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# DATA CONDITIONING AND ITS IMPROVEMENTS ON THE PRESTACK INVERSION: A CASE STUDY FROM THE XINGMA AREA, CHINA

CHUNYAN FAN [1], YUANYIN ZHANG [2], MINGWEI SUN [3], MO CHEN [3] and
XUEFENG JIANG [4]

[1] *China University of Petroleum Beijing, Beijing, P.R. China. fcnxnr@163.com*
[2] *Oil and Gas Survey Center, China Geology Survey, Beijing, P.R. China.*
[3] *PetroChina Daqing Oil field Company, Daqing, P.R. China.*
[4] *PetroChina Liaohe Oil field Company, Panjin, P.R. China.*

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## ABSTRACT

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Seismic data used for prestack inversion and corresponding reservoir characterization should be of high quality, while any undesired prestack seismic phenomena that need to be diminished prior to inversion could possibly suppress the real geology. In an effort to improve the seismic data quality of Xingma area, Liaohe Oil field, China, data conditioning is used in this paper to optimize the match between the synthetic data, used in the prestack inversion, and the real data. The conditioning processes include multiple removal, random noise attenuation, and gather flattening. As the offset increases, the raw amplitudes of target area initially change from weak to strong, and subsequently from strong to weak. But after data conditioning, the amplitudes change from weak to strong. This kind of AVO anomaly is coincident with the synthetics. A comparison of wavelets extracted from four angle stacks found the amplitude and phase spectra of conditioned data to be much more stabilized in 0-42Hz. After data conditioning processing, the average RMS amplitude ratios of inversion residual to seismic demonstrate at least 20% drop in the amplitude, while the inverted Vp/Vs attribute shows a much more compact signature, providing a significant improvement on the accuracy of prestack inversion and corresponding reservoir characterization.

KEY WORDS: data conditioning, prestack inversion, multiple attenuation,
reservoir characterization.

## INTRODUCTION

Although AVO (Amplitude Versus Offset) inversion analysis has become a standard procedure in seismic interpretation and reservoir characterization, it is severely influenced by the input prestack data quality. The traditional data processing technology that is beneficial for structural prospecting may degrade reservoir characterization. The impact of processing on reflection could possibly depress or destroy the effect of AVO. Castagna (2001) discussed the myriad of factors that affect seismic reflection amplitudes, the importance of prestack noise suppression techniques and its influence on AVO analysis. In fact, almost every seismic data acquisition and processing step brings changes to reflection in a certain form, and the waveform of reflection is damaged unavoidably as a result of accumulations of these changes (Wang et al., 2009).

As the combined interpretation and processing for the end goal that accurately characterizes the reservoir and produces the highest resolution data that matches the true reflectivity in time and offset (Cook et al., 2016), data conditioning focuses on the removing of artifacts from both acquisition and processing, and provides the most interpretable AVO data possible. However, each technique selected during the conditioning process needs to be carefully estimated so that noise can be suppressed without biasing or corrupting the reflectivity variation with offset (Yu and Liu, 2012). Skidmore et al. (2003) took the CRP (common reflection point) data apart into three primary elastic components using amplitude decomposition, and measured the accuracy of input data. Singleton (2008, 2009) applied a series of conditioning processes to address signial-to-nosie ratio (SNR), offset-dependent frequency loss and gather alignment. Liu (2013) discussed the effects of Structural Filter and Trim Statics on AVO inversion. Zhang et al. (2014) developed a three-step workflow to perform data conditioning and especially attack “hockey sticks” at far angles. Estrada et al. (2015) proposed the target-oriented data conditioning process and applied it in an unconventional case. Though the conditioning processes are substantially complicated depending on the data quality, it is generally recommended to analyze and compare the AVO background of the seismic and synthetics at well locations and apply an appropriate angle scaling to compensate (Estrada et al., 2015).

The structural pattern and deposition configuration in the Sha 3 Member of Xingma area, Liaohe Oil field in China are complicated and variable due to multi-period tectonic pressures (Gao et al., 2007). Besides, because of complex surface conditions, poor acquisition and processing, some strong coherent multiples as well as random noise are always present in the CRP gathers after prestack time migration (PSTM), and some coherent events in far offsets are not horizontal either in this area. Therefore, pre-stack inversion is seldom acceptable. To improve the gather quality, three conditioning processes are chosen in this paper: (1) multiple removal, (2) random noise attenuation, and (3) gather flattening. The correlation degree between gathers with synthetics is chosen as the QC standard of the conditioning procedure. Furthermore, the raw and conditioned data are inverted respectively, and their differences in intermediate products at each stage in the inversion workflow are measured. In particular, these measurements are mainly focused on four aspects: (1) gather quality (in terms of signal to noise ratio (S/N) and the reflection consistency, etc.) and AVO characteristics; (2) wavelets; (3) inversion residuals; and (4) pay delineations.

