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Application of Surface-Related Multiple Elimination Technique to Enhance 2D Seismic Data, Matruh Canyon, North Western Desert, Egypt

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ABSTRACT

Marine seismic data are usually embedded with surface-related multiples energy, which are troublesome in imaging an accurate seismic cross-section. In this paper, surface-related multiple elimination (SRME) technique is introduced and applied for attenuating surface-related multiples energy in 2D seismic data from Matruh Canyon.

Surface-related multiple elimination (SRME) is an algorithm that predicts all surface multiples by a convolutional process applied with minimal preprocessing. Once multiples are predicted, the multiples are removed from the data by adaptive subtraction**.**

SRME is a simple and effective technique that gives satisfactory results and great enhance the seismic data by removing multiples without effect on the primaries and no need for the subsurface model.

Keywords: SREM technique, multiples, seismic data processing

INTRODUCTION

Surface related multiples are those multiples (i.e., seismic waves reflected multiple times) that have a bounce in the water-layer on the source or receiver side. The number of downward reflections at the shallowest reflecting boundary indicates the order of multiple reflection events. These surface related multiples are classified into two categories (Dragoset and Jercevic, 1998). Water bottom multiples, which represents energy that propagates up and down in the water layer without ever travelling below the water bottom. Water layer reverberations, which are events that have reflected below the water bottom once, and have one or more multiple reflections in the water layer. Note that these reverberations can be found at the source side, at the receiver side or both. Typically, the surface-related multiples have large amplitudes because of the strong contrasts in layer properties at the air/water (free surface) and at the water/sea bed interfaces.

The presence of multiples in the seismic data causes ambiguities in the processing and interpretation of seismic data. The basic models in seismic processing assume that reflection data only consist of primaries (Weglein, 1999). So far, multiples are considered as noise in seismic data. These multiples must be eliminated prior to migration, inversion, AVO analysis, and stratigraphic interpretation. Otherwise, multiples can be misinterpreted as, or interfere with, primaries and dramatically change the results of migration, inversion, AVO analysis, and stratigraphic interpretation (Xiao et. al, 2003).

Many different techniques are used to solve the problem of multiples and enhance the marine seismic data in the last four decades. These techniques are classified into three categories. Firstly, filtering techniques are applied to separate the multiples from the primaries, based on the fact that multiples have travelled along a different path in the earth, and thus have seen different seismic velocities and/or different reflecting structures. These techniques require a prior knowledge and interpretation (Yilmaz 1987).

The second category of techniques depend on the fact that, multiples are defined as events that appear in severely repetitive pattern. By statistical assumption, this repetition pattern is eliminated. In these techniques multiples are predicted from its generating primaries then they are subtracted from the input data. Both in the prediction or subtraction steps assumptions need to be made.

The third group of techniques, wavefield prediction and subtraction, are based on the wave equation. These techniques use recorded data to predict multiples by wave extrapolation and inversion procedures then subtract these predicted multiples from the seismic data. The greatest advantage of wavefield prediction and subtractions techniques over other methods is its ability to suppress multiples that interfere with primaries without coincidentally attenuating the primaries. These methods seek data with minimum energy by adaptive subtraction of the predicted multiples, given the knowledge of the source function or the reflectivity.

Accordingly, the wavefield techniques are broadly classified into two categories: one based on the estimate of the source function, referred to as source–related multiple–suppression methods, and the other requiring knowledge of the reflectivity of the structure, referred to as reflectivity–based multiple–suppression methods (Liu et. al, 2000).

Surface-Related Multiple Elimination (SRME) technique belongs to wave-field a prediction and subtraction method that is a reflectivity–based multiples suppression method. It mainly suppresses surface–related multiples generated at water layers and ocean bottom (Lokshtanov, 2002).

The basic principle of SRME technique has been developed rapidly in the last periods to make the technique more successively in different conditions as examples; Dragoset et. al (2010) introduced 3D SRME methods , (Hung and Yang, 2011), (Naidu et. al, 2013), Kostov et al. (2015), applied SRME methods in complex topography on the sea bed and Siahkoohi et. al (2019) introduced the prediction of multiples by neural network.

STUDY AREA

SREM technique is applied on the 2D seismic data from Matruh Canyon that is located at the north shelf of the Western Desert in the shallow and transitional water depth area. The water depth is ranging from 100m at the south to 3000m in the northern part of the canyon (Figure 1). It crosses cut the Shelf and the Transform Margin perpendicular to the coastline.

Matruh Canyon is bounded on the north by the Herodotus basin and on the south by the Western Desert. It is considered as an offshore extension of the onshore Jurassic- Cretaceous Matruh Basin. A prominent Cretaceous shale accumulation developed within the basin fill of the Matruh Canyon producing several listric-faults bounded supra-association hydrocarbon targets. The stratