Missing trace interpolation and its enhancement of seismic processes

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ABSTRACT

Many multi-channel seismic algorithms assume that the input seismic data have a regular trace spacing. Unfortunately, this is not always so because of incomplete or noisy acquisition. This leads to problems with procedures such as DMO and prestack migration. In this paper, a method based on the least-squares f-x prediction filter is developed to interpolate the missing traces to regularize the data set. This filter is applied to a synthetic data set and a field data set from Pine Creek, Alberta. It is shown in synthetic test that the filter is successfully predicted the conflicted dips and interpolated as much as one-third of the data. The result is also shown to be superior than the conventional f-x deconvolution. The field example shows that the missing trace interpolation can lead to considerable improvement in the final processed results.

INTRODUCTION

In a 2-D seismic survey, it is desirable to sample the sub-surface uniformly by placing sources and receivers in a regular fashion. However problems generally exist in acquisition which disturbs the regularity to some degree. By proper binning, the data does regularize to some extent and helps stacking and poststack migration. For some prestack algorithms, like some DMO and prestack migration that work directly from the geometry of the shots and the receivers, the binning method may not help at all.

In this paper a data set from Pinecreek, Alberta is used to demonstrate the effect of missing traces on the stack, the DMO stack and the prestack time migrated stack. A missing trace interpolation method based on the least-squares f-x prediction filter is proposed to eliminate some of the problems encountered. A number of authors (e.g., Abma and Claerbout, 1995; Soubaras, 1995) are also currently investigating the development of applying f-x filters.

THE PROBLEM AT PINE CREEK

A P-P data set from Pine Creek, Alberta is used to demonstrated the effect of missing traces on the processing. The 2-D 3-C data set is recorded on a 240-channel instrument. It contains 411 shots with 25 m group spacing and is shot at every station. The nominal fold of the data is 40 with an end-on shooting configuration. The nearest and largest offsets are 150 m and 2125 m respectively, except shooting into and off the line. Shown in Figures 1, 2, and 3 are NMO, DMO and prestack time migrated stacks. Artifacts are observed at CDP locations around 2300 and 3750. By looking at the prestack data in a common offset plane at 1165 m (Figure 4), it is concluded that this artifact noise is generated from the missing traces. A CDP gather at location 3775 together with its velocity semblance shown in Figure 5 is further evidence of this conclusion.

F-X DOMAIN INTERPOLATION

It was shown by Canales (1984) that linear events convolved with the same wavelet were perfectly predictable with a one-step ahead convolutional prediction filter in the f-x domain. In other words, the predicted event, at each frequency, is a linear combination of a set of complex sinusoids in the x-direction. Spitz (1991) extended this idea for trace interpolation in the f-x domain, without picking the dips. His trace interpolation scheme has two steps. First, the prediction filter coefficients are estimated for the data with half of the original trace spacing. Then the interpolated traces are solved in a least-squares sense. The missing trace interpolation scheme follows the same procedure as the trace interpolation. First, the prediction coefficients are estimated for the data with regular trace spacing. It is found that if the missing traces are only small part of the data, the coefficients can be estimated from the data with missing traces replaced by the zeros to maintain regular spacing. Figure 6 is a synthetic record without missing traces for the test of the algorithm. Shown in Figure 7 are three records: The first one is the synthetic record with some missing traces. The second one is the result of applying traditional f-x deconvolution. The difference between the original (Figure 6) and the interpolated record is shown in the last record. Figure 8 is the same as in Figure 7, except that the second record is the result of the least-squares f-x prediction interpolation. By comparing the third records on both Figure 7 and 8, the f-x interpolation produces a better result. The same tests are repeated for a large gap missing traces and are shown in Figure 9 and 10, the f-x interpolation still produces a better result.

FIELD EXAMPLE

The f-x interpolation is based on the predictability of the linear events. The natural domain to apply this technique to the field data will then be common offset planes. In these common offset planes the signals are more or less linear without any NMO corrections. Shown in Figure 11 is the result of applying this technique to the same common offset plane as in Figure 4. After applying the interpolation to each common offset plan, the data are sorted back into CDPs and a semblance plot at the same location as in Figure 5 is shown in Figure 12. The coherence of the events are improved and easier to follow with the eyes. The results of the NMO stack, DMO stack and prestack time migrated stack are shown in Figure 13, 14 and 15. Artifacts of the missing traces are now suppressed.

CONCLUSIONS

In this paper, it is shown that a least-squares f-x prediction filter can be used for missing trace interpolation. In this method, dip information is estimated automatically by the prediction coefficients. Velocity information is not required if it is applied to the common-offset domain. Furthermore, the interpolation helps to suppress artifacts generated from operator noise in the DMO and migration. The interpretation of data can be made more straightforward.

APPENDIX

The prediction filtering can be written as convolution, or in a matrix form as:

$$FX' = Y' \tag{1}$$

where F is a convolution matrix that contains the prediction filter coefficients for a particular frequency, X' is a vector that contains the data at the corresponding frequency in the X-direction, and Y' is a vector contains the shifted version of X’ in a perfectly predictable situation. For missing trace interpolation, some of the elements in both of X' and Y' are unknowns. After some re-arrangement, equation (1) can be re-written as:

$$AX = BY(2)$$

where X contains all the known values of X’ and Y’, and Y contains all the unknown values of X’ and Y’ at the missing trace locations. A and B are the matrices resulting from the re-arrangement of F.The least-squares solution for the new equation (2) becomes:

$$Y = (B^{*}B)^{-1}B^{*}AX \quad (3)$$

where * denotes the conjugate transpose.

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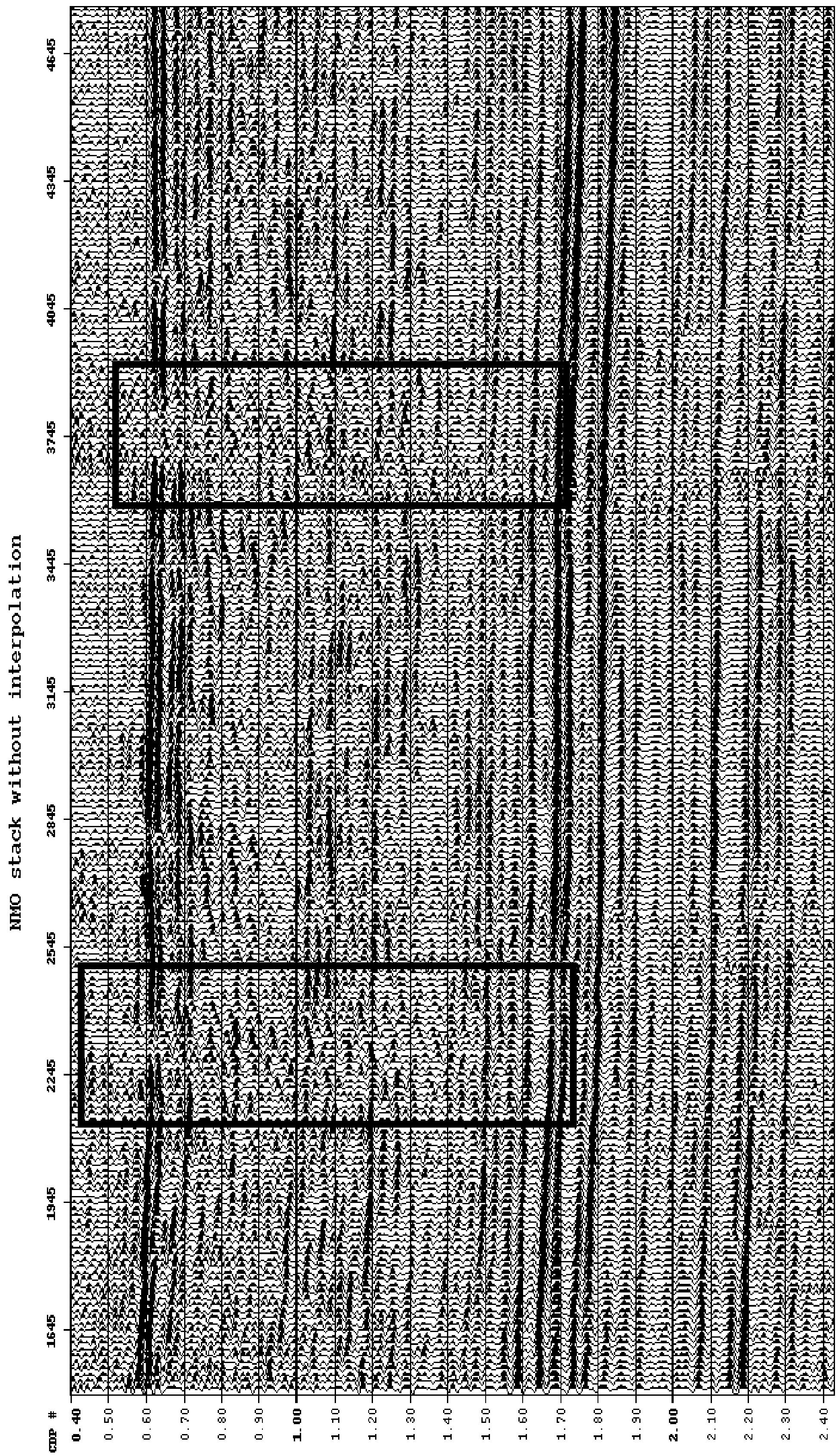

