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Post migration processing of seismic data

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Abstract: Seismic processing is aimed at providing a clear and accurate image of the subsurface geology. Various processing techniques such as deconvolution, dip moveout (DMO), and migration have been developed to achieve this objective. Most post migration sections are almost optimally processed using standard processing sequence. There are however, a few aspects which can still be improved. In this paper, a simple processing scheme is used for the enhancement of migrated seismic data of a field in Malaysia. An important aspect in this paper is that the processing is carried out on an interpretation workstation. Using this simple processing scheme, the processed section reveals encouraging lateral and vertical improvements.

INTRODUCTION

The main objective of seismic processing is to provide a clear and accurate image of the subsurface geology. The task, however, is not simple, since a lot of perturbing factors contribute to the character of the recorded seismic trace. As seismic energy propagates through the earth, it experiences various changes in frequency and phase characteristics due to variations in the subsurface geology, absorption, and scattering. Multiples, ghosts, and other random energy add complications to the trace. Consequently, the recorded seismic trace may not provide true information about the subsurface. Seismic data processing as one of the important aspects in reflection seismology, is basically aimed at unravelling the information and putting it in an interpretable form. Most standard modern processing sequences consist of six stages;

- correction for the amplitude loss due to inelastic attenuation and spherical divergence,
- removal of noise and compression of wavelet through filtering and deconvolution,
- definition of survey geometry,
- normal moveout (NMO) and stacking,
- migration, and
- filtering and scaling.

In geologically complex areas, processes such as dip moveout (DMO) and depth migration are commonly applied to seismic data to achieve correct positioning and focusing of the reflections. DMO is applied to pre stack data to correct for dipping reflectors. That is why DMO is also known as Partial Pre Stack Migration. Depth migration, on the other hand, can be applied to either pre stack or post stack data.

Until recently, the processing of seismic data is carried out by processing geophysicists with little intervention by the interpreters. With the development of computer based interpretation systems, interpreters now are able to perform certain post stack processing sequences such as deconvolution and filtering on an interpretation workstation. This capability certainly gives interpreters the freedom to test different working hypotheses based on their geological knowledge, without investing a lot of time, or increasing the cost. In this paper, the capability of the interpretation workstation in enhancing migrated data is demonstrated. Even though post migration data, in most cases, have been almost optimally processed, there are a few aspects which can still be improved, such as suppression of remaining multiples and noise, and applying zero phase correction to the data. These aspects are very important especially in the identification and delineation of stratigraphic features.

Figure 1 shows a migrated seismic section of a line over a field in Malaysia, passing through Well T-5. The 48-fold data is about 15 km long and was acquired using dual air gun arrays as the energy source with single streamer. The hydrophone group interval is 26.66 m. The data is 4 second-long with 4 ms sample rate and has been processed using the processing sequence shown in Figure 2. The quality of the data is poor, especially on the crest of the structure and within the pay zones. This poor quality data is most probably due to structural faulting, multiples, aliasing, and gas chimney effect.

PROCESSING SCHEME

Seismic sections with high vertical and lateral resolution are very essential to interpreters to correctly identify subtle features such as thin sand

