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The Role of Post-Stack Deconvolution in Seismic Reflection Multiple Reduction in the Rasafa Region, Central Syria.

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□ ABSTRACT □

The presence of multiples on seismic data has 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 multiples suppression. The parameters were computed from autocorrelation functions and tested on different panels of the seismic sections. The test includes 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.

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دور فك الثني بالتكديس في إضعاف السايزمية المتكررة على مثال منطقة الرصافة، وسط سوريا

الدكتور نديم أحمد*

(قبل للنشر في 2005/6/28)

□ الملخّص □

يرمي هذا البحث إلى إضعاف الأمواج المتكررة Multiples ، التي تعيق إظهار الانعكاسات الأولية Primary reflection events ، من خلال تطبيق تقنية فك الثني Deconvolution ، لما بعد التكديس للمعطيات السايزمية.

يتضمن البحث حساب بارامترات محددة بإجراء عملية الارتباط الذاتي Autocorrelation ، على نطاقات مختلفة من المقاطع السايزمية، بما فيها تقدير المسافة المتوقعة Offset ، وطول العامل Operator ، لاختيار أفضل وأنسب البارامترات، التي نحتاجها لإجراء فك الثني.

أوضحت هذه الدراسة من خلال مقارنة المقاطع النهائية المكدسة Final Stack ، التي تم الحصول عليها مع المقاطع الزمنية Time seismic sections ، قبل عملية التكديس اللاحق Post-Stack ، أن تحسنا ملموسا قد طرأ لصالح الانعكاسات الأولية ، على الرغم من أن إضعاف الأمواج المتكررة ليس بالأمر السهل، لاحتوائها على مدى واسع من الخواص ، مما يعرقل إلى حد ما الوصول إلى ما نصبو إليه، ويتيح الفرصة للتخلص من المتكررات، التي تتوافق مع القياسات المطبقة.

الكلمات المفتاحية: *فك الثني، الأمواج السايزمية، دمشق.*

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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.

It has been mentioned by Yilmaz (1987) that post-stack deconvolution often has to be applied firstly because pre-stack deconvolution can never 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 the 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 implementation of stacking methods, moveout filters, predictive and adaptive deconvolution, and wave equation. They suggested that multiples 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 multiples interference which obscured the recognition of the primary reflection events. The predictive deconvolution technique (Peacock, 1969; Robinson 1967, 1979) is also used for multiples suppression. In this method, the parameters are 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 was applied. The comparison is to evaluate the effect of the designed deconvolution parameters on multiples attenuation and any improvement in data quality.

DECONVOLUTION TYPES:

Different deconvolution methods are being currently used for deconvolution of CMP seismic data. 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 is 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). 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 used 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 attenuation 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 the 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 multiples attenuation; however, it has weaknesses as well. There are two main weaknesses. At early times and long offsets the multiple periods are 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 part 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 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 (Figs. 1-3). 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 predictive 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 multiples suppression.

Computational Procedures

a. Design gate (window)

The gate should cover the full seismic trace to obtain the optimum statistical properties, but it is limited to avoid high noise zones, and may also be varied for different reverberations on early and later parts of the 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 affecting 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 tialling three different gates (Figs 4, 5, and 6). The gates covered the time intervals between 500-2500, 1000-2000 and 1000-3000 ms. The selection of three gates is used 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 minor differences in the extent of multiple duration, which might reflect the types of multiples existing at each gate. They also show the effect of the applied deconvolution parameters on multiples 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.

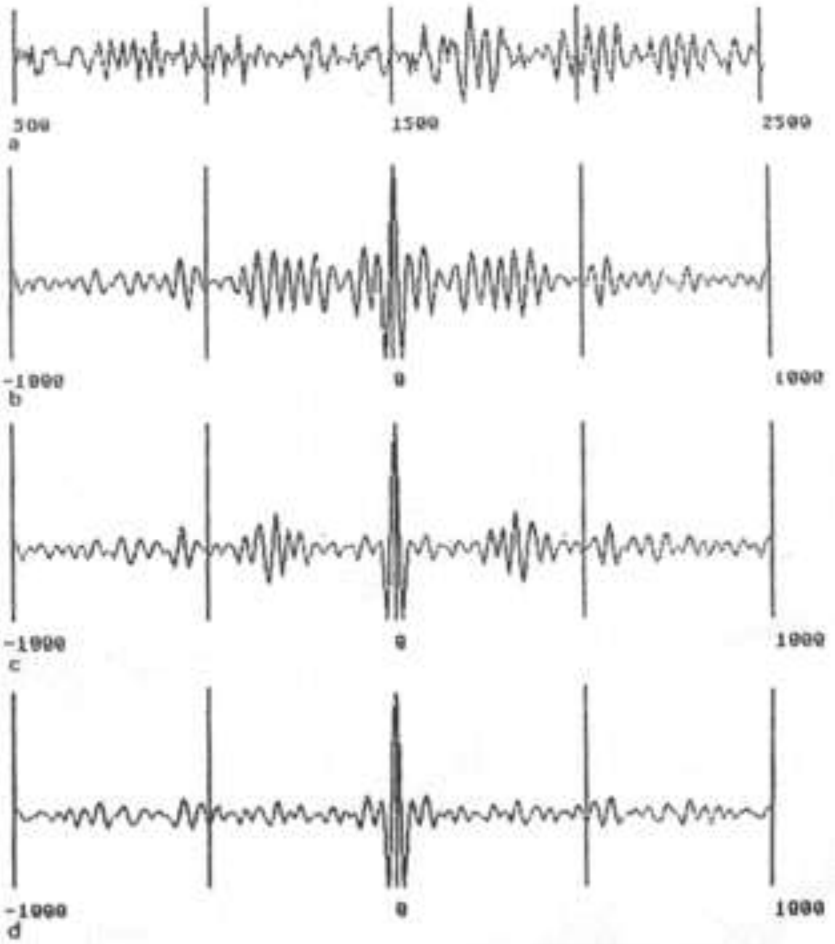

FIG. 1. Autocorrelation functions generated from a seismic section CH-81-37, CMPs 1790-1810, design gate 500-2500. (a) Input data trace window from stack. (b) Function of input traces before deconvolution. (c) After deconvolution of 32 ms gap length and 300 ms operator length applied. (d) After 600 ms operator length applied. Refer to FIG. 7 for deconvolution effect in multiples attenuation.

