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온누리호 탄성파 자료의 신호대 잡음비 향상연구

(Karhunen-Loéve 변환을 이용한 다중반사 제거)

Improvement of the Signal to Noise Ratio of Multichannel Seismic Data Acquired on the R/V Onnuri

(Multiple Suppression via the Karhunen-Loéve Transform)

1993. 3.

한 국 해 양 연 구 소

제 출 문

한국해양연구소장 귀하

본보고서를 "온누리호 탄성파자료의 신호대 잡음비 향상연구"과제의 최종보고서로 제출합니다.

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요 약 문

I. 제 목

온누리호 탄성파 자료의 신호대 잡음비 향상연구
(Karhunen-Loéve 변환을 이용한 다중반사 제거)

II. 연구개발의 목적 및 중요성

한국해양연구소는 다중채널 탄성파 탐사를 이용하여 한반도 주변해역의 심부지질구조를 연구하는 능력을 확장하고 있다. 지금까지 탄성파자료의 표준처리 및 특수처리기법을 활용하는 최적의 탄성파 자료처리 시스템의 확립을 위한 많은 연구가 진행되어 왔다. 현재 널리 사용되고 있는 상용의 탄성파 자료 처리 소프트웨어 팩키지는 다중반사의 제거, 탄성파 분해능, 탄성파 모델링, 그리고 합성 음향검층과 같은 특수한 문제를 다루는 데에 한계를 보이고 있다.

해양 탄성파자료의 경우, 해저면 다중반사는 속도분석과 자료해석시에 심각한 악영향을 끼칠 수 있으나 현재 사용되는 상용 처리 소프트웨어는 다중반사의 제거에 비효율적이다. f-k 필

터링을 이용하는 방법도 널리 사용되고 있으나 wrap-around, 공간적인 aliasing, 그리고 통과/거부 영역간 경계에서의 감쇠와 같은 실제적인 문제를 지니고 있다. f-k 필터링의 대용으로서 K-L (Karhunen-Loéve) 변환이 다중반사의 제거에 강력한 수단으로 고려되고 있다.

이 보고서는 K-L 변환을 이용하여 다중반사를 제거하기 위한 방안을 개발하는 것을 목적으로 한다. 일차적으로 K-L 변환방법을 실행화하는 것에 중점을 두었으며 합성 및 실제자료를 이용하여 적절한 처리기준을 유도하고자 한다.

III. 연구개발의 내용 및 범위

이 연구에서는 K-L 변환을 활용하는 다중반사 제거방법을 실행화하여 해양연구소의 종합조사선 온누리호를 이용하여 동해에서 얻은 다중채널 탄성파자료에 적용하였다. 다중반사의 제거를 위한 연구방안은 다음과 같다 :

(a) 부적합 영상복원 : NMO된 CMP자료에서 K-L 변환을 이용하여 직접 일차반사파만을 추출한 후 역 NMO를 하여 중합하였다.

(b) 연구방법의 검증 : 다중반사를 제거하기 전과 제거한 후의 CMP자료의 속도분석과 중합을 비교하여 이 연구의 성과를 검증하였다.

IV. 연구개발 결과 및 활용에 대한 건의

K-L 변환은 특히 천해환경에서 심각한 문제를 야기시키는 다중반사의 제거에 효과적으로 적용할 수 있다. 이 보고서에서는 탄성파자료의 특수 처리방안으로 K-L변환을 이용하여 다중반사를 제거하는 방법을 연구하여다. 이 연구의 주요 결과는 다음과 같다 :

(a) 다중반사의 제거를 위해서는 부적합 영상복원방법을 실행화하여 합성 및 실제자료에 성공적으로 적용하였다.

(b) 탄성파자료에서 다중반사파를 제거함으로써 지질단면도의 품질을 향상시킬 수 있었다.

(c) 근거리 탄성파자료에서 다중반사파를 완전히 제거하는 것은 어렵다고 알려져 있다. 부적합영상복원은 근거리 탄성파자료에서 다중반사를 제거하나 일차반사파의 일부를 소실시키는 경향이 있다.

(d) 다중반사를 제거시킨 후 중합단면에서 트레이스간의 진폭변화를 효과적으로 억제시켜 전체 자료의 수평적인 상관성을 높일 수 있었다.

부적합영상의 복원후 근거리자료의 다중반사파를 효율적으로 제거시키기 위해 자료적응형 가중필터가 차후에 개발되어야 할 것으로 생각되는 바 현재 연구중에 있다.

SUMMARY

I. Title

IMPROVEMENT OF THE SIGNAL TO NOISE RATIO OF MULTICHANNEL SEISMIC DATA ACQUIRED ON THE R/V ONNURI
(Multiple Suppression via the Karhunen-Loéve Transform)

II. Significance and Objectives of the STUDY

The Korea Ocean Research and Development Institute (KORDI) is expanding its ability to complement its commitment to investigating the deep geologic structures of the Korean Seas with the use of a multi channel seismic method. Efforts have been made to establish a proper data processing system comprising both the standard and special shemes. The popular seismic data processing software packages widely used are limited in their abilty to handle special topics such as multiple attenuation, noise removal, seismic resolution, seismic modeling, and syntheic sonic logs.

In marine seismic data the multiples of the water-bottom reflction often have malignant effects on velocity analysis and, more seriously interpretation. The conventioanl standard processing schemes are not so effective in multiple suppression, although much works have been devoted to this subject. One popular technique exploiting the f-k (frequency-wavenumber) filtering method has practical problems such as wrap-around, spatial aliasing, and tapering over the boudary between the pass/reject zones. An alternative to the f-k filtering approach is the K-L (Karhunen-Loéve) which is considered as a powerful tool for this problem.

This report aims to develope a special data processing scheme for multiple suppression. We adopted the K-L transform for the suppression of water-bottom multiples, and placed emphasis on the implementation of the K-L transform method and the derivation of the suitable processing criteria on the basis of synthetic and real seismic data acquired aboard the R/V Onnuri in the East Sea of Korea in the year of 1992.

III. Scope of the Study

In this study, the multiple elimination method utilizing the K-L transform was implemented and applied to the seismic data acquired in the East Sea employing the multi-channel seismic system installed on the R/V Onnuri. Various schemes were tested to suppress multuples in the following way :

(a) Misfit reconstruction : Primaries were extracted from the NMOed CMP gather via the K-L transform.

(b) Verification of the proposed method : The CMP gathers with multiple suppression was compared to the unprocessed CMP gather in terms of velocity analysis and stacking.

IV. Results of the Study and Future Suggestions

The K-L transform can be utilized to suppress multiple arrivals which pose a serious problem in shallow water environments. In this report the water-bottom multiple suppression method via the K-L transform was implemented as a special seismic data processing tool and then applied to the synthetic and real data sets. The main results of this study can be stated as follows :

(a) The misfit reconstruction was implemented and applied to synthetic and real data sets.

(b) The seismic section after the suppression of multiples shows an improved quality.

(c) Multiples in the near offsets are known to be difficult to remove completely. The misfit reconstruction can remove multiples in a quite selective way, but some of primaries appears to be lost.

(d) The lateral balancing of a stacked section was improved since this method incorporates the concept of common signal extraction.

The data adaptive noise cancellation method incorporating the weighting function is under comtemplation to effectively restore the weakened primaries in the near offsets.

IMPROVEMENT OF THE SIGNAL TO NOISE RATIO OF MULTICHANNEL SEISMIC DATA ACQUIRED ON THE R/V ONNURI

(Multiple Suppression via the Karhunen-Loéve Transform)

CONTENTS

LIST of FIGURES

1. INTRODUCTION

Multiple suppression is often made on the basis of the moveout difference between primaries and multiples.

One popular technique exploits the f-k (frequency-wavenumber) domain separation of primaries and multiples in CMP gathers by selective filtering. In essence, the f-k domain multiple suppression method can be written as follows. NMO (normal moveout) is applied using a velocity in between the primary and multiple velocity functions. This forces the primaries to have negative dip and multiples to have positive dip. Consequently they lie in different quadrants of the f-k domain. The quadrant corresponding to positive dip is then attenuated with appropriate tapering and the NMO correction removed (Hatton et al., 1986). In practice, there are variations in selecting the moveout velocity. Some prefer to apply NMO correction using the multiple velocity, then zeroing the energy along the frequency axis and the multiple quadrant of the f-k spectrum. Thus, the practical problems occur such as wrap-around, spatial aliasing, and tapering over the boudary between the pass/reject zones (Yilmaz, 1987).

An alternative to the f-k filtering approach is the K-L (Karhunen-Loéve) transform to separate one type of coherent waveform from a different one, or from incoherent energy. Applications of the K-L method to seismic data procesing were considered by Hemon and Mace (1978), Jones (1985), and more recently by Jones and Levy (1987). In the field of image processing, the K-L transform has been widely applied to data transmission and analysis (Mallick and Murthy, 1984) and digital image enhancement (Ready and Wintz, 1973; Ahmed and Rao, 1975; Huang and Narendra, 1975; Freire and Ulych, 1988).

Mostly the application of the K-L transform has been made to two specific problems (Jones and Levy, 1987), namely:

(a) the separation of signal from incoherent and dipping coherent noise in stacked seismic data,

(b) the suppression of multiples in CDP (common-depth-point) or CMP (common-mid-point) gathers by isolating coherent energy associated with a particular velocity, from other coherent energy.

In this report the the K-L transform technique to suppress water bottom multiples is implemented and applied to the seismic data acquired in the Korean shelf. The data acquisition was conducted in the East Sea employing the R/V Onnuri belonging to KORDI (Korea Ocean Research and Development Institute) in November, 1992.

