III. CURRENT DECONVOLUTION METHODS

A. Direct Methods

The simplest solution to the deconvolution problem assumes that a time window on the seismogram contains only a single event and the wavelet superimposed is the source wavelet. If several recordings are available they can be averaged to reduce the noise component. Given an adequate representation of the source wavelet, a least square spiking filter or Wiener (2) inverse can be designed. This inverse filter when convolved with the sourve wavelet yields an impulse whose duration depends on the resolution obtainable in the presence of noise and the sampling rate.

If f_t represents the inverse filter, then

$$b_t * f_t = \delta(t) \tag{3-1}$$

where $\delta(t)$ is the impulse function. Convolving the inverse filter with the observed seismogram should then yield the reflectivity series as

$$\begin{aligned}(y * f)_t &= [(x * b) * f]_t \\ &= [x * (b * f)]_t \\ &= x * \delta(t) \\ &= x_t \end{aligned} \tag{3-2}$$

In earthquake seismology it is often possible to isolate events because different phases travel different paths through the earth causing their arrivals at recording stations to occur at separated intervals in time. In reflection seismology marker horizons can often be isolated in data recorded on land. With marine data the sea floor reflection is sometimes extracted to represent the sourve waveform. An idea explored by coworkers Estevez and Fulp for marine seismic data was to use the direct arrivals for the source estimate. This failed because the receiver array response varied spatially and was difficult to estimate.

Another simple procedure is to directly record the source waveform. This fails for land data because the near surface waveform differs considerably from that observed at depth. This is due to non-linear effects near the source and the effect on the waveform of passing through the less consolidated weathering layer. In marine environments these problems are not as severe, and the recording of the source waveform is becoming a standard practice (3).

B. Homomorphic Methods

Homomorphic deconvolution is a method first investigated by Ulrych (4) which attempts to separate the wavelet from the reflectivity series in the cepstral domain. It does not require assumptions regarding the phase of the source wavelet or character of the reflection coefficients.

Since convolution in the time domain is multiplication in the frequency domain, taking the inverse transform of the logarithm of the spectrum yields the cepstrum which is the sum of the cepstrums of the reflectivity series and the source wavelet. If the amplitude spectrum of the source is spiky in comparison to that of the reflectivity series, the cepstrums may be separated by high and low time gating.

This method is still in the research stage as problems are associated with the correct unwrapping of the phase of the complex logarithm. A method recently proposed by Tribolet (5) seems to be the best solution to this problem. The handling of additive noise still remains a problem. It has been partially solved by averaging the cepstrums for many seismograms to suppress the noise and reflectivity series. The resulting low time portion of the cepstrum then represents the source wavelet (6).

C. Predictive Methods

Most commonly used for deconvolution are variations on prediction error filtering (7). These methods are derived from four assumptions. First, the reflectivity series is assumed to be white. This is often violated by reflection seismograms as the reflectivities are the result of a differential process being applied to the acoustic impedances. In many sedimentary basins thin beds are present which causes the reflectivity series to be correlated in sign. Inspection of the autocorrelation of a reflectivity sequence derived from a well log will show this sign correlation. Figure 3-1 illustrates this concept. Gapping the prediction error filter generally remedies this problem but causes a loss of resolution.

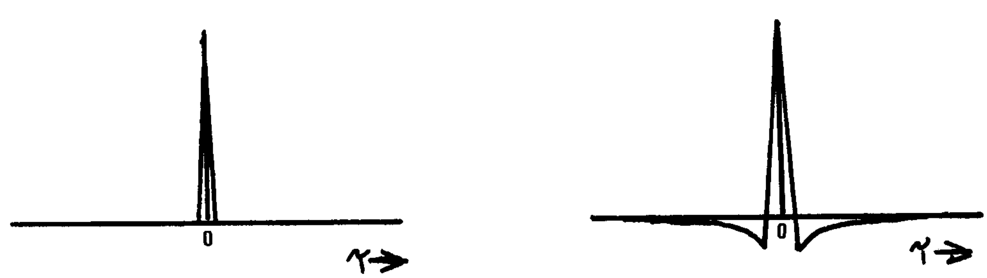

FIGURE 3-1. Idealized autocorrelation functions, white noise on left, reflectivity series on right. τ is the lag time.

The second assumption in prediction error filtering requires the source wavelet be minimum phase, one which has energy occurring as close as possible to zero time while still satisfying the autocorrelations of the observed seismograms. This assumption is valid for several explosive sources, such as dynamite, but for more complicated sources, such as those used in marine exploration, it is only approximate.

The third assumption requires the reflectivity series and noise to be statistically independent and stationary in time. Spherical divergence and attenuation violate the stationary assumption. Adaptive deconvolution methods (8) overcome these violations but these methods often destroy primary events.

A fourth assumption is implicit in estimating the prediction error filter. The least squares criterion which is normally used is appropriate only when the prediction errors (the reflectivity series and noise) have a Gaussian distribution. Statistical tests on several reflectivity series indicate their kurtosis is much higher than that expected for a Gaussian reflectivity series. Use of other criteria for prediction error filtering, such as the L_1 norm, is a subject of current research (9).