## CONDITIONING METHODS

### Multiple removal

Firstly, a method named parabola radon transform developed by Hampson (Hampson, 1987) is used to remove multiples. This method assumes that all the coherent signals within a gather can be modeled as a linear combination of a series of parabolic shapes of constant amplitude. Since it is usually applied to NMO-corrected data, the primary events should have a moveout of about 0 ms, while any multiples having positive movement can be removed.

### Radom noise attenuation

Noise existed in seismic data can be roughly divided into random and coherent, so that the random noise remaining in this area after conventional processing and former coherent multiple removal should be seriously considered. To destroy the random, uncorrelatable energy component, the 3D Edge Preserving Smoothing method (Albinhassan et al., 2006) is chosen in this case. This method works on 3D gathers by first separating with the AVO signature of the gather, then performing the dip scanning in a running window on all traces surrounding the target trace to determine the dip with the greatest semblance. Once the local dip is determined, correlation coefficients of all surrounding traces are calculated along the local dip. Edge detection is performed by eliminating correlations below a user-specified amount, thus preserving discontinuities such as faults. The remaining trace samples are then summed in a Gaussian filter after they have been normalized and weighted with their respective correlation coefficients.

### Gather flattening

The measured gathers used for pre-stack inversion should be flattened, because the AVO theory is constructed based on the basic assumption that the reflectors being measured are horizontal. The two basic strategies to realize gather flattening might be termed “velocity-based” or “statics-based”. Velocity-based methods assume that non-flat reflectors are caused by residual NMO, and thus can be corrected by high resolution estimation of the 2nd and 4th order RMS velocity field (Swan, 2001). Statics-based methods assume local velocity perturbations on the seismic ray path causing random undulations in gather reflectors. These cannot be removed using an overall velocity field, so they are treated as static errors (Hinkley et al., 2004; Gulunay et al., 2007). The "statics-based" approach (Singleton, 2009) minimizes a least-squares ($l_2$ norm) error in a reflector by determining a local statics shift on each gather traces is used in this paper.

# RESULTS

## Gathers & stacks comparison

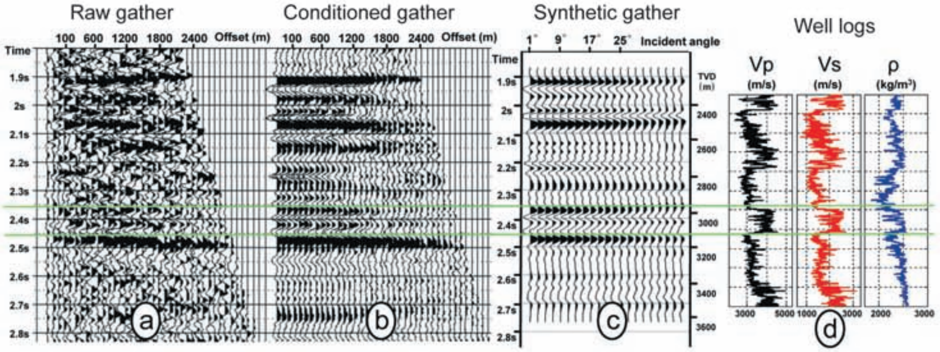

Fig. 1. Raw (a) and conditioned (b) gathers, synthetics (c) as well as well logs (Vp: P-velocity; Vs: S-velocity; ρ: density) (d) at the well L182 location. Ricker wavelet with the dominant frequency of 25 Hz (same to that of seismic data in the target layer) was used for modeling. The AVO anomaly characteristic after conditioned processing is similar to the synthetics in the interesting reservoir zone indicated by two red lines.

Given the well-known assumptions of a prestack inversion, acceptable data conditioning will result in the following: flat gathers, optimal signal-to-noise ratio (S/N), spatially consistant amplitudes and bandwidth, as well as improved resolution (Estrada et al., 2015). The effort to "ground truth" our seismic data has lead to many techniques for comparison of wireline data with seismic data. The common denominator is the reflectivity series derived from the measurement of elastic parameters in the wellbore. These "elastic data" are direct measurements of the subsurface by wireling tools, and are precise enough to depict the properties at the seismic scale that we are most interested in (Skidmore et al., 2003).