Fig. 1. Final NMO stack without interpolation. Artifacts are observed in both boxes where there is low fold.

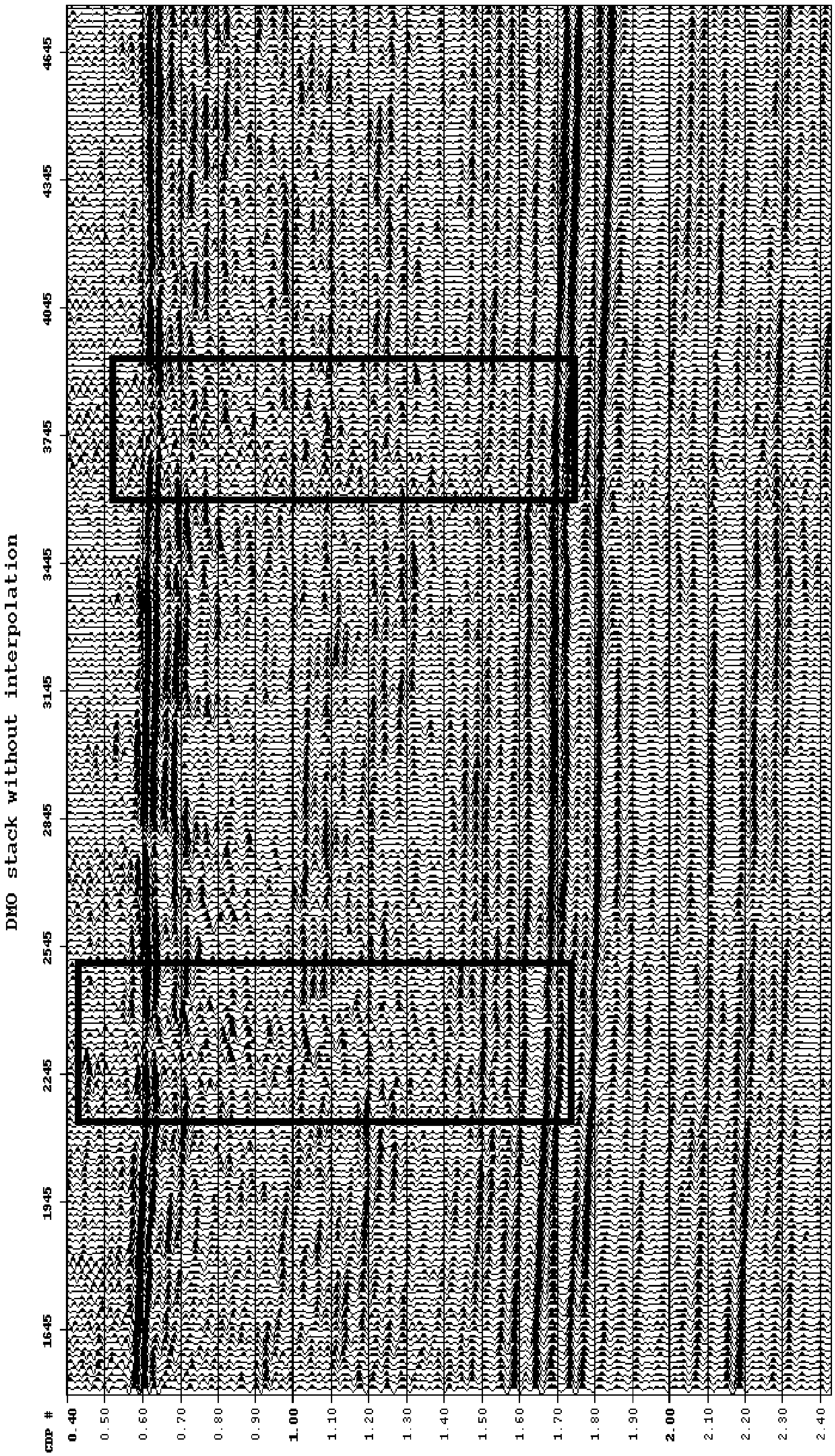

Fig. 2. DMO stack without interpolation. Artifacts are observed in both boxes where there is low fold.

Fig. 3. Prestack time migrated stack without interpolation. Artifacts are observed in both boxes where there is low fold.

