LONG-PERIOD SURFACE-RELATED MULTIPLE SUPPRESSION IN 2D MARINE SEISMIC DATA USING PREDICTIVE DECONVOLUTION AND COMBINATION OF SURFACE-RELATED MULTIPLE ELIMINATION AND PARABOLIC RADON FILTERING

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ABSTRACT

Some of the important petroleum reservoirs accumulate beneath the seas and oceans. Marine seismic reflection method is the most efficient method and is widely used in the petroleum industry to map and interpret the potential of petroleum reservoirs. Multiple reflections are a particular problem in marine seismic reflection investigation, as they often obscure the target reflectors in seismic profiles. Multiple reflections can be categorized by considering the shallowest interface on which the bounces take place into two types: internal multiples and surface-related multiples. Besides, the multiples can be categorized on the interfaces where the bounces take place, a difference between long-period and short-period multiples can be considered. The long-period surface-related multiples on 2D marine seismic data of the East Coast of the United States-Southern Atlantic Margin were focused on this research. The seismic profile demonstrates the effectiveness of the results from predictive deconvolution and the combination of surface-related multiple eliminations (SRME) and parabolic Radon filtering. First, predictive deconvolution applied on conventional processing is the method of multiple suppression. The other, SRME is a model-based and data-driven surface-related multiple elimination method which does not need any assumptions. And the last, parabolic Radon filtering is a moveout-based method for residual multiple reflections based on velocity discrimination between primary and multiple reflections, thus velocity model and normal-moveout correction are required for this method. The predictive deconvolution is ineffective for long-period surface-related multiple removals. However, the combination of SRME and parabolic Radon filtering can attenuate almost long-period surface-related multiple reflections and provide a high-quality seismic images of marine seismic data.

Keywords: *Long-period multiple reflections, Marine seismic reflection survey, Multiple reflections, Petroleum exploration, Surface-related multiple reflections*

INTRODUCTION

The Marine seismic reflection method is widely used in the petroleum industry to map and interpret the potential of petroleum reservoirs. The marine zones of marine seismic exploration include the shallow-water areas (water depth of less than

30 to 40 meters) and the deep-water areas associated with seas and oceans. When the energy of the seismic wave travels through the water surface and reflects back to receivers, each reflected signal in the seismic record theoretically has only one reflection point, it is called primary reflection. Many problems limit the ability of marine seismic exploration and generate noise even if they are random noise from environment activities or coherent noise such as swell noise, generated by streamer cables, and the big problem; multiple reflections, due to the strong reflector with a reflectivity close to unity. Multiple reflections are the events in the seismic record and have the reflection point more than one before traveling to the receivers. They are treated as unwanted events. Multiple reflections can be classified by considering the shallowest interface on which the bounces take place [1]. Two subdivisions of multiples are internal multiples and surface-related multiples. The internal multiples have a downward bounce at the reflector below the surface. The surface-related multiples have a downward bounce at least one at the surface. Besides, the multiples can be categorized on the interfaces where the bounces take place, a difference between long-period and short-period multiples can be made. The long-period or long-path multiples having the distinct arrival times from the primaries are the multiple events that can be differentiated from the primary events. On the other hand, short-period or short-path multiples generated by thin layer and interfering with the primaries are the multiples that cannot be separated from the primaries.

Due to the multiples being the unwanted events, subsurface imaging without removing them may be the big problems and misunderstanding for the interpreters. Several multiple removal techniques are used in seismic data processing. However, the well-known techniques, predictive deconvolution, surface-related multiple eliminations (SRME) and parabolic Radon filtering will be discussed in this research.

Predictive deconvolution can remove not only the seismic wavelets but also the repetitive events [2]. However, predictive deconvolution becomes less acceptable as the water depth increases and the complex structure. The large of the multiple reflection period and the complexity of structure yield the poor estimation of the periodic events [3], [4]. SRME [5], [6], [7], [8], [9] and Parabolic Radon filtering [8], [9], [10], [11] are the complementary methods effectively removing the surface-related multiple reflections for the complex geological setting data.

This research attempt to eliminate the surface-related multiples on marine seismic data. The two separated flows will be used for multiple removals. The first processing flow includes predictive deconvolution. The other contains SRME and parabolic Radon filtering.

