PRJ, Vol. 5 (January 1993); P. 22-36, 12 FIGS.

POST-STACK DECONVOLUTION AND MULTIPLES ATTENUATION

M.M. Elazezi*

التخلص من الإنعكاسات السيزمية المتكررة باستخدام طريقة اللف العكسي (ديكونفولوشن)

محمد مسعود العزيزي

تعمل الإنعكاسات المتكررة الموجودة بالمعلومات السيزمية على حجب أسطح الإنعكاس الأساسية والمهمة ، لذلك فقد تم إجراء عملية تصفية لما بعد التكدس بتطبيق طريقة التصفية التوقعية (الإستقرائية) للمعلومات السيزمية النهائية للتخلص من هذه الإنعكاسات.

لقد تم حساب القياسات أو المعايير المطلوبة باجراء عملية المقارنة الذاتية ثمّ بعدها إختبار هذه القياسات على أجزاء من المقاطع السيزمية. تضمن الإختبار كيفية إختيار أحسن المقاسات المطلوبة مثل مسافة التنبؤ وطول المشغل الخاصة باجراء عملية التصفية (DECONVOLUTION)، كما تم مقارنة المقاطع السيزمية قبل وبعد تطبيق المعايير المختارة.

أعطت المقارنة نتائج مشجعة جداً وذلك من خلال إبراز أسطح الإنعكاس المتميزة وطمس الإنعكاسات المتكررة.

إن التخلص التام من مثل هذه الإنعكاسات هو النتيجة المستهدفة ، ولكن يبدو أن الإنعكاسات المتكررة ذات نطاق كبير من الخواص ، ولذلك فانه يتم فقط التخلص من الإنعكاسات التي تتوافق مع المعايير والقياسات التي تم تطبيقها.

ABSTRACT

The presence of multiples on seismic data have obscured the recognition of primary reflection events of interest. Post-stack deconvolution was carried out using final-stacked seismic data. The predictive deconvolution technique is used for multiple suppression. The parameters were computed from autocorrelation functions and tested on different panels of the seismic sections. The Test include mainly the prediction distance and operator length to select the best parameters required to attenuate the existing multiples. The obtained sections were compared with the final sections before post-stack deconvolution was applied. The tested parameters gave very encouraging results by bringing out a distinctive reflector and suppressing multiples. Complete suppression of multiples is the desired result from the application of the selected deconvolution filter; however, multiples seem to exhibit a range of properties and so only those multiples which conform to the predicted assumptions were removed.

*Petroleum Research Centre, P.O. Box 6431, Tripoli, G.S.P.L.A.J.

INTRODUCTION

The seismic trace is assumed to be the convolution of seismic wavelet with the earth reflectivity function. The wavelet is composed of source signature, recording filter, surface reflections, and geophone response (Yilmaz, 1987). In order to remove the effect of the wavelet from the seismic trace, thus retrieving the earth's reflectivity function, a filter is required. Such a filter is called an inverse filter and the process is called deconvolution (Arya, 1979).

It has been mentioned by Yilmaz (1987) that post-stack deconvolution often has to be applied firstly, because deconvolution never can completely compress the basic wavelet, contained in the pre-stack, into spike, and secondly, since a CMP stack is an approximation to the zero-offset section, predictive deconvolution aimed at removing multiples may be a viable process after stack.

Hardy *et al.* (1989, 1990) and Hardy and Hobbs (1991) have mentioned that there is no optimum method for multiple suppression and have proposed the implementaton of stacking methods, moveout filters, predictive and adaptive deconvolution, and wave equation. They suggested that multiple suppression should only be applied where necessary to improve interpretation; otherwise multiple identification schemes should be used. Post-stack deconvolution was carried out using final-stacked seismic data which still show high amplitude multiple interference which obscured the recognition of the primary reflection events. The predictive deconvolution technique (Peacock, 1969; Robinson, 1967, 1979) is used for multiple suppression. The parameters were computed from autocorrelation functions generated at several parts of the seismic sections and tested on different panels of these sections. The obtained sections were compared with the final sections before post-stack deconvolution applied. The comparison is to evaluate the effect of the designed deconvolution parameters on multiple attenuation and any improvement in data quality.

DECONVOLUTION TYPES

Different deconvolution types are being currently used for deconvolution of seismic data (Arya, 1979). These deconvolution types are designed to be applied before and after stacking depending on the type of multiples to be removed and the resolution required for data improvement. Deconvolution before stack is applied for wavelet shaping and attenuating multiple reflections. It has the advantage of operating upon traces before the normal move out correction has been applied. Deconvolution after stack is applied for further wavelet shaping and attenuation of multiples that remain after stack, taking into consideration the effect of the intermediate processing on the nature of the wavelet and its reverberant train of events.

The common types of deconvolution techniques include the following:

a. Wavelet deconvolution

This is a type of deconvolution which can be used to correct poor source signature and instrument phase distortion (Berkhout, 1977; Treitel, 1977). It involves changing the shape of the wavelet to some more desirable shape. The zero phase wavelet technique is used to produce a symmetrical wavelet with the energy concentrated in the centre lobe.

b. Adaptive deconvolution

This is a time-varying deconvolution method based upon adaptive linear filtering techniques (Griffiths *et al.*, 1977). The procedure consists of changing the prediction gap at every sample down the trace to find the best gap. Thus a different operator is used at each data point in the trace as the processor moves along the reflection seismogram. The technique can be very successful in suppressing multiples with a short time-varying period, but can become unstable in the presence of noise.

c. Spiking and predictive deconvolutions

Spiking deconvolution is a special case of predictive deconvolution in which the operator is to predict and remove energy starting at the first zero crossing after the zero lag value of the autocorrelation. The deconvolution technique has been discussed by Peacock (1966), Robinson (1967, 1979), and Yilmaz (1987). Predictive deconvolution is one of the most common seismic processing techniques. It is a very useful tool for multiple attentuation because multiples are highly predictable whereas the reflection series with which they are convolved is normally highly unpredictable. It is also used to increase the resolution of seismic data.

Predictive deconvolution is used in this study for investigating the possible improvement in data quality, as explained in the following section.

PREDICTIVE DECONVOLUTION

Design Principles

The filter assumes that a seismic trace is made up of two types of components, namely predictable and unpredictable. It is designed to predict, and then to remove, the predictable components from a trace. The predictable components consist of multiple and the effective source wavelet. The filter parameters are designed from the autocorrelation of a trace which shows the amplitude of the primary and multiples, and also the time extent of the existing multiples. When a primary is encountered on the trace the occurrence of the next primary cannot be predicted from it. This is because the reflection coefficient sequence is random and therefore has no time-invariant characteristics which enable such a prediction to be made. Predictive deconvolution has its power in wavelet resolution and multiple attentuation; however, it has its weaknesses as well. There are two main weaknesses. At early times and long offsets the multiple period is not constant and predicted times are inaccurate. Predictive deconvolution predicts the first multiple from the presence of the primary, the second multiple from the first multiple, and so on. If one number of the sequence is absent, weak, or distorted, the prediction will be in error accordingly.

Design and Operation

The Starting point of designing the operator is the autocorrelation function of the seismic trace. Autocorrelation of functions or time series occurs when the function or series is correlated with itself. The autocorrelation of the seismic trace is always symmetrical about the zero shift and the zero shift value is always the maximum value (Dobrin and Savit, 1988). The desired effect of deconvolution is assessed by inspecting the autocorrelation function before and after the filter parameters are applied. The filter has three sections: the first is a single point of unit amplitude at time zero, the second is a sequence of zero amplitude samples forming the prediction distance, also known as the gap length and measured in milliseconds; the third part of the filter is the prediction operator length which is usually a few hundred milliseconds (Dobrin and Savit, 1988). The "Ethos" software is used to obtain the autocorrelation function. Different panels of seismic data were produced after the selected deconvolution parameters were applied to study their effect on multiple suppression.

Computational Procedures

a. Design gate (window)

The gate should cover the full seismic trace to obtain the greatest statistics, but it is limited to avoid high noise zones, and also may be different reverberation on early and later part of trace. Several design gates were tested to select the proper position of the time gate which covers the primary reflection events of interest and leads to the removal of multiples effecting these events. The trials involved changing the upper and lower time limits of the design gates. The choice of the proper design gate was started by the selection of three different gates (Figs 4, 5, and 6). The gates covered time intervals between 500–2500, 1000–2000 and 1000–3000 ms. The selection of three gates is to investigate the effect of the existing type of multiples at each gate, their time duration and also the effect of the applied deconvolution parameters in removing such effects and increasing resolution. The autocorrelation functions generated from the three selected design windows (Figs 1, 2, and 3) show slight differences regarding the extent of multiple duration which might be as a result of the types of multiples existing at each gate. They also show the effect of the applied deconvolution parameters on multiple attenuation. Figs. 4, 5, and 6 show a significant reduction in multiple energy in comparison with the same parts of the sections before filter parameters are applied. These sections also show the improvement regarding continuity and resolution of the primary events at each time interval. For example, an improvement is shown in Fig. 5 where onlap (white arrow) of the reflection event at 1650 ms is much clearer. The section with the 1000–3000 ms window (Fig. 6) is slightly crisper than the other two sections as shown at the time interval between 1600 and 1800 ms. The deconvolution parameters seem to have a similar effect in the three windows regarding multiple attenuation around and below the basement reflector at 1800 ms.

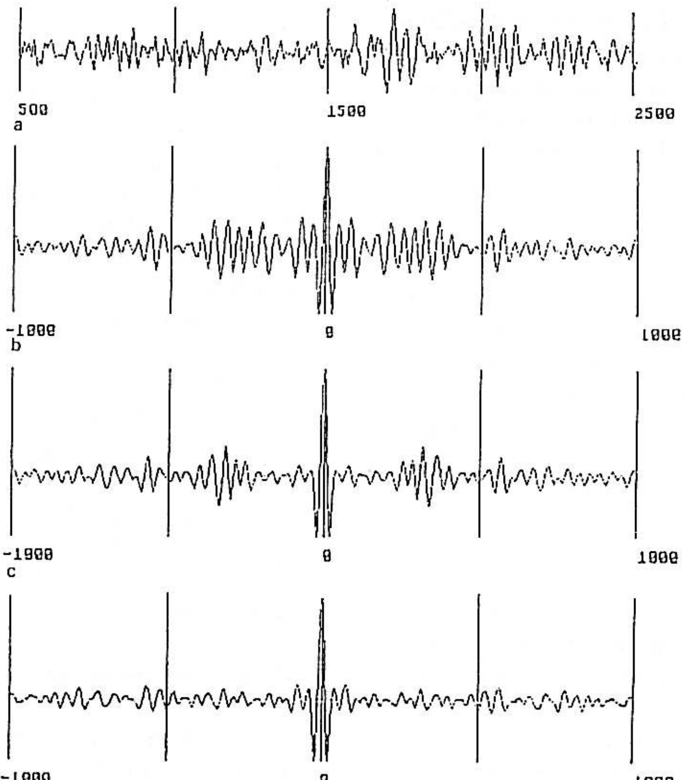


FIG. 1. Autocorrelation functions generated from a seismic section V100, CMPs 1790–1810, design gate 500–2500. (a) Input data trace widow. (b) Function of input traces before deconvolution. (c) After deconvolution of 32 ms gap length and 300 ms operator length applied. (d) After 600 ms operator length applied. Refer to FIG. 7 for deconvolution effect in multiples attentuation.

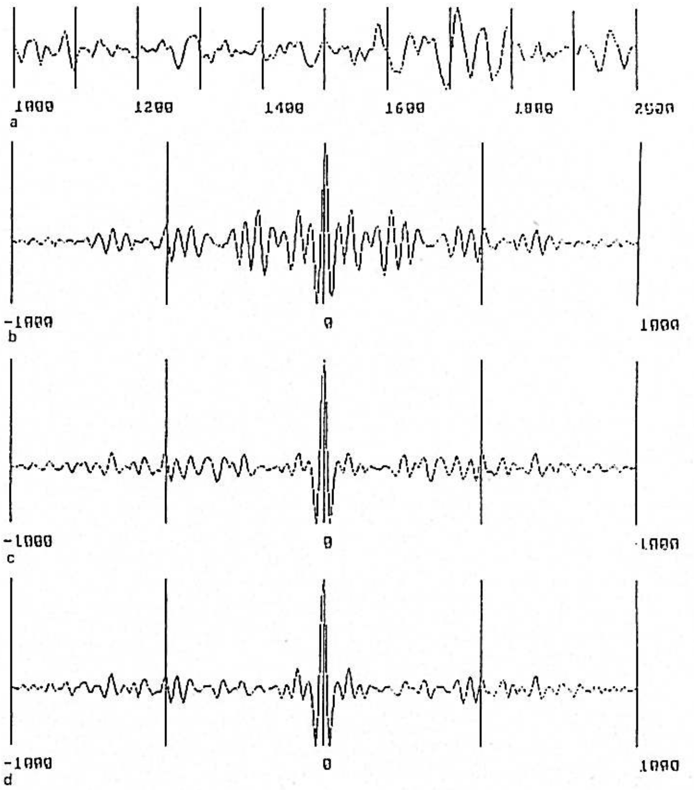


FIG. 2. Autocorrelation functions generated from a seismic section V100, CMPs 1790–1810, design gate 1000–2000. (a) Input data trace window. (b) Function of input traces before deconvolution (c) After deconvolution of 32 ms gap length and 300 ms operator length applied. (d) After 600 ms operator length applied. Refer to FIG. 8 for deconvolution effect in multiples attenuation.

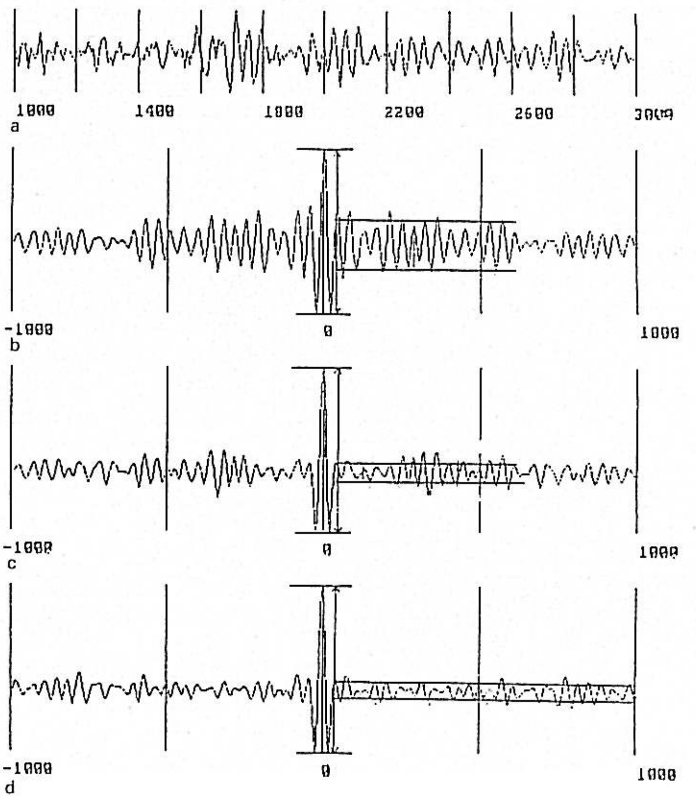
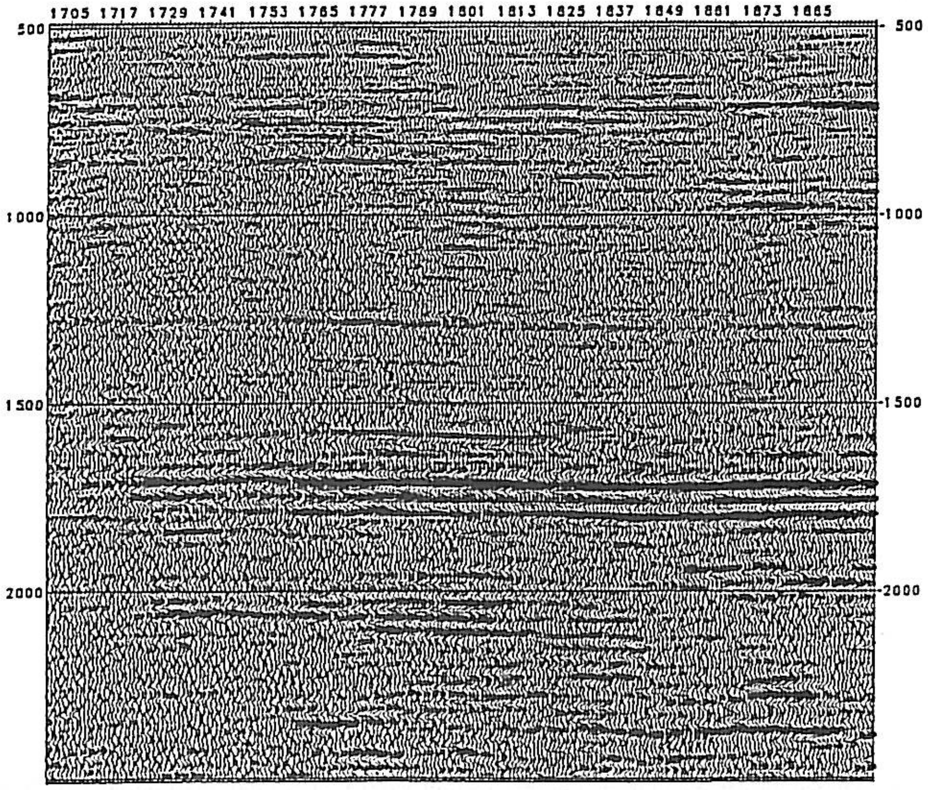


FIG. 3. Autocorrelation functions generated from a seismic section V100, CMPs 1790–1800, design gate 1000–3000. (a) Input data trace window. (b) Function of input traces before deconvolution. (c) After deconvolution of 32 ms gap length and 300 ms operator length applied. (d) After 600 ms operator length applied. Refer to FIG. 9 for deconvolution effect in multiples attenuation.

A



B

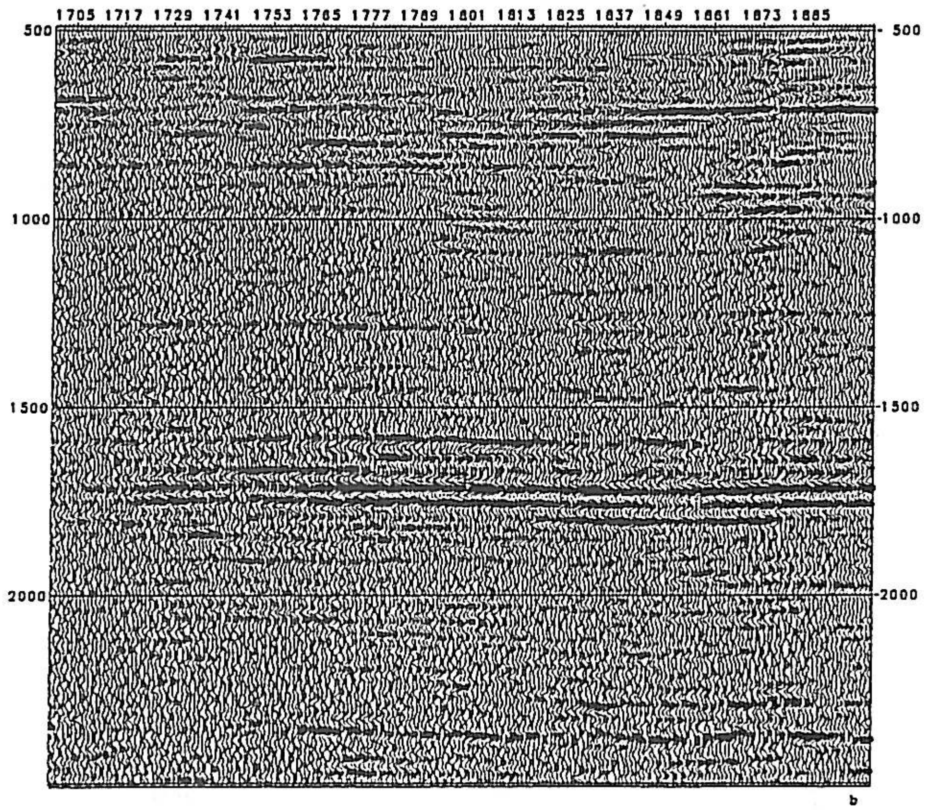


FIG. 4. Design gate of 2000 ms (500–2500). Seismic section V100, CMPs 1700–1900. (a) Before. (b) After post-stack deconvolution of 32 ms gap length and 600 ms operator length applied.