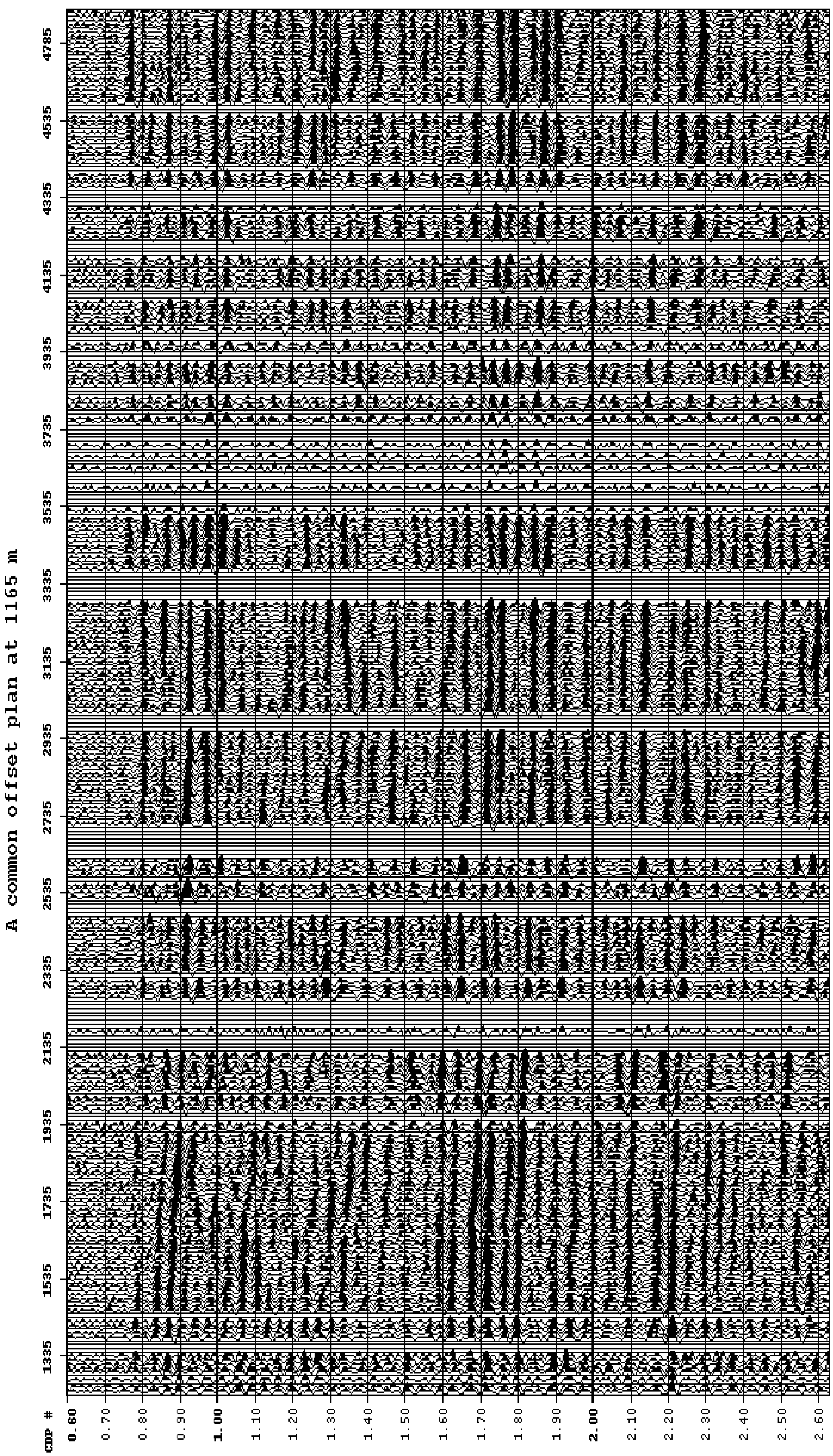

Fig. 4. A common offset section at 1165 m with missing-trace locations shown.

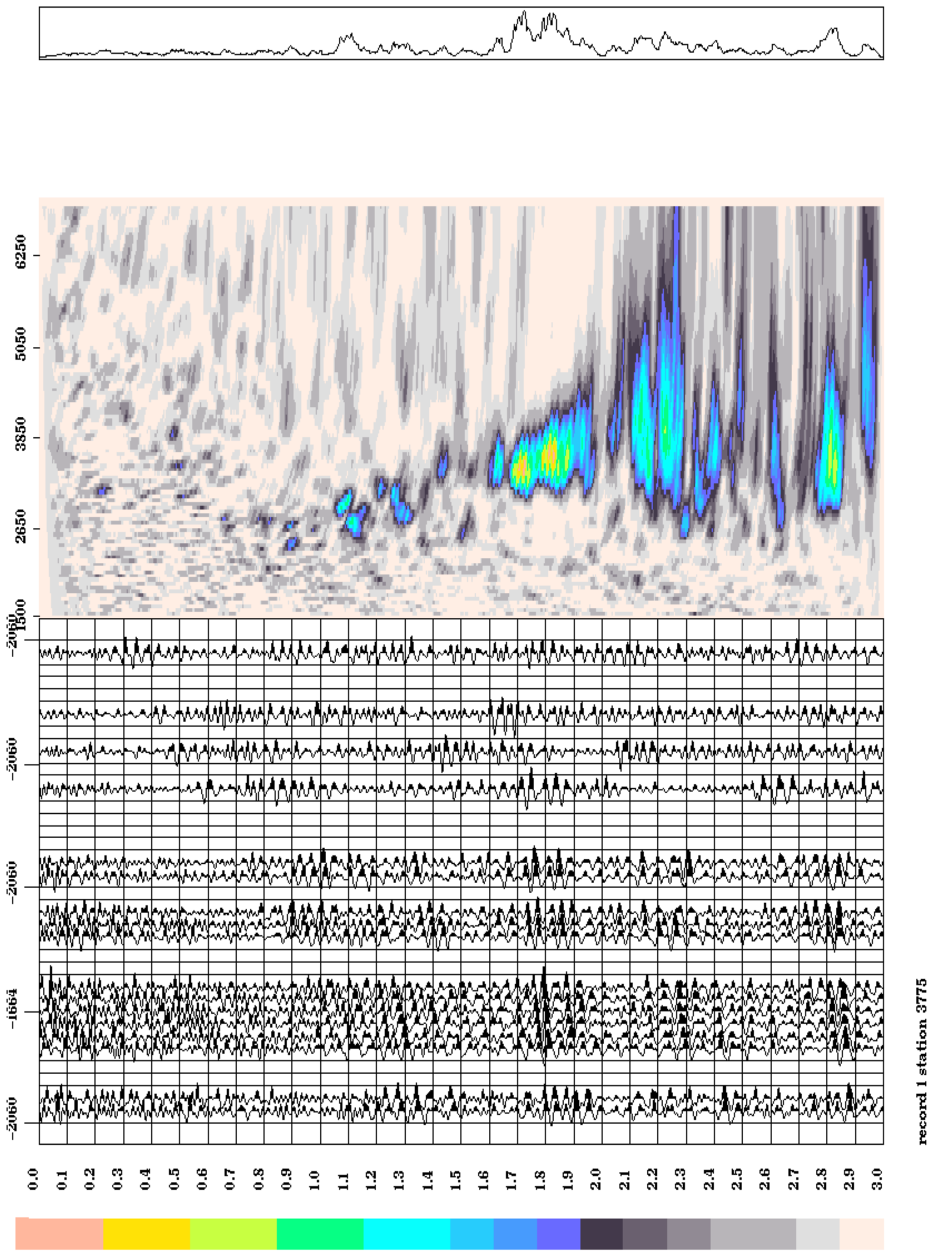

Fig. 5. A cmp gather at location 3775 is shown on the left, and its velocity semblance is shown on the right. Because of the missing traces, events are not easy to follow on the gather.