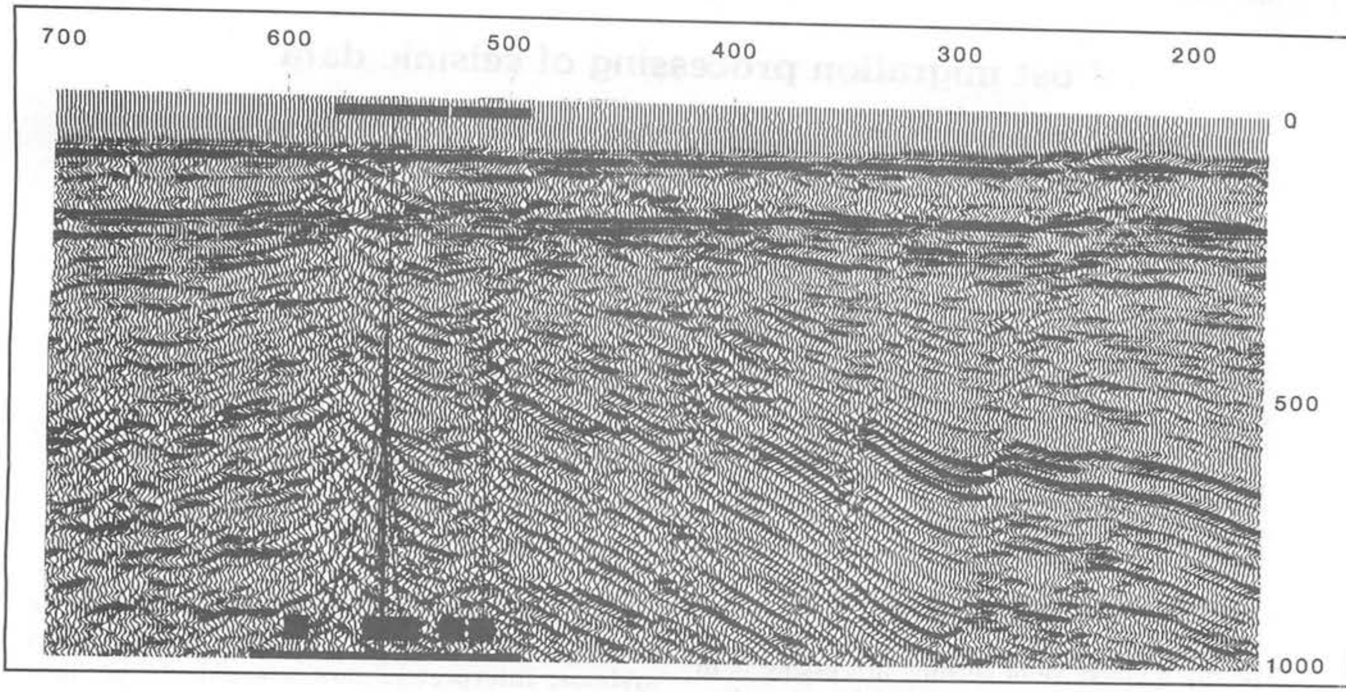

Figure 1(a). Migrated seismic data passing Well T-5.

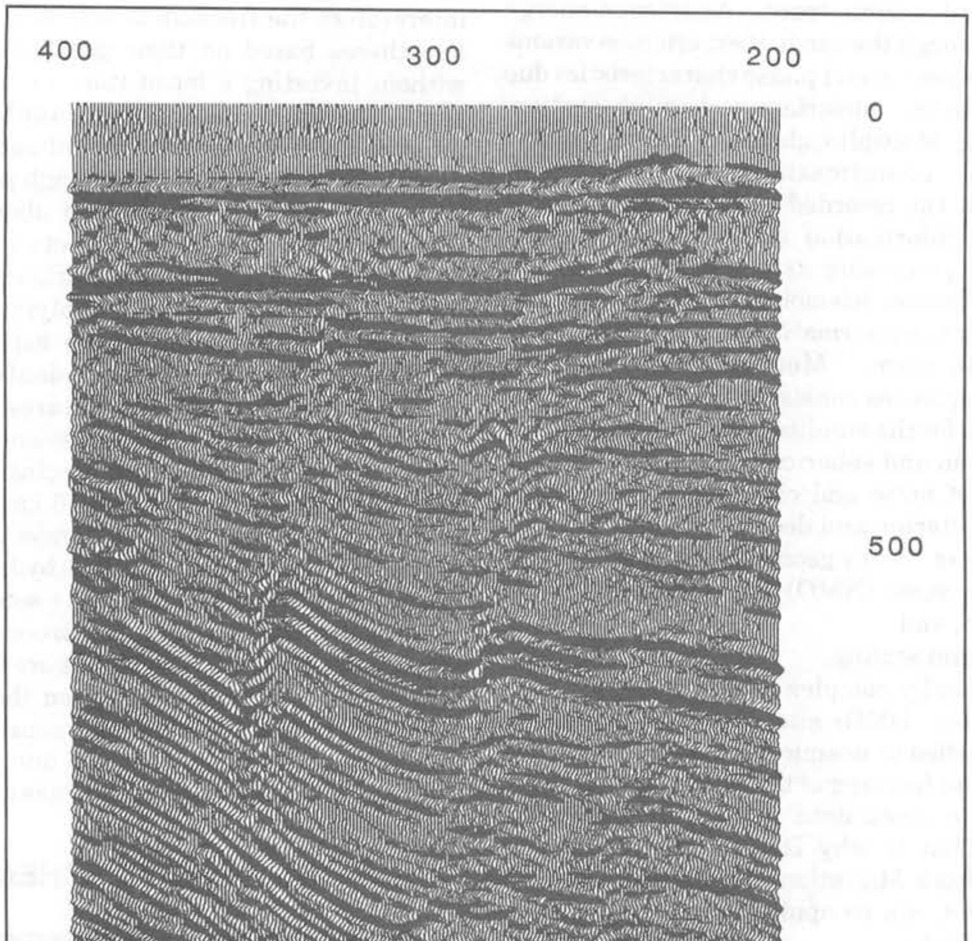

Figure 1(b). Zoomed section showing CDP 200 through CDP 400.