The conditioning methods above have made a significant contribution to gather quality enhancement (in terms of signal to noise ratio (S/N) and the reflection consistency, etc.) and AVO analysis, illustrated by the comparison of raw, conditioned gathers and synthetics at the well L182 location in Fig. 1. This well penetrated good turbidite sandstone reservoirs between 2.35-2.45 seconds, marked by two red lines. The good reservoir always shows high P-, S- velocity and density comparing to that of adjacent shales. The obvious peak (2.35 s) and trough (2.44 s) of seismic wave can be

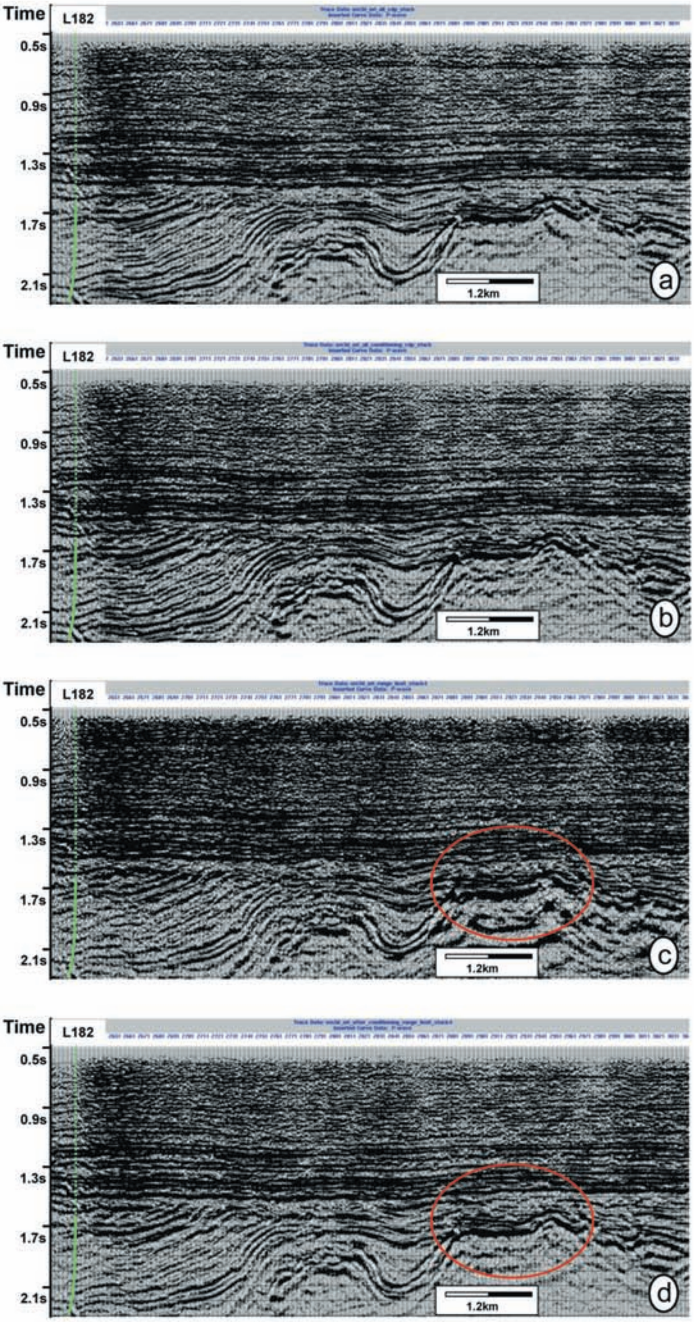

Fig 2. The different angle stacks across the well L182 of raw and conditioned data (a: full-stack raw data; b: full-stack conditioned data; c: 30°-40° raw stack; d: 30°-40° conditioned stack). Although few differences exist in full angle ranges, far angle stacks do really indicate the contaminations made by noise especially multiples (marked by red circles) in raw data.

clearly observed on the top and base of target sandstone reservoirs, respectively. The strong coherent multiples and random noise present in the raw CRP data (Fig. 1a) have been diminished in the conditioned data (Fig. 1b), while the reflection events after data conditioning are relatively more flat. Obviously, the AVO anomaly of conditioned gather are better than that of raw gather and are closer to that of the synthetic. In particular, as the offset increases, the raw amplitudes at about 2.37 seconds initially change from weak to strong, and subsequently from strong to weak. On the contrary, after data conditioning, the amplitudes change from weak to strong, revealing a clear AVO signature coincident with the synthetics. In fact, the core data at about 3015.7 m (2.37 seconds) is siltstone with perfect reservoir quality, which belongs to the most important turbidity deposits, and usually shows Type 1 AVO anomaly in this area.