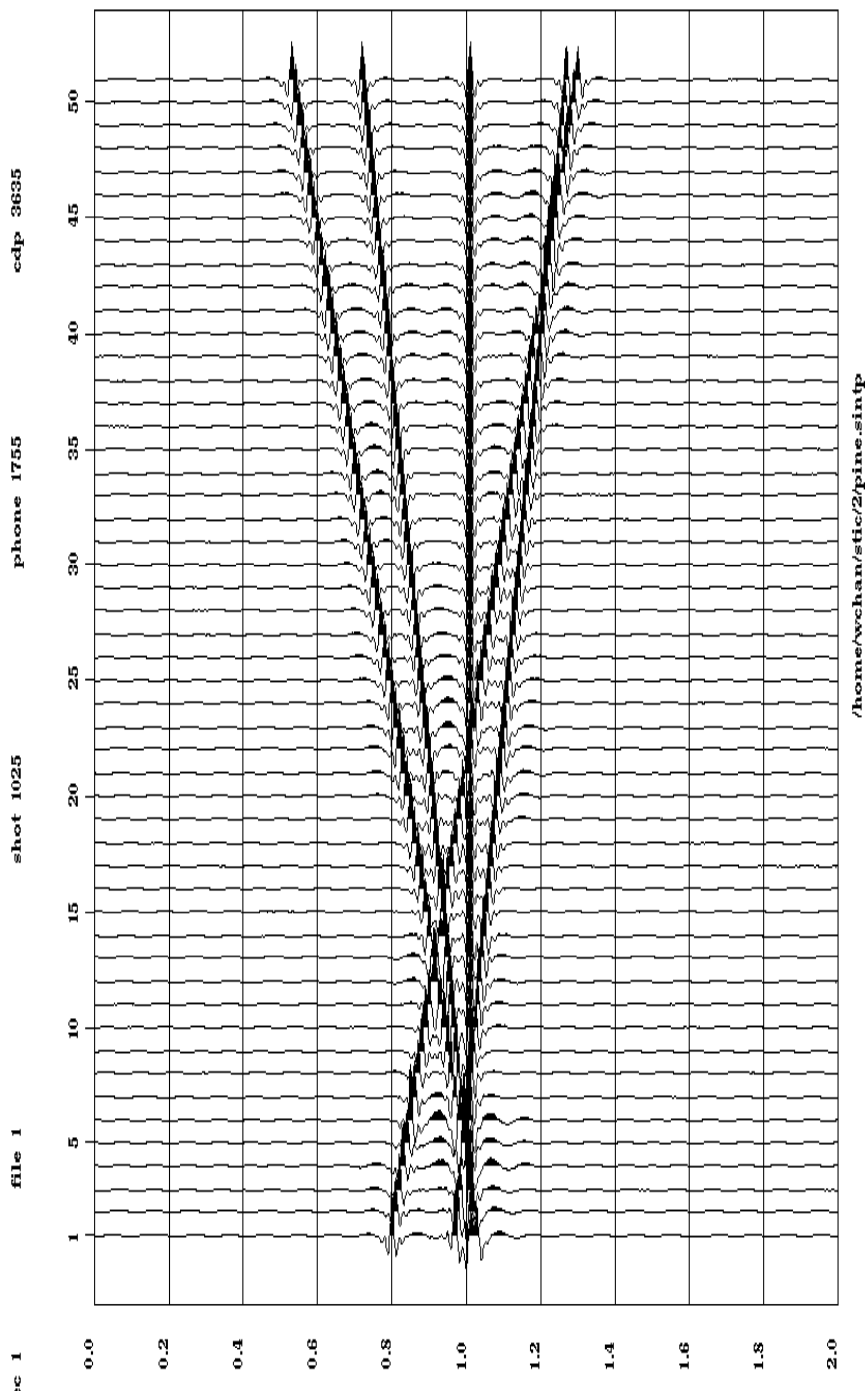

Fig. 6. A synthetic record without missing traces.

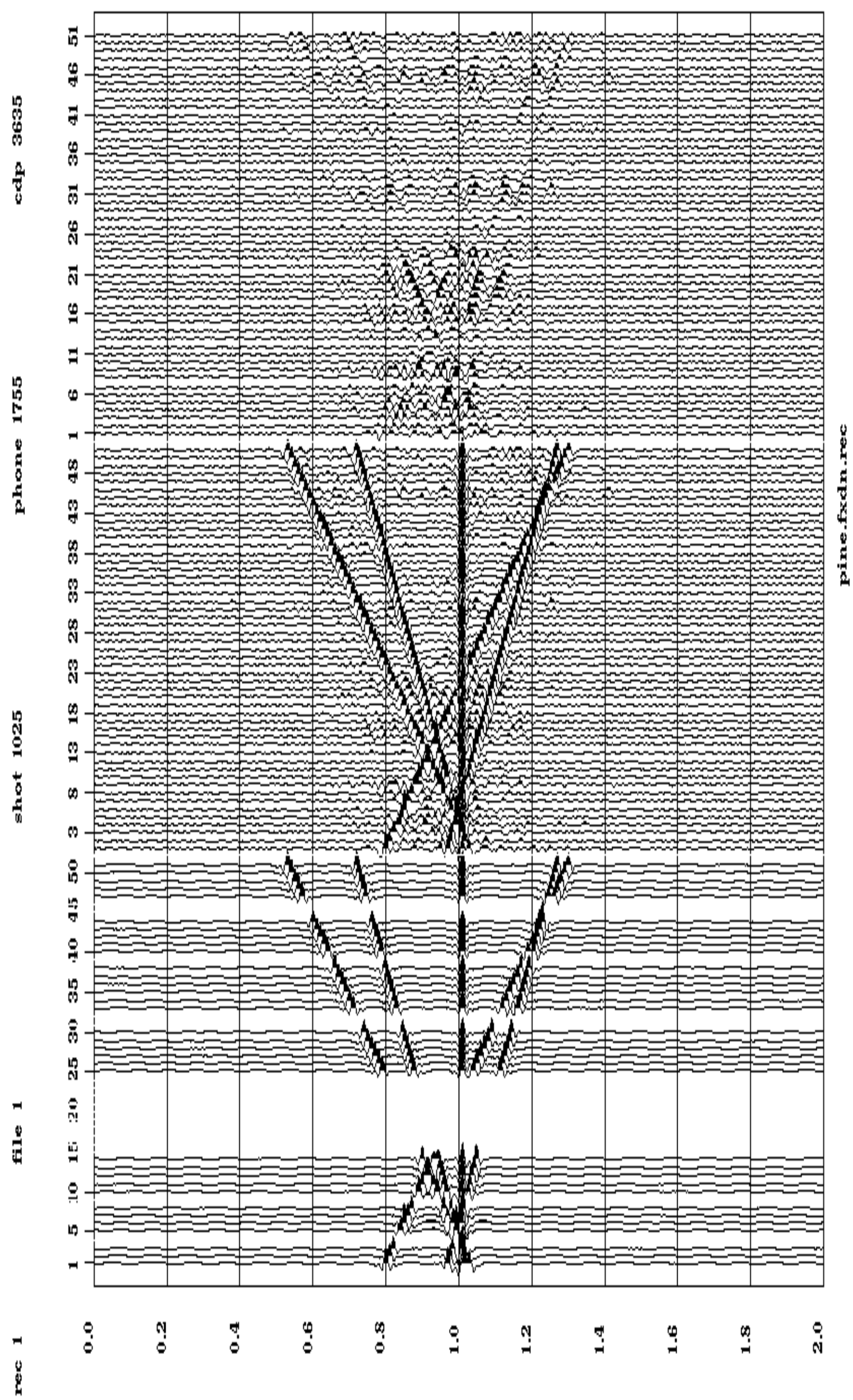

Fig. 7. Missing trace interpolation with conventional f-x deconvolution. The first record is the result of removing some traces from Figure 6. The second record is the result of applying f-x deconvolution. The third record is the difference between Figure 6 and the interpolated result.

