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Predictive deconvolution in seismic data processing in Atala prospect of rivers State, Nigeria

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ABSTRACT

Predictive deconvolution is the use of information from the earlier part of a seismic trace to predict and deconvolve the latter part of that trace. In processing procedure, the information recorded in the field is put into a form that most greatly facilitates geological interpretation. Predictive deconvolution is an attempt to attenuate multiples which involve the surface or near-surface reflectors. The prediction filter was designed which yields the predictable component (the multiples) of a seismic trace, while the remaining unpredictable part, the error series is essentially the reflection series. The shaping filter so designed is used to convert the recording signature to its minimum-phase equipment and apply it to the input record. The output has been processed by predictive deconvolution using operation length of 160ms and prediction lags. When the data from the field are fully processed, geological interpretation could easily be harnessed. The various stages, procedure and figures are shown clearly. The theory of predictive deconvolution of processing was exhaustively discussed. The unprocessed data got from the field operations are fed into automatic computer whose programme is written in line with the theory.

Keywords: deconvolution, prediction lag, prediction filters, autocorrelation, Cross correlation, desired input.

INTRODUCTION

The basic objective of all seismic processing is to convert the information recorded in the field into a form that most greatly facilitates geological interpretation. One objective of the processing is to eliminate or at least suppress all noise in form of reverberation and multiples (Egbai and Ekpekpo, 2003).

Predictive deconvolution is the use of information from earlier part of a seismic trace to predict and deconvolve the latter part of that trace. Some types of systematic noise, such as, reverberation and multiples can be predicted. The difference between predicted value and the actual value is called the prediction error; it is sensitive to new information such as primary reflections. Predictive deconvolution may also be used in a multitrace sense, where one tries to predict a trace from neighbouring traces. It is also an attempt to attenuate multiples which involve the surface or near-surface reflectors.

The Levinson principle generally can be used to compute recursively the solution of linear equations. It can also be used to update the error terms directly. This is used to do single-channel deconvolution directly on seismic data without computing or applying a digital filter. (Milton and Bjorn 2007).

The Wiener prediction filter has been an effective tool for accomplishing dereverberation when the input data are stationary. For non-stationary data, however the performances of Wiener filter is often unsatisfactory. This is not surprising since it is derived under the stationary assumption (Wang, 2006). According to Wang, the result of applying the Wiener prediction filter adaptive predictive deconvolution on non-stationary data indicate that the adaptive method is much more effective in removing multiples. It has been found by him that the output trace from the adaptive predictive deconvolution is rather sensitive to some input parameters, and that the prediction distance is by far the most influential parameter.

Zhang et al, (2009) arrived at a conclusion that : (1) In trace gather, the move out of multiple is changeable and to remove multiples in entire trace gather, the selection of predictive length must take far traces into account; (2)Predictve deconvolution to remove multiplies not completely same as other process of enhancing resolution, and it is difficult to attenuate multiple exactly using a very short predictive length;(3) The length of predictive operator must be larger than the period of multiple, because it may increase fake energy after processing. These were totally in agreement with our findings.

Robinson (2006) computed the transmission energy spectrum as the difference of input energy spectrum and the reflection energy spectrum. This is in agreement with our result. Hence from the computed energy spectrum of the transmitted wave we can compute the prediction-error operator that contracts the transmitted wave to a spike.

Margrave and Lamoureux (2010) are of the view that non-stationary predictive deconvolution compares reasonably well to gabordecon when the prediction distance is in unity. That is not quite as good as gabordecon is attributed to the fact that the deconvolution operators are designed independently rather than simultaneously. Encouraging results were obtained when cascading the algorithm with different prediction lags.

Taner (1980) proposed predictive deconvolution in the tau-p domain as a remedy for the first effect. Later other similar ideas have been tested such as tpredictive deconvolution in the radical trace domain (Perez and Henley, 2000). Margrave and Lamoureux, 2001, Margrave et al, 2004 developed a nonstationary spiking deconvolution in the Gabor domain which has been very successful in dealing with the nonstationary effects of an elastic attenuation.

