Practical Understanding of Internal Multiple Identification and Suppression

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Keywords

Internal Multiples, Generalized Primaries, Long-Period Multiples

Summary

The presence of internal multiples in seismic data creates significant interpretive issues; specifically, long-period multiples generate new events while short-period multiples distort the wavelet leading to reduced event resolution. Long-period multiples need to be suppressed. However, a major drawback has been the final validation of the suppression process. "Is the multiple suppression correct?" We present a physical understanding of how short- and long-period multiples manifest themselves in seismic data. This approach is the basis for building step-by-step QC procedures at well locations to validate the various processing stages of multiple suppression. Primary-only and multiple-only 1D synthetics are generated with time-varying wavelets that contain the scattering attenuation associated with short-period multiples.

Introduction

After the invention of the sonic tool in the mid1950s, the synthetic seismogram with primary reflections was introduced by Peterson et al. (1955). Wuenschel (1960) provided the theoretical solution for primary-plus-multiple synthetics, which was followed by numerous articles in the mid1960s advocating different processing techniques to remove multiples. More recent multiple-suppression work has been itemized by Verschuur (2013) and Weglein (2003).

Our approach to multiple suppression is two-fold, we first introduce a method to decompose a multiple-plus-primary synthetic into a multiple-only synthetic plus a primary-only synthetic based on the concept of a generalized primary, which was introduced by Hubral (1980). Then, we simplify the mathematics for estimating 1D multiples from seismic data using concepts developed by Löer (2016) and by Anstey and Newman (1966). In short, a physical understanding of internal multiples and how they relate to well-log synthetics evolves into an efficient process to assist the interpreters during multiple suppression.

Multiple Estimation

The Inverse Scattering Series (ISS) estimate for 1D internal multiples is given by Löer (2016) as

$$d_3^{\mathrm{IM}}(\omega)=\left(\frac{-2i\omega}{c_0(0)}\right)^2\int_{\substack{t_1>t_2\\ t_3>t_2}} D(t_1)D(t_2)D(t_3)e^{i\omega(t_1-t_2+t_3)}\mathrm{d}t_1\mathrm{d}t_2\mathrm{d}t_3$$

where d(ω) represents the multiple and D(t), the seismic data. This triple integral provides an intriguing software programming challenge but does not deliver any physical insight as to how multiples are estimated much less guide the interpreter in a direction to achieve their goals.

To better understand a physical means of identifying and estimating multiples, we examine two practical methods previously developed to estimate internal multiples.

In 1966, Anstey and Newman identified how the autocorrelation function of a seismic trace contains information on the multiple reflection activity in the trace. The energy associated with the primary reflections is contained in the initial time of the autocorrelation function followed by noise coda from internal multiples.

In 2016, Katrin Löer et. al. at The University of Edinburgh implemented the ISS mathematics in support of Anstey's graphical solution. Figure 1 illustrates the means by which internal multiples are estimated by focusing the seismic trace with the negative lag autocorrelation of the trace.

Integrating Examination of Internal Multiples into QC Process Flow

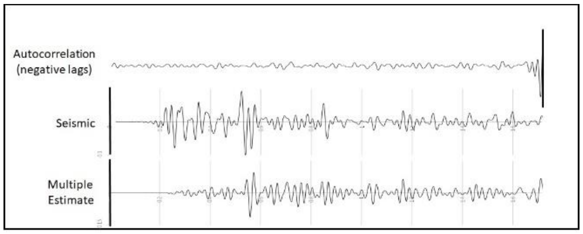

Figure 1. Using the autocorrelation to focus multiples in the seismic trace.

This approach yields an effective means of estimating the internal multiples in seismic data. Further, by applying adaptive subtraction techniques, a version of the seismic data with the long-period multiples suppressed can be produced. The estimated internal multiples and the multiple-suppressed trace are both validated during the QC process.

As previously stated, one of the goals of the interpreter is to QC the seismic data using well logs. To embark on this endeavor, we first refer to a conceptual model of the one developed by Peter Hubral in 1980. Figure 2 is a simplified representation of his model.

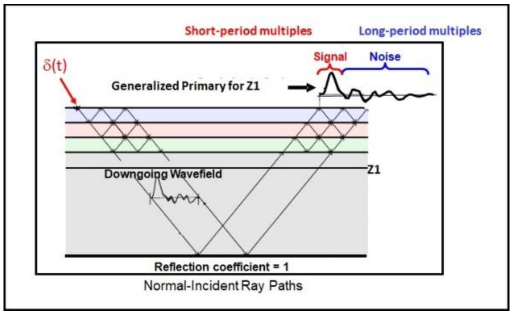

Figure 2. Simplified representation of internal multiples resulting in signal distortion (short-period multiples) and noise coda events (long-period multiples).