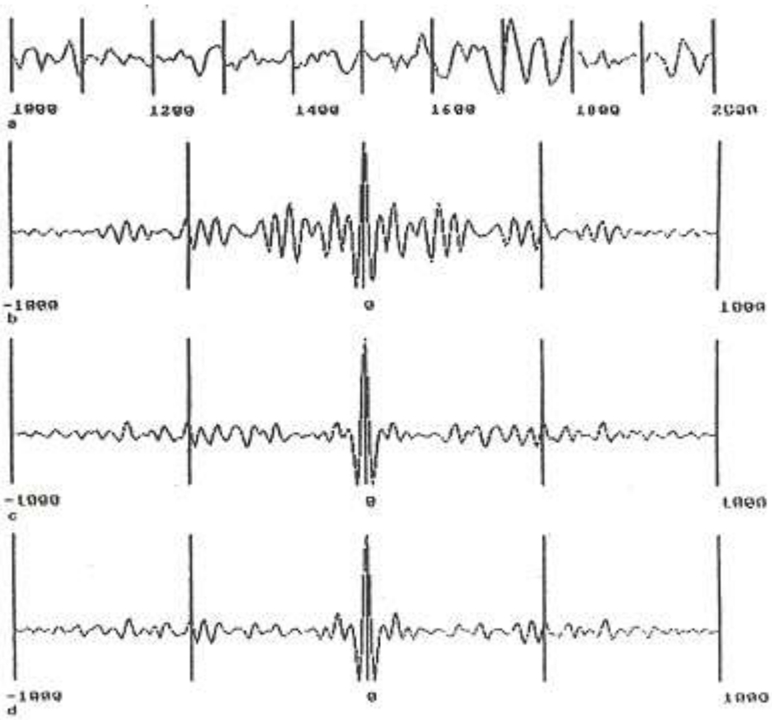

FIG. 2. Autocorrelation functions generated from a seismic section CH-81-37, CMPs 1790-1810, design gate 1000-2000. (a) (a) Input data trace window. (b) Function of input traces before deconvolution. (c) After deconvolution of 32 ms gap length and 300 ms operator length applied. (d) After 600 ms operator length applied. Refer to FIG. 8 for deconvolution effect in multiples attenuation.

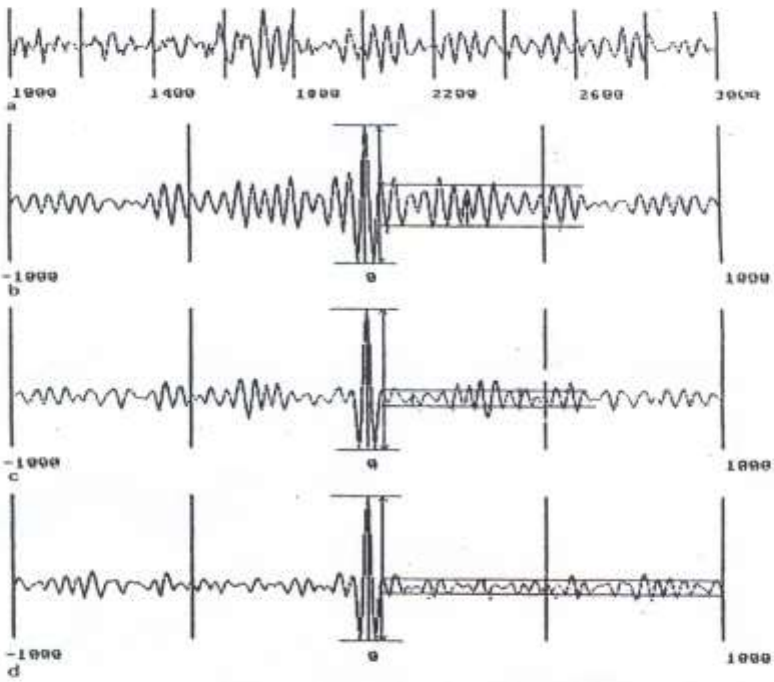

FIG. 3. Autocorrelation functions generated from a seismic section CH-81-37, CMPs 1790-1800, design gate 1000-3000. (a) (a) Input data trace window. (b) Function of input traces before deconvolution. (c) After deconvolution of 32 ms gap length and 300 ms operator length applied. (d) After 600 ms operator length applied. Refer to FIG. 9 for deconvolution effect in multiples attenuation.