Other works on this could be seen from the work of very renowned geophysicists such as, Dobrin (1976), Claerbout (1976) and Gibson and Learner (1982)

THEORY

Assuming $x(t)$ is the desired input and $(t+\gamma)$ is the predicted value at some future time, where γ is the prediction lag. It can be shown that the filter used to estimate $x(t+\gamma)$ can be computed by using a special form of the matrix equation shown in equation (1) (Robinson and Treitel, 1980). As the desired output $x(t+\gamma)$ is the time-advanced version of the input $x(t)$, we need to specialize the right side of the equation for prediction problem.

$$\begin{bmatrix} r_0 & r_1 & r_2 & --- & r_{n-1} \\ r_1 & r_0 & r_1 & & r_{n-2} \\ r_2 & r_1 & r_0 & & r_{n-3} \\ , & , & , & & , \\ , & , & , & & , \\ , & , & , & & , \\ r_{n-1} & r_{n-2} & r_{n-3} & & r_0 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ , \\ , \\ , \\ a_{n-1} \end{bmatrix} = \begin{bmatrix} g_0 \\ g_1 \\ g_2 \\ \\ \\ \\ g_{n-1} \end{bmatrix} \qquad (1)$$

If we consider a five-point input time series x_i, where $i = 0,1,2,3,4$ and $\gamma = 2$. The autocorrelation of x_i is computed as shown in Table 1 below.

Table 1: Autocorrelation lags of the input series $[x_0, x_1, x_2, x_3, x_4]$

$$r_0 = x_0^2 + x_1^2 + x_2^2 + x_3^2 + x_4^2$$
$$r_1 = x_0x_1 + x_1x_2 + x_2x_3 + x_3x_4$$
$$r_2 = x_0x_2 + x_1x_3 + x_2x_4$$
$$r_3 = x_0x_3 + x_1x_4$$
$$r_4 = x_0x_4$$
$$r_5 = 0$$
$$r_6 = 0$$

The cross-correlation between the desired output $x(t+2)$ and the input $x(t)$ is shown in Table 2 below.

Table 2: Cross-correlation between output $x(t+2)$ and input $x(t)$

$$g_0 = x_0x_2 + x_1x_3 + x_2x_4$$
$$g_1 = x_0x_3 + x_1x_4$$
$$g_2 = x_0x_4$$
$$g_3 = 0$$
$$g_4 = 0$$

Comparing tables 1 and 2 and noting that $g_i = r_i + \gamma, r = 2$, and $i = 0,1,2,3,4$. Equation

(1) could be rewritten as shown below.

$$\begin{bmatrix} r_0 & r_1 & r_2 & r_3 & r_4 \\ r_1 & r_0 & r_1 & r_2 & r_3 \\ r_2 & r_1 & r_0 & r_1 & r_2 \\ r_3 & r_2 & r_1 & r_0 & r_1 \\ r_4 & r_3 & r_2 & r_1 & r_0 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} = \begin{bmatrix} r_2 \\ r_3 \\ r_4 \\ r_5 \\ r_6 \end{bmatrix} \qquad (2)$$

The prediction filter coefficients a_i where $i = 0,1,2,3,4$, could be computed from equation (2). The actual output could be computed as shown in Table 3.

Table 3: Convolution of prediction filter $\gamma(t)$ with input series to compute actual output $y(t)$

$$y_0 = a_0x_0$$
$$y_1 = a_1x_0 + a_0x_1$$
$$y_2 = a_2x_0 + a_1x_1 + a_0x_2$$
$$y_3 = a_3x_0 + a_2x_1 + a_1x_2 + a_0x_3$$
$$y_4 = a_4x_0 + a_3x_1 + a_2x_2 + a_1x_3 + a_0x_4$$

As we are trying to predict the time-advanced form of input, the actual output is an estimate of the series $x_i + \gamma$, where $\gamma = 2$. The prediction error series is shown in the table below.