METHODOLOGY

Predictive Deconvolution

The recorded seismic signal is considered as the convolutional model in the time domain. The source wavelet, $w(t)$, is sent through the subsurface and convolved with the Earth response (Earth's reflectivity), $r(t)$, to produce the seismic traces. Random noise, $n(t)$ is generated by activities in environment while the seismic acquisition is working. The seismic records, $s(t)$, can be mathematically expressed as

$$s(t) = w(t) * r(t) + n(t) \tag{1}$$

Deconvolution is the inverse of the convolution process. The inverse filter operator, $h(t)$, estimated from seismic traces is convolved with the seismic records, $s(t)$. In principle, the deconvolution process sharpens the seismic traces by removing source wavelet and yields only the Earth's reflectivity.

$$r(t) = h(t) * s(t) \tag{2}$$

In practice, because the seismic data is not noise-free data, this condition may reduce the effectiveness of the deconvolution process and cause errors.

Predictive deconvolution is the most commonly used technique in seismic processing. This procedure not only removes the source wavelet but also suppresses the repetitive events in seismic data. Fig. 1 shows the autocorrelation functions of seismic traces containing long-period multiples. The α parameter indicates the repetition of the seismic events. In predictive deconvolution, the prediction lag α must be designed to predict and suppress the multiples [12].

In Fig. 2, the prediction lag (α) and prediction operator length (n) were designed.

The shorter prediction lags yield more compression of the source wavelet. While the prediction lag increases, the effectiveness the compression wavelet is reduced [12].

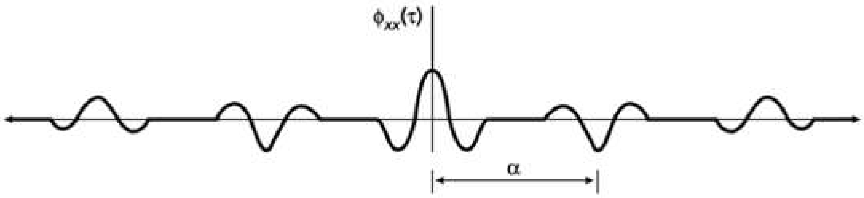

Fig. 1. *Autocorrelation functions of seismic traces containing with long-period multiples, [modified from [13]].*

The shorter length of n is the length of the first-order event and the longer length of n is the length of the second-order event. The prediction operator length (n) can be defined in order to suppress one or more orders of multiples. The autocorrelation of the output trace shows the very low energy of repetitive patterns after the deconvolution process.

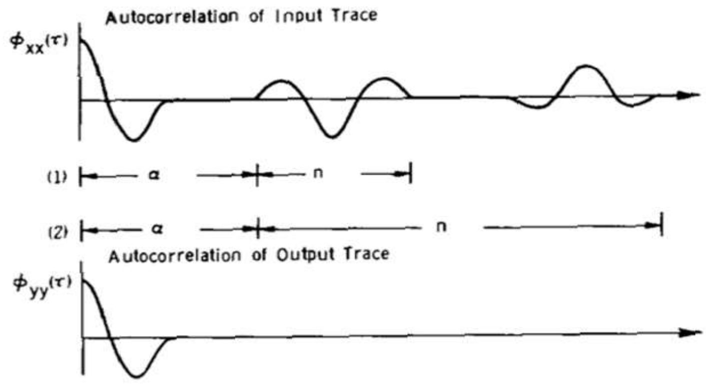

Fig. 2. *Upper diagram illustrates the autocorrelation of trace with long-period multiples. Lower diagram illustrates the autocorrelation output after applying predictive deconvolution, [modified from [2]].*

Surface-related Multiple Elimination (SRME)

The principle of SRME process is that multiples are a combination of primaries. First-order multiples are the spatial convolution of primaries and primaries, second-order multiples are the spatial convolution of primaries and the first-order multiples, and so on. These steps are referred to the prediction of the multiple reflection model.

First, the forward model of surface-related multiples for the 1D situation is explained. The impulse response of the Earth is defined by and contains all primary and multiple reflections. When these events hit the free surface, they all reflect back into the medium. Hence each event in the primary response acts as a new source wave for the complete round trip. Each event from the impulse response will be convolved with the complete impulse response to become a sequence of the first-order multiples. The construction of the first-order surface-related multiples can be expressed as [1].

$$m_1(t) = -x_0(t) * x_0(t) \tag{3}$$

where the minus sign describes the reverse phase of the signal. Next, these events arrive at the surface again, and each first-order multiple acts as a source for the second-order multiples. Thus, the second-order multiples can be written as

$$m_2(t) = -x_0(t) * m_1(t) = x_0(t) * x_0(t) * x_0(t) \tag{4}$$

The total response *x(t)* with all surface-related multiples becomes a series as

$$x(t) = x_0(t) - x_0(t) * x_0(t) + x_0(t) * x_0(t) * x_0(t) - \ldots \tag{5}$$

The surface-related multiples response from the full wavefield can be expressed by a series of auto-convolutions as

$$x_0(t) = x(t) + [(x)t * x(t)] + [x(t) * x(t) * x(t)] + [x(t) * x(t) * x(t) * x(t)] + \ldots \tag{6}$$