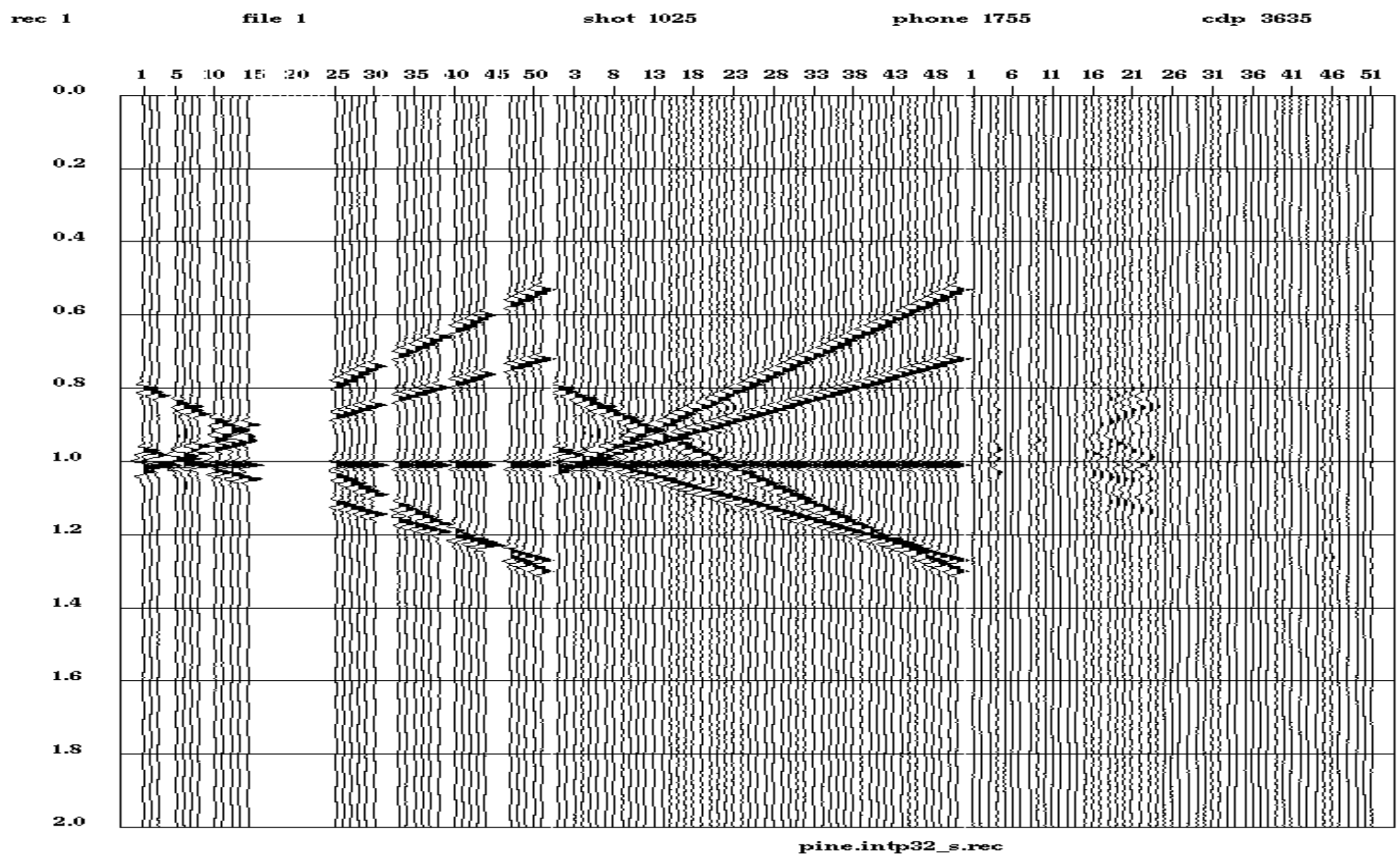

Fig. 8. Missing trace interpolation with the least-squares f-x prediction. The figure is this same as in Figure 7, except the second record is the result of applying the least-squares prediction, and the last record is the difference between Figure 6 and the least-square prediction.

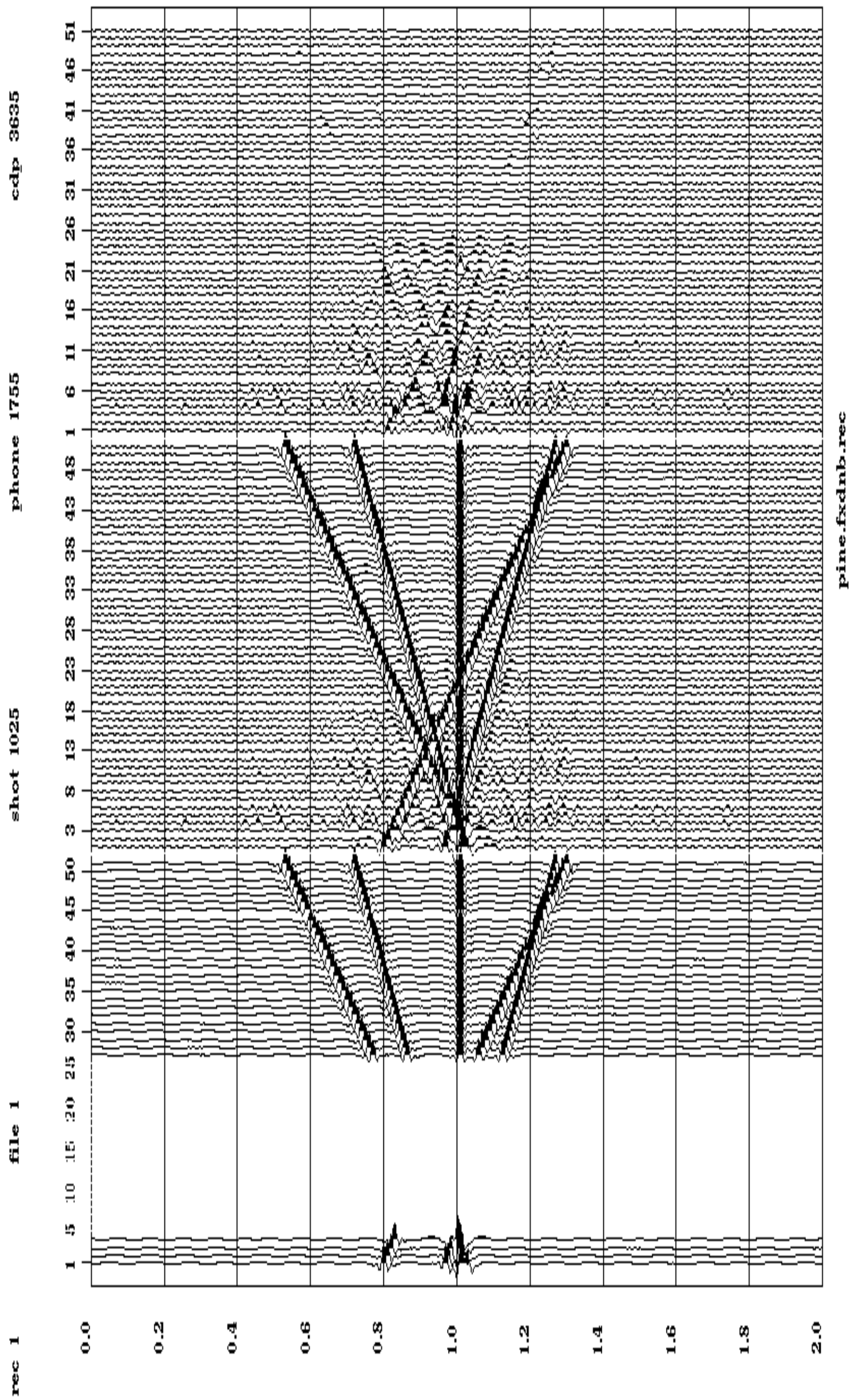

Fig. 9. Another example of missing trace interpolation using convolution f-x deconvolution on a bigger gap record. The last record shows a bigger difference than in Figure 7.