Table 4: The error series $\beta_{i+2} = x_{i+2} - y_i$.

$$\beta_2 = x_2 - a_0 x_0$$
$$\beta_3 = x_3 - a_1 x_0 - a_0 x_1$$
$$\beta_4 = x_4 - a_2 x_0 - a_1 x_1 - a_0 x_2$$
$$\beta_5 = 0 - a_3 x_0 - a_2 x_1 - a_1 x_2 - a_0 x_3$$
$$\beta_6 = 0 - a_4 x_0 - a_3 x_1 - a_2 x_2 - a_1 x_3 - a_0 x_4$$

The results of table 4 shows that error series could be obtained directly by convolving the input series with a filter with coefficients $(1,0,-a_0,-a_1,-a_2,-a_3,-a_4)$, as shown in table 5.

Table 5: Correlation of filter coefficients $[1,0,-a_i], i = 0,1,2,3,4$ with input $x_i, i = 0,1,2,3,4$

$$\beta_0 = x_0$$
$$\beta_1 = x_1$$
$$\beta_2 = x_2 - a_0 x_0$$
$$\beta_3 = x_3 - a_1 x_0 - a_0 x_1$$
$$\beta_4 = x_4 - a_2 x_0 - a_1 x_1 - a_0 x_2$$
$$\beta_5 = 0 - a_3 x_0 - a_2 x_1 - a_1 x_2 - a_0 x_3$$
$$\beta_6 = 0 - a_4 x_0 - a_3 x_1 - a_2 x_2 - a_1 x_3 - a_0 x_4$$

The results of table 4 and 5 are identical for $\beta_2, \beta_3, \beta_4, \beta_5$ and β_6 . The series $(a_0, a_1, a_2, a_3, a_4)$, is known as prediction filter and the series $(1,0,-a_0,-a_1,-a_2,-a_3,-a_4)$ is called the prediction error filter. Applying this on the input series, the filter yields the error series in the prediction processes.

The prediction filter yields the predictable component (the multiples) of a seismic trace, while the remaining unpredictable part, the error series is essentially the reflection series (Yilmaz, 1998).

Equation 2 can be generalized for the case of an n-long prediction filter and an $\gamma -$ long prediction lag as shown in equation (3).

$$\begin{bmatrix} r_0 & r_1 & r_2 & --- & r_{n-1} \\ r_1 & r_0 & r_1 & & r_{n-2} \\ r_2 & r_1 & r_0 & & r_{n-3} \\ , & , & , & & , \\ , & , & , & & , \\ , & , & , & & , \\ r_{n-1} & r_{n-2} & r_{n-3} & & r_0 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ , \\ , \\ , \\ a_{n-1} \end{bmatrix} = \begin{bmatrix} r_\gamma \\ r_{\gamma+1} \\ r_{\gamma+2} \\ \\ \\ \\ r_{\gamma+n-1} \end{bmatrix} \quad (3)$$

The design of the prediction filters require only autocorrelation of the input series. There are two approaches to predictive deconvolution. The designed may be carried out using equation 3 and applied on input series as shown in figure 1. An alternative is to design and convolve the input series, the prediction error filter as shown in figure 2.

Figure 3 shows a flowchart for interrelations between various deconvolution filters. It shows that it can be used to solve a wide range of problems and that predictive deconvolution is an integral part of seismic data processing aimed at compressing the seismic wavelet, thereby increasing temporal resolution. Certain assumptions are made in predictive deconvolution during the processing processes. These assumptions according to Yilmaz, (1987) are