KORDI is expanding its ability to investigate the deep geologic structures of the Korean Seas with the use of a multi channel seismic method. Thus efforts has been made to establish a proper data processing system comprising both the standard and special shemes. This report aims at developing a special data processing scheme for the purpose of multiple suppression using the K-L transform. Emphasis is placed on the implementation of the K-L transform method and the derivation of the suitable processing criteria on the basis of synthetic and real data examples.

The methematical relations and their implications related to basic theories are written as little as possible in this report, since they are well described in the literature.

2. THE K-L TRANSFORM

The K-L (Karhunen-Loéve) transfrom, long been known and well utilized in image processing (Ahmed and Rao, 1975), has been applied to geophysical data processing field, though relatively scant. The basic tenet behind this transform is that in seismic data processing the linear trace-to-trace coherency may be projected into a space where the coherent information is compressed into the smallest possible number of 'alternative data' traces. This compression separates the correlated from uncorrelated parts of the input data.

2-1. Properties of the K-L Transform

The K-L transfrom can be implemented in different ways. Ulych (1988) showed that the K-L transform can be derived by the SVD (singular value decomposition) approach.

Let X be a seismic data matrix which contains M traces each with N data points (generally $M < N$), i.e.,

$$\mathbf{X} = \{ X_{ji} \},\ \ i=1,2,\ldots,M;\ j=1,2,\ldots,N. \qquad (1)$$

The SVD of **X** is given by

$$X = \sum_{i=1}^{r} \sigma_i \ u_i \ v_i^T \qquad (2)$$

where subscript T indicates transpose, r is the rank of X, u_i is the i th eigenvector of X X^T, v_i is the i th eigenvector of X^TX, and σ_i is the i th singular value of X.

Band-pass X_{BP}, low-pass X_{LP}, and high-pass X_{HP} SVD images can be defined in terms of the ranges of singular values used. The band-passed images is reconstructed by rejecting highly correlated as well as highly uncorrelated traces and is given by

$$X_{BP} = \sum_{i=p}^{q} \sigma_i \ u_i \ v_i^T, \qquad 1<p\leq q<r. \qquad (3)$$

The summation for X_{LP} is from i=1 to p-1 and for X_{HP} from i=q+1 to r. It may be simply shown that the percentage of energy which is contained in a reconstructed image X_{BP} is given by E, where

$$E = \sum_{i=p}^{q} \sigma_i^2 \ / \ \sum_{i=1}^{r} \sigma_i^2 \ . \qquad (4)$$

The sigular values σ_i are equal to the square root of the eigenvalues λ_i of the covariance matrix X^TX. X_{LP} and X_{HP} are called principal component and misfit reconstruction, respectively.

The followings are important for the applications of the K-L transform to seismic data procesing (Jones and Levy, 1987) :

(a) The K-L transform produces a set of uncorrealted (orthogonal) principal components from the data set; the size of the j th eigenvalue is a measure of the amount of coherent energy present in the j th principal component. Hence, reconstruction of the original signals using only those principal components which are associated with 'fairly large' eigenvalues amounts to the reconstruction of the coherent energy present in the input seismograms. Here, "coherent" refers to events which are similar horizontally in a trace-to-trace sense. Conversely, reconstruction of the original data from those pricipal components associated with the smaller eigenvalues amounts to the reconstruction of the less coherent or 'anamalous' parts of the input data.

(b) If the original data $x_i(t)$ consists of scaled version of some basic signal, then all the eigenvalues of the covariance matrix $\mathbf{X}^T\mathbf{X}$ with the exception of λ_1 are zero and the first principal component is a scaled version of the same basic signal.

(c) If the original data possess no trace-to-trace coherency (i.e., if they are orthogonal), then X^TX is diagonal and data set itself corresponds to the set of principal components. Hence no advantage can be gained by using the transform.

2-2. Water-bottom multiple suppression

Fig.1a shows the synthetic CMP gather with 48 seismic traces consisting of seven primaries including water-bottom reflections (Fig.1b) and the multiples associated with the water-bottom (Fig.1c). The K-L transform enables both primary and multiple energy to be extracted from the CMP gather. This is achieved by NMO correcting the gather using a velocity function corresponding to the mutiple velocity of 1500 m/sec (Fig.2a). Fig. 2b shows the extracted water-bottom reflections including multiple energy after a principal component reconstruction using two singular values. In Fig.2b primaries are completely removed as is desired, but water-bottom reflection waveforms aligned along 350 ms in the far offsets differs severely from those in Fig.2a. In this example stretch mute was applied to NMO