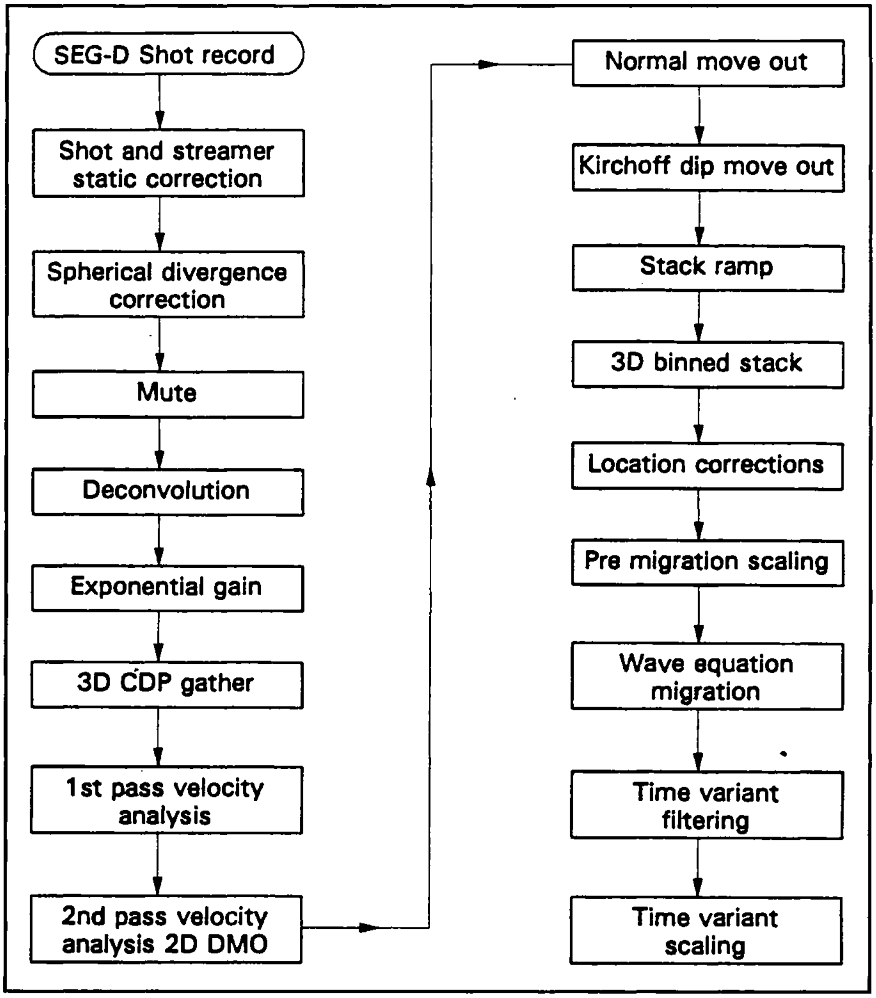

Figure 2. 3-D processing sequence.

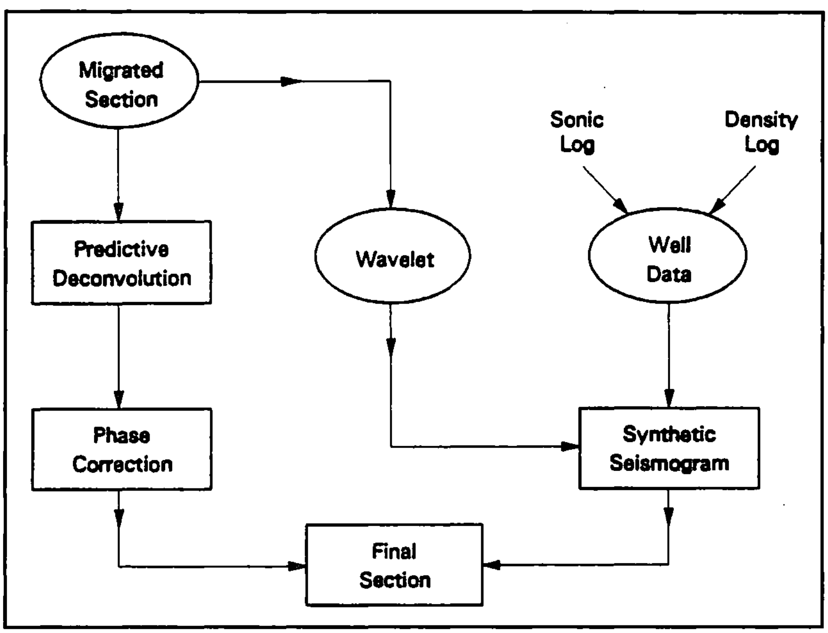

Figure 3. Post stack processing scheme.

beds, small reefs, and pinch outs. Identification of these features may provide indication of possible hydrocarbon accumulations. Resolution is defined as *the ability to tell that more than one feature is contributing to an observed effect* (Sheriff, 1986). Considerable amount of effort has been focused on the processing of seismic data with the objective of identifying these subtle features. This processing method is commonly known as *wavelet processing* (Budny, 1991; Lindsey, 1988; Mazzotti and Mirri, 1991; Neidell, 1991; Stone, 1983).