(a)(i) The earth is made up of horizontal layers of constant velocity

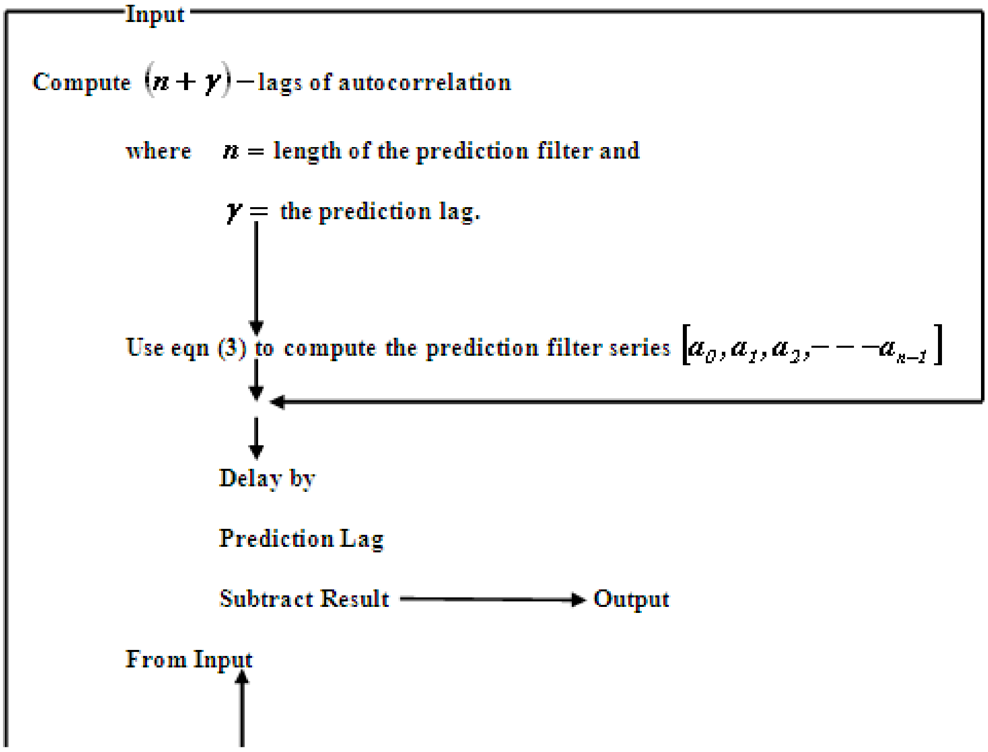

Fig. 1: A flowchart for predictive deconvolution using predictive filters (Yilmaz, 1988).

(a)(ii) Compressional plane wave that impinges on layer boundaries at normal incidence are generated at source. In this case no shear waves are generated.

(b) The waveform source does not change as it travels in the subsurface. This means that it is stationary.

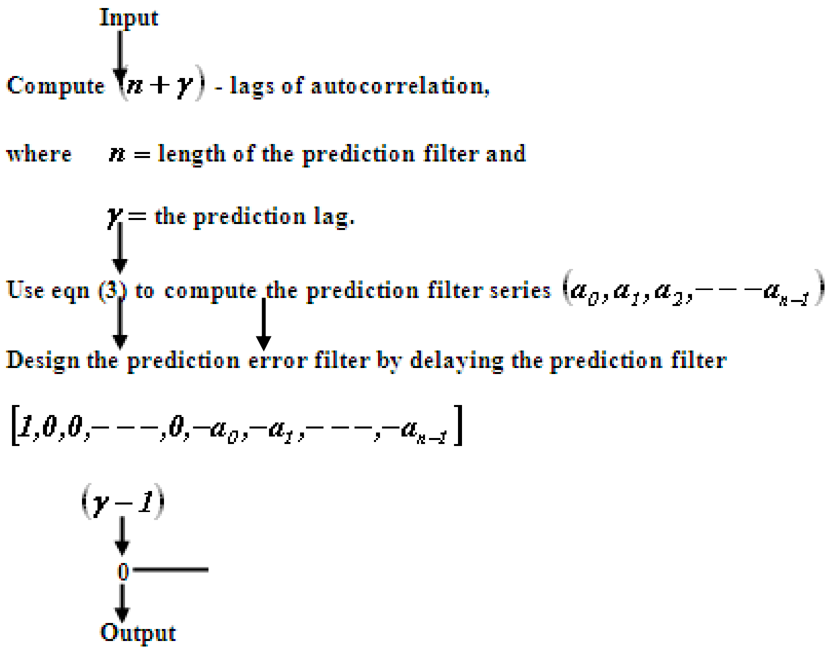

Fig. 2: A flowchart for predictive deconvolution using prediction error filters (Yilmaz, 1988)