The internal multiples are a result of the down-going signal interacting with reflectors to produce noise in the measured response. The added events beyond the signal are categorized long-period multiples while the added events that occur within the period of the signal are short-period multiples, which distort the waveform of the signal. This distortion impacts the apparent arrival time of the primary signal.

The stated objective of performing QC with well logs during the various stages of multiple-suppression processing leads to the generation of 4 different 1D synthetics.

We begin with the Acoustic Impedance log (AI) as a function of time as shown under (A) in the left portion of Figure 3. At a depth of Z_1, we repeat the AI at Z_1 down to a depth of Z_2, where a large variation of AI is introduced. The resulting (A) synthetic due to an impulse source appears in Figure 3.

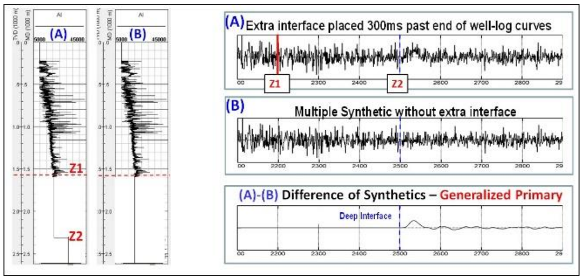

Figure 3. Generalized Primary generated from well log synthetics with and without extra interface.

The response in the synthetic seismogram (A) from Z_1 to Z_2 is the result of internal multiples. Further, the large reflector at Z_2 manifests itself as a low-frequency response with high-frequency noise superimposed. This is Model A.

Next the AI log is repeated but the large AI variation at Z_2 is removed and another synthetic seismogram is generated (Model B). The Model B synthetic without the large interface at Z_2 will only contain multiples below Z_1. In order to visualize just the reflector placed at Z_2, Model B synthetic is subtracted from Model A synthetic (Figure 3) and the result was named a *generalized primary* (GP) by Hubral et al. This generalized primary is associated with the two-way time to Z_1. The extra thickness between Z_1 and Z_2 was added so that multiple bounces between Z_1 and Z_2 were not included in the major portion of the GP. The signal portion of the GP is approximately the first 50 ms from 2500-2550 ms. The peak is delayed by about 25 ms as the wavelet is distorted by short-period multiples. All energy after 2550 ms is long-period multiples.

We now have the tools to create three well-log synthetics in addition to the traditional primaries-only synthetics generally used in the QC process. The versions of the synthetic are:

1. Primaries Only (traditional)
2. Primaries + Multiples
3. GP Multiples-Only
4. GP Primaries-Only

The traditional synthetic involves convolving a stationary wavelet with the primary reflectivity. To produce the other synthetics, the concepts used to describe GP are applied.

The approach is to create a GP at every time sample. This non-stationary catalog of GPs is convolved with the primary reflectivity to produce a synthetic that contains primaries and multiples (Figure 4). This synthetic result is exactly the same as that obtained using Wuenschel’s method (1960).

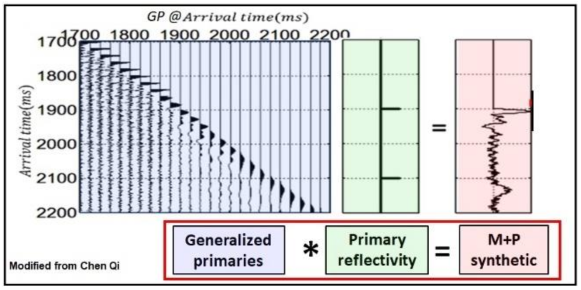

Figure 4. Catalog of Generalized Primaries to create well-log synthetic consisting of multiples and primaries.

Again, note the delay of the deeper reflection at 2100 ms caused by the GPs changing shape due to scattering attenuation. The resulting Primaries + Multiples synthetic (version listed above) will become part of the QC process.

At this juncture, our QC process could consist of migrated seismic data, primaries-only synthetic and a primary plus multiple synthetic. If our seismic data doesn’t have internal multiples, well-ties would be performed on the seismic data with the primaries-only synthetic. If there are internal multiples, then the primary plus multiple synthetic would be applied.

The next QC check is to evaluate a multiple-only synthetic against the estimated multiples from the ISS methodology of Anstey and Löer. For this, we return to the generalized primary model as shown in Figure 4.

