Understanding stratigraphic filtering effects on interpretation

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Three types of multiples are common in seismic data. Of these, surface-related multiples and long-period internal multiples are suppressed with current processing techniques. The third multiple type, short-period thin-bed multiples introduce difficulties in seismic interpretation that are often not recognized. As an example, the primary-only synthetic in the left panel of Figure 1 might be stretched continuously to match the seismic. However, stretch is unnecessary when internal multiples are added to the synthetic algorithm (right panel of Figure 1). But as will be shown in our presentation, even the right panel in Figure 1 is not a good well tie, as seismic events do not correlate to borehole data. This seemingly illogical statement is our starting point for understanding thin-bed internal multiples or stratigraphic filtering (SF) effects on interpretation.

Figure 1. Synthetic to seismic match. Synthetic algorithm in left panel generates primary-only reflections, while the right panel synthetic generates primary and multiple events.

The seismic in Figure 1 comes from Cooper Basin, Australia which has severe SF effects due to numerous Permian coal beds. Our study area is the Hassi D-Zabat Field in Algeria which contains a mixture of evaporites and clastic sediments from the Cambrian and Ordovician periods. While the SF is not as severe in our study area as that shown in Figure 1, the additional presence of surface and long-period multiples complicates the interpretation. The velocity and density curves displayed in Figure 2 are from a recent well drilled in the Hassi D-Zabat Field. The two expanded depth intervals in Figure 2 will generate reflection coefficients larger than |0.6|. While these two depth intervals generate thin-bed multiples that contribute to SF, there are also relatively quiet intervals (small impedance variations) in this well that will contribute to long-period internal multiples.
We will graphically examine the SF wave propagation effects. As a spike source travels to the reservoirs, which are at a depth of 2km, it travels through numerous high-impedance thin beds and transforms into a front-loaded Gaussian-type wavelet whose spectrum is dominantly below 20-25Hz. However, following the Gaussian signal portion of the propagating wavelet is a noise coda consisting of multiples that have a spectrum greater than 25Hz. The noise portion of the propagating wavelet continues for \( \approx 1 \) s or so. In this basin, when a synthetic with multiples is created as a time-varying convolution with the primary-only reflectivity, the wavelets must be that at least 0.6s in length to match a multiple synthetic to seismic data. A catalog of wavelets that propagate from the surface to specified reflectors and back to the surface illustrates the effects of SF (Figure 3). The wavelets reflecting from shallow boundaries near the surface are displayed on the left side and they remain basically a spike for these shallow reflections, while the wavelets reaching the deeper reflectors are shown on the right side of the figure. The impedance log at the top depicts the geology through which a wavelet passes. In the figure, each wavelet is static corrected to their individual arrival times. Near the reservoirs at TD, the seismic wavelet reflecting from an interface has a signal portion (similar to Gaussian wavelet) that is 50ms in time duration and the low amplitude noise following the signal portion is multiple noise. Obviously, preserving low frequency during acquisition and processing is essential.
Three phases of synthetics are applied to match the seismic data: (1) primary-only, (2) primary plus internal multiples, and (3) primary, internal and surface-related multiples. The comparison between the different synthetics and the near-offset seismic stack, improves from synthetic-(1) to synthetic-(3). With the best synthetic-seismic match occurring when multiples are included. It’s apparent that internal multiple suppression would assist the interpretation. Note, stretch-squeeze operations are not performed when making synthetic comparisons as the synthetic-to-seismic misalignment often disappears as internal multiples are included, such as shown in Figure 1.

For long-period internal multiple elimination by inverse scattering series, a time-varying autocorrelation is needed to estimate the internal multiple periods. However, the internal-multiple period signature in the autocorrelation is often swamped by the signature from the SF noise that is in the transmitted wavelets. This problem is addressed by first separating signal from SF noise in the frequency-time domain (spectral decomposition domain) followed by signal enhancement and then ISS internal multiple suppression.

Lastly, suppression for surface-related multiples requires knowledge of multiple generators. In fact, identification of multiple generators is also a benefit to quantitative interpretation and we approached this task with three methods. The first involves the generation of upgoing, downgoing and total VSP synthetics where the upgoing wavefield assists in identifying multiple events on the near-offset stack. The second approach for identifying multiple generators uses the time-varying wavelets in the wavelet dictionary for time-varying deconvolution. This technology has a secondary benefit if the deconvolved trace after each time-varying step is saved as the process goes from the surface to TD. The process starts with the multiple synthetic and ends when the primary-only synthetic remains. This provides a convenient method to tie seismic data with multiples to borehole data, such as identifying the seismic event on the near-offset stack that corresponds to the top of the reservoir.

Because of the complex interactions between the three types of multiples, de-multiple improvement for areas such as the Hassi D-Zabet Field is still active research and starts with suppressing the SF multiples.

The following are a few observations, developments, and conclusions derived from this SF study that will be discussed in our presentation.
• Time-varying propagating wavelets delay reflection times and have low-frequency signal and high-frequency noise.
• Well-log editing principles need revisiting to ensure correct reflection coefficients. This is essential, as it partially compensates for the array effects of borehole logging sondes.
• For multiple synthetics, the time sample rate is continuously decreased until no significant changes in the synthetic occur.
• Low-frequency synthetics provide robust matches to seismic. As synthetic frequency is decreased, primary-only and internal multiple synthetics begin to have a higher correlation.
• Field data VSP time-depth measurements need adjusting to account for wavelet delay in the upgoing path, which can be as much as 20ms additional delay.
• Estimating multiple generators provides a simple technique to correlate primary-only synthetics to primary-plus-multiple synthetics and thus accurately tie the borehole to seismic.
• Quantitative processing flows and subsequent quantitative interpretation are developed by examining the sensitivity of SF.