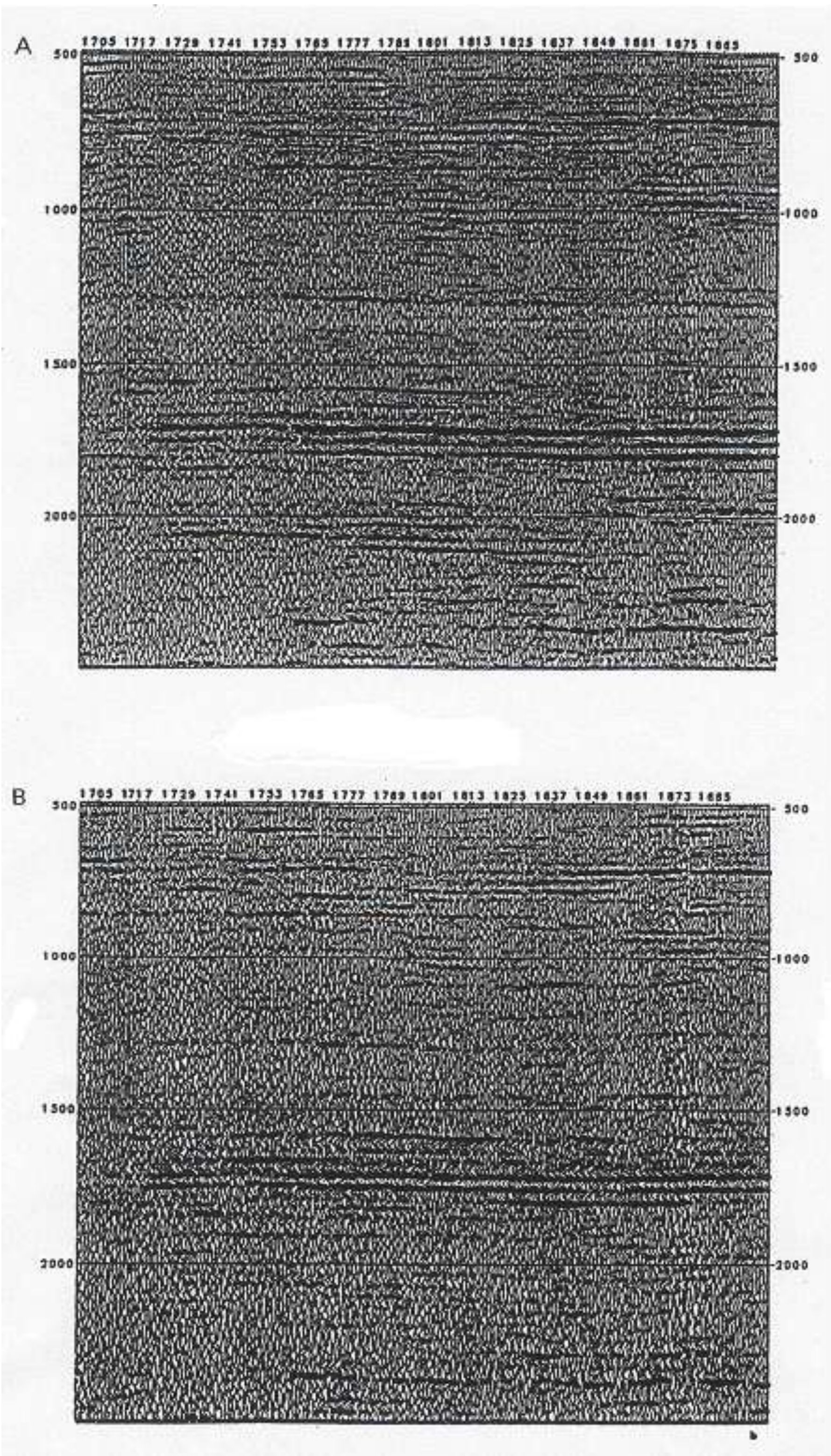

FIG. 4. Design gate of duration 2000 ms (500-2500). Seismic section CH-81-37, CMPs 1700-1900. (a) Before. (b) After post-stack deconvolution of 32 ms gap length and 600 ms operator length applied.