The recorded seismic wavelet is affected by many different factors such as source wavelet, receiver response, and filtering effect of the earth. Wavelet processing is aimed at removing these effects and replacing them with a wavelet of known and desirable characteristics. It has been agreed among geophysicists that the most desired wavelet is a zero phase wavelet, which is a symmetrical, noncausal wavelet with a large portion of the energy being concentrated in the central lobe. Noncausality of the wavelet means that it is only mathematically but not physically realizable.

The processing scheme used in this paper consists of two important processes: predictive deconvolution and zero phase correction. Predictive deconvolution is aimed at suppressing remaining or residual multiples in the migrated data. Zero phase correction is necessary for reshaping the minimum phase data into a zero phase condition. This is achieved through a phase rotation applied to the data. A synthetic seismogram which is calculated from sonic and density logs and an estimated zero phase wavelet is used for correction purposes. To determine the phase correction required for the data, a constant phase rotation is applied to the synthetic seismogram. The best correlation is then used to identify a constant phase rotation to be applied to the seismic data. The application of a correct phase rotation will produce an almost zero phase condition. Figure 3 summarizes the post migration processing sequence.

PREDICTIVE DECONVOLUTION

Predictive deconvolution enjoys a widespread acceptance in seismic data processing. The primary objectives of predictive deconvolution are to compress the wavelet effect, thus increasing the bandwidth of the seismic data, and to remove any repetitive events or multiples. The basis for deconvolution is the convolutional model (Robinson, 1984). In the convolutional model, a seismic trace is viewed as a convolution of the source wavelet with a series of reflection coefficients.

$$x(n) = r(n) * w(n) + n(n) = \sum_{k=0}^{N-1} r(n)w(n-k) + n(n) \qquad (1)$$

$n = 0, 1, ..., N-1$

where $x(n)$ is the recorded trace, $r(n)$ is the reflectivity series, $w(n)$ is the source wavelet and $n(n)$ is the noise. N is the number of sample points. Here, it is assumed that the operation is discrete over a finite duration and the wavelet is causal. The application of deconvolution process on seismic data is governed by three important assumptions:

i. the seismic trace $x(n)$ is stationary,
ii. the reflectivity series $r(n)$ is a random sequence with white spectrum, and
iii. the wavelet $w(n)$ is minimum phase.

The validity of these assumptions is critical in ensuring the effectiveness of the deconvolution process.

In predictive deconvolution, three parameters are of primary importance. These are the operator length, the autocorrelation window and the prediction gap. Careful determination of these parameters will give a good prediction operator. The prediction operator is derived from the well known *normal equation*,

$$\phi_{xx}(\alpha + n) = \sum_{k=0}^{N-1} h(k)\phi_{xx}(n-k)$$

$$\begin{bmatrix} \phi_{xx}(0) & \phi_{xx}(1) & \dots & \phi_{xx}(N-1) \\ \phi_{xx}(1) & \phi_{xx}(0) & \dots & \phi_{xx}(N) \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{xx}(N-1) & \phi_{xx}(N-2) & \dots & \phi_{xx}(0) \end{bmatrix} \begin{bmatrix} h(0) \\ h(1) \\ \vdots \\ h(N-1) \end{bmatrix} = \begin{bmatrix} \phi_{xx}(\alpha) \\ \phi_{xx}(\alpha+1) \\ \vdots \\ \phi_{xx}(\alpha)+N-1 \end{bmatrix} \qquad (2)$$

where $\phi_{xx}(\alpha + n)$ is the crosscorrelation of the input with its time-advanced version, $\phi_{xx}(n)$ is the autocorrelation of the input, and $h(n)$ is the prediction operator.