For the 2D situation, the integral expression of multiple prediction is given by

$$M_0(x_r, x_s, f) = -\sum_{x_k} X_0\,(x_r, x_k, f) P(x_k, x_s, f) \tag{7}$$

where X_0 is the primary impulse response function, P is the total recorded field, x_s is the source location, x_r is the receiver location and x_k is the lateral coordinate over which the data are summed [14]. Fig. 3 illustrates the construction of the first-order multiple for 2D seismic data.

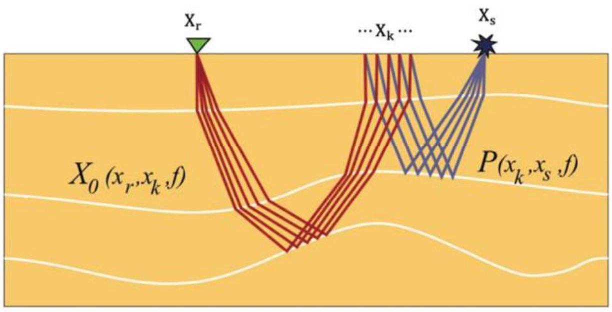

Fig. 3. *The construction of the first-order multiple [1].*

The model of multiple reflections from (7) is subtracted from the input data using a least-square method with a matching operator *A(f)* expressed as (8). The operator $A(f)$ is an inverse source property relating between data with and without multiples. The correct operator $A(f)$ obtains the minimum energy of multiples in the output [15].

$$P_0(x_r, x_s, f) = P(x_r, x_s, f) - A(f) M(x_r, x_s, f) \tag{8}$$

Parabolic Radon Filtering

The Radon transform is a mathematical technique having been widely used in the seismic data processing. This method transforms the input data from the offset-time (x-t) domain to the Radon domain, where it is modified and then transform back to the x-t domain. In this research, the parabolic Radon filtering is used for multiple removals. The forward parabolic Radon transform is expressed as

$$m(q, \tau) = \sum_{n=1}^{N} d(x_n, t = \tau + q x_n^2) \tag{9}$$

where $d(x_n, t)$ is the data in offset-time *(x-t)* domain, *N* is the number of traces and $m(q, \tau)$ is the data in parabolic Radon domain [10]. The transformed data are a function of the curvature q and the zero offset intercept time τ. After a temporal Fourier transformation, the parabolic Radon transform is calculated for each temporal frequency component ω. The forward and inverse transform are expressed in (10) and (11), respectively [10].

$$M(q,\omega) = \sum_{n=1}^{N} D(x_n,\omega)exp(j\omega q x_n^2) \tag{10}$$

$$D(x_n,\omega) = \sum_{i=1}^{N_q} M(q_i,\omega)exp(-j\omega q_i x_n^2) \tag{11}$$

where $M(q,\omega)$ and $D(x_n,\omega)$ are the temporal Fourier transform of $m(q,\tau)$ and $d(x_n,t)$, respectively, and N_q is the number of q values.

Parabolic Radon filtering is the process based on the moveout differences between primary and multiple reflections in common depth point (CDP) gather. The schematic of parabolic Radon filtering is illustrated in Fig. 4. The normal moveout (NMO) correction with the velocities of primary reflections is applied to input CDP gather. After NMO correction, the primary reflections turn into straight lines and the multiple reflections turn into parabolas. The NMO corrected CDP gather is transformed to the $\tau - q$ domain by parabolic Radon domain transform, the primaries and multiples can be discriminated, and the multiples are muted out. The muted data is transformed back to the CDP domain, and the inverse NMO correction is applied to obtain the data without multiples.

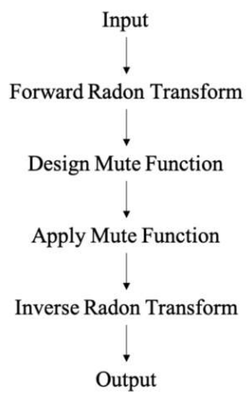

Fig. 4. *The procedure of parabolic Radon filtering.*

2D MARINE SEISMIC DATA

The 2D marine seismic data of the East Coast of the United States-Southern Atlantic Margin used for this research are the open data and available on the U.S. Geological Survey website. A number of survey lines were carried out approximately 25,000 km with multichannel seismic reflection survey between 1974 and 1978 to address hydrocarbon resource potential and stratigraphic history. The used dataset is a second quarter part of line number 31. The details of shot and receiver parameters collected from the USGS report and observer’s log are shown in Table 1.