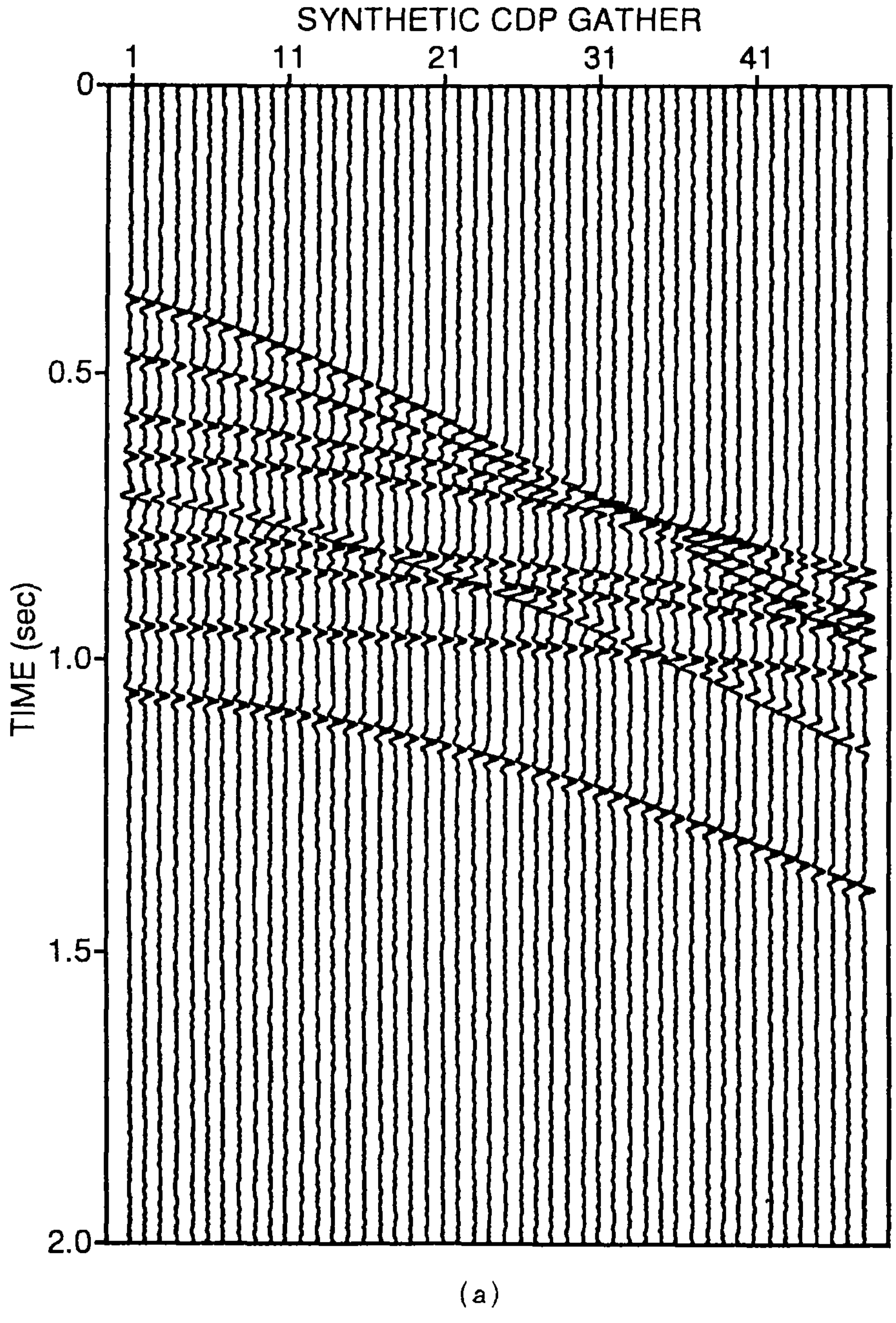
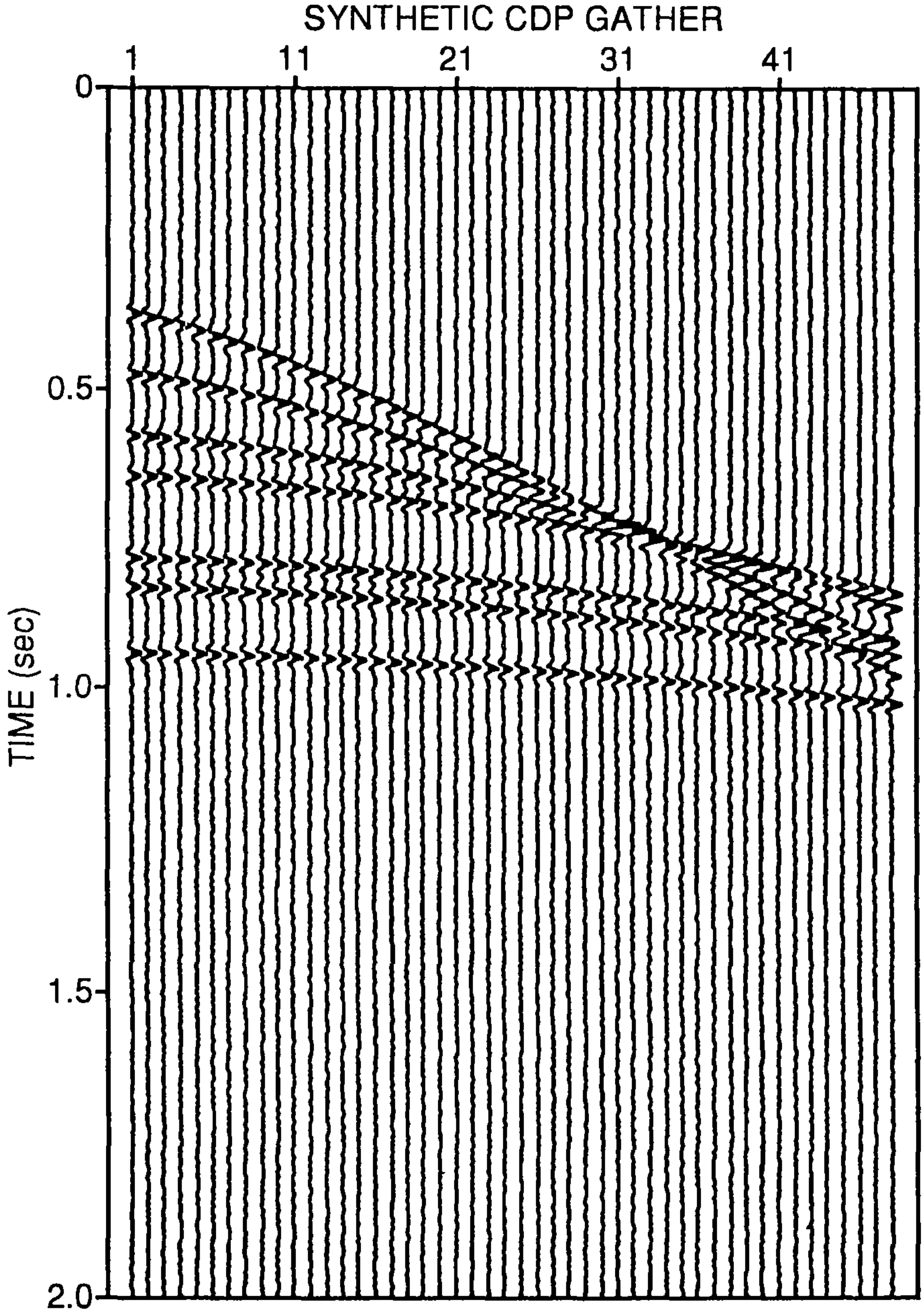
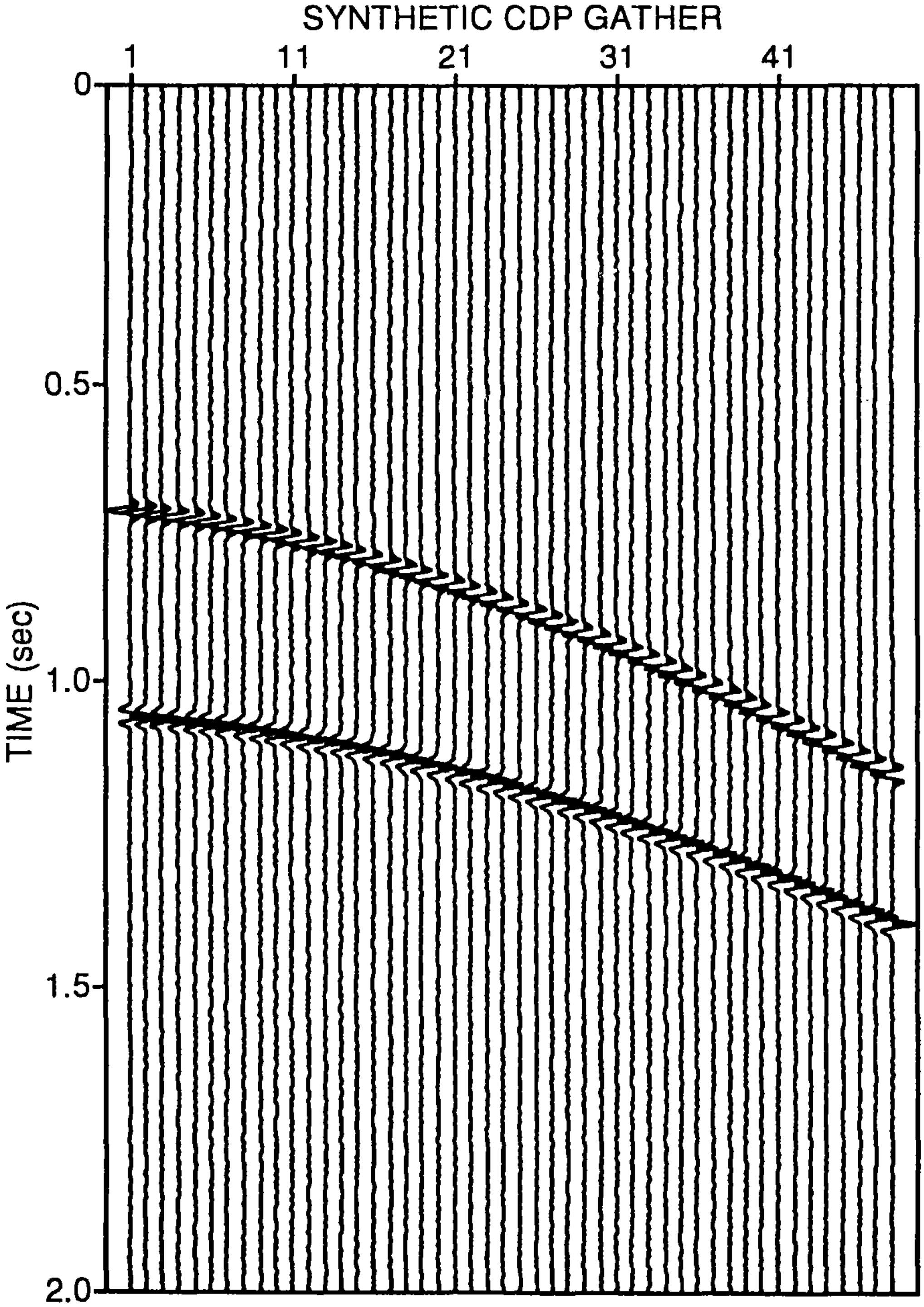


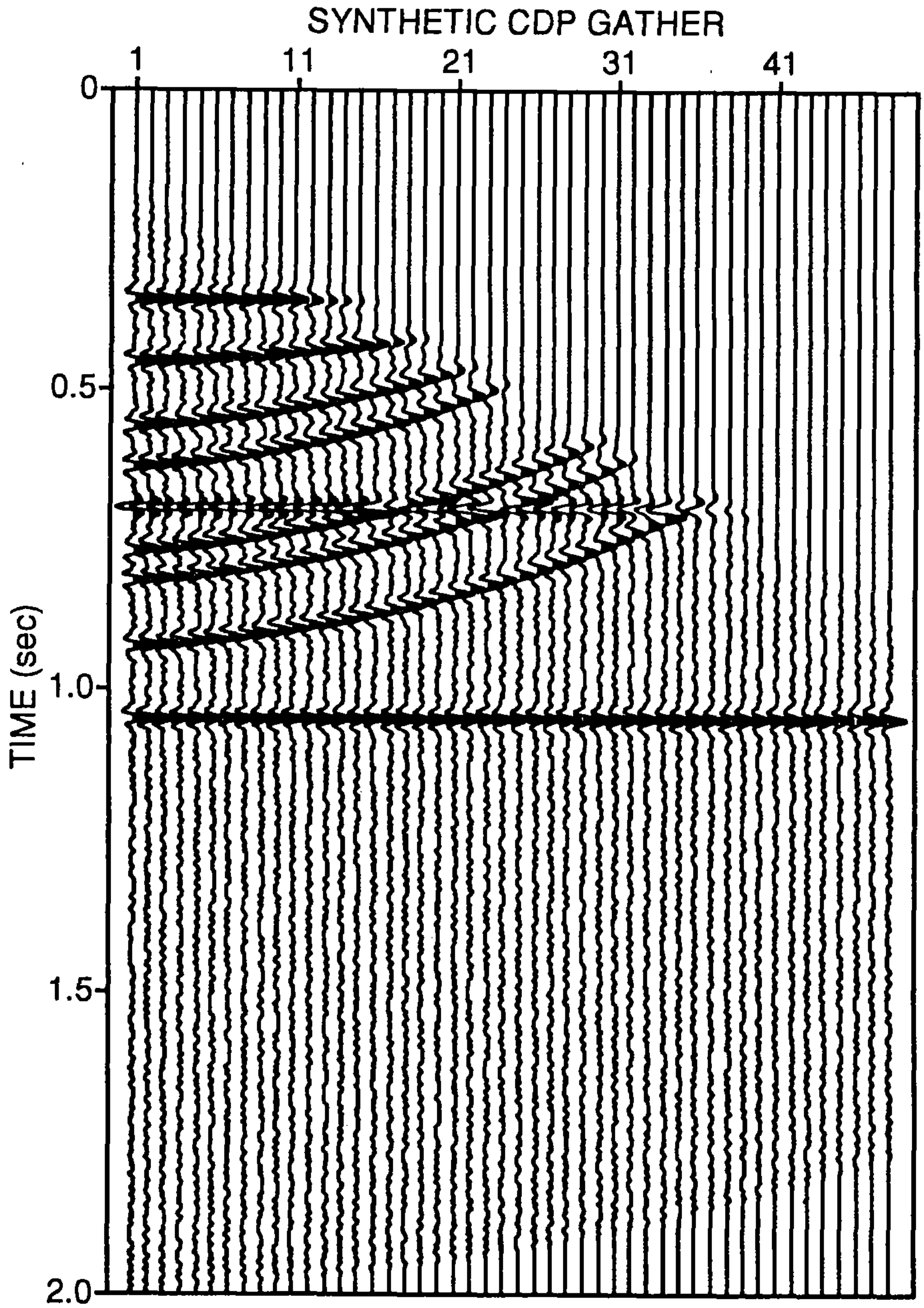
Fig. 1. Synthetic CMP gathers containing (a) primaries and water-botto multiples by the superposition of (b) primaries and (c) multiples.



