the service companies and is also the result of a tradeoff since more than six outputs might lead to important delays in the processing project. It should be stressed that the described method is too heavy to be used for testing processing parameters. It does not substitute conventional testing. Early stages of QQC can help selecting the most relevant areas for testing.

However, should there be an unexpected regression in one of the defined directions, a rerunning of the last processing stage with different parameters or a change of processing module or approach should be considered. This method helps validating the main options of the processing workflow or adjusting to some unexpected difficulty. At the end of the processing, there should be no surprise: the quality of the processed dataset is known and graded; it is ready for Quantitative Interpretation (QI) or Seismic Reservoir Characterization (SRC) studies coming next.

**Acknowledgments**

The authors are grateful to the management of Total for permission to publish this paper.

**References**