We know from earlier analysis that the large lobes running along the diagonal of the generalized primaries represent the primary signal, while the data below represents the long-period multiples. To create synthetics that are multiples only, the signal portion of the generalized primaries are nulled out and we then convolve with the primary reflectivity to generate a multiples-only synthetic which we will term the GP multiple-only synthetic. This concept is depicted in Figure 5.

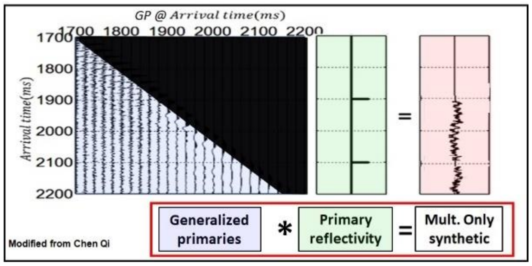

Figure 5. Use of muted GP to create synthetic consisting of multiples only.

The final QC check is the comparison of seismic data with multiples suppressed to the GP primary-only synthetic. To produce this synthetic, the black triangle in Figure 5 would be mirrored so that the long-period multiples just below the signal portion of the GPs is nulled. Then convolve with the primary-only reflectivity to yield the GP primary-only synthetic.

The QC process flow is now defined and the necessary sets of data can be generated to complete the process as shown in Figure 6.

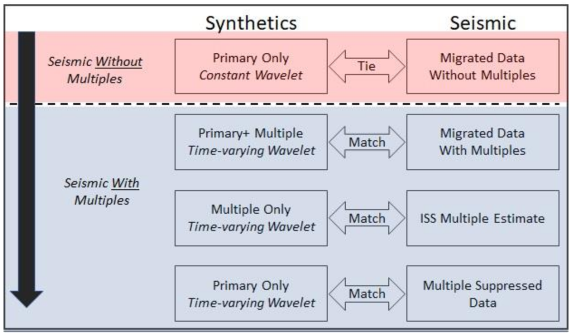

Figure 6. QC Process flow considering seismic data with internal multiples.

Australian Field Data Example

Using well logs from Cooper Basin which traverse the Permian coals, 4 synthetics are produced as described earlier. They include the Primary Only (stationary wavelet) and the 3 GP synthetics: GP Primary Only, GP Multiples Only and GP Primary plus Multiples. These synthetics are shown in Figure 7.

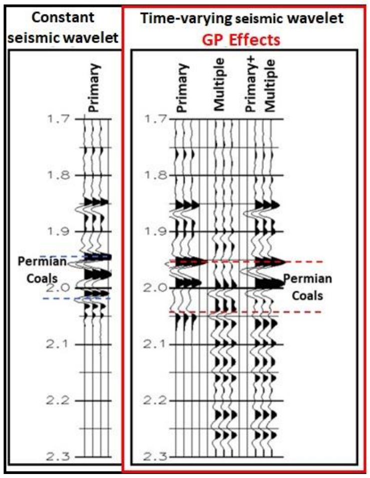

Figure 7. Four synthetics that traverse Permian coal beds.

The first step in our process flow is to attempt to tie the conventional primary-only synthetic to the migrated seismic data and then to match the same seismic data to a GP Primary + Multiple synthetic. In Figure 8, it is seen that the match to the migrated seismic data clearly indicates that the seismic data contains the effects of internal multiples.

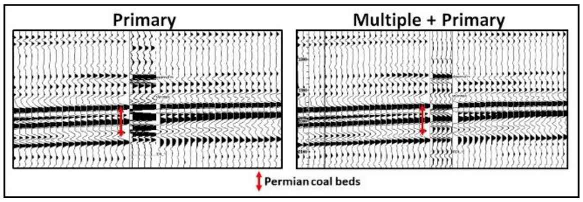

Figure 8. Well tie with constant wavelet Primary and well match with time-varying Primary + Multiple. No stretch/squeeze.

An intermediary step in the process is shown to highlight how the presence of internal multiples can impact the analysis of the seismic data. We take the GP Multiple plus Primary synthetic which we have just shown in Figure 8 to match the migrated seismic data, and gradually reduce the presence of multiples until we are left with our Primary-only synthetic. Figure 9 depicts the seismic field data on the left (Primary + Multiples) and the Primary synthetic on the right. In this figure, the interpreter is tempted to stretch the conventional primary-only synthetic to achieve what would appear to be a solid well tie.

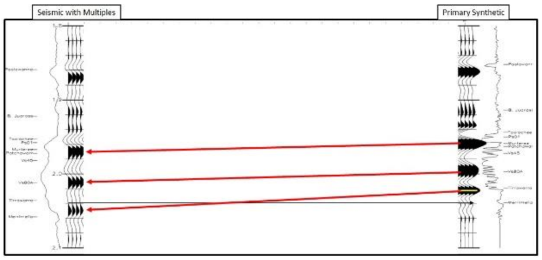

Figure 9. Comparison of Primary synthetic to GP Primary plus Multiple Synthetic.