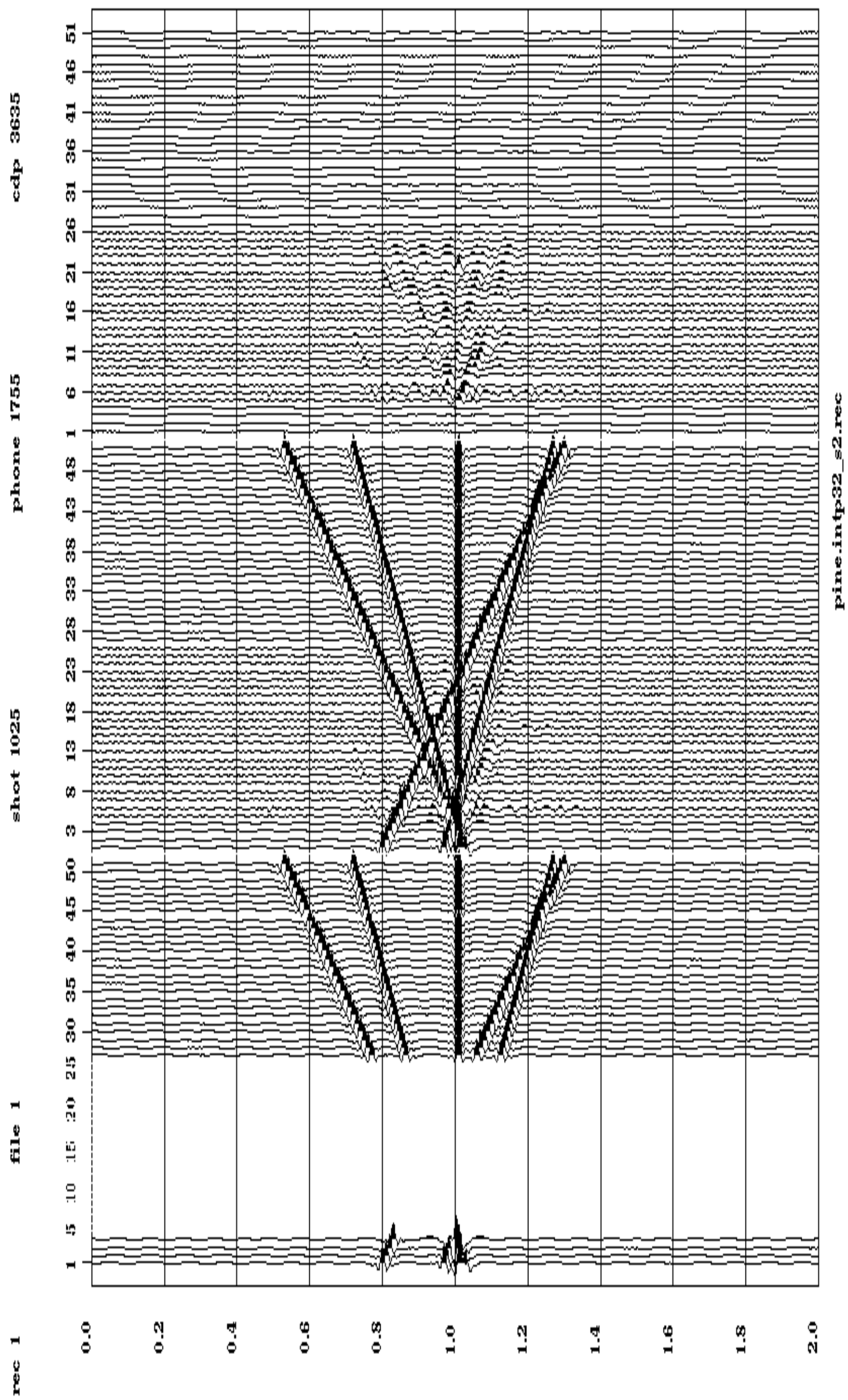

Fig. 10. Missing trace interpolation with the least-squares f-x prediction on a bigger gap record. The last record shows less difference than in Figure 9.

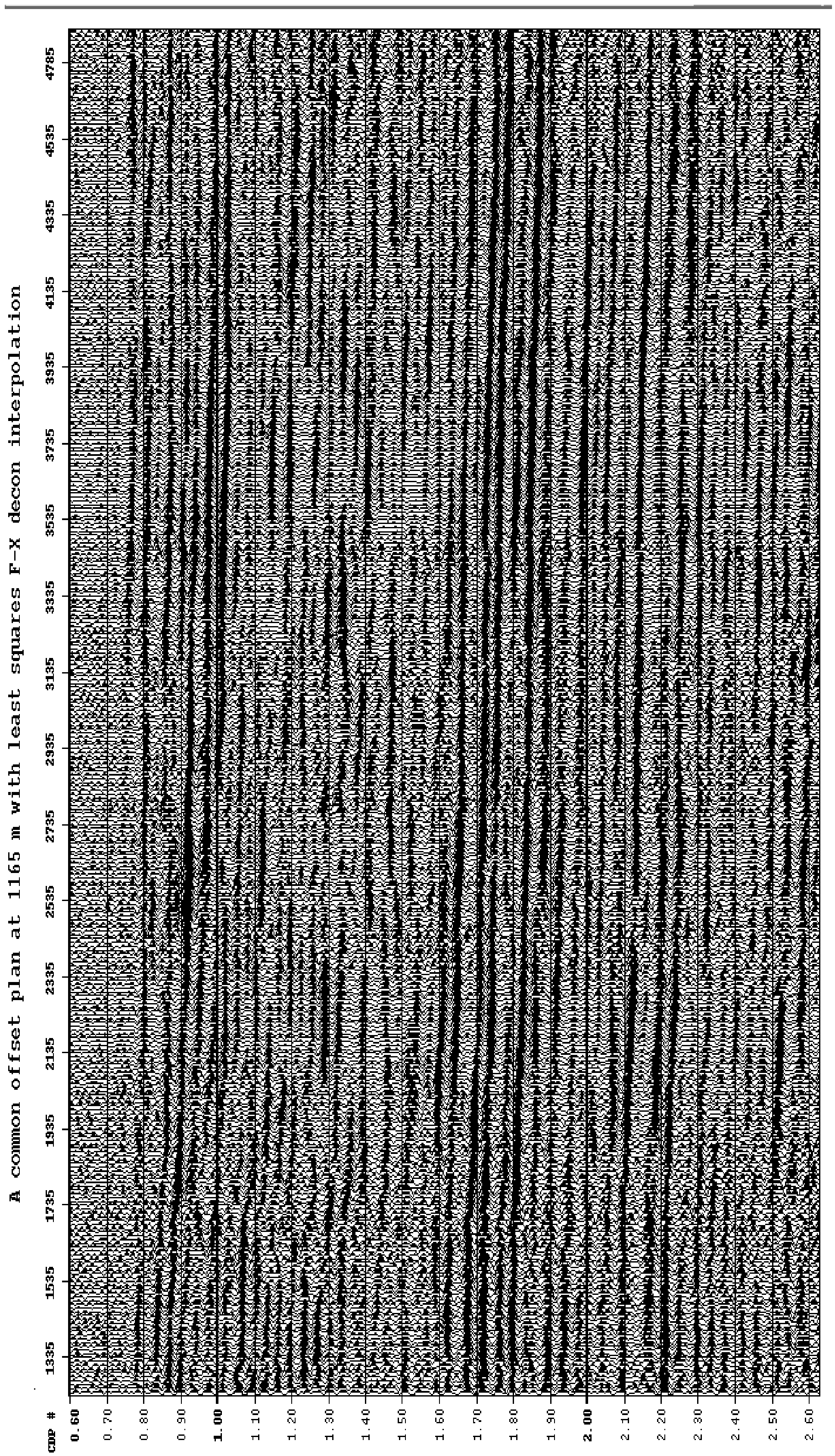

Fig. 11. A common offset section at 1165 m with missing traces filled by the least-squares prediction.