As can be seen in Eq. (2), the autocorrelation function is very important in deconvolution. The autocorrelation of any function will have a peak value at time zero or zero lag, i.e. when the two identical functions are aligned together. If a function is random, such as white noise or reflectivity series (assumption (ii)), the autocorrelation of the function is only a spike at zero lag and zero elsewhere. This result is very important for deriving the deconvolution operator. An example of an autocorrelation is shown in Figure 4. Notice the major peak at zero lag. There are a few secondary peaks which can be observed in the data. There are two reasons for these occurrences,

i. the reflectivity series is not truly random (as in cyclic deposition). Therefore the autocorrelation of the trace is not a pure clean spike, and

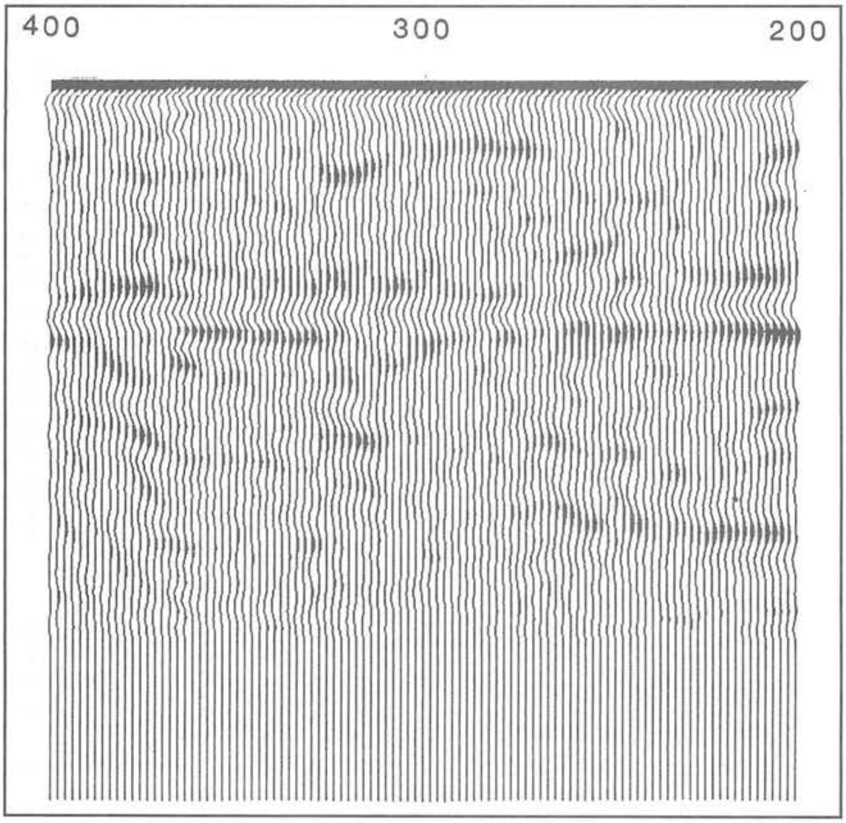

Figure 4. Autocorrelation function of CDP 200 through CDP 400.