(c) The noise component is $n(t)$ is zero.

(d) Reflectivity is a random process meaning the seismogram has seismic wavelet characteristics.

(e) The seismic wavelet is minimum phase since it has a minimum-phase inverse.

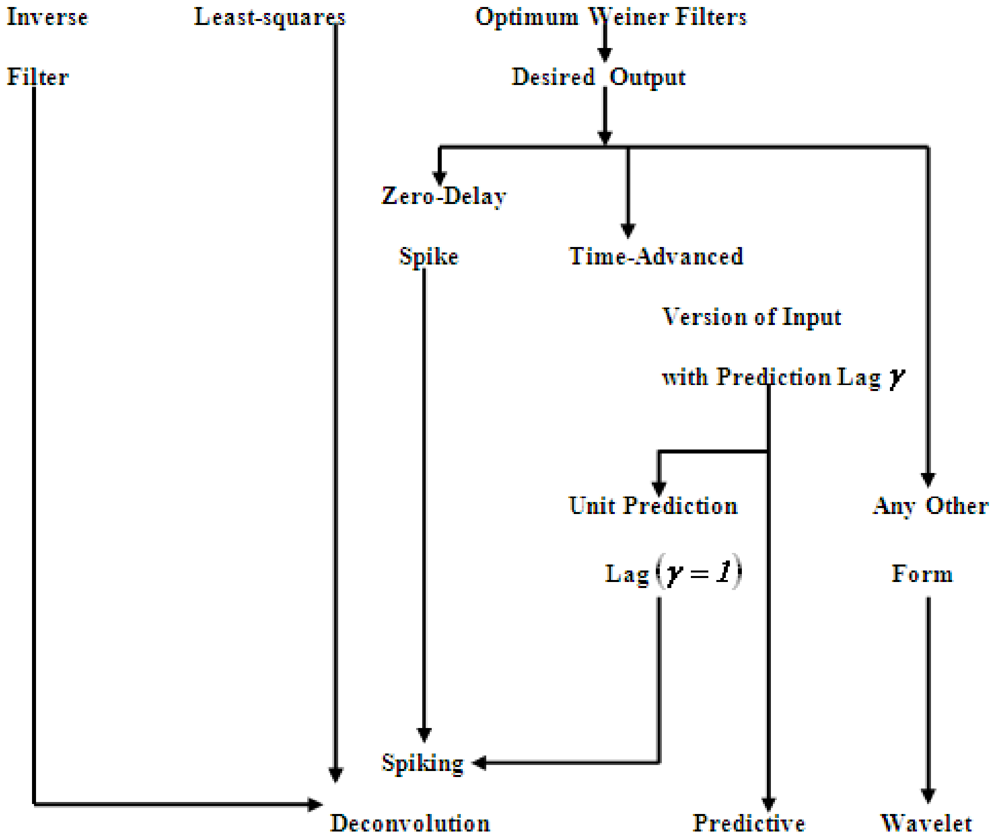

Fig. 3: A flowchart for interrelations between various deconvolution filters (Yilmaz, 1988).

LOCATION

The trans-Atala 3-D prospect where the data were obtained spans a large area of OMLS (Omission Lines) 35 and 46. The total surface area of the prospect is approximately 256 square kilometers. The area is swampy and low-lying with surface elevation gradually rising from 2.28m in the south to 1.98m up north.