Before a stretch is applied to the synthetic, we will examine the contribution of the internal multiples by incrementally increasing their contribution as we move from the conventional primary to the GP primary plus multiple synthetic. In Figure 10, the intermediate traces represent an incremental increase of internal multiple contribution from no presence on the right to full contribution on the left.

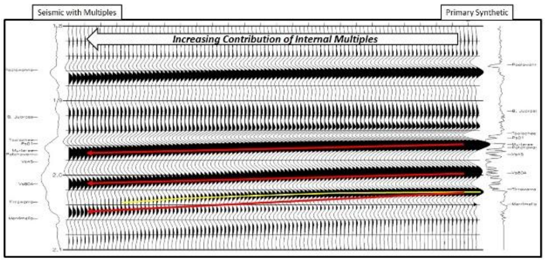

Figure 10. Identification of influence of internal multiples.

The glaring observation from this step is that the event on the seismic data that was originally identified as a primary event around 2.05 seconds (left) is actually a multiple. If standard stretch of the conventional primary synthetic had been performed to tie the seismic data, an incorrect horizon would have been selected by the interpreter.

The next QC step is to match the GP multiple-only synthetic to the ISS multiple estimation of the field data at the well location (Figure 11).

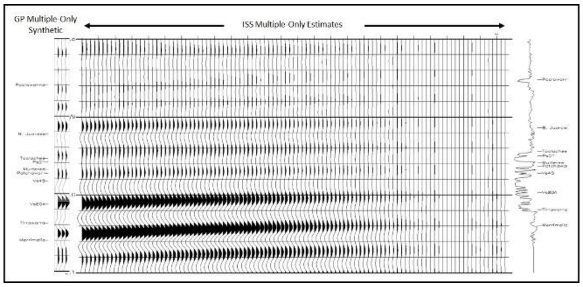

Figure 11. Well match between ISS Multiple Estimate and GP multiple-only synthetic.

This step of the QC process (Figure 11) is clearly validated as the ISS multiple-only estimate from the field data matches the well-location estimate of the multiple only. The final QC step is to match the seismic data with multiples suppressed via adaptive subtraction to the GP primary-only synthetic that has the non-stationary wavelets. The results of this step are shown in Figure 12.

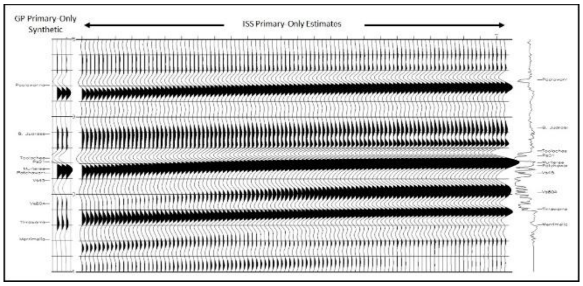

Figure 12. Well match between the GP primary-only synthetic and the adaptive subtraction of the ISS multiples from the migrated field data. Again, non-stationary wavelets are employed.

The final comparison for this field example shown in Figure 13 indicates how the true pick of the base of the coal beds was determined only after application of this QC process. This warns not to stretch synthetics too quickly to get a well match.

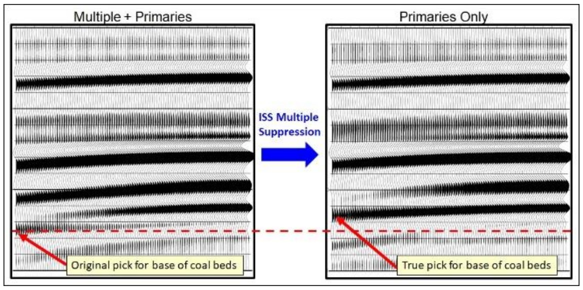

Figure 13. Field data vs. multiple-suppressed field data (primaries-only).

Conclusions

A thorough examination of the physical relationship between internal multiples, seismic data and well logs has been shown to highlight the method for incorporating this analysis into the QC process flow. The creation of 4 versions of seismic synthetics not only results in the ability to examine the impact of multiples within seismic data, but also enhances the validity of the interpreter's evaluation of the data. Failure to identify, estimate, suppress and validate the impact of internal multiples may result in dramatic errors in identifying geologic structures and the presence of hydrocarbons. The tools and techniques have also been shown to fit nicely into the process flow to permit this level of examination in a timely and efficient manner.

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