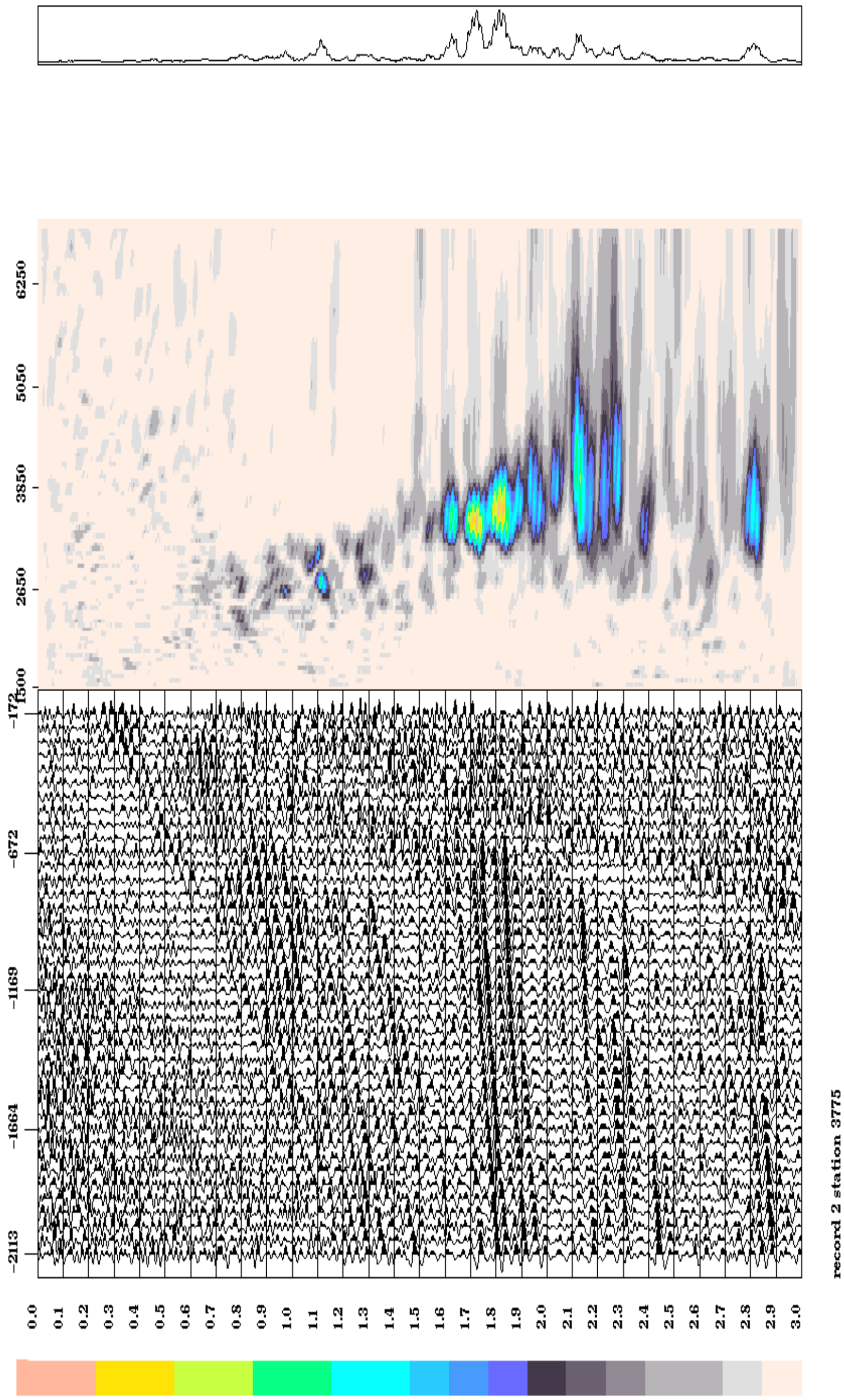

Fig. 12. A CMP gather and its velocity semblance after missing trace interpolation. The cmp gather is at the same location as in Figure 5. After interpolation, events are much easier to follow.

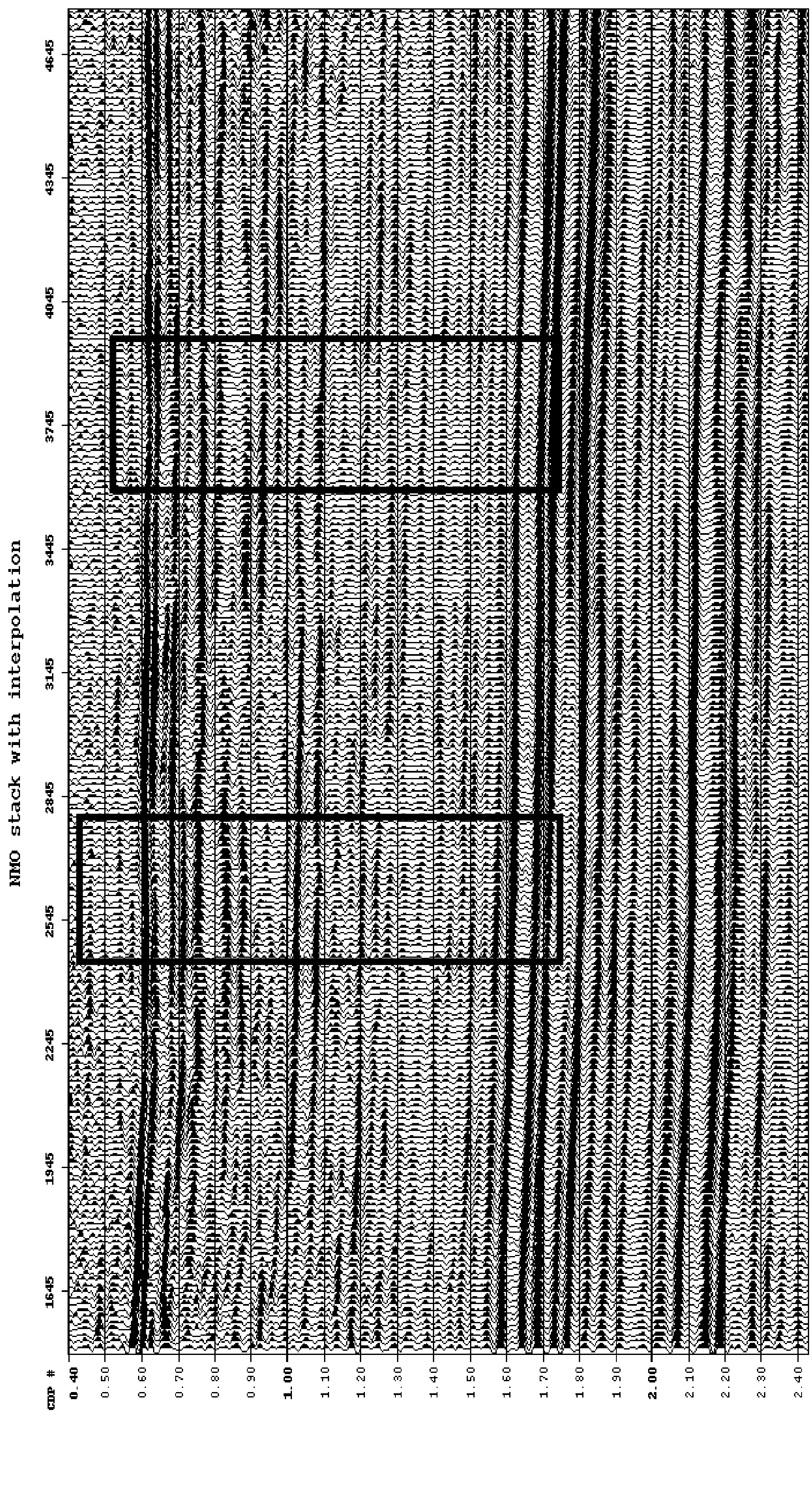

Fig. 13. Final NMO stack with the least-squares f-x interpolation. Artifacts are suppressed.