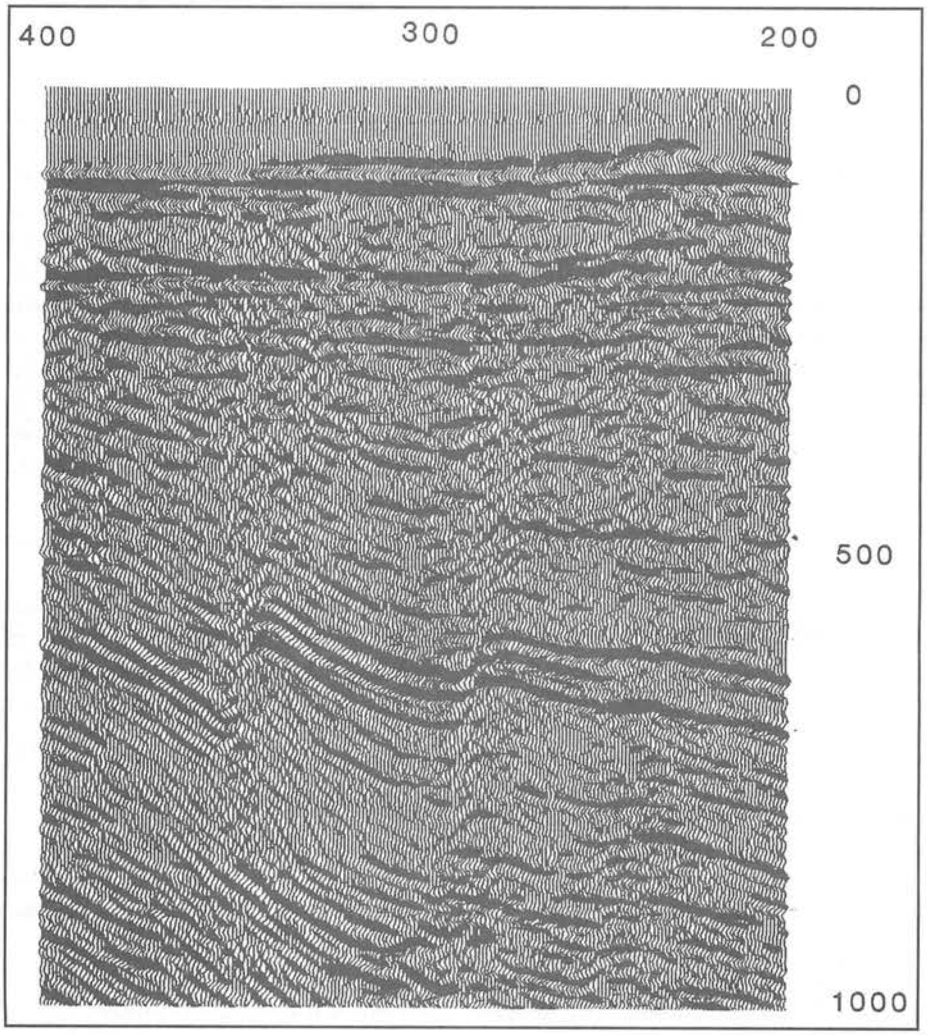

Figure 5. Deconvolved section using operator length of 256 ms, autocorrelation window of 500 ms, and prediction gap of 64 ms.

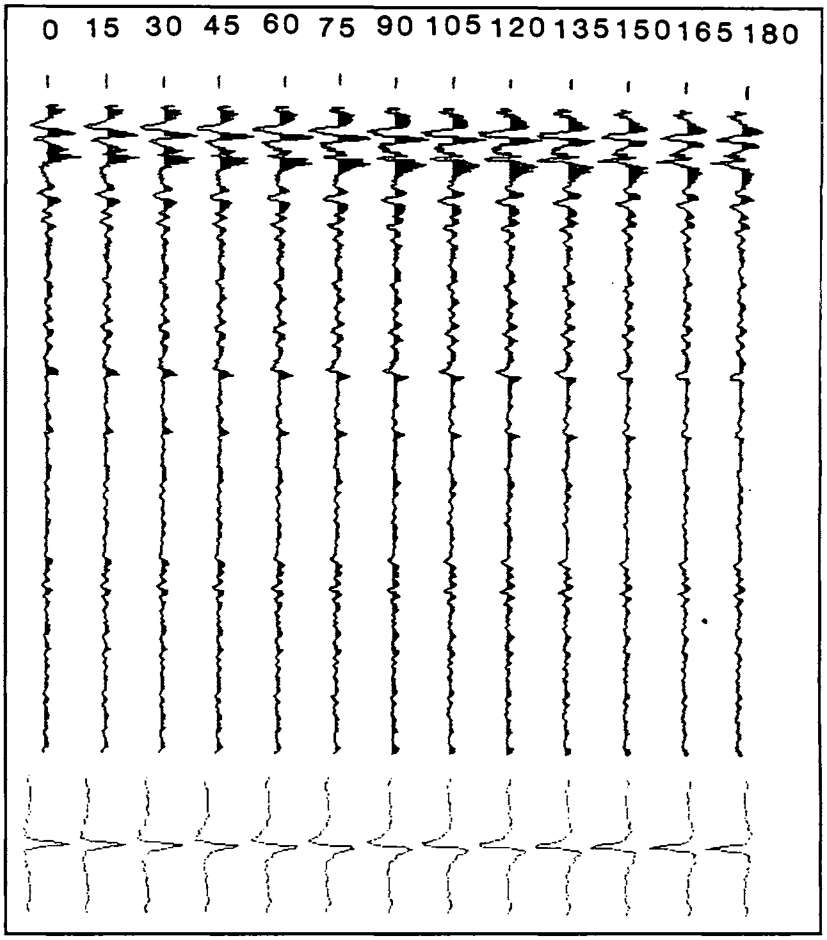

Figure 6. Synthetic seismogram rotated at constant interval of 15°.

ii. there are multiples and other form of noise contamination associated with primary reflection.

Figure 5 shows the migrated section after an application of predictive deconvolution with operator length of 256 ms, autocorrelation window of 500 ms, and prediction gap of 64 ms. Substantial suppression of multiples at 0.8 s (below strong carbonate reflector) has been achieved. In this particular example, the prediction lag has to be chosen carefully due to the cyclic nature of carbonate deposition. A bad choice of prediction lag will not only attenuate multiples but also primary reflectors.

PHASE CORRECTION

The seismic wavelet is an important factor in vertical resolution. The vertical resolution depends upon the sharpness of the wavelet. The sharpness of the wavelet is critical especially in stratigraphic interpretation. It is generally agreed that the best wavelet for maximum vertical resolution is a zero phase wavelet.