The extensive difference between raw and conditioning gathers is unclear in the stacks comparsion (Figs. 2a and 2b), because of the stacking process owns the benefit of the S/N ratio. Also this suggests that those data qualified for structural interpretation may be unqualified for prestack inversion. Noise especially multiple contaminations are clearly displayed by comparing far angle (30°-40°) stacks of raw and conditioned data in Figs. 2c and 2d. The effects of noise on far stacks are marked by red circles. This phenomenon also concludes that the raw data in Xingma area acquired and processed previously meet the requirement of structural but not lithologic interpretation.

## Prestack Inversion Comparison

In the first step of inversion, wavelets are respectively extracted from four angle stacks (0°-10°, 10°-20°, 20°-30°, and 30°-40°) for both the raw and conditioned data, based on the principle that their convolution with the well reflectivity series could have the best match with seismic trace. This process is emphasized on the target reservoir layer we researched, and the time windows of wavelet estimation and calculation of seismic-synthetics correlation coefficients are rigorously located at, or near the interesting Sha 3 Member.

Two sets of angle stack wavelets for raw and conditioned data are shown in Fig. 3. The raw wavelets had severe reverberation on their tails, which is due to noise and instability in the seismic data. Besides the wavelet shapes, both the amplitude and phase spectrums for raw estimated wavelets are different. In comparison, data conditioning in this case has relatively reduced the noise contamination and fairly generated much similar and stable wavelets in 0-42 Hz in different angle stack ranges, except for a minor fall-off in the amplitude spectra of far angle stack. This is caused by the shortage of incidence angle information and can be diminished by de-weighting far components during the inversion.

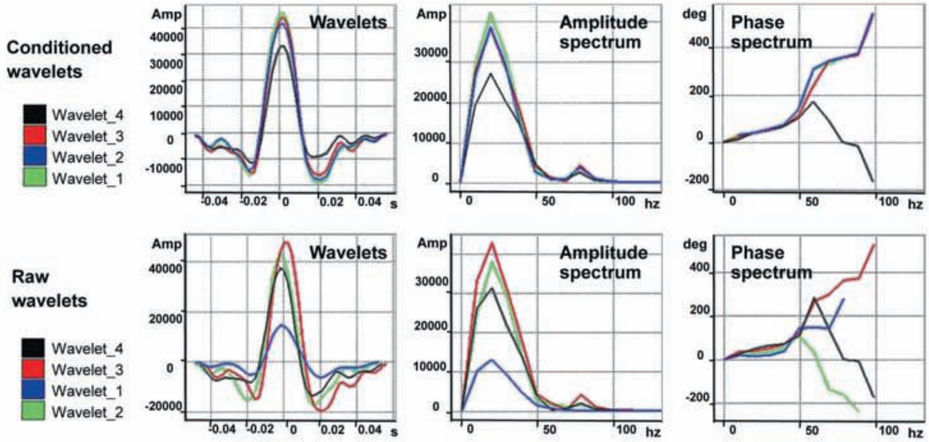

Fig. 3. Raw (lower) and conditioned wavelets (upper) estimated from the four angle stacks (wavelet_1: 0°-10°; wavelet_2: 10°-20°; wavelet_3: 20°-30°; and wavelet_4: 30°-40°).

