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# What is all the buzz about?

*BE is a novel technique for extending the usable bandwidth of seismic data.*

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"I don't have enough bandwidth in my seismic! We had to filter out the low frequencies during acquisition to attenuate the ground roll, and the high frequencies were absorbed during transmission down to my target and back up to the surface. So I am left with data that has only about 15-50 Hz of usable frequency. That might be okay if I were looking for thick sands, but I'm not — my targets are thin, which means I need frequencies up in the 90 or 100 Hz range to have any chance of really seeing them."

This is typical of what we hear from most of our clients these days. Gone are the days when a company could just go out and drill a structure and hope to find oil or gas — most of those structures already have been drilled. Today, most targets are thinner and much more stratigraphic in nature than those we were exploring for a decade ago.

There are hundreds of thousands of square miles of existing 3-D seismic data in places all over the earth. New acquisition methods are available that make it possible to get somewhat higher frequencies (usually about another 15 Hz on the high end), but those are very expensive — and 15-Hz improvement usually is not enough. The ideal solution, then, is to find a method that can extend the spectrum on existing data in a meaningful way. That is where Bandwidth Extension (BE) comes in.

## Recovering a filtered signal

BE is a new approach to obtaining the frequencies needed to image reservoirs. It uses a wavelet transform (WT) to decompose the data into discrete sub-bands and then analyzes the characteristics of the signal, specifically the harmonics, to model missing parts of the spectrum. Some question whether it might even be possible to recover missing frequencies because, as we were all taught in school, if the transmitted wavelet is limited to the lower frequencies, it filters out any higher (or lower) frequencies from the earth reflectivity. This is true, of course, but only in certain types of convolution — not the kind that takes place during seismic recording. The work of Widess (Geophysics, 38, no. 6, 1176-1254, 1973) established that reflectivity as little as one-eighth of a wavelength has an effect and can be seen in the amplitude response of the wavelet. Due to the presence of noise (and reduction in the signal-to-noise ratio) in real life, we often are limited to one-fourth wavelength as the limit of resolution.

Leveraging the fact that the seismic wavelet response reflects information of bed thickness as little as one-fourth of the wavelength, it is possible to use modeling and *a priori* information to "recover" the lost frequencies and resolve very thin beds.

## Recovering lost frequencies

This method involves the modeling of high and low frequencies by computing

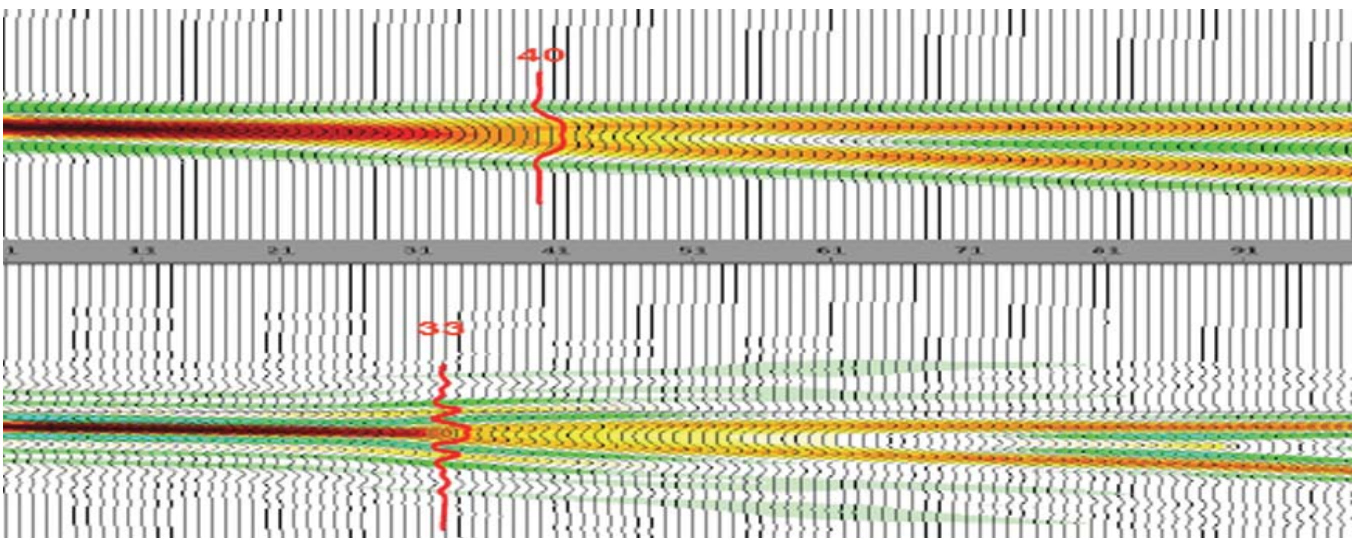


*Figure 1.* *Wedge model before and after BE. Upper plot shows a simple wedge at typical acquired bandwidth. The lower plot shows the data after BE. Note how the "tuning" region shrinks as a consequence of applying BE, allowing resolution of thinner beds. (Images courtesy of Geotrace)*