(b)

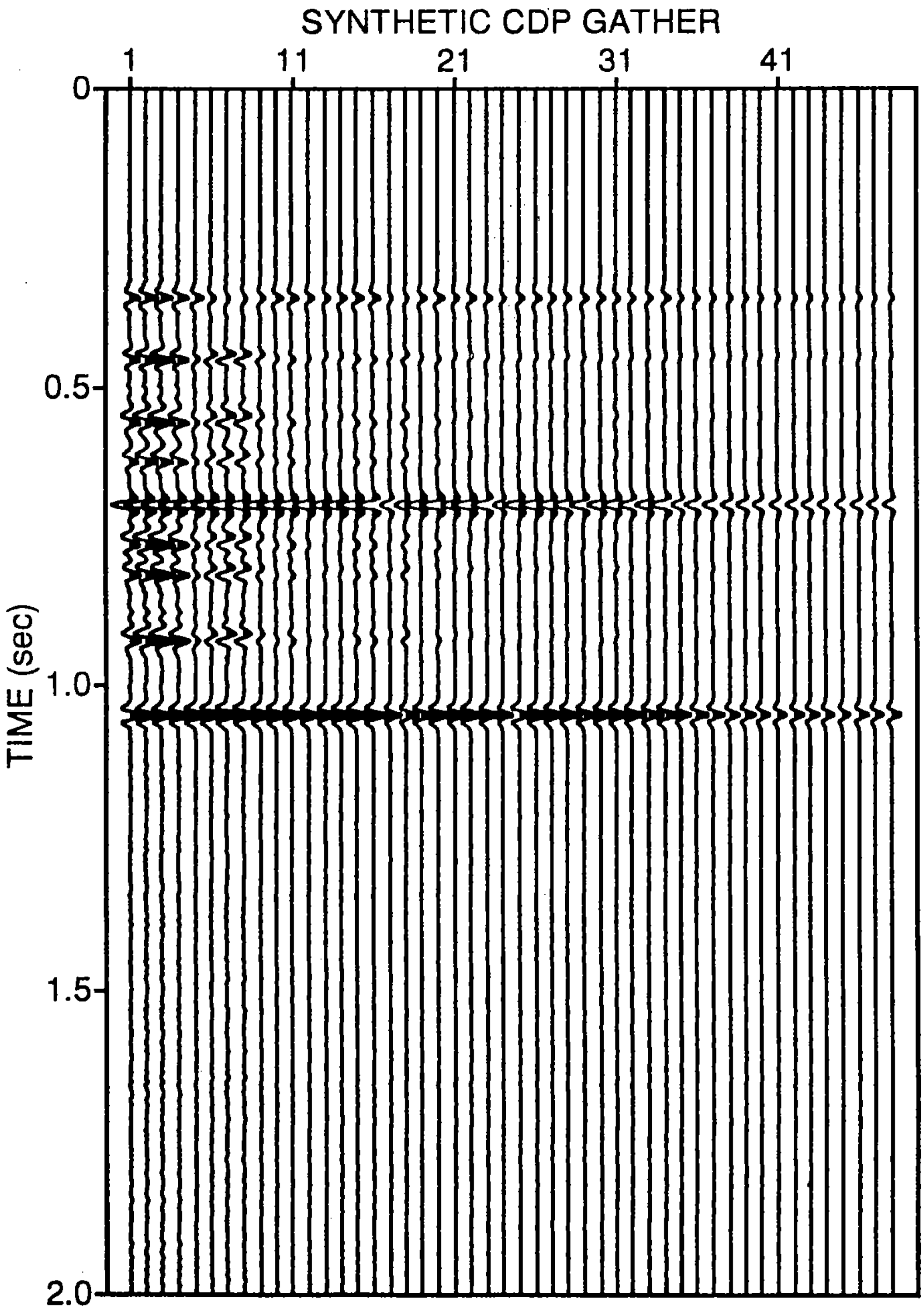


(c)



(a)

Fig. 2. (a) The CMP gather in Fig. 1a after NMO correction using a velocit function of the multiple (b) The result of a principal componen reconstruction using the first two singular values, (c) The result o a misfit reconstruction ommiting the first two singular values.

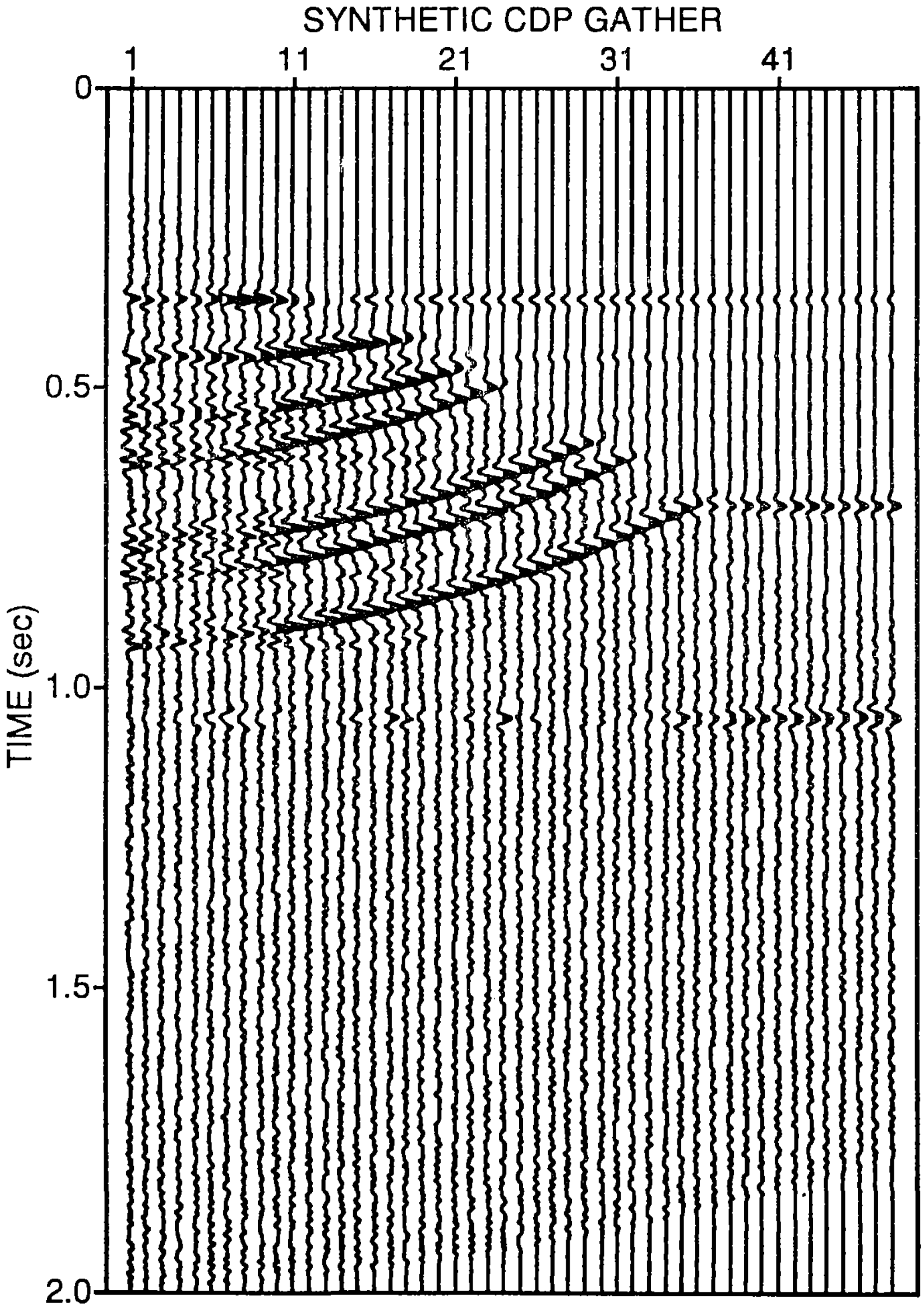


(b)

and inverse NMO as is usual in conventioanl data processing, to avoid the large stretch of waveforms in the far offsets. Thus, waveforms severely stretched in the far offset relative to the near offset were all gone out. However, the principal component reconstruction (Fig.2b) tends to fill the locations of missing events with attenuated continuations of significant waveforms, which will act as the coherent artificial noise throughout the procedures. The misfit reconstruction (Fig.2c) shows that multiples can be removed completely. In Fig.2c, some residual noise remains in the locations formerly occupied by the multiple events, but this is largely incoherent, and will not stack to produce a noticeable effect. The problem of artificial noise arised again in the far offsets where water-bottom reflections disappeared due to the stretch mute.

Fig.3 shows the semblance velocity analysis (VA) of the synthetic data. We can see multiple energy at 0.35, 0.70 and 1.05 sec with a charateristic velocity of 1500 m/sec. Fig.4 shows a VA of the data after multiple suppression processing. The comparison of Fig.3 and Fig.4 tells that the events related to water-bottom reflections of 1500 m/sec velocity were effectively removed from the data.

The performance of multiple suppression by the K-L



(c)

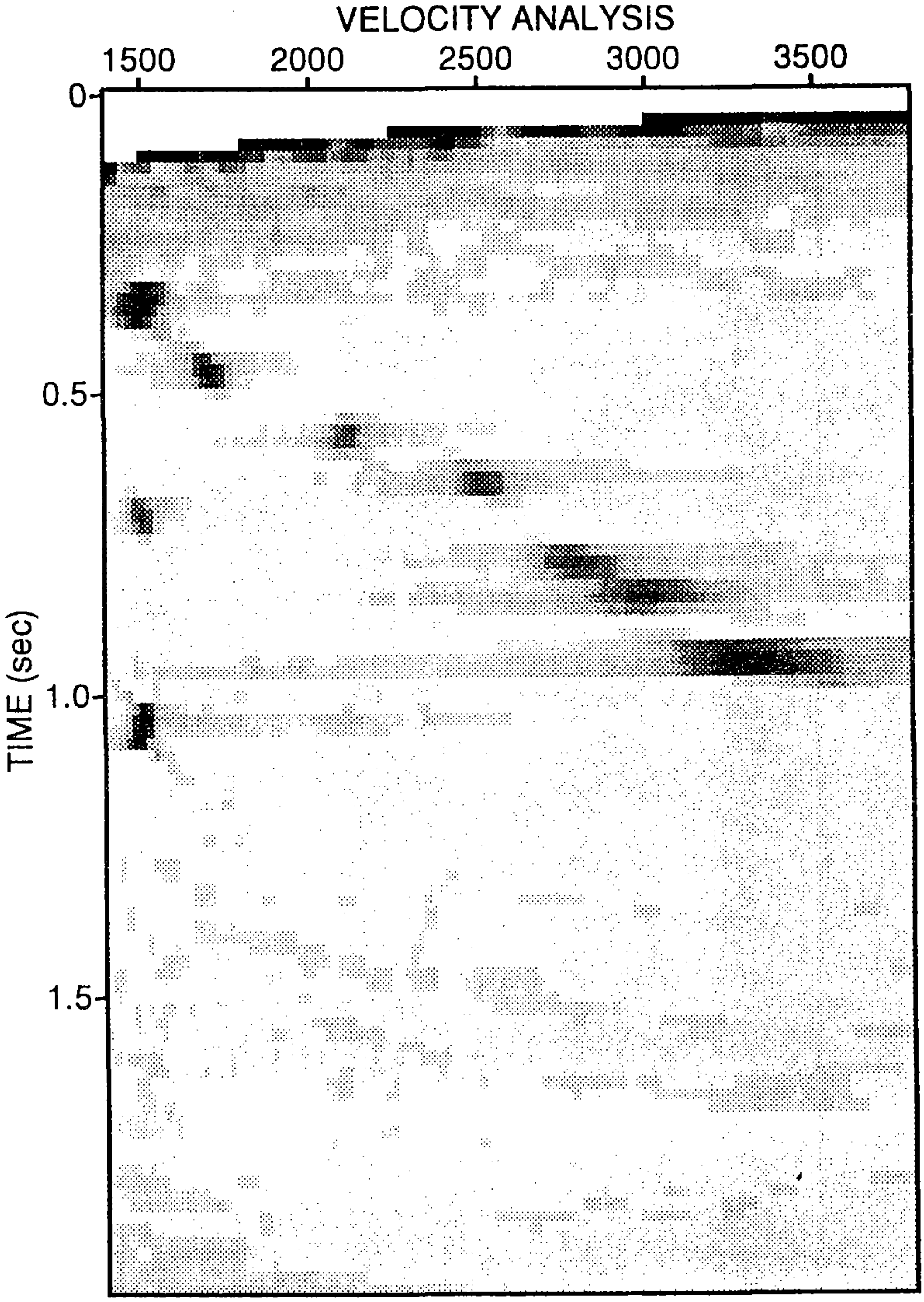


Fig. 3. Velosity spectrum of the CMP gather in Fig. 1a.

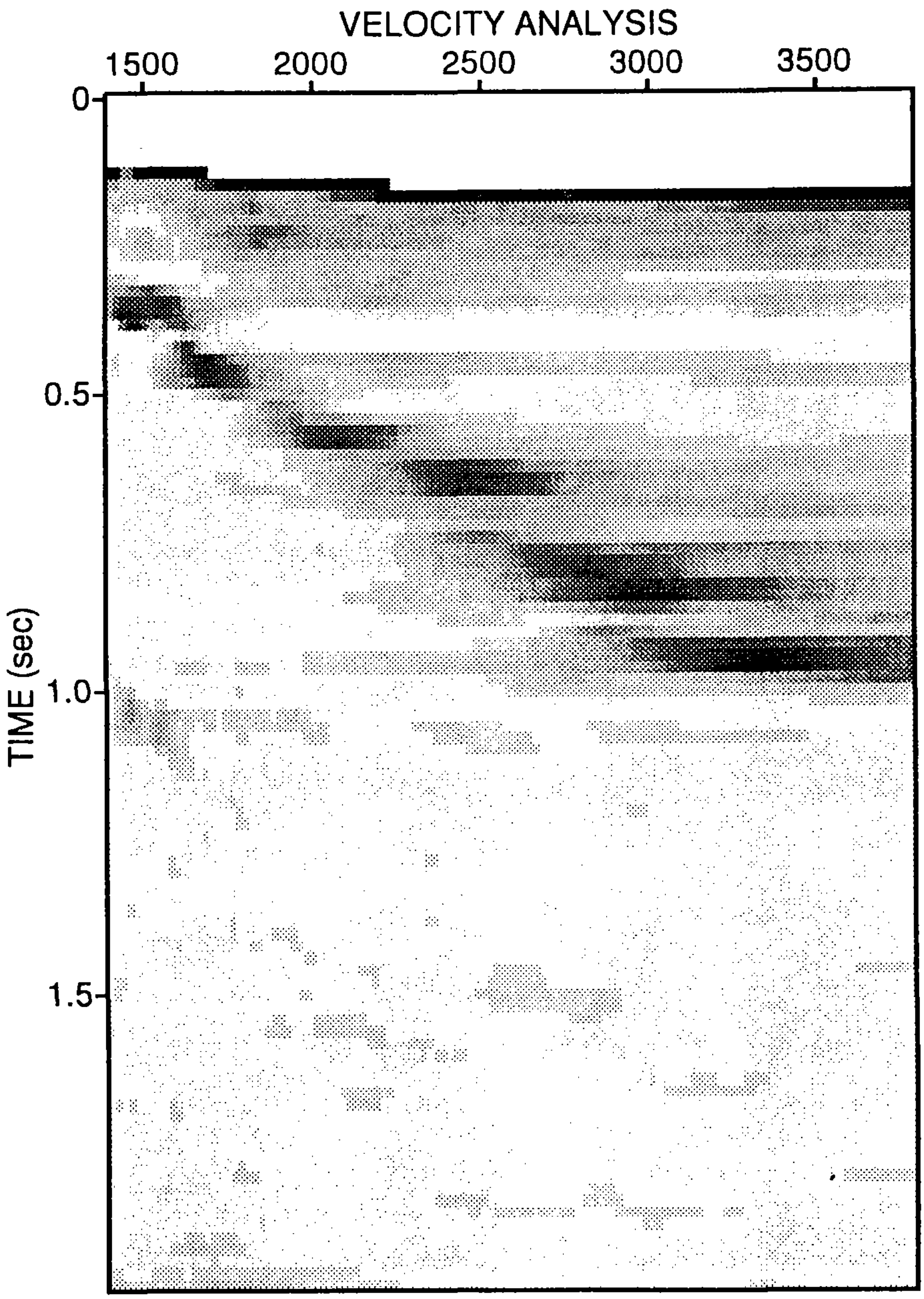


Fig. 4. Velocity spectrum of the CMP gather after multiple suppression.

transform was tested on real seismic data. Fig.s 5 and 6 show a CMP gather of marine seismic data shot in the East Sea of Korea and the NMOed gather using a 1500 m/sec velocity, respectively. The water-bottom primary and multiples were flattened and especially noticeable in the near offsets. The misfit reconstruction of the data in Fig.6 omitting the first two principal components was shown in Fig.7. We see the flattened events corresponding to the water-bottom were removed completely but some of primaries were lost in the near offsts, too. The loss of primaries in the near offset can not be avoided, since there is not any distinguishable differnece between multiples and primaries in this region, however the primaries can be enhanced by stacking. Fig.s 8 and 9 show velocity analysis of the gather before and after multiple suppression. Note the absence of the band of multiple energy in early time.

Fourty gathers of data were processed in this way, and a comparison of the conventionally stacked data with a stack of the multiple suppresed data is made in Fig.s 10 and 11. The noticeable features in the multiple suppressed section are: the clearly defined events at 0.6 sec and around 1.5 sec, and the absence of the events at 1.5 sec (CDP# 22-29) and 2.9 sec (CDP# 28-37). One of the most attractive features in this real data example is that the events at