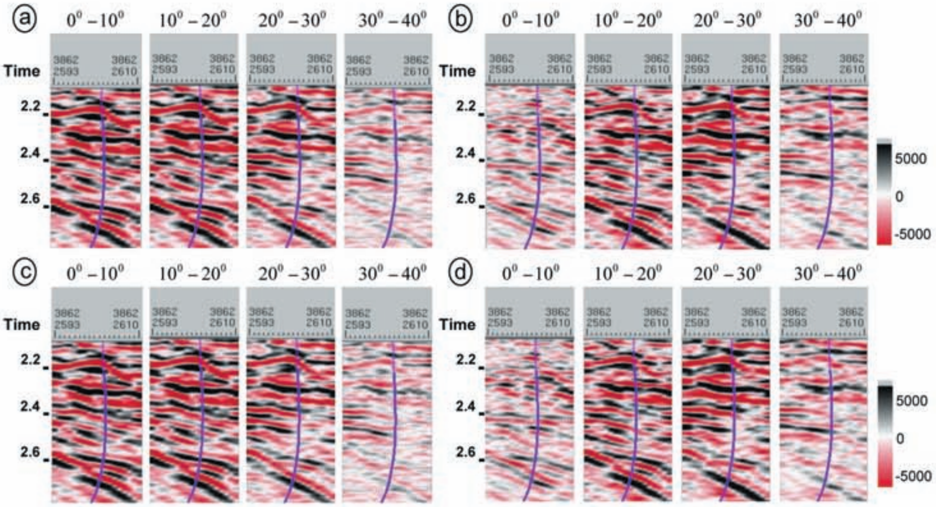

Fig. 4. The comparison between four angle stacks (a: conditioned; b: raw) and inversion residuals (c: conditioned; d: raw).

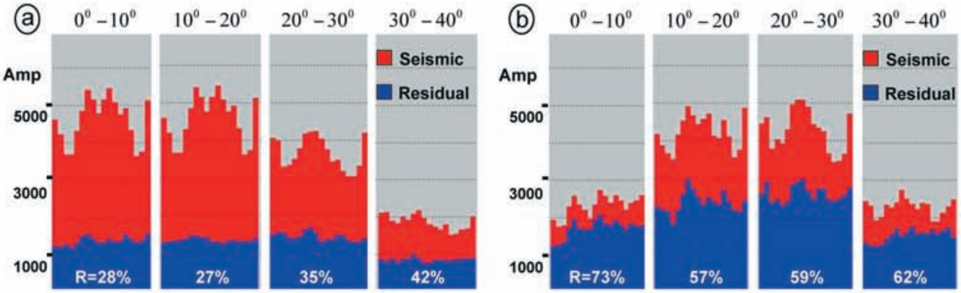

Fig. 5. The residual (blue) / seismic (red) RMS amplitudes of conditioned (a) and raw (b) data at each trace in Fig.4 for four angle stacks. R marked in each pannel is the average RMS amplitude ratios of residual to seismic.

The two sets of angle stacks are respectively inverted to P-, S-impedance and Vp/Vs ratio with the pre-stack simultaneous inversion algorithm provided by JGW (CGG: Geosoftware, 2018) software. A visual comparison of the inversion residuals at different angle stacks for both raw and conditioned data (Fig. 4, on the inline across the well L182) indicates many coherent events still present in the raw inversion residuals, especially in the near angle stacks, while the conditioned invertion residuals are comparably slight and close to a random distribution. Quantitatively, we computed the average RMS amplitude of each trace in the panel of Fig. 4, and used red and blue color to respectively represent the input data and inverted inversion resuduals. We further calculated the total average residual/seismic RMS amplitude ratio for each panel and marked by R in Fig. 5. Notably, through data conditioning application, the average RMS amplitude ratios of residual to seismic in four angle ranges are reduced by 45%, 30%, 24% and 20% respectively.

Fig. 6 illustrates the two inverted Vp/Vs sections from both raw and conditioned data. The most obvious differences were marked by two black

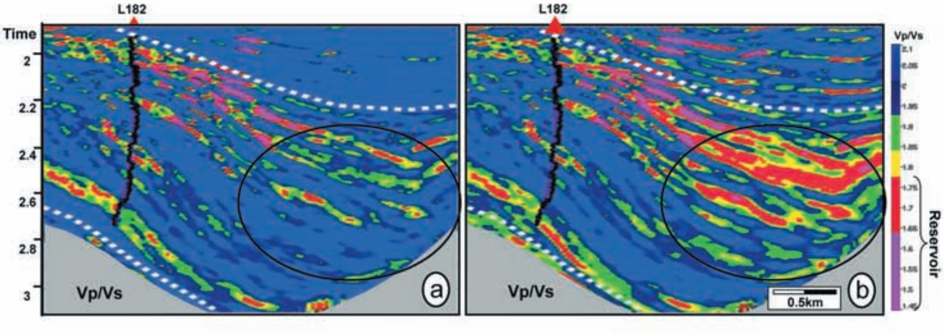

Fig. 6. Comparison of the Vp/Vs inversion results of raw and conditioned data. Wells are shown with P-sonic logs. Sha 3 Member locates at the area between the two dashed lines marked in the picture.

cycles. Obviously, the raw result is contaminated by noise especially multiples, and the predicted reservoir is substantially greater than that of conditioned result. Thus, using the raw data would lead to the overestimate of reservoir.