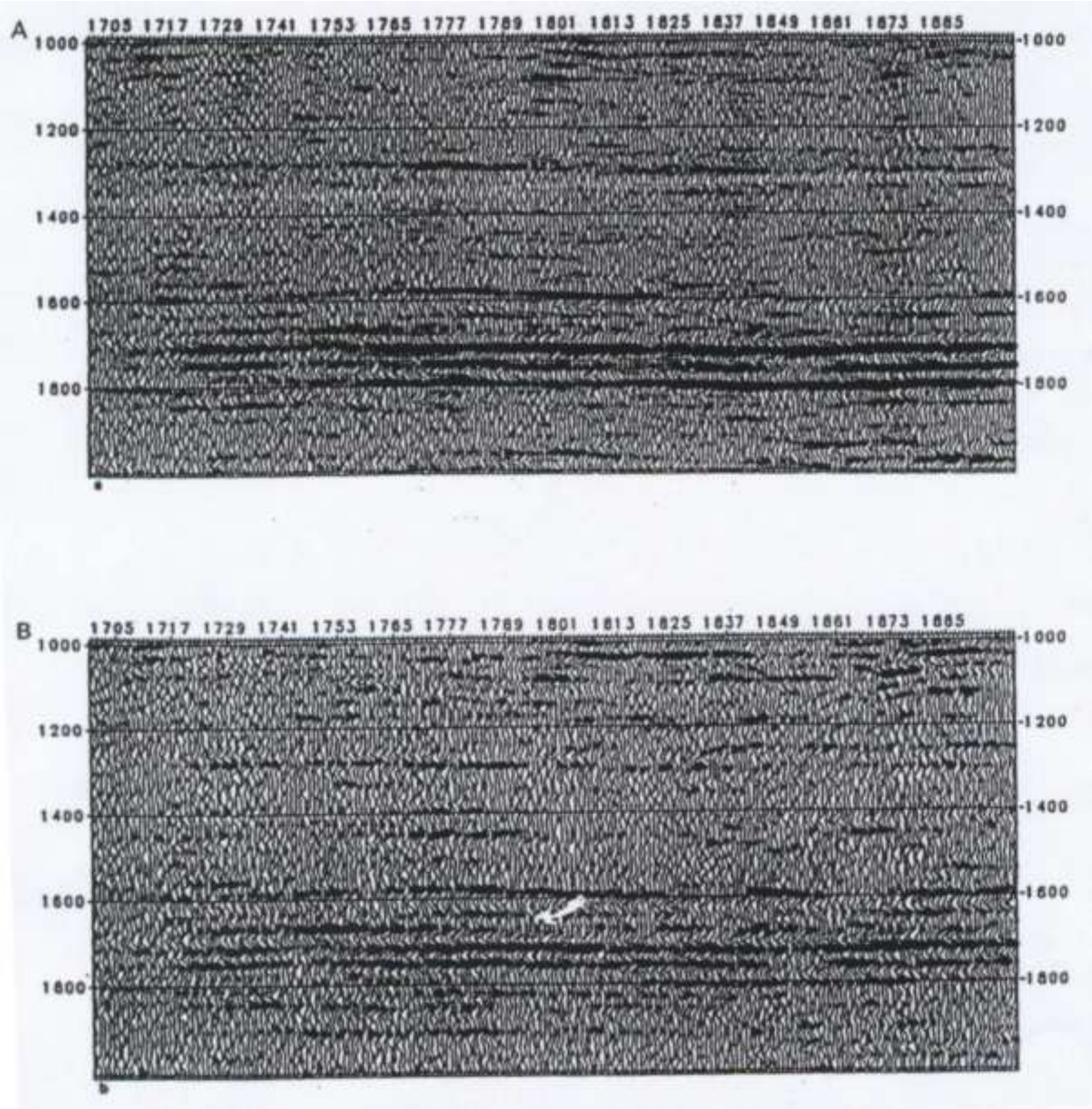

FIG. 5. Design gate of duration 1000 ms (1000-2000). Seismic section CH-81-37, CMPs 1700-1900. (a) Before. (b) After post-stack deconvolution of 32 ms gap length and 600 ms operator length applied.

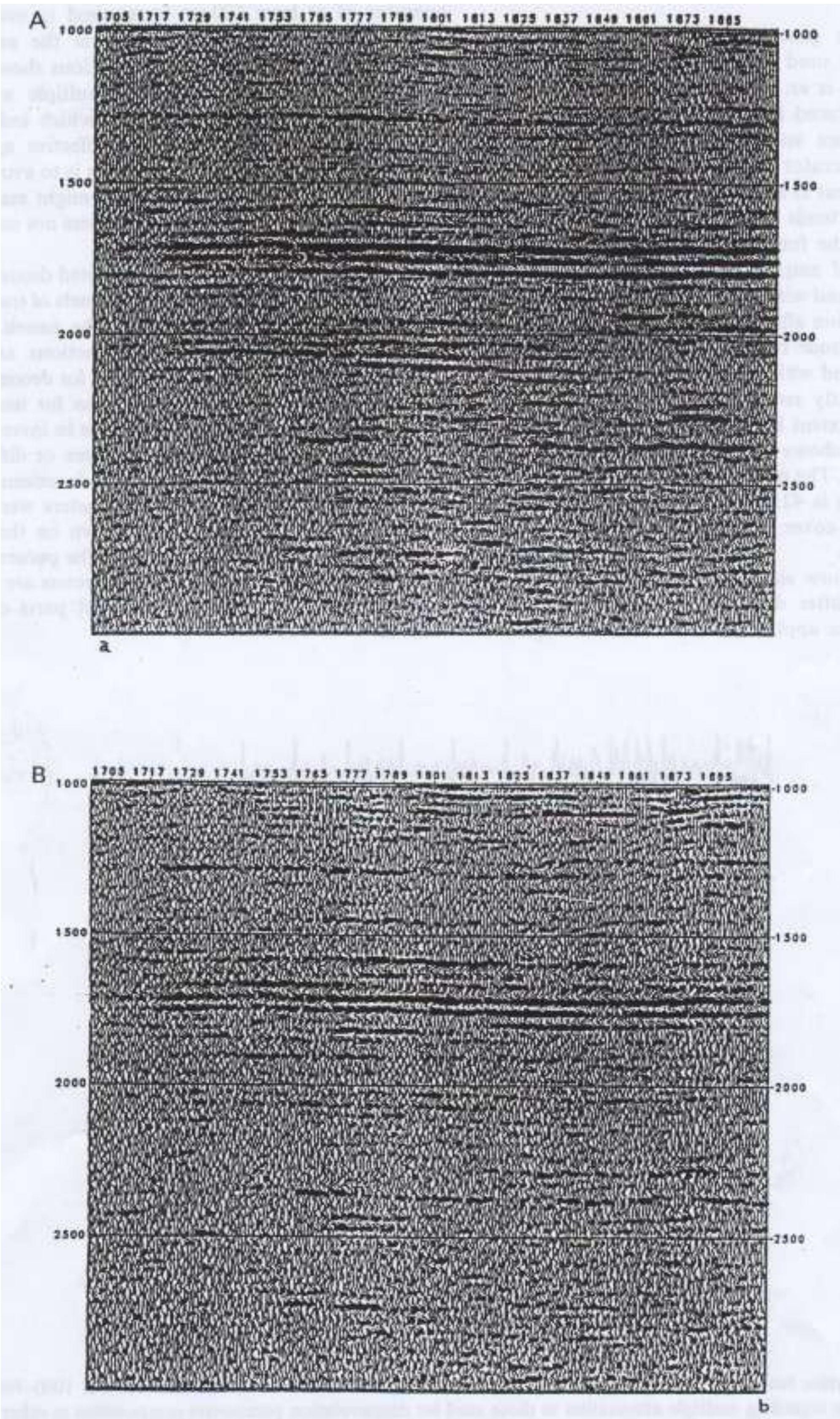

FIG. 6. Design gate of duration 2000 ms (1000-3000). Seismic section CH-81-37, CMPs 1700-1900. (a) Before. (b) After post-stack deconvolution of 32 ms gap length and 600 ms operator length applied.