The prospect covers Burigbene and Ogbotobo fields. The adjoining communities are Ekurugbene, Bassan, Lobia and so on. These are all in Western Ijaw Local Government Area of Rivers State.

FIELD DATA EXAMPLES AND DISCUSSION

Field data examples are now used to examine the deconvolution parameters. Figure 4 shows a CMP (Common – midpoint) gather that contains five reflection at around 1.1, 1.35, 1.85, 2.15 and 3.05s. There exist reverberations associated with these reflections.

In figures 4 through 7 and figure 8 the input CMP gather was 6s long, but only the first 4s are displayed. The analysis of the time gate to estimate the autocorrelation function will begin with examination of the deconvolution parameters. Figure 4 shows autocorrelation window test used to design deconvolution operators. The solid bars indicate the window boundaries. The entire 6-s length was included in ***a***. The autocorrelograms are displayed beneath the records. In general, the autocorrelation window should include the part of the record that contains useful reflection signal and should exclude coherent or incoherent noise (Yilmaz, 1988).

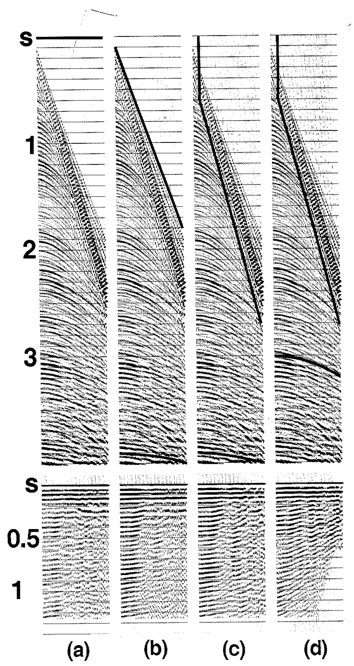

Fig. 4: An autocorrelation window

Figure 5 shows test of operator length. The corresponding autocorrelation is beneath each record. The window used in autocorrelation estimation is shown in figure 4c. Figure 5a shows input gather Deconvolution using prediction lag = 4ms (spiking deconvolution), 0.1 percent prewhitening, and prediction filter operator lengths (b) 40ms, (c) 80ms, (d) 160ms, (e) 240ms. From the analysis of the single spike, sparse spike, and reflectivity models, the short (40-ms) operator leaves some residual energy corresponding to the basic wavelet and reverberating wave train in the record. For a (60-ms) operator, no remnant of the energy is associated with the basic wavelet and reverberations. Operator longer than 60ms does not change the result significantly.

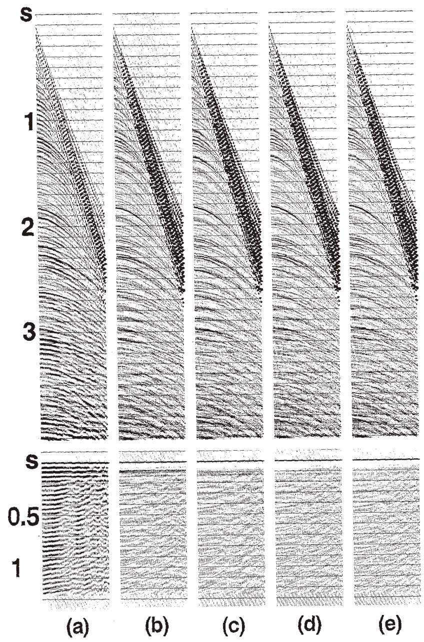

Fig. 5: Test of operator length

The effect of prediction lag is examined in figure 6. Here, 160-ms operator length and 0.1 percent prewhitening are fixed while prediction lag is varied. An increase in the prediction lag will result in the deconvolution process which makes it less effective in broadening the spectrum. In the extreme, the deconvolution process is ineffective for a 128-ms prediction lag. It is a common practice if the prediction lag are unity (spiking deconvolution) or the first or second zero crossing of the autocorrelation function (predictive deconvolution).