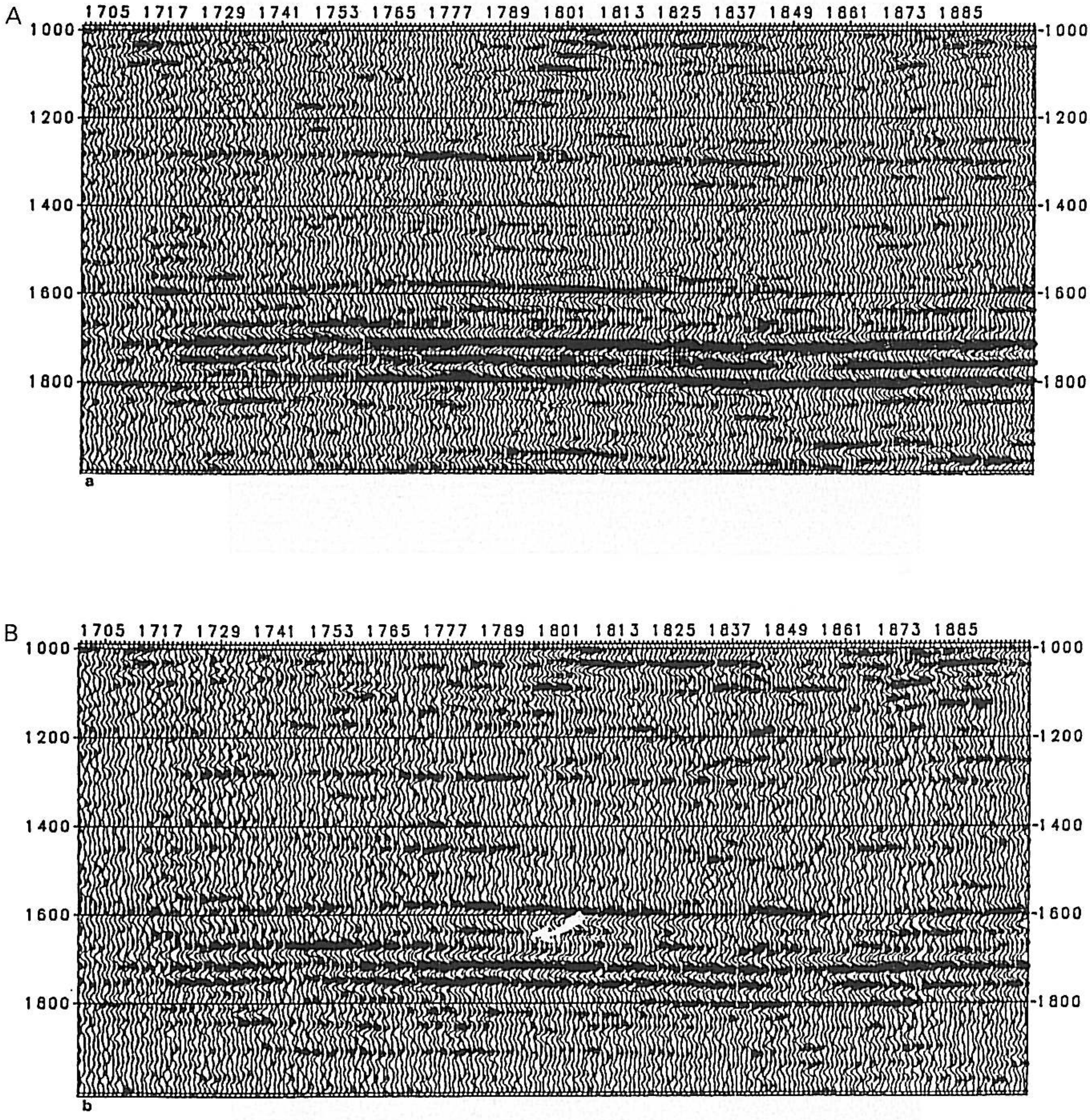


FIG. 5. Design gate of 1000 ms (1000–2000). Seismic section V100, CMPs 1700–1900. (a) Before. (b) After post-stack deconvolution of 32 ms gap length and 600 ms operator length applied.

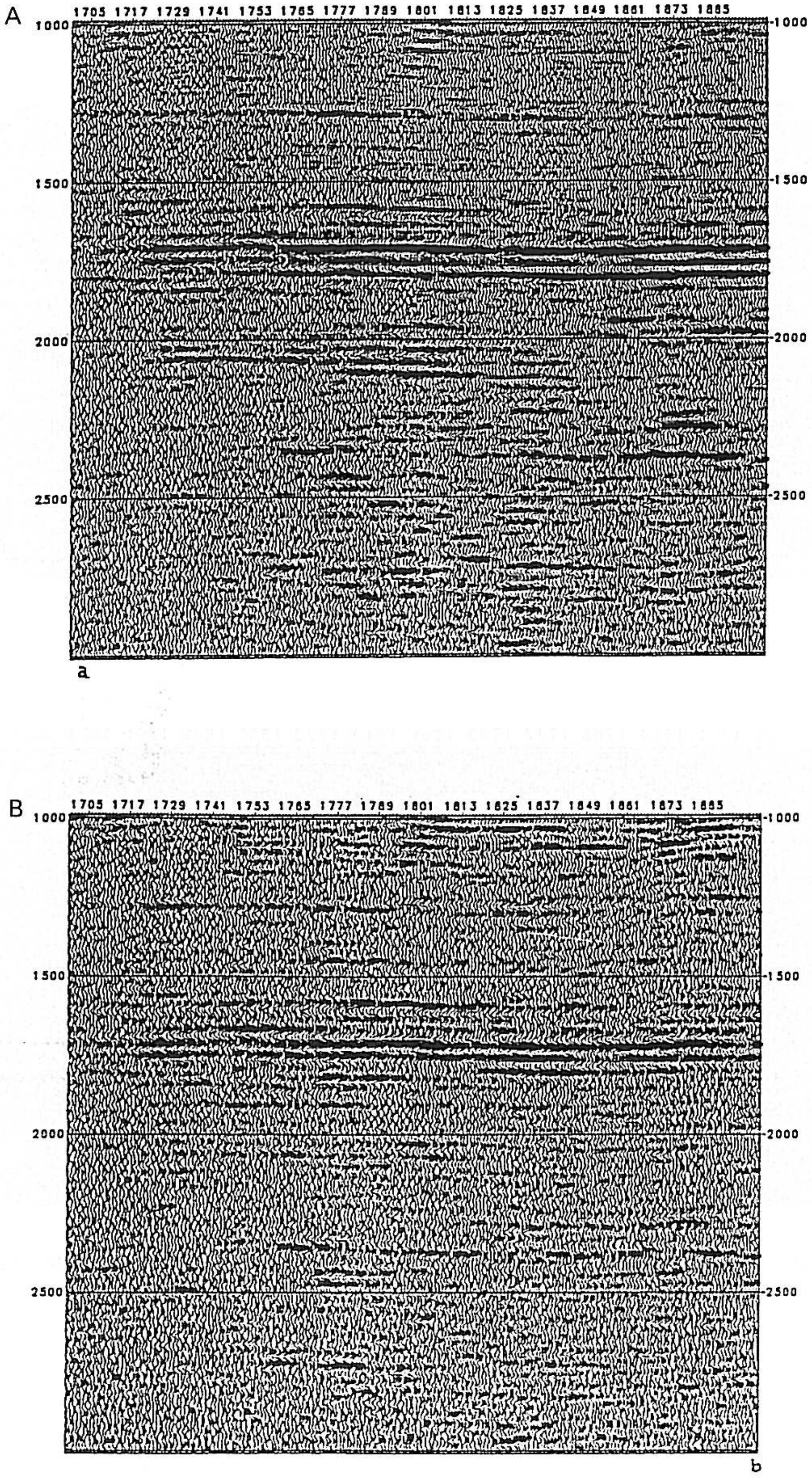


FIG. 6. Design gate of 2000 ms (1000–3000). Seismic section V100, CMPs 1700–1900. (a) Before. (b) After post-stack deconvolution of 32 ms gap length and 600 ms operator length applied.

b. Autocorrelation traces

The functions are generated from an average of 20 traces and are used for determining the filter's parameters. Fig. 3 is an example of an autocorrelation function produced from a design gate between 1000–3000 ms before and after deconvolution with 300 and 600 ms operator length. The multiple following the primary event at zero time crossing is showing very clearly and extends to 600 ms.

Fig. 3b shows the function before deconvolution where the ratio of amplitude of primary event to multiples is 42:13 and with time extent of 600 ms. Fig. 3c shows the function after 300 ms operator length is applied. The amplitude ratio of the primar events to multiples is 42:4 and with time extent of 300 ms. The operator has slightly reduced the ampitude of the multiples at time extent later than 300 ms with ratio of 42:8. Fig. 3d shows the function after 600 ms operator is applied. The ratio of amplitude of primary events to multiples is 42:4 and time extent of more than 600 ms which cover the time period of the main multiple reflections.