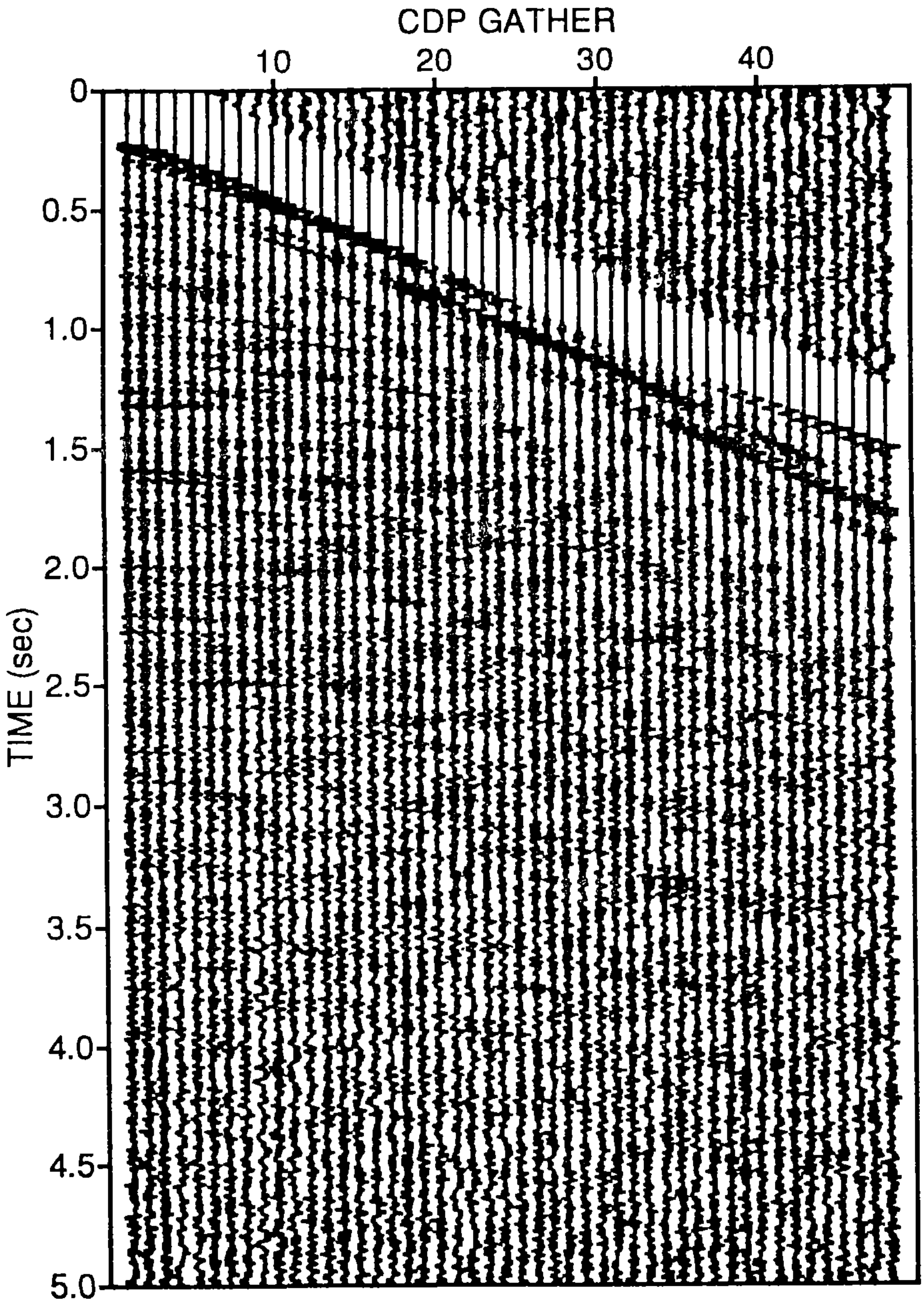


Fig. 5. A marine CMP gather acquired in the East Sea of Korea.

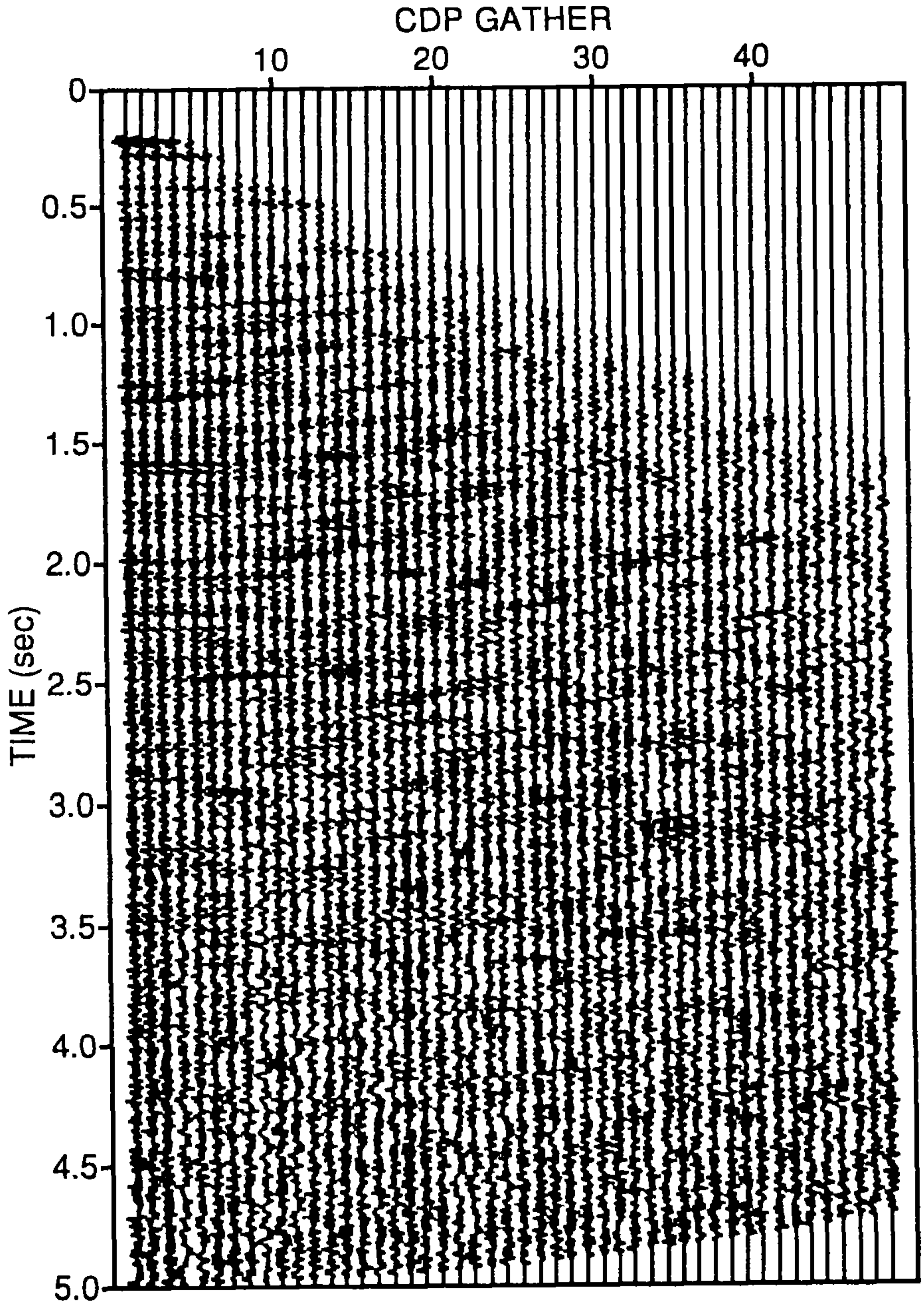


Fig. 6. The CMP gather in Fig. 5 after application of NMO using a velocity of 1500m/sec and AGC.

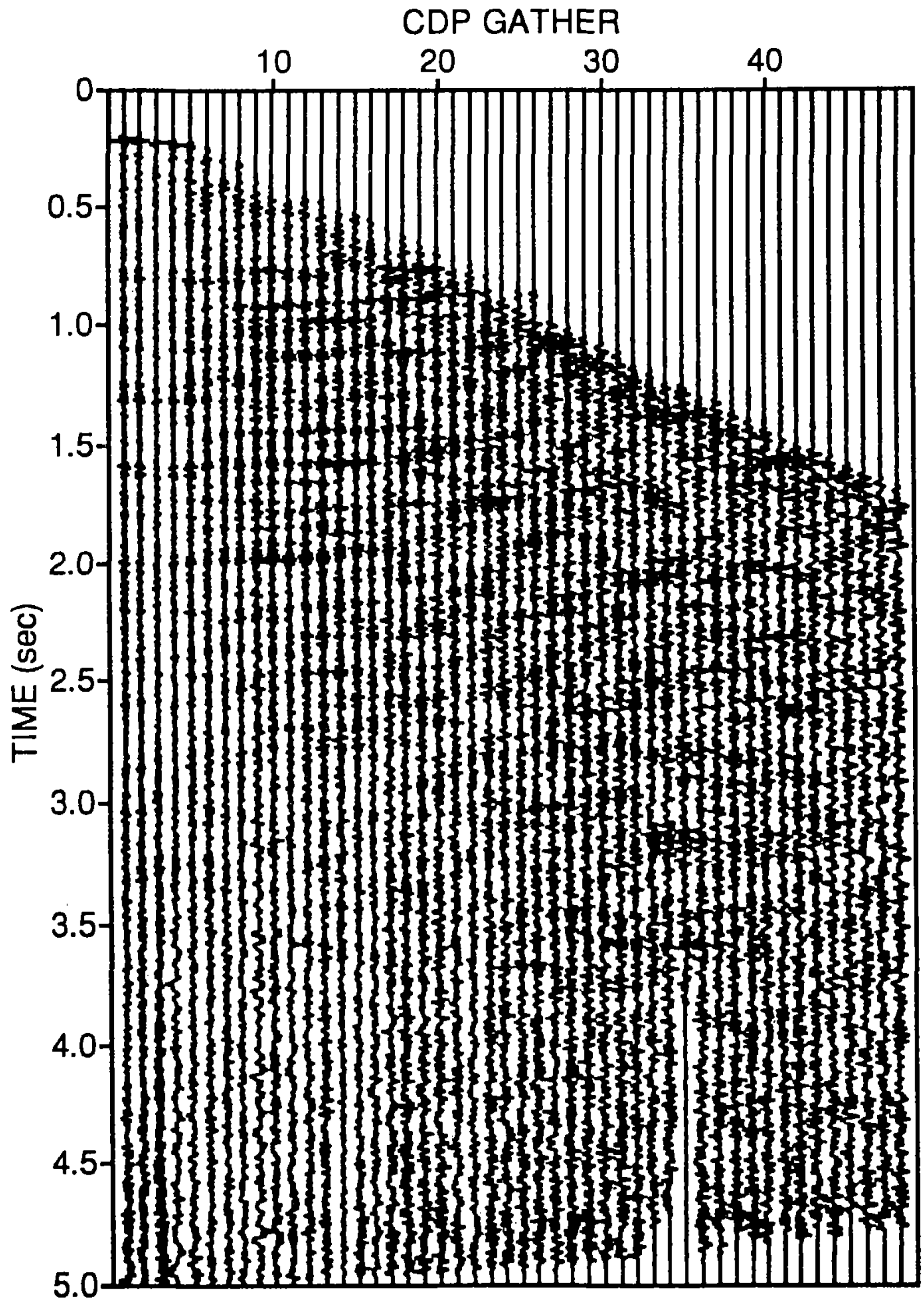


Fig. 7. A marine CMP gather of Fig. 6 after misfit reconstruction ommiting the first two principal components.