## CONCLUSIONS

To be able to meet the increasingly stringent demands of reservoir characterization, seismic data need to be carefully checked and conditioned to remove as many undesirable effects as possible. Data conditioning provided a significant impact on the inversion results by improving the accuracy and geologic meaning of the potential reservoir zone. It is generally recommended to appraise the conditioning quality via comparing the AVO background of the seismic and synthetics at well locations. Three data conditioning techniques including multiple removal, random noise attenuation, and gather flattening are verified to be crucial for the data quality improvement in the Xingma area, Liaohe Oil field in China.

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## REFERENCES

Albinhassan, N.M., Luo, Y. and Mohammed, N.A., 2006. 3D edge-preserving smoothing and application. Geophysics, 71(4): P5-P11. doi.org/10.1190/1.2213050.

Castagna, J.P., 2001. Recent advances in seismic lithologic analysis. Geophysics, 66: 42-46. doi.org/10.1190/1.1444918.

CGG: Geosoftware, 2018. https://www.cgg.com/en/What-We-Do/GeoSoftware.

Cook, D., Constance, P., Singleton, S. and Harris, P., 2016. Introduction to special section: Seismic data conditioning. Interpretation, 4(2): SGi-SGi. doi.org/10.1190/INT-2016-0314-SPSEINTRO.1.

Estrada, J., Aaron, P. and Eden, R., 2015. Target oriented data conditioning for prestack inversion in an unconventional reservoir, a Canadian case study. Interpreation, 4(2): SG11-SG18. doi.org/ 10.1190/INT-2015-0149.1.

Gao, X.Z., Li, X.G, Li, J.S, Shan, J.F, Xie, Y.B. and Liu, B.H., 2007. Sandstone distribution pattern and the exploration of lithologic reservoirs in the Es_3 member of Xinglongtai area, Liaohe Depression. Petrol. Explor. Develop., 34: 187-189.

Gulunay, N., Magesan, M. and Roende, H., 2007. Gather flattening. The Leading Edge, 26: 1538–1543. doi.org/10.1190/1.2821939.

Hampson, D., 1987. The discrete Radon transform: A new tool for image enhancement and noise suppression. Expanded Abstr., 57th Ann. Internat. SEG Mtg., New Orleans: 141-143. doi.org/10.1190/1.1892134.

Hinkley, D., Bear, G. and Dawson, C., 2004. Prestack gather flattening for AVO. Expanded Abstr., 74th Ann. Internat. SEG Mtg., Denver: 271-273. doi.org/10.1190/1.1839719.

Liu, D., 2013. The effects of prestack seismic data conditioning on AVO analysis. Expanded Abstr., 83rd Ann. Internat. SEG Mtg., Houston: 452-456. doi.org/10.1190/segam2013-1323.1.

Singleton, S., 2008. The effects of seismic data conditioning on pre-stack simultaneous impedance inversion. Expanded Abstr., 78th Ann. Internat. SEG Mtg., Las Vegas: 1506-1510. doi.org/10.1190/1.3059200.

Singleton, S., 2009. The effects of seismic data conditioning on prestack simultaneous impedance inversion. The Leading Edge, 28: 772-781. doi.org/10.1190/1.3167776.

Skidmore, C., Kelly, M. and Ford, D.A., 2003. Quality controlling AVO inversion products: examples of Amplitude Decomposition into rock property contrasts. Expanded Abstr., 73rd Ann. Internat. SEG Mtg., Dallas: 246-249. doi.org/10.1190/1.1817886.

Swan, H.W., 2001. Velocities from amplitude variations with offset. Geophysics, 66: 1735-1743. doi.org/10.1190/1.1487115.

Wang, U., Wang, X.M. and Du, Q.Z., 2009. The impact of processing on AVO and primary waveform extraction for AVO. Expanded Abstr., 79th Ann. Internat. SEG Mtg., Houston: 351-355. doi.org/10.1190/1.3255595.

Yu, J.B. and Liu, D., 2012. An application of structural filter and Gabor deconvolution for AVO processing. Expanded Abstr., 82nd Ann. Internat. SEG Mtg., Las Vegas: 1-4. doi.org/10.1190/segam2012-1472.1

Zhang, B., Chang, D.S., Lin, T.F. and Marfurt, K.J., 2014. Improving the quality of prestack inversion by prestack data conditioning. Interpreation, 3(1): T5-T12. doi.org/10.1190/INT-2014-0124.1.