b. Autocorrelation traces

The autocorrelation functions are generated from an average of 20 traces and are used for determining the filter's parameters. Fig. 3 shows examples of autocorrelation functions 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 for 600 ms in Fig 3b.

Before deconvolution the ratio of amplitude of primary event to multiples is 42:13 with time extent of 600 ms. Fig. 3c shows the function after 300 ms operator length is applied. The amplitude ratio of the primary events to multiples is 42:4 and the time extent of 300 ms. This operator has slightly reduced the amplitude of the multiples at time extent later than 300 ms with a ratio of 42:8. Fig. 3d shows the function after the 600 ms operator is applied. The ratio of amplitude of primary events to multiples is 42:4, and the time extent of more than 600 ms covers 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 multiples duration is between 400 and 600 ms. Therefore, an operator of at least 600 ms is required in order to remove a major part of the existing multiples. Both the sections and autocorrelation functions show considerable improvement with respect to multiple attenuations after the operator is applied, which indicates that the design parameters are effective against multiples. The testing of three windows is to avoid the selection of an improper gate and application of parameters that are not suitable for the type of multiples that exist in the data.

Figs. 7 and 8 show the same computed deconvolution parameters applied to different panels of traces in other parts of the seismic section. The panels were used to produce autocorrelation functions, for deconvolution parameter computation and also for multiple duration estimation. This comparison investigates whether these parameters have the same or different effects on multiples attenuation. The functions produced after the deconvolution parameters were applied show similar effects to those shown on the earlier tests. This indicates that the design parameters are effective and can be applied to different 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 crossing on the autocorrelation function (Fig. 9). The prediction distance specified as the zero crossing (Peacock and Treitel, 1969) varies with the predominant frequency.

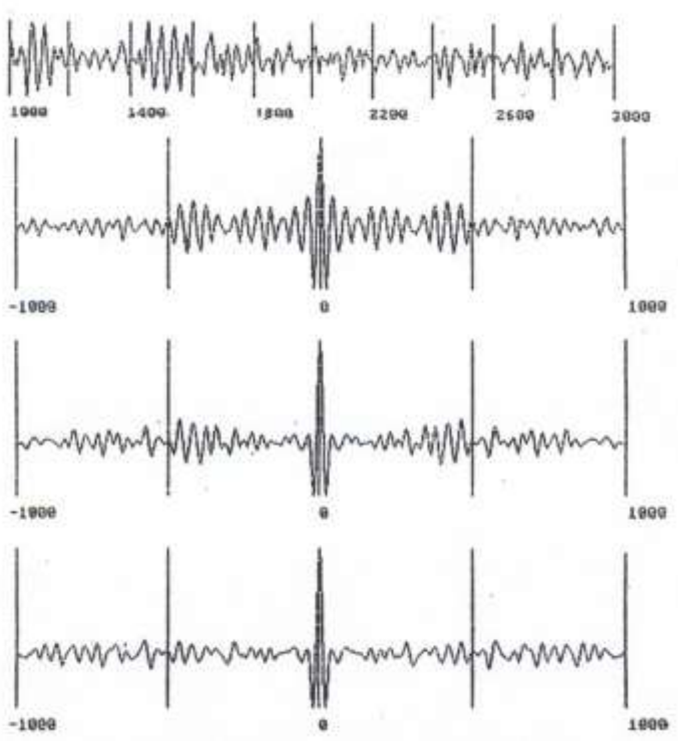

FIG. 7. Autocorrelation functions generated from seismic section CH-81-37, CMPs 2220-2240, and time interval 1000-3000 ms. Similar effect is shown regarding multiple attenuation to those used for deconvolution parameters computation in other parts of the sections.

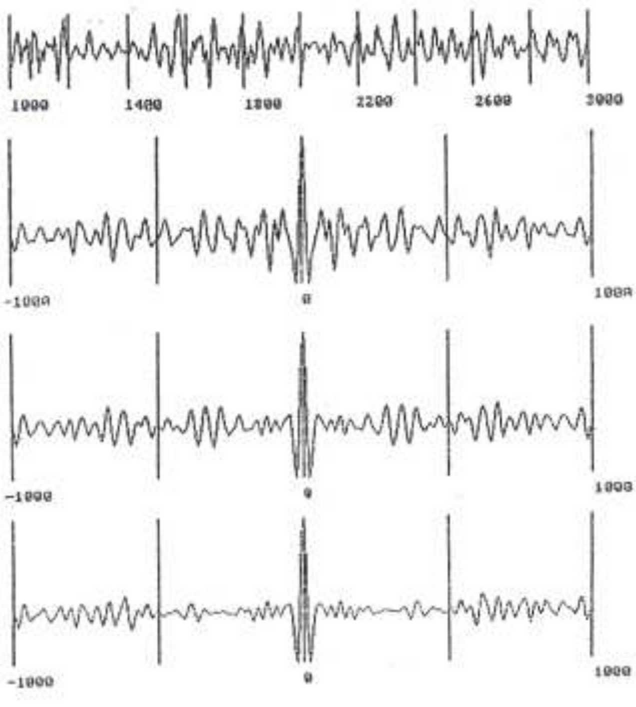

FIG. 8. Autocorrelation function generated from seismic section CH-81-36, CMPs 1240-1260, and time interval 1000-3000 ms. Similar effect is shown regarding multiple attenuation to those use for deconvolution parameters computation in other parts of the sections.