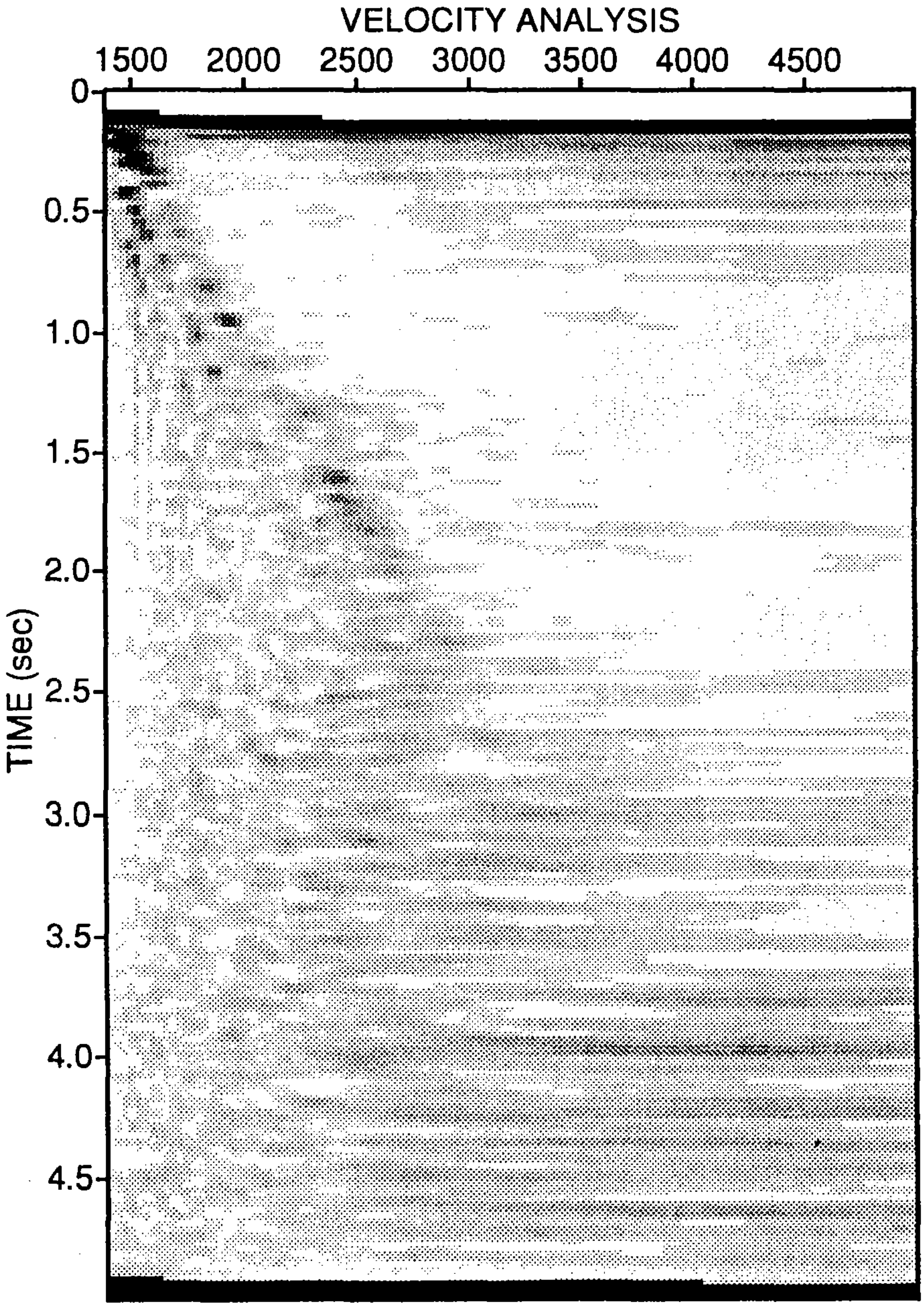


Fig. 8. Velocity analysis of the data in Fig. 5.

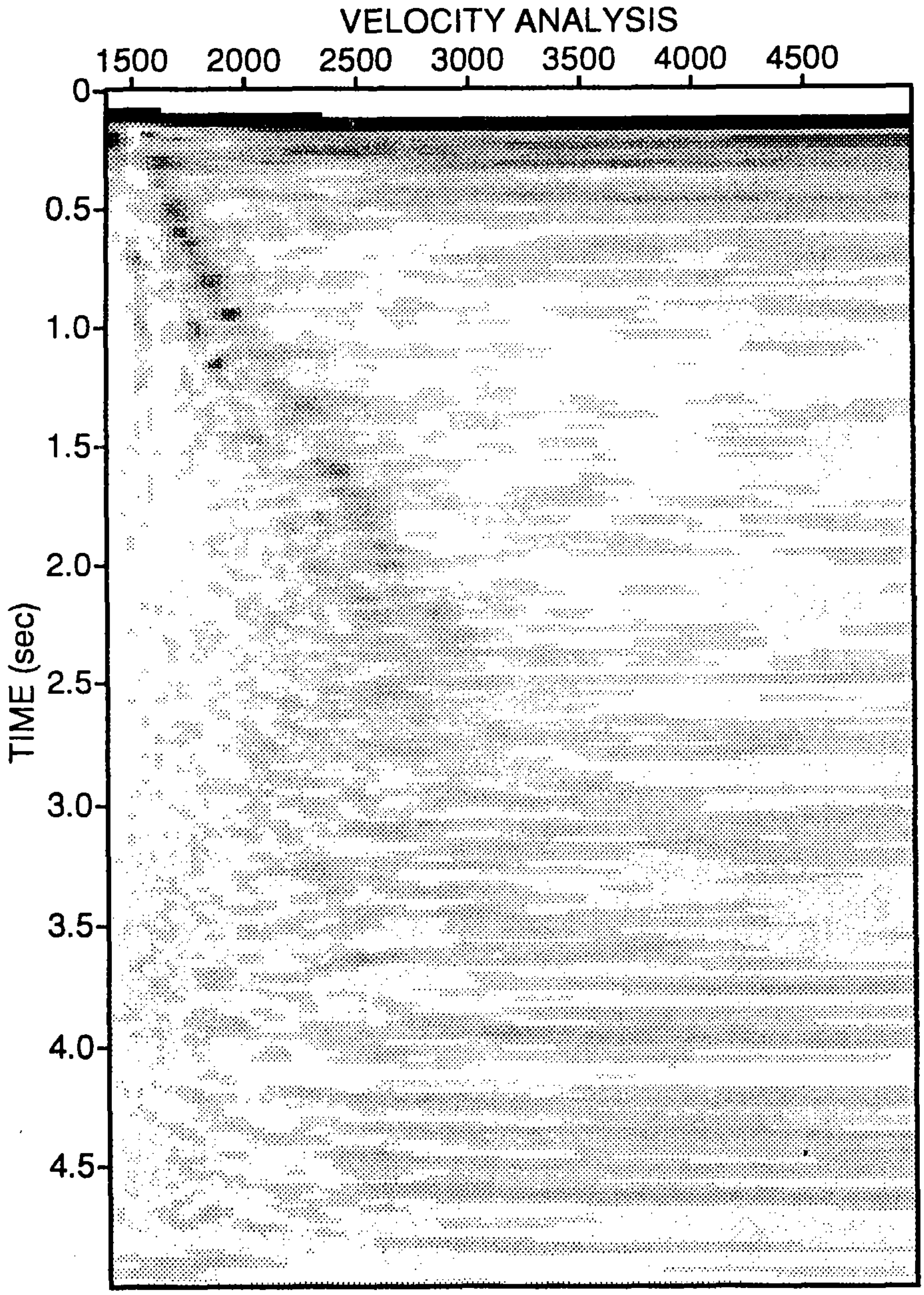


Fig. 9. Velocity analysis of the data in Fig. 5 after multiple suppression.