Figs. 1 and 2 show similar autocorrelation functions before and after deconvolution operators of 300 and 600 ms are applied. The extent of multiple duration is between 400 and 600 ms. Therefore, an operator of at least 600 ms is required in order to significantly remove a major part of the existing multiples. Both the sections and functions show considerable improvement regarding multiple attenuations after the operator is applied which indicates that the designed parameters are effective against multiples The testing of three windows is to avoid the selection of an improper gate which might result in computing and then applying parameters not suitable for the type of multiples that exist.

Figs. 7, and 8 show the same computed deconvolution parameters applied at different panels of traces in other parts of the seismic section. The panels were used to produce autocorrelation functions and to compare the functions with those used for deconvolution parameters computation and also for multiple duration estimation. The comparison is to investigate whether these parameters have the same or different effects on multiple attentuation. The functions produced after the deconvolution parameters were applied show similar effect to that shown on the functions used for producing and testing the parameters. This indicates that the designed parameters are effective and could be applied at different parts of the sections.

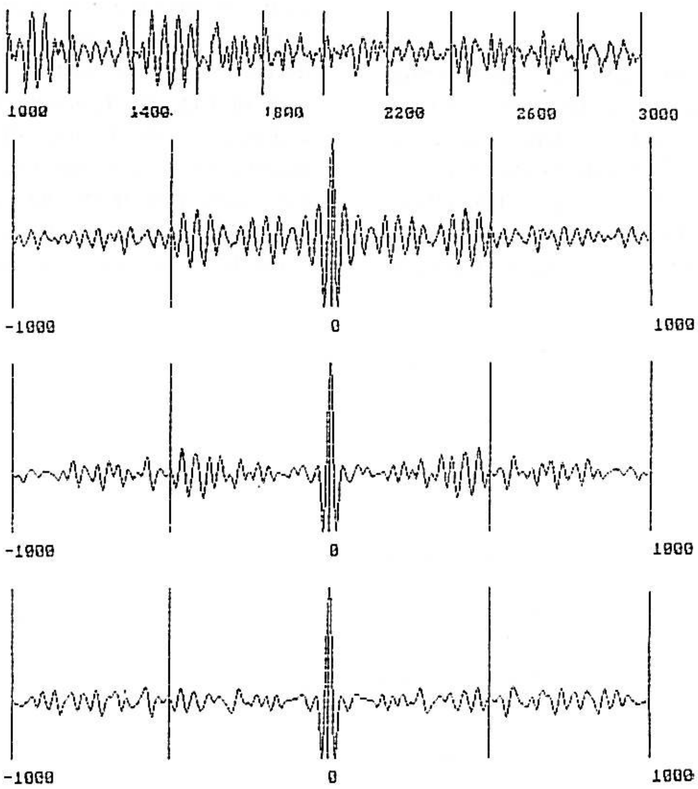


FIG. 7. Autocorrelation function generated from seismic section V100, CMPs 2220–2240, and time interval 1000–3000 ms. Similar effect is shown regarding multiple attenuation to those used for deconvolution parameters computation in other parts of the sections.

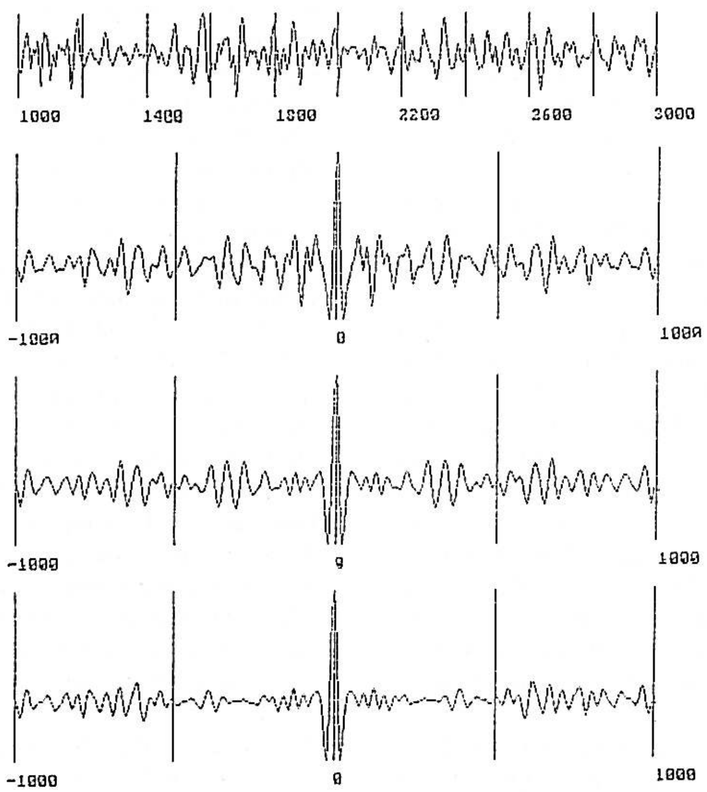


FIG. 8. Autocorrelation function generated from seismic section V109, CMPs 1240–1260, and time interval 1000–3000 ms. Similar effect is shown regarding multiple attenuation to those used for deconvolution parameters computation in other parts of the sections.

c. Prediction distance

The autocorrelation functions were used to compute deconvolution prediction distance. The zero crossing technique is used to measure prediction distance which is the time of zero amplitude point or crossing on the autocorrelation function. Prediction distance is specified as the second zero crossing (Peacock and Treitel, 1969) which actually will vary as the predominant frequency varies.

Fig. 9 shows the same input trace as Fig. 2a and an enlarged part of the autocorrelation function of Fig. 2b. It illustrates the computation procedures of prediction distance by applying the second zero crossing technique. Several functions were obtained from the same time intervals along the seismic sections and were used to compute the prediction distances at these parts of the sections.

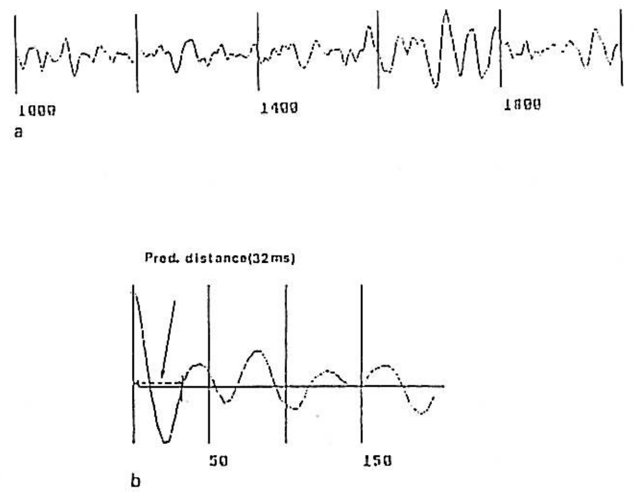


FIG. 9. (a) Input trace from seismic section V100, and design window 1000–2000 ms. (b) Autocorrelation of the input trace showing the computation of prediction distance by applying the second zero crossing technique. Also showing enlarged portion of the existing multiples. Refer to FIG. 2b for multiple time duration.