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 procedure for 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. These functions showed that the prediction distances varied slightly from one part of the section to the other. Such variation could be 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 because low frequency becomes predominant with increasing depth.

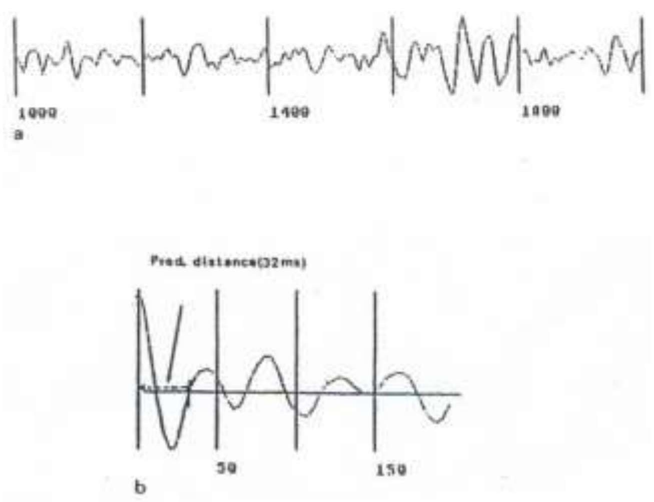

FIG. 9. (a) Input trace from seismic section CH-81-37, and design window 1000-2000 ms. (b) Enlarged segment of the autocorrelation of the input trace showing the computation of prediction distance by applying the second zero crossing technique. Refer to Fig. 2b for multiple time duration.

d. Prediction operator length

The estimation of operator length for post-stack deconvolution was carried out by using the autocorrelation function to estimate 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 attenuation 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 operator lengths 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 parts of the seismic sections before and after a deconvolution filter of 32 ms gap length, and either 300 or 600 ms operator lengths applied. The sections are part of seismic sections CH-81-37 and CH-81-36 and show the time interval between 1000-2000 ms. The sections obtained after deconvolution show progress in multiples attenuation as filter operator length increases. The reduction in multiples effect continues until the operator length reaches 600 ms. When the 750 ms operator is applied no noticeable improvement is observed. Therefore, the extent of multiples duration is believed to be around 600 ms and the required operator should be not less than 600 ms to work effectively against existing multiples.

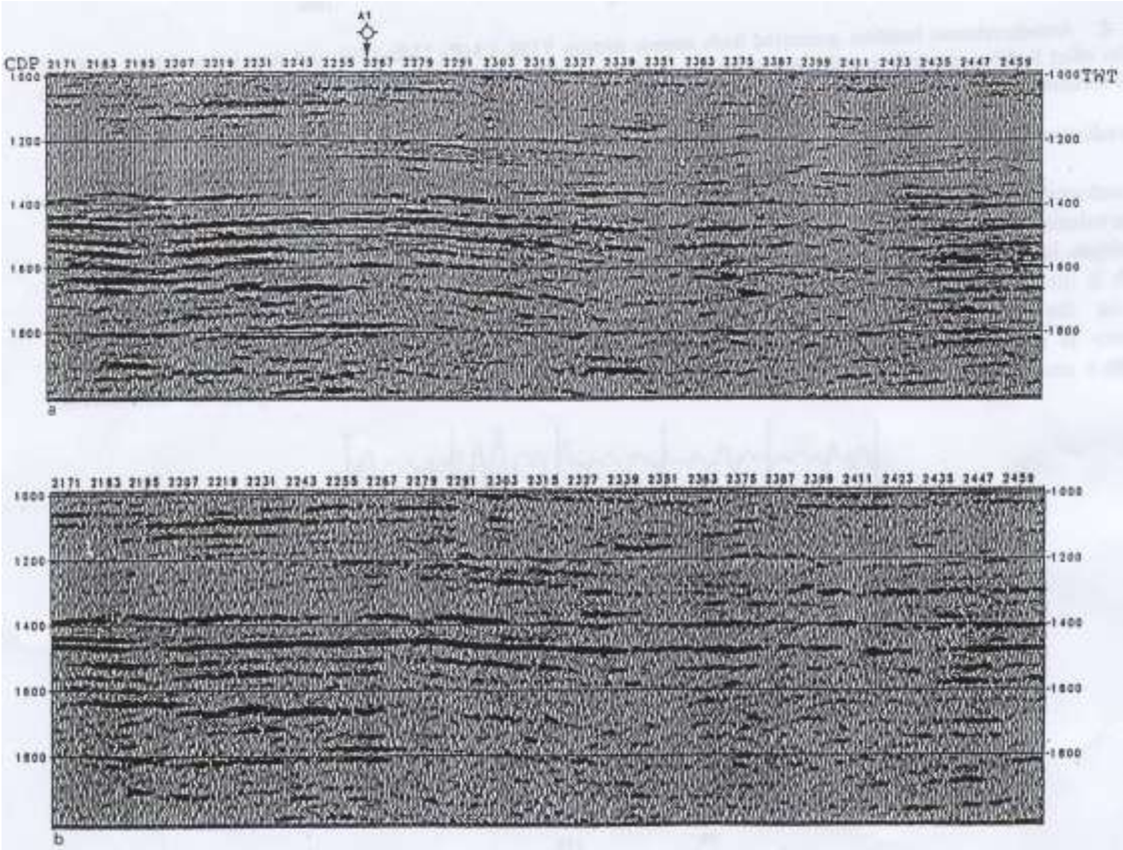

FIG. 10. Part of seismic section CH-81-37, CMPs 2166-2466. (a) before post-stack deconvolution reflections are buried in multiple energy. (b) After post-stack deconvolution with 32 ms gap length and 600 ms operator length is applied. Significant amount of multiples related noise is removed and prominent reflections are more easily distinguished.