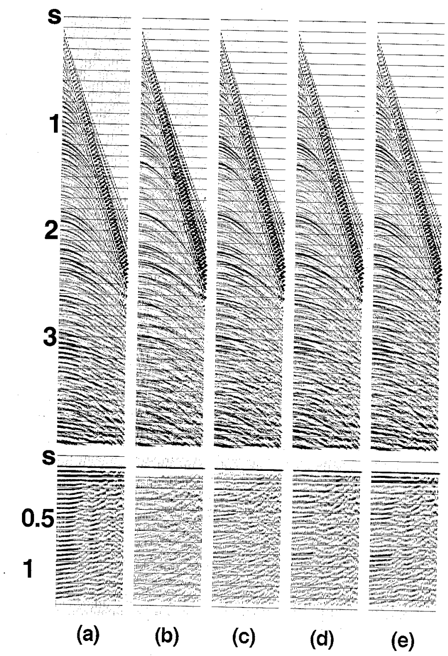

Fig. 6: Test of prediction lag.

The test of percent prewhitening is shown in figure 7. Here the corresponding autocorrelation is beneath each record. The window used in autocorrelation estimation is shown in figure 4. By the deconvolution process, it becomes less effective when the percent prewhitening is increased. Deconvolution using prediction filter operator length of 160-ms.

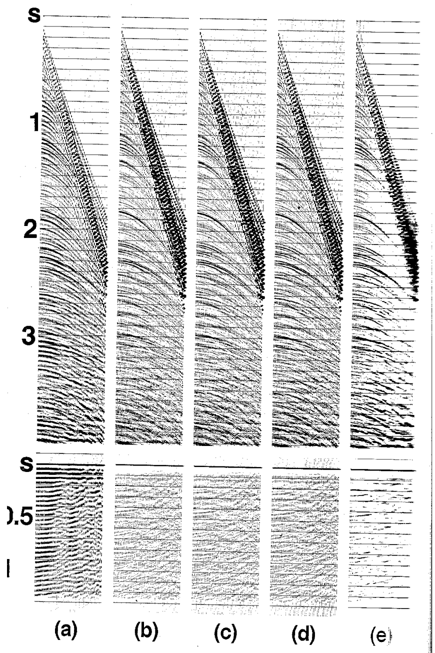

Fig. 7: Test of percent prewhitening

Finally, figure 8 shows signature processing. At this point a shaping filter is designed to convert the recording signature to its minimum-phase equivalent and apply it to the input record a. The output, b then has been processed by predictive deconvolution using operator length of 160ms and prediction lags, c shows 4ms spike deconvolution while d and e are 12ms and 32ms respectively.

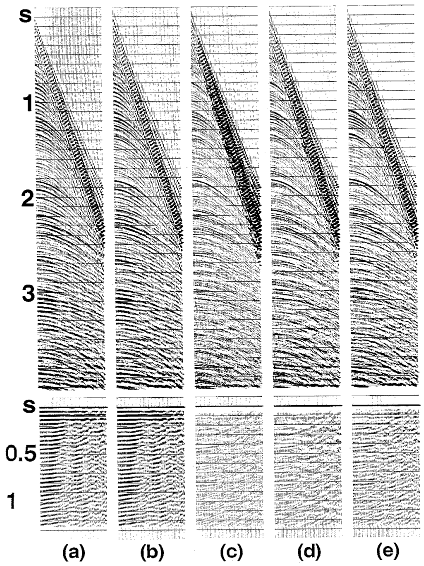

Fig. 8: Signature processing.

CONCLUSION

Predictive deconvolution is a process of applying information from the earlier part of a seismic trace to predict systematic noise such as reverberation and multiples. It attempts to attenuate multiples which involves the surface or near-surface reflectors.

The predictive deconvolution involves the design of the prediction filters which require only autocorrelation of the input series. For this work, the output has been processed using operation length of 160-ms and prediction lags.

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