The functions showed that the prediction distances varied slightly from one part of the section to the other. Such variations could be as a result of lateral change in the characteristics of primary and multiple reflections which affected the frequency of the propagated seismic energy. The variation also could result from a change in frequency with depth which produces an increase in prediction distance as the low frequency become predominant with increasing depth.

d. Prediction operator length

The estimation of operator length for post-stack deconvolution was carried out by using the autocorrelation function for observing the energy of the primary event at zero time amplitude, and the amplitude and extent of multiples following the primary (Figs 1b, 2b and 3b). The testing of multiple attentuation was started by applying the same prediction distances computed from the functions while changing the operator lengths. The selection of the best operator length was started by using operators ranging between 140 and 750 ms and observing their effect on multiple attenuation. As it has been described previously and shown in Fig. 3b, the ratio of the amplitude of the primary to multiple reflections before deconvolution parameters were applied is 3.23:1 and the time extent of multiples is 600 ms. On the deconvolved trace (Fig. 3c–d) the ratio is 10.5:1. Figures 10, 11, and 12 show part of the seismic sections before and after a deconvolution filter of 32 ms gap length, and 300 and 600 ms operator length are applied. The sections are parts of seismic sections V100 and V109 and time interval between 1000–2000 ms. The sections obtained after deconvolution show progress in multiple attenuation as filter operator length increases. The reduction in multiple effect continued until the operator length reached 600 ms. When the 750 ms operator is applied no noticeable improvement is observed. Therefore, the extent of multiple duration is believed to be around 600 ms and the required operator should be not less than 600 ms to work effectively against the existing multiples.

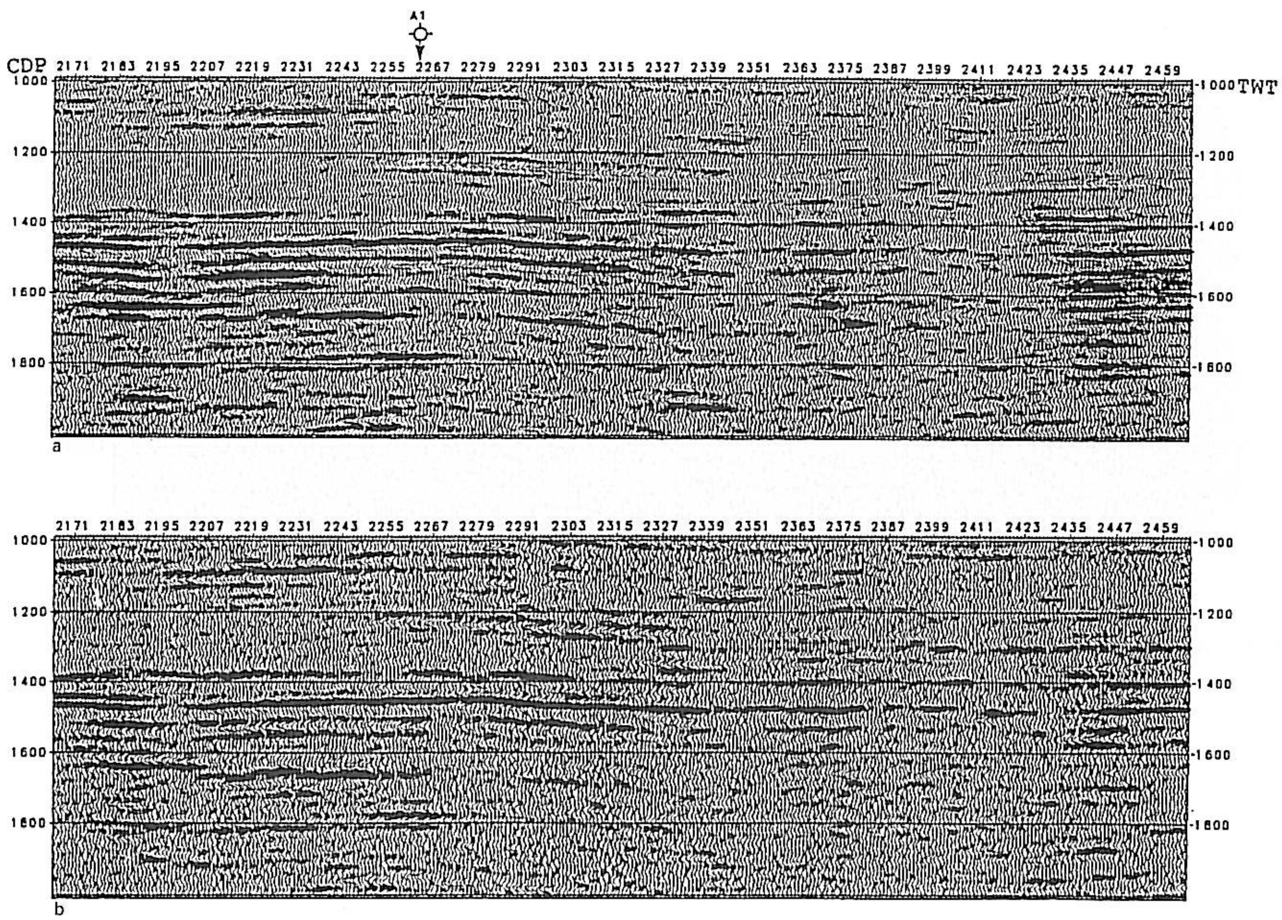


FIG. 10. Part of seismic section V100, CMPs 2166–2466. (a) Before post-stack deconvolution reflections are buried in multiple energy. (b) After post-stack decovolution of 32 ms gap length, 600 ms operator length is applied. It removed a significant amount of multiples and helped distinguish prominent reflections.