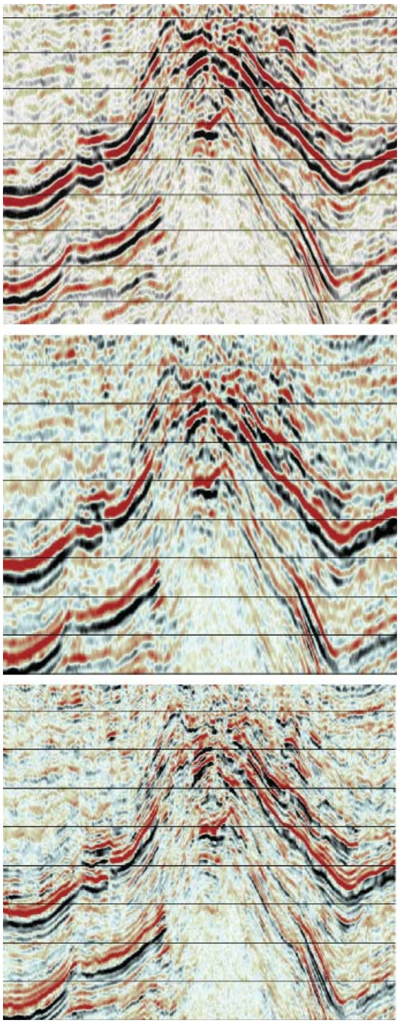

*Figure 2. Salt dome before BE. (top); salt dome after low-frequency BE (middle); salt dome after high- and low-frequency BE (bottom).*

the harmonics and sub-harmonics of the available frequencies in the signal.

Harmonics simply are integer multiples of a fundamental frequency, and sub-harmonics are integer fractions of a fundamental frequency. The fundamental frequencies, in our case, are defined by the recorded bandwidth of the seismic data.

To model these harmonics and sub-harmonics, it is necessary to do some type of time-frequency analysis that defines the fundamental frequency in time. The method chosen for time-frequency analysis is in WT.

WT permits the analysis of a time series in a manner that minimizes the uncertainty in the time-frequency relationship. It turns out that in time-frequency analysis, there always is a tradeoff between the accuracy with which we can measure the frequency of a signal and its exact location in time. The WT, with its non-stationary properties, is the ideal technique for such an analysis.

At low frequencies, WT provides good frequency resolution and poor time resolution, while at high frequencies, it offers good time resolution and poor frequency resolution.

With WT, it is possible to analyze the signal and find the fundamental frequencies and their time relationships. From these fundamental frequencies models of harmonic and sub-harmonic frequencies can be computed and added back. These new frequencies effectively extend the bandwidth of the signal and improve the overall resolution of the seismic data.

## Examples

Figure 1 shows a simple wedge model at a typical acquired bandwidth. Trace 40 on the upper plot shows the limit of resolution of the wedge, at which it is impossible to distinguish the two events. This is called the tuning region. The lower image shows the wedge after BE has been applied on the high end of the frequency spectrum. Note that the tuning region has been pushed back from trace 40 to trace 33.

Figure 2 (top) shows a salt dome from Breton Sound offshore Louisiana before any bandwidth extension was applied. The middle image shows the result of applying BE to the lower end of the spectrum. The increase in bandwidth shows a marked decrease in the "ringy" character evident on the input data in the right image.

Figure 2 (bottom) shows the results after BE has been applied to both the high and low ends of the spectrum. The appearance of sharp minor faults, pinch-outs, thin beds and other features that were unrecognizable in the lower frequency section are evident.

## Discussion

BE has been demonstrated to be possible and fruitful for seismic enhancement and interpretation. Skeptical geoscientists should reevaluate their judgment of such processes in light of the successes demonstrated over the last several years.

The Widess Model suggests that there is seismic reflectivity available below the dominant frequency wavelength. This information can be extracted, resulting in an increase in resolution by adding harmonic frequencies back to the data. Once this is done, many features come to light. All of these features can have a significant impact on data interpretation.

The remarkable feature of this technique hinges on the fact that by using *a priori* information, it is possible to extend the low, the high or both ends of the spectrum simultaneously with the very same technique. There is something extremely satisfying about such a principle that seems to capture the true essence of the physical processes under way.

***Acknowledgments***

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