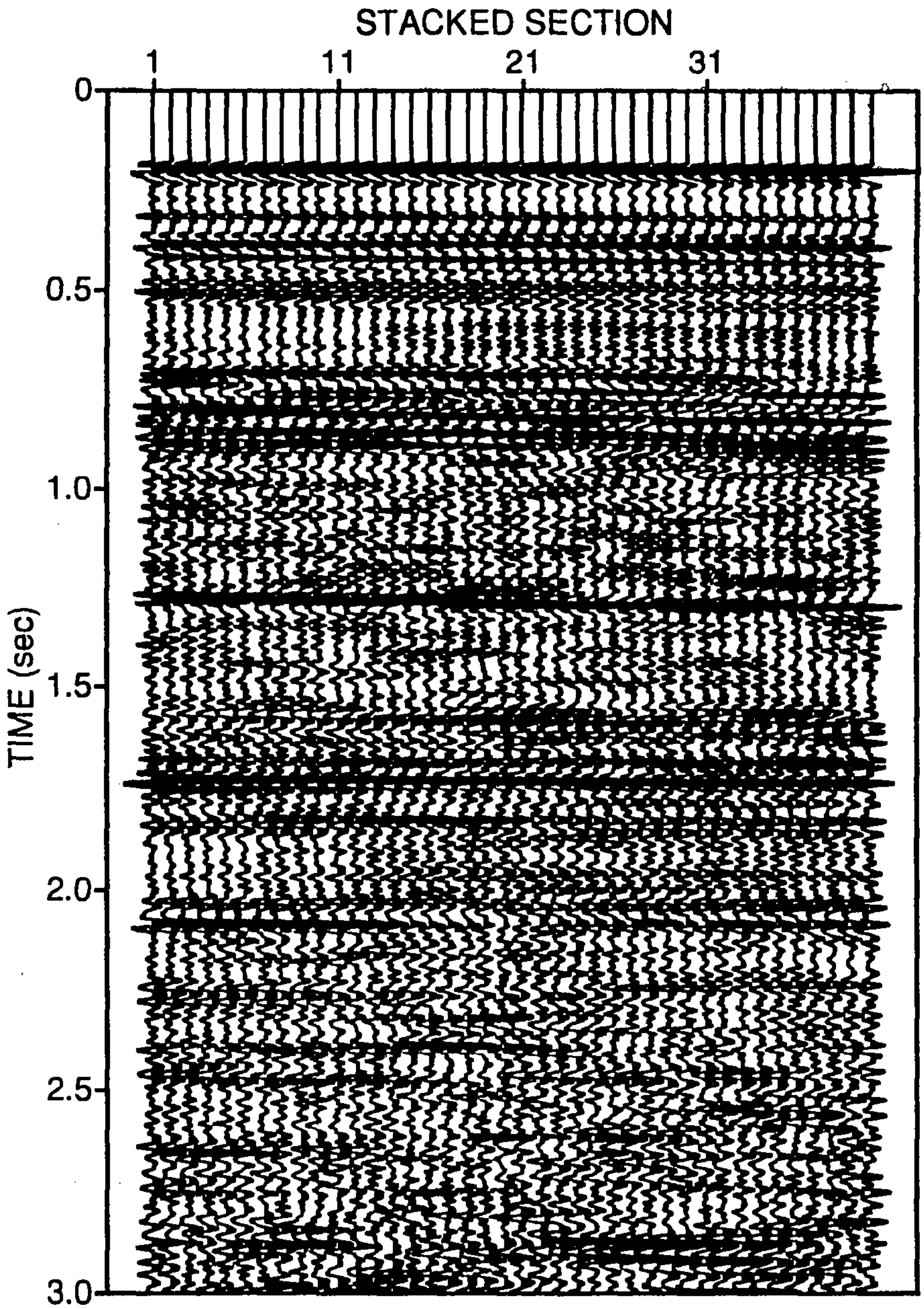


Fig. 10. The stack of 40 gathers.

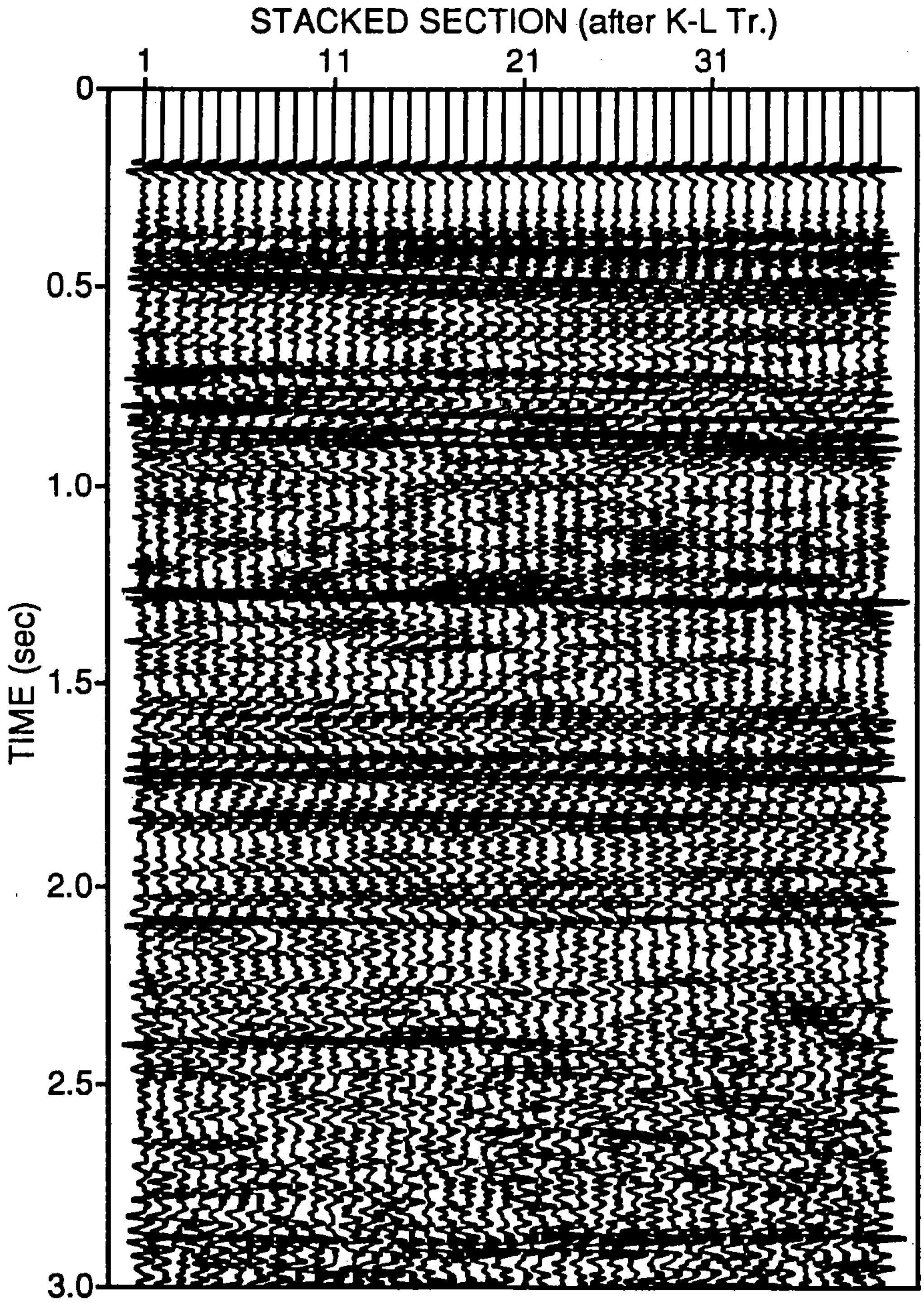


Fig. 11. The same stacked section after multiple suppression.

2.3 to 2.5 sec range appears to be drastically changed to reveal the primaries and suppress the multiples. Another promising property of this processing is that unbalancing effects at CDP# 20 in the conventioanlly stacked data were removed completely to improve the lateral consistency over the entire traces.

The additional attractions of the K-L transform in addition to the suppression of water-bottom multiples can be stated in a brief summary as follows :

(1) the waveforms are not distorted.

(2) the pratical problems encountered in f-k filtering such as wrap-around and spatial aliasing dont' pose any seriousness.

(3) the lateral balancing of CDP traces was improved since this method incorporates the concept of common signal extraction.

A defect of K-L filtering is a loss of primary energy in the near offset, which is especially noticeable in the real data example. To recover the weakened primaries after K-L filtering, a data adaptive singnal restoring method is proposed.

CONCLUSION

The K-L transform can be utilized to suppress multiple arrivals which pose a serious problem in shallow water environments. In this report the water-bottom multiple suppression method via the K-L transform was implemented as a special seismic data processing tool and then applied to the synthetic and real data sets. The main results of this study can be stated as follows :

(a) The misfit reconstruction was implemented and applied to synthetic and real data sets.

(b) The seismic section after the suppression of multiples shows an improved quality.

(c) Multiples in the near offsets are known to be difficult to remove completely. The misfit reconstruction can remove multiples in a quite selective way, but some of primaries appears to be lost.

(d) the lateral balancing of a stacted section was improved since the K-L transfrom incorporates the concept of common signal extraction.

The data adaptive noise cancellation method incorporating the weighting function is under comtemplation to effectively restore the weakened primaries in the near offsets.

REFERENCES

Ahmed, N. and Rao K. R., 1975, Orthogonal transforms for digital image processing: Verlag J. Springer, p.189-224.

Freire, S. L.. M. and Ulych, T. J., 1988, Application of singular value decomposition to vertical seismic profiling: Geophysics, v.53, p.778-785.

Hatton, L., Worthington, M. H. and Makin, J., 1986, Seismic data processing : Blackwell Sci. Pub.

Hemon, C. H. and Mace, D., 1978, Use of the Karhunen-Loéve transformation in seismic data processing: Geophysical Prospecting, v.26, p.600-626.

Huang, T. S., and Narendra, P. M., 1975, Image restoration by singular value decomposition: Appl. Opt., v.14, p.2213-2216.

Jones, I. F., 1985, Application of the Karhunen-Loéve transform in reflection seismic processing: Ph. D. Thesis, Univ. British Columbia, Canada.

Jones, I. F. and Levy, S., 1987, Signal-to-noise ratio enhancement in multichannel seismic data via the Karhunen-Loéve transform: Geophysical Prospecting, v.35, p.12-32.

Mallick, K., and Murthy, Y. V. S., 1984, Pattern of

Ladsat MSS data over Zawar lead-zinc mines, Rajasthan, India: First Break, v.2, p.16-21.

Milligan, S. D., LeBlanc, L. W., and Middleton, F. H., 1978, Statistical grouping of acoustic reflection profiles: J. Acoust. So. Am., v.64, p.759-807.

Ready, R. J., and Wintz, P. A., 1973, Information extraction, SNR improvement, and data compression in multispectral imagery: IEEE Trans. Commun., v.COM-21, p.1123-1130.

Yilmaz, O., 1987, Seismic data Processing: Soc. Expl. Geophys., Oklahoma, U.S.A.