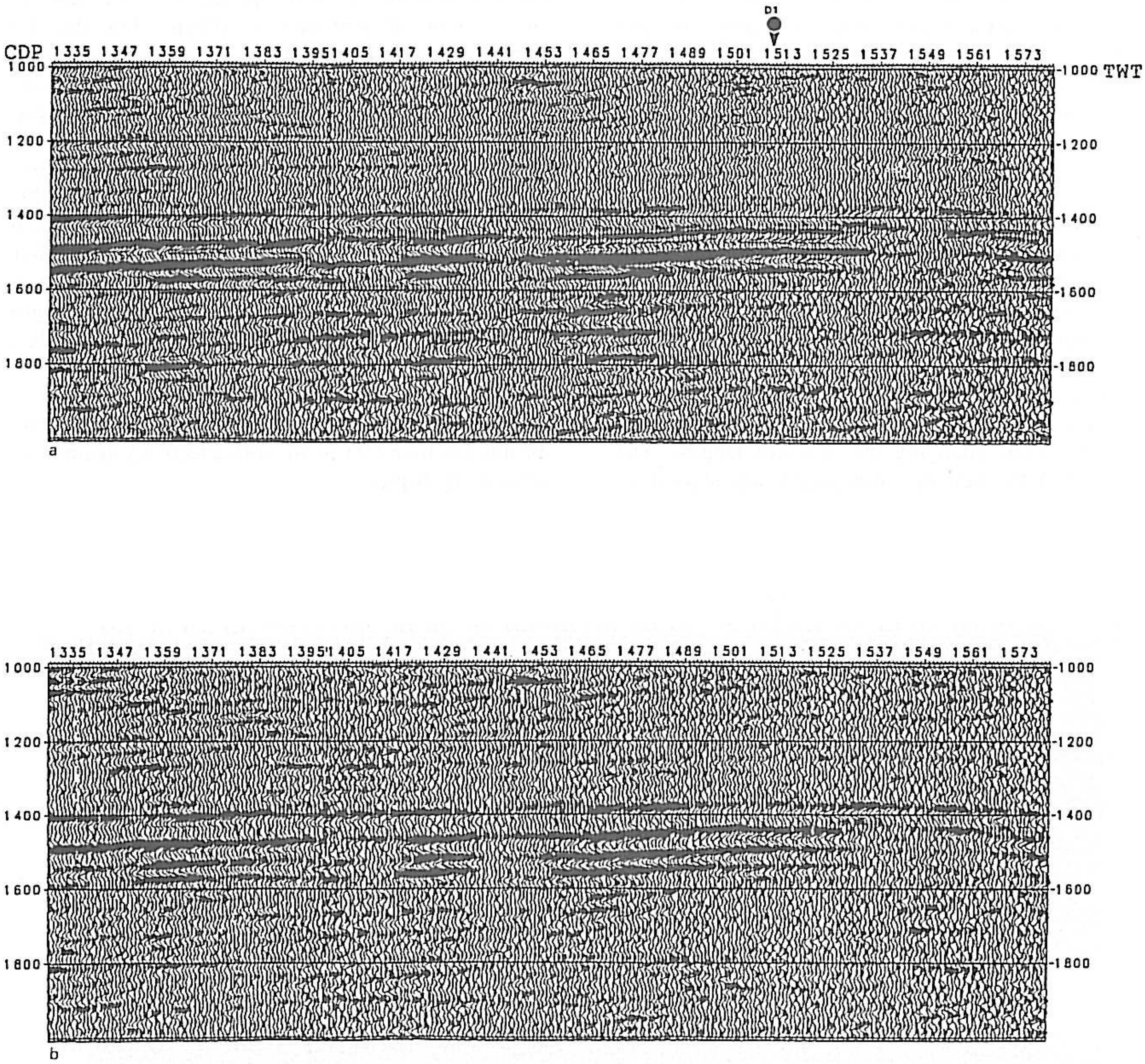


FIG. 11. Part of seismic section V100, CMPs 1330–1580. (a) Before. (b) After post-stack deconvolution applied. It has similar effect as in FIG. 10.

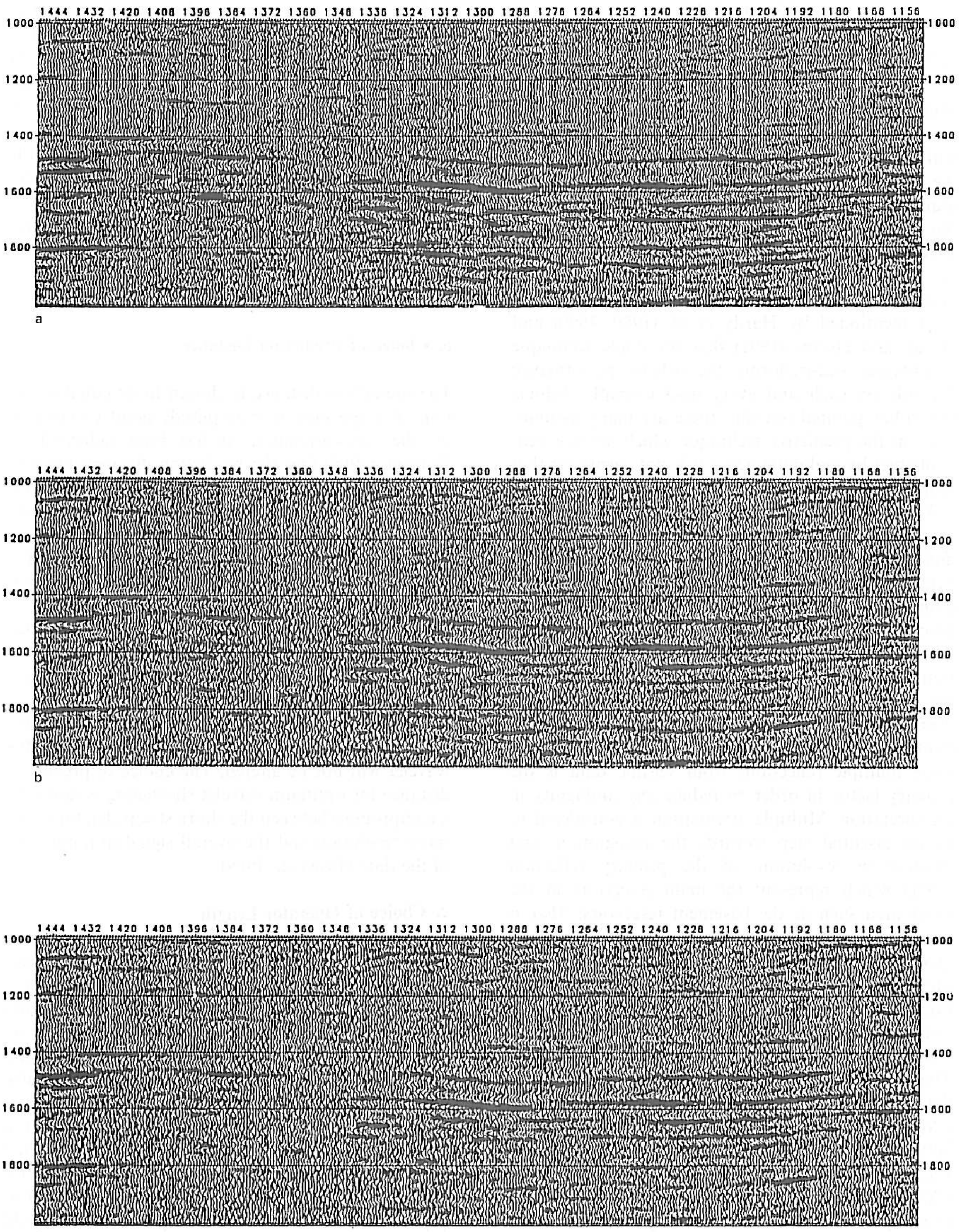


FIG. 12. Part of seismic section V109, CMPs 1151–1449. (a) Before deconvolution, multiple energy is strongly visible especially around and below 1800 time line. (b) After deconvolution of 32 ms gap length, 300 ms operator length applied. (c) After 600 ms operator length is applied. Multiples are suppressed and primary reflections became prominent.

DISCUSSION

a. Multiples

Multiples have been defined by Robinson (1979) as events that make one or more round-trip paths within the sedimentary layers before returning to the surface of the earth. Multiple attenuation techniques are conventionally classified according to the criteria by which they distinguish multiples from primary events. These criteria are the periodic nature of multiples and the move-out difference between multiples and primary reflectors. It has been mentioned by Hardy *et al.* (1989, 1990) and Hardy and Hobbs (1991) that no single technique consistently out-performs the others; performance depends on each and every data example. Yilmaz (1989) has pointed out that there are many assumptions in the predictive technique which are not generally met by real data; hence it is not surprising that multiples are not effectively suppressed.

The source and type of these multiples are not very clear and they could be the result of surface multiples or reverberation within sedimentary units. Multiples can be divided into two main categories: long-path and short-path multiples (Badley, 1985). Stacking and deconvolution are the two main processing steps applied for the removal and attenuation of multiples. It is important that multiples are recognized so that they are not interpreted as primary reflections. Applying the proper technique (Sinton *et al.*, 1978; Hardy *et al.*, 1989) to remove these multiple reflections from seismic data is the primary factor in order to reduce any ambiguity in interpretation. Multiple attenuation is considered to be an essential step towards the recognition, and increase in resolution, of the primary reflection events which represent the main reservoirs in the study area such as the basement reservoirs. Also, it is very important for the enhancement of data quality in order to carry out other processing steps such as attribute analyses and inverse modelling. Final stacked seismic data is used for the recognition and possible establishment of seismic criteria to categorize the primary reflection events of interest. The multiples are clearly visible especially below the basement reflector such as in Fig. 10 between CMPs 2166–2280 and 1400–1800 ms; and Fig. 11 between CMPs 1330–1525 and 1550–1800 ms; and Fig. 12 between CMPs 1449–1345 and below 1700 ms. They appear to have severely affected the primary events and obscured any detailed stratigraphic analysis. Multiples interfere with the primaries, hence, recognizing major reflections events and their extension along the seismic section becomes very difficut. The seismic sections obtained after the predictive deconvolution technique is applied show that weak remnant multiples still exist. These remnant multiples are probably the result of relatively high amplitude interlayer multiples which are not explicitly predicted by the deconvolution operator. Complete suppression of multiples is the desired result from the application of various multiple suppression techniques; however, multiples on a section exhibit a range of properties and so only those multiples which conform to the predicted assumptions made will be removed.