In most cases, processed seismic data are minimum phase. This is due to the fact that almost all the perturbing factors affecting the seismic trace are minimum phase. The earth, most of the energy sources, hydrophones, and recording instruments are all minimum phase. It is desirable, especially for the interpreters, to make the data zero phase. This can be achieved through a constant phase rotation applied to the data using a phase shift filter. A phase shift filter is a filter with unit amplitude spectrum and a specified value of phase spectrum. The phase of the filter is chosen to make the seismic data zero phase. The seismic wavelet can be described in term of its amplitude and phase spectra,

$$W(w) = |W(w)|\, e^{i\theta(w)} \tag{3}$$

where $|W(w)|$ is the amplitude spectrum and $\theta(w)$ is the phase spectrum. w is the radian frequency, $w = 2\pi f$. Applying a phase shift filter with a phase spectrum of $-\theta(w)$ will result in a zero phase wavelet,

$$\begin{aligned} W(w) &= |W(w)|\, e^{i\theta(w)} \\ H(w) &= e^{-i\theta(w)} \\ W^0(w) &= W(w)H(w) \\ &= |W(w)|\, e^{i\theta(w)}e^{-i\theta(w)} \\ &= |W(w)|\, e^{i(\theta(w)-\theta(w))} \\ &= |W(w)| \end{aligned} \tag{4}$$

which is indeed zero phase.

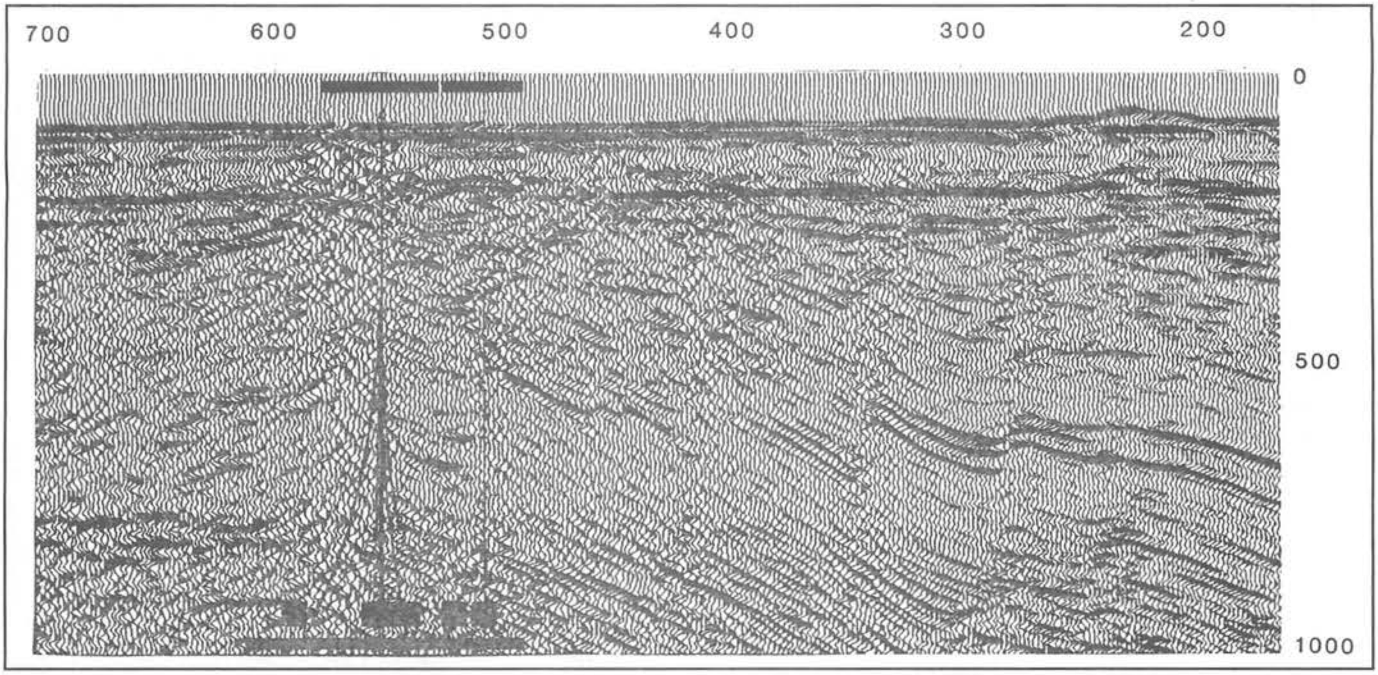

Figure 7(a). Final section after post stack processing.

