Amplitude Mapping of Reservoirs in North Africa

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Summary

A good "rule of thumb" criterion for amplitude mapping is to have the quarter wavelength resonance frequency within the band limit of the seismic data. A 20m thick reservoir with a 4000m/s sand velocity would thus require a minimum upper frequency limit of 50hz in the seismic data to allow basic amplitude mapping. Typical recording parameters in the desert areas of North Africa include a sweep with frequencies in excess of 70hz, but the near surface complexities usually limit the useable frequencies of the processed seismic data to below 40hz, reducing the reliability of amplitude mapping in defining these reservoirs.

There are several processing approaches that can be taken to bring the resolution of the seismic data up to the required level, but these have had varying degrees of success because the assumptions of these processing algorithms are often violated by the complexities introduced by the near surface.

An old technology that is readily available coupled with the newer VSP technology has given excellent results in addressing this problem. The basic "match filter" or "transfer function" can be used to match the seismic data to the VSP greatly increasing the resolution of the seismic data to the point that the reservoirs can be mapped by amplitude with a reasonable level of fidelity.

Theory and Method

The near surface in these desert areas consists of unconsolidated dry sand with layers of "hardpan" interspersed at random intervals. The sand is highly absorptive of the frequencies above 35hz to 40hz. This results in a lowering of the amplitude of these frequencies to a level that is beyond the minimum phase assumption for a relationship between frequency and phase. The "hardpan" layers set up complex interbed multiples that impose a resonance effect on the amplitude spectrum of the wavelet and results in further differences from the minimum phase assumptions. The net result is that deconvolution algorithms that rely on the minimum phase assumption, are only capable of producing a stable wavelet up to about 40hz, beyond which the energy is very low and mixed phase.

The deconvolution process of a VSP does not encounter the same problems because the actual down-going wavelet is measured directly and not determined by assumption. The autocorrelation of the VSP wavelet removes all of the phase and produces a theoretically perfect zero phase wavelet. The amplitude spectrum of the VSP wavelet can then be adjusted to any predetermined shape within the bounds of the VSP frequencies, and the resultant wavelet of the VSP can be considered a perfect zero phase wavelet with a known amplitude spectrum.

A “match filter” is a simple convolution filter designed on the difference in phase and amplitude spectra between two wavelets. An operator is designed on this difference and applied to one data set to make it match the other. A seismic trace represents the convolution of a wavelet, in this case a complex and unknown wavelet, with a reflectivity sequence. A VSP trace at the same location represents a “perfect” zero phase wavelet convolved with this same reflectivity sequence. The cross-correlation of these two traces essentially defines the differences in amplitude and phase spectra between the wavelets of these two traces, and an operator can be designed on these spectral differences. Since the VSP has a “perfect” zero phase wavelet, the operator designed on the difference between the two wavelets applied to the seismic data will cause the wavelet of the seismic data to match the wavelet of the VSP.

The net result is the restoration of the upper frequencies to the seismic data and the alignment of these frequencies at zero phase. Intuitively one would assume that this would best be done at the pre stack stage of processing in order to optimize such resolution dependent processes as velocity determination and statics. Match filtering at this stage has met with little success because there are several other variables and factors involved.

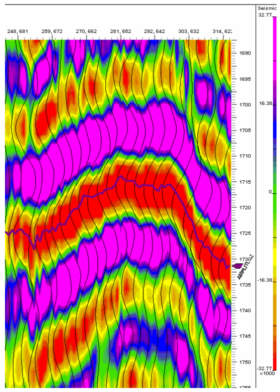
First of all, noise levels are very high at this stage in processing, limiting the effectiveness of the match. There are also many spatial inconsistencies that are addressed by surface consistent processes and the averaging effect of stack. There are also significant variations with depth, and design window becomes a critical factor.

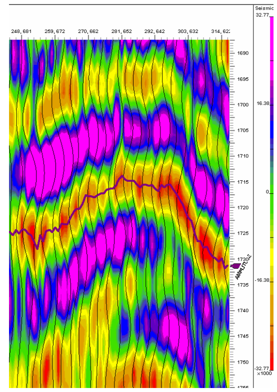
Most of these problems are minimized when the seismic data is fully processed and the best time for the application of a match filter is as a final processing step at the processing center, or as an interpretation process on a workstation. The key to the successful application of a match filter is to interactively optimize the parameters for its application. The three key parameters are the design window, the frequency band limits of the operation, and the amount of amplitude boost that the data will tolerate.

The key diagnostic displays necessary for the successful application of a match filter are the data itself, the cross correlation, and the phase and amplitude spectra displays. The phase spectra display is particularly useful in determining the useable frequency spectrum of the seismic data, because the valid data will exhibit a relatively smoothly varying phase, but the random noise will only show as erratic phase. The cutoff between the useable frequency and the random noise is usually clearly evident on the phase display.

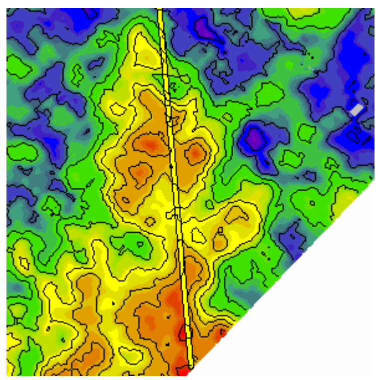
Typically a single optimized match filter is all that is required for an entire 3D survey, provided that the original data is not too variable over the survey area. By aligning the frequencies at zero phase there is usually a significant improvement in signal to noise because this process essentially strengthens the signal but does not enhance the noise, and in particular the low frequency noise.

After the application of the match filter there is generally a significant change in the character of the seismic data and a surprising amount of amplitude detail is now visible. The following is a portion of a seismic line from one of these desert areas before and after the match filter. The section on the left without the match filter applied, shows a nearly constant amplitude compared to the match filtered section on the right, which shows significant amplitude variation.





The following amplitude map was constructed from the interpreted horizon on the match-filtered section. There is sufficient amplitude character to define the mapped feature. The validity of the amplitudes defined by the match-filtered data is demonstrated by the subtle amplitude of the crosshatch pattern of the acquisition overprint that is now visible.



This process can be done either at the processing center as a special volume of the processed data, or on a workstation if this programming is available. The particular advantages of applying a match filter on a seismic workstation are that the process is virtually cost free, and all the data is already available on the workstation.

If there is no VSP available, the process can still be done with similar results using traces from a synthetic seismogram. There is a small amount of additional effort required matching to a synthetic seismogram because the synthetic needs to be stretched and squeezed to compensate for the differences between the seismic velocities and the sonic velocities recorded.

Regardless of whether this is done at a processing center or on a workstation, with either a VSP or a synthetic seismogram as a reference, the matched-filtered seismic data can be brought to an improved resolution level that allows amplitude mapping of reservoirs that was not possible without the match filter.

Conclusions

Most of the resolution problems in desert areas result from complexities in the near surface that cannot be fully addressed by conventional deconvolution.

By using a VSP or a synthetic seismogram as a reference, a match filter can bring the resolution of the seismic data up to a level that allows mapping of amplitudes to define reservoirs.

References

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