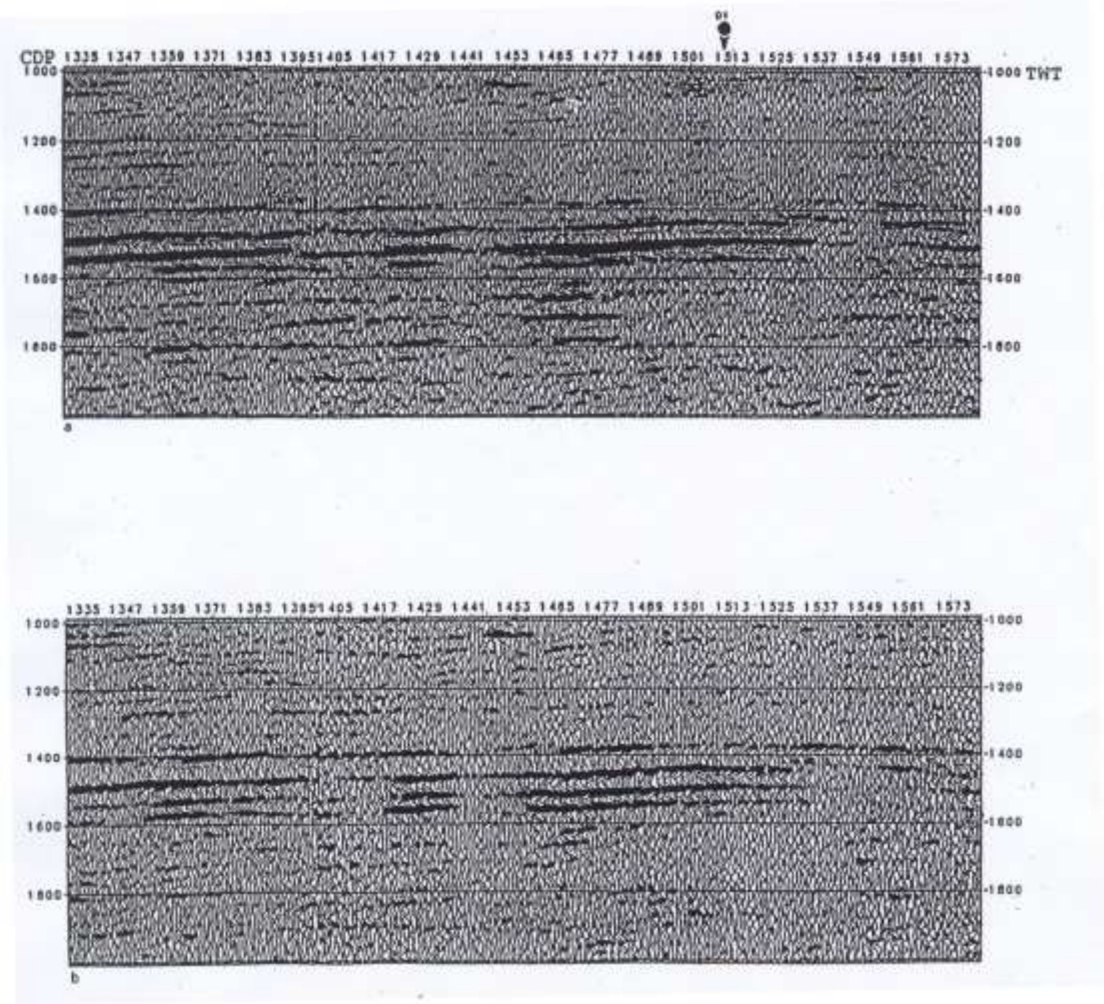

FIG. 11. Part of seismic section CH-81-37, CMPs 1330-1580. (a) Before deconvolution. (b) After post-stack deconvolution was applied with same parameters (and similar effect) as Fig. 10.