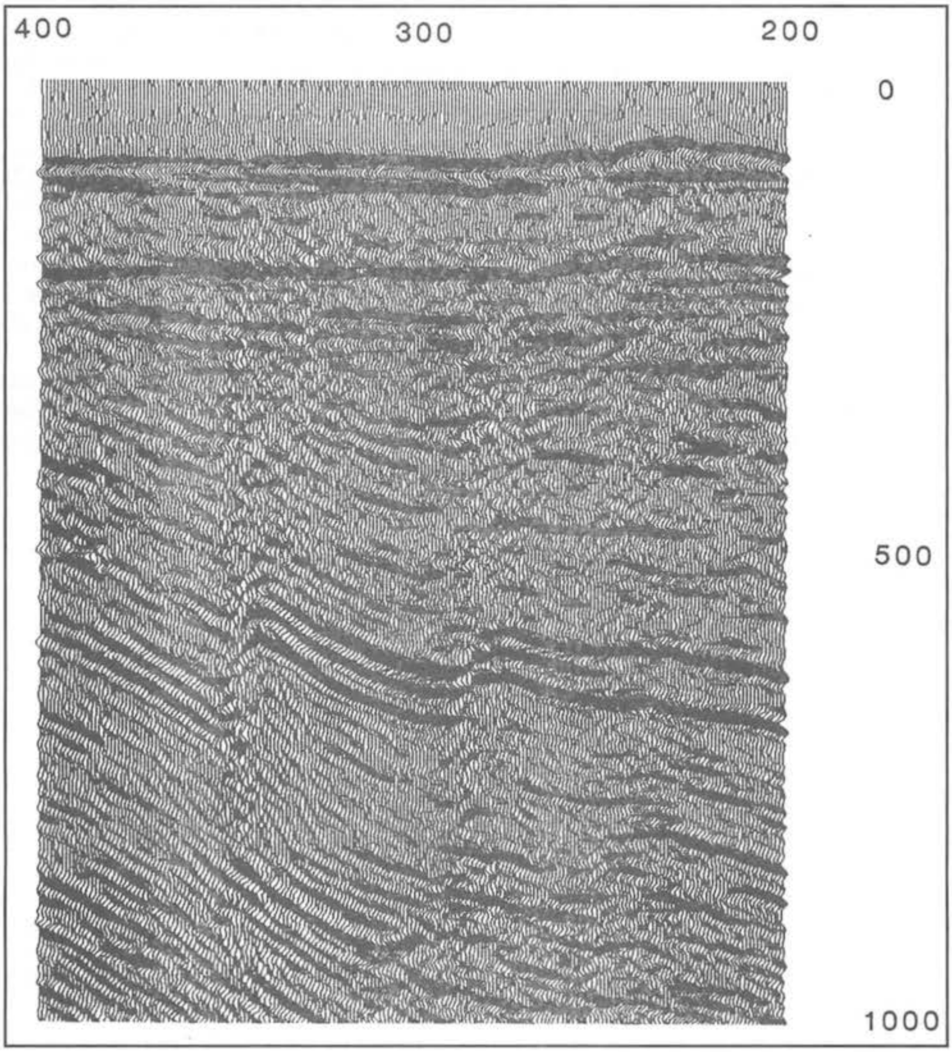

Figure 7(b). Zoomed section showing CDP 200 through CDP 400.

The amount of phase shift required to be applied to the data is determined using a synthetic seismogram. The synthetic seismogram is calculated from sonic and density logs and a zero phase equivalent of the minimum phase wavelet in the seismic data. The synthetic is rotated at a constant interval or 15°. The best correlation between the synthetic and the data will determine the phase shift required to be applied to the data. For this particular case, a phase shift of 60° provides the best correlation. Therefore, a phase shift of –60° needs to be applied to the data to make it zero phase. Figure 6 shows a series of synthetic seismograms rotated at a constant interval of 15°. Figure 7 shows the deconvolved seismic section after an application of a phase shift filter. A lateral improvement on the shallow horizon around 100 ms can be clearly seen. The improvement can also be observed at 700 ms (CDP 350 - 400).

CONCLUSION

In this paper, a simple processing scheme is used to enhance migrated seismic data of a field in Malaysia. The processing scheme involved an application of predictive deconvolution and phase shift filtering. A synthetic seismogram derived from well data was used to calibrate and validate the processing results. The processed data showed encouraging lateral and vertical improvement. The poor quality of the data especially over the crestal part of the structure, coupled with the limited capability of the interpretation workstation, prevented further improvement of the data.

An important aspect of this study is that the processing was performed on an interpretation workstation. Currently, available interpretation workstations provide certain processing capabilities for interpreters to further enhance seismic data for interpretation.

Even though limited, these processing capabilities give interpreters the flexibility and freedom to test different working hypotheses based on their geological knowledge without investing more time and money.

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