Table 1. *The information of 2D marine seismic data*

Line number	31
Distance	52250 m
Number of shots	999
Number of receivers	48
Shot interval	50 m
Group interval	50 m
Minimum offset	359 m
Maximum offset	2709 m
Trace length	12 s
Sampling rate	4 ms
Fold coverage	24

RESULT AND DISCUSSION

2D marine seismic data contain the long-period surface-related multiple reflections. Predictive deconvolution, surface-related multiple eliminations (SRMEand parabolic Radon filtering were conducted to remove surface-related multiple reflections. Predictive deconvolution was limited to suppress the long period of multiple reflections and dipping reflectors in 2D marine seismic data. The multiple reflections are remained as shown in Fig. 5 and Fig. 6 and indicated by the rectangle and the ellipse.

SRME and parabolic Radon filtering can efficiently remove surface-related multiple reflections. While SRME successfully removed near-offset multiple reflections, however far-offset multiple reflections had remained. For the reason that the construction of multiples model uses an approximate velocity from the input data. The amplitude between the estimated model of multiples and the original input data are different, especially in far offset. Thus, this situation limits the ability of SRME. However, the residual far offset multiple reflections were removed by parabolic Radon filtering.

The random noise appearing in 2D marine seismic data was very problematic. Due to this troublesome noise, the performance of multiple removal methods was limited. The stacked section at CDP numbers around 12000 to 13200 contains the noise obscuring the reflectors. SRME and parabolic Radon filtering could remove the most of multiple reflections, however they have remained. The residual multiple reflections in noisy data are shown in Fig. 7 and indicated by the rectangle. Nevertheless, Fig. 8 displays the results from the success of SRME and parabolic Radon filtering. The long period multiples reflections were almost removed, the results will not give any misunderstandings in the interpretation.

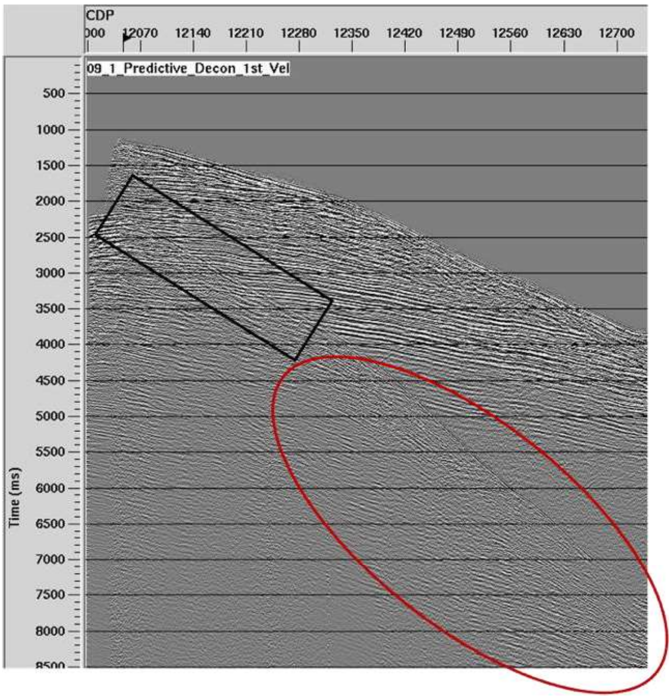

Fig. 5. *The stacked section of 2D marine seismic data at CDP numbers 12000 to 12730 from multiple removals by the predictive deconvolution.*

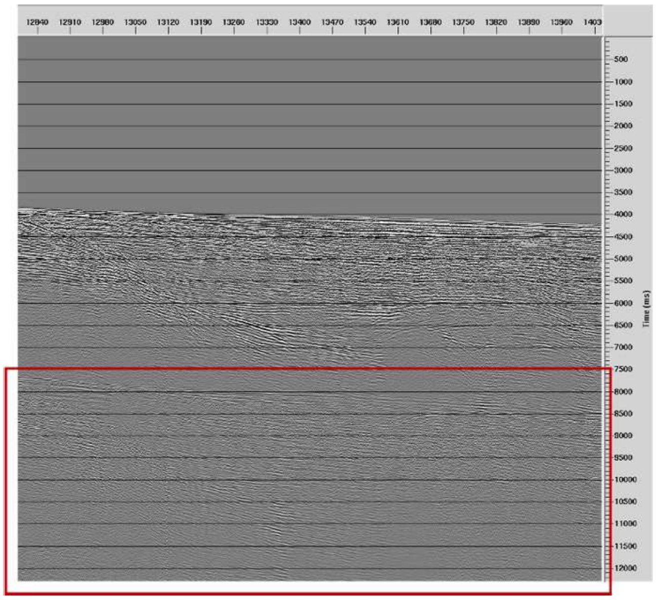

Fig. 6. *The stacked section of 2D marine seismic data at CDP numbers 12800 to 14030 from multiple removals by predictive deconvolution.*

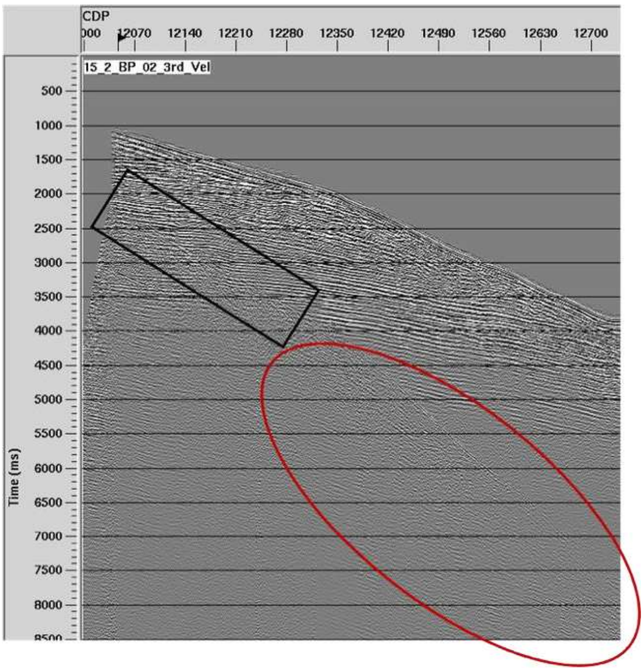

Fig. 7. *The stacked section of 2D marine seismic data at CDP numbers 12000 to 12730 from multiple removals by the combination of SRME and parabolic Radon filtering, respectively.*

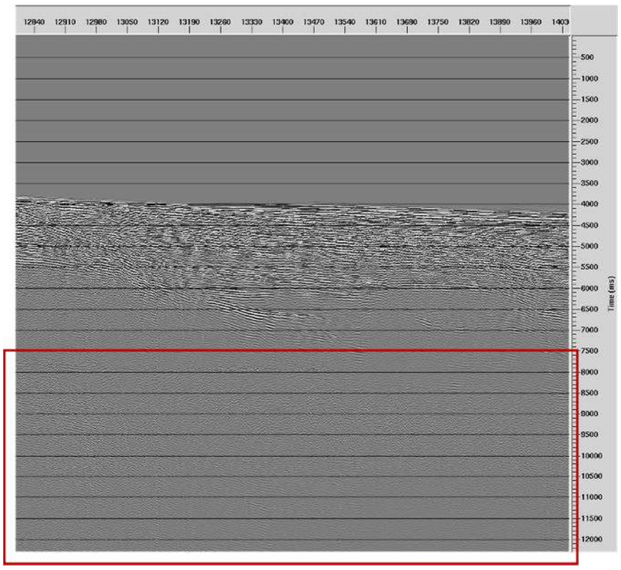

Fig. 8. *The stacked section of 2D marine seismic data at CDP numbers 12800 to 14030 from multiple removals by the combination of SRME and parabolic Radon filtering, respectively.*

CONCLUSION

This research used three multiple removal methods in order to analyze the long-period surface-related multiple reflections. The predictive deconvolution cannot attenuate the long-period multiple reflections in seismic data. The performance of the predictive deconvolution process is degraded when the multiple period changes, such as the dipping reflectors and the complexity of geological structures. SRME and parabolic Radon filtering are effective in removing long-period surface-related multiple reflections. The combination of these two methods increases signal-to-noise ratio. The near-offset multiples are effectively removed by SRME. The residual far-offset multiples are suppressed by parabolic Radon filtering. However, the performance of multiple removal methods is limited by the random noises obscuring the signals. The more noise is cleaned, the better results will be.

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