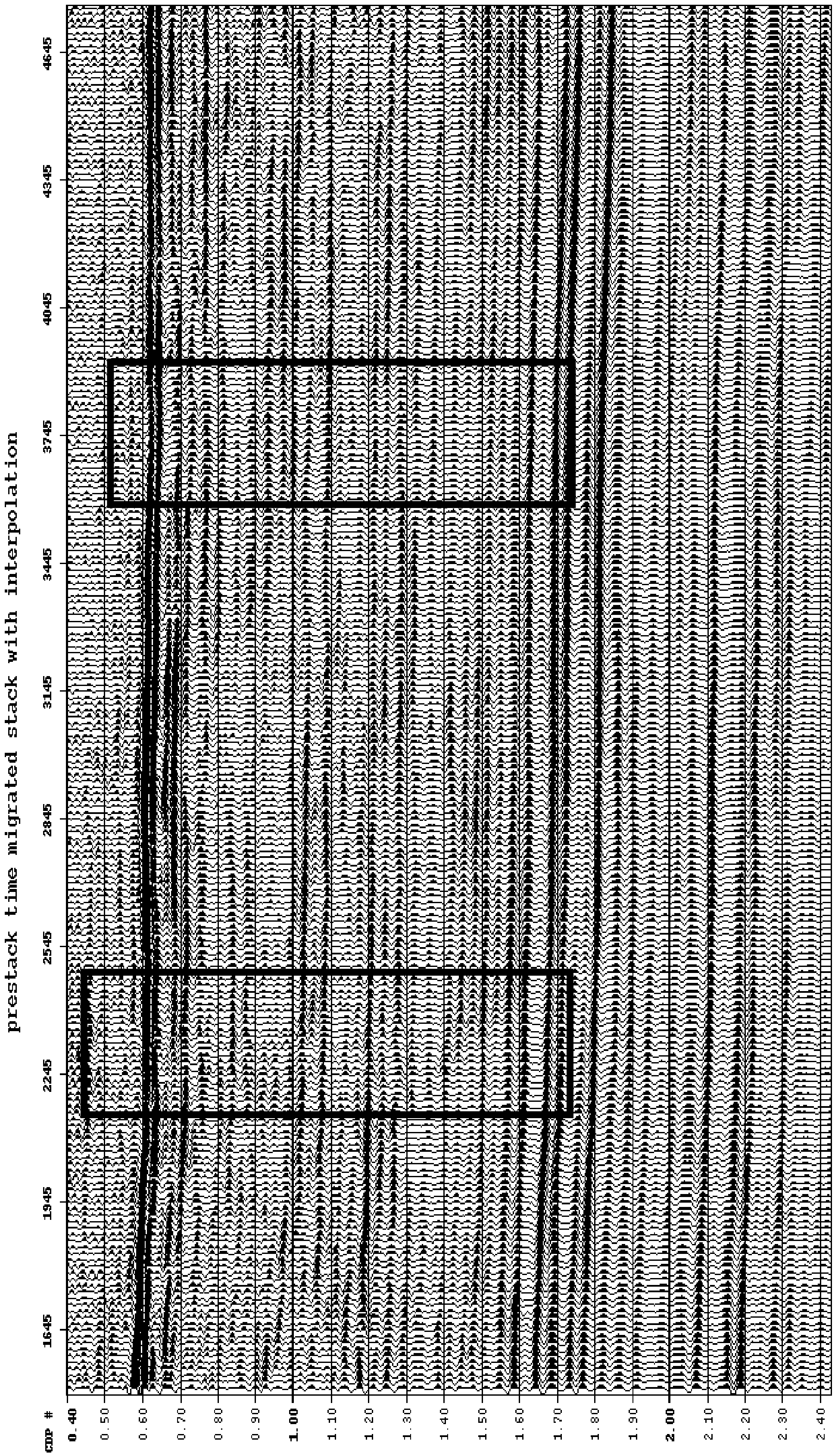

Fig. 14. DMO stack with the least-squares interpolation. Artifacts are suppressed.

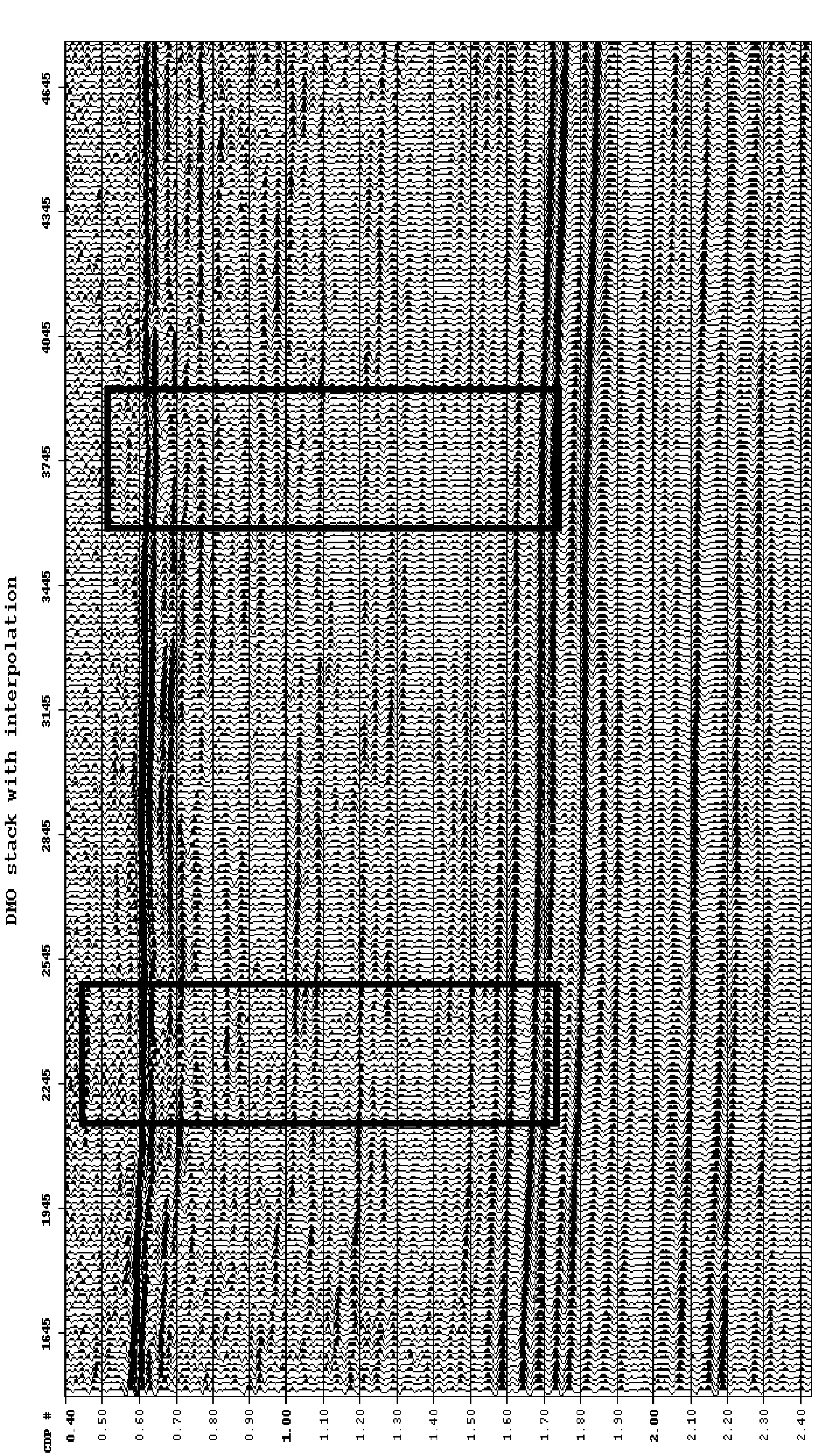

Fig. 15. Prestack time migrated stack with the least-squares interpolation. Artifacts are suppressed.