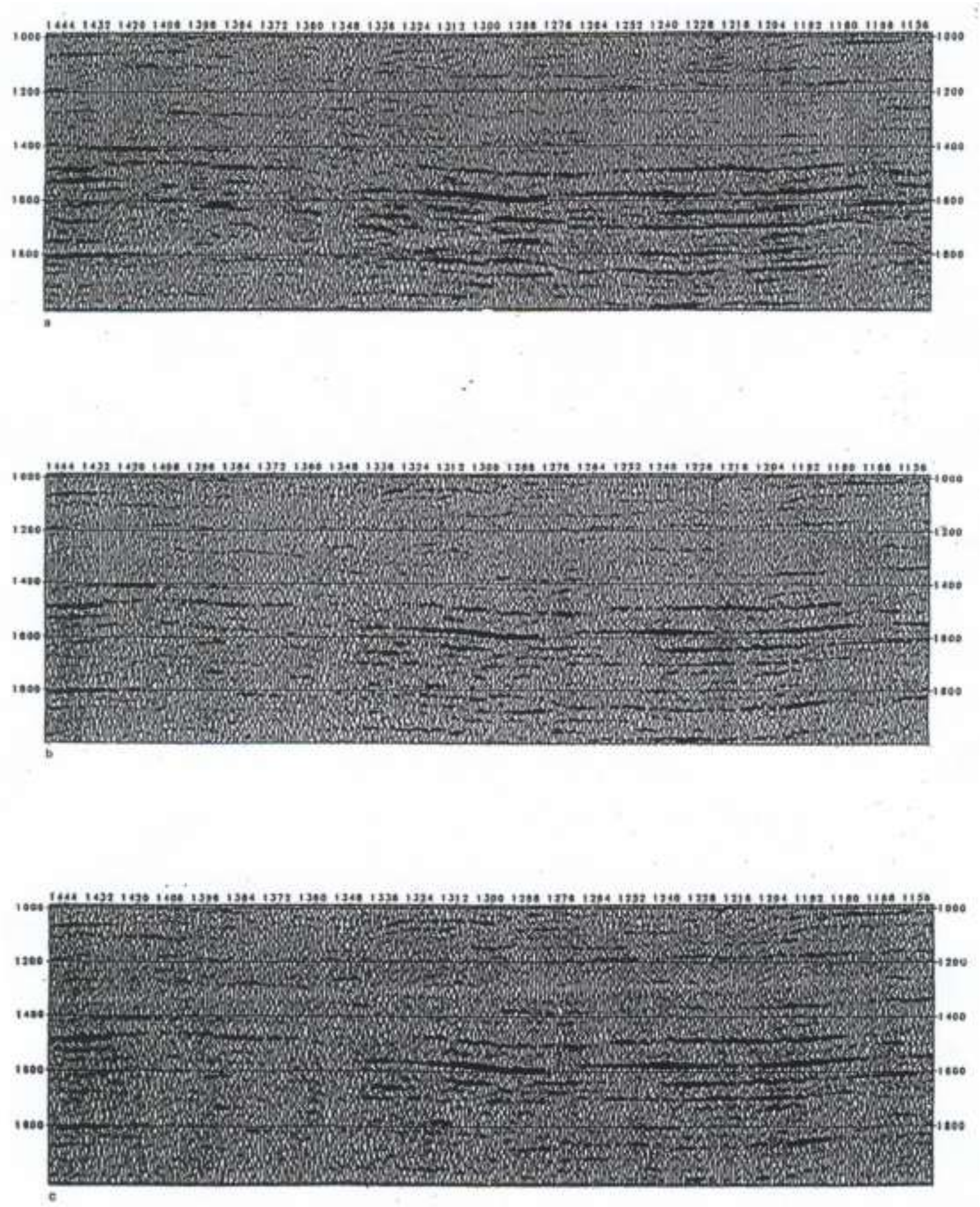

FIG. 12. Part of seismic section CH-81-36, CMPs 1151-1449. (a) Before deconvolution, multiples energy is strongly visible, especially around and below 1800msec time line. (b) After deconvolution with 32 ms gap length and 300 ms operator length applied. (c) After 600 ms operator length is applied. Multiples are suppressed and primary reflections have became more prominent.

DISCUSSION:

a. Multiples

Multiples have been defined by Robinson (1979) as events that make one or more round-trip paths within sedimentary layers before returning to the surface of the earth. Multiples 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 varies for 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 always effectively suppressed.

The source and types 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 (Bradley, 1985). Stacking and deconvolution are the two main processing steps applied for the removal and attenuation of multiples. It is important that multiples are recognised 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 the aim of reducing any ambiguity in interpretation. Multiples attenuation is considered to be an essential step towards the recognition, and increase in resolution, of the primary reflection events which typically represent the main reservoirs in the study area. Also, it is very important for the enhancement of data quality to carry out other processing steps such as attribute analyses and inverse modelling. Final stacked seismic data are used for the recognition and possible establishment of seismic criteria to categorize the primary reflection events of interest. Multiples that 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 appear to have severely affected the primary events and obscured any detailed stratigraphic analysis. Multiples interfere with the primaries; hence, recognizing major reflection events and their extension along the seismic section becomes very difficult. 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 post-stack 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, though 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 (19987) 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 tend 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 the 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 ratio of design gate to operator length falls far short of the required operator as indicated by the test autocorrelation functions shown in Figs. 1, 2, and 3. In those tests the extent of multiples is still clear even when the 300 ms operator was applied. In this set of data a gate interval of 3000 ms and a filter with operator length of 600 ms are shown to be the most effective combination for attenuating the existing multiples.

CONCLUSIONS AND RECOMMENDATIONS:

This study shows that further investigation is required regarding the estimation and application of the deconvolution parameters in relation to multiples suppression during seismic data processing. The sources of multiples 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, mainly for pre-stack deconvolution, relate operator length to design gate, have not proved practical for the dataset described here. In this dataset a deconvolution filter with 32 ms prediction distance and operator length of 600 ms is shown to be the most effective post-stack 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 multiples suppression. Therefore, elaborate planning procedures prior to the acquisition of seismic reflection data might improve the quality of the seismic data. This planning could include the generation of modelled sections from the CDP gathers and well data. If the contractor can provide a model of the CDP gather with multiples included, the multiples effects might be minimized by use of different patterns during the gathering of field data. The optimum recording and optimum offset could be designed to cancel the multiples at certain intervals by choosing source-receiver offsets which have a suitable angle for receiving the reflected seismic energy from primary reflectors and rejecting energy from the multiples.

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