b. Choice of Prediction Distance

The prediction distance is chosen to be equal to the time of a specified zero amplitude point or crossing on the autocorrelation. It has been indicated by Peacock (1969) that the prediction distance equal to the second zero crossing (Fig. 9) is generally the best choice and it will obviously vary as the predominant frequency varies. Sinton *et al.* (1978), during their study of deep crustal reflections in the western Gulf of Mexico, have applied predictive deconvolution operators containing gap lengths with a duration of 4 to 5 sec. They have been used to suppress long delay multiple reflections which obscure primary reflections from within the earth's crust. The prediction distance of a predictive filter can be used to control the length of the reflection wavelet on output data. If the prediction distance is longer than the basic wavelet then the wavelet will not be altered. The choice of prediction distance for optimum wavelet shortening is normally a compromise between the shortest wavelet, for maximum resolution and the overall signal-to-noise ratio of the data (Peacock, 1969).

c. Choice of Operator Length

The choice of proper deconvolution operator length has been discussed by many workers such as Foster *et al.* (1968), Hatton *et al.* (1986), Yilmaz (1987) and White (1987). It has been mentioned by Hatton *et al.* (1986) that as a rule of thumb, the window length (design gate) is to be ten times the maximum autocorrelation lag (operator length). Another suggestion by Yilmaz (1987) for pre-stack deconvolution indicated that the window should be no less than eight times the operator length. Short windows embracing few reflections yield poor statistics. For post-stack deconvolution the parameters should be determined by trials. Foster (1968) and White (1987) have discussed the estimation problem in the deconvolution process. They have pointed out that lengthening the deconvolution operator tends to compress the output wavelet more. The resulting improvement is represented by a decrease in distortion of output with increasing operator length. The autocorrelation functions obtained from different design gates (Figs 1, 2, and 3) show that the operator length is exceeding the suggested rule of thumb estimates. The main multiples extend to around 600 ms as shown in Fig. 3 which suggests that the filter should have the same length in a gate of only 2000 ms. The suggested rule of thumb percentage between the design gate and operator length fall far short of the required operator as indicated by the obtained autocorrelation functions. Figs. 1, 2 and 3 indicate that the extent of multiples is still clear even when the 300 ms operator was applied. In this set of data a time interval of 3000 ms a filter with operator length of 600 ms is shown to be the most effective operator for attenuating the existing multiples.

CONCLUSIONS AND RECOMMENDATIONS

The study shows that further investigation is required regarding the estimation and application of the deconvolution parameters in relation to multiple suppression during the seismic data processing. The sources of multiple generation seem to be more complicated than generally assumed, and the suppression of multiples effectively requires the availability of detailed information about the reflectors and their geometry. It seems that there is no practical and clear computational procedure in the literature about how the deconvolution parameters should be estimated and applied for pre-stack and post-stack deconvolution. The suggested rule of thumb techniques, which are mainly for pre-stack deconvolution to relate operator length to design gate, have not described the practical conditions in which such techniques should be applied. In this set of data a deconvolution filter with 32 ms prediction distance and operator length of 600 ms is shown to be the most effective operator for attenuating the existing multiples.

It is evident from this study that although the applied post-stack deconvolution on the observed seismic data gave encouraging results, they still have not shown the expected improvement regarding multiple suppression. Therefore, elaborate planning procedures prior to the acquisition of seismic reflection data might improve the quality of the seismic data. The planning includes the generation of modelled sections from the CDP gathers and well data. The company should ask the contractor to provide model of CDP gather with multiples included. This could aid in the assessment of the existing type of multiples. The multiple effects might be minimized by testing different patterns during the gathering of field data. The optimum recording and optimum offset could be designed to cancel the multiple at certain intervals by the choice of source-receiver offset which has a suitable angle for receiving the reflected seismic energy from primary reflectors and rejecting energy from the multiples.

ACKNOWLEDGEMENT

I would like to express my thanks to the management of the Petroleum Research Centre, special thanks go to Mr M. Idris the Secretary of People's Committee of the PRC for permission to publish this paper. I wish to thank Dr W. Ashcroft from the Geology and Petroleum Geology Department, University of Aberdeen for his help, guidance and valuable discussions in preparing this work. Thanks are also extended to the management and staff members of the Libyan National Oil Corporation and Zuetina Oil Compay for providing the data of the study area.

REFERENCES

Arya, V.K. and Agwal, J.K. (Eds.), 1982. Deconvolution of seismic data: Hutchinson Ross Publishing Company.

Badley, M.E., 1985, Practical seismic interpretation: IHRDC, Publisher.

Berkhout, J.A., 1977. Least-squares inverse filtering and wavelet deconvolution, Geophysics 42, 1369–1383.

Dobrin, M.B. and Savit, C.H., 1988. Introduction to geophysical prospecting (4th ed.). McGraw-Hill book Company, Singapore.

Foster, M.J., Sengbush, R.L. and Watson, R.J., 1968. Use of Monte Carlo techniques in optimum design of the deconvolution process, Geophysics 33, 945–95949.

Griffiths, L.J., Smolka, F.R. and Tremly, L.D., 1977. Adaptive deconvolution: a new technique for processing time-varying seismic data. Geophysics 42, 742–759.

Hardy, R.J.J. and Hobbs, R.W., 1991. A strategy for multiple suppression. First break 9, 139–144.

Hardy, R.J.J., Hobbs, R.W., Jones, I.F. and Warner, M.R., 1990. The reliability of multiple suppression. First Break 8, 297–304.

Hardy, R.J.J., Warner, M.R. and Hobbs, R.W., 1989. Labelling long-period multiple reflections. Geophysics 54, 122–126.

Hatton, L., Worthington, M.H. and Makin, J., 1986. Seismic data processing: Theory and practice, Blackwell, Scientific Publisher, London.

Peacock, K.L. and Treitel, S., 1969. Predictive deconvolution: theory and practice. Geophysics 34, 155–169.

Robinson, A.E. and Durrani, T.S., 1986. Geophysical signal processing. PHI publisher. p. 481.

Robinson, E.A., 1979. Predictive deconvolution. Development in geophysical exploration methods-2, A.A. Fitch, (Ed.). 1979, p. 77–106.
Robinson, E.A., 1967. Predictive decomposition of time series with application to seismic exploration. Geophysics 32, 418–484.
Siton, J.B., Ward, R.W. and Watkins, J.S., 1978. Suppression of long-delay multiple reflections by predictive deconvolution: Geophysics 43, 1352–1367.
Treitel, S. and Robinson, E.A., 1966. The design of high resoution fiters. Inst. Electr. Electron. Eng., GE-4: 25–38.
White, R.E., 1987. Estimation problem in seismic deconvolution, in: Deconvolution and inversion: M.H. Worthington (Ed.). Blackwell scientific publications p. 5–37.
Yilmaz, O., 1987. Seismic data processing. Investigations in geophysics, Vol. 2: S.M. Doherty (Ed.). Society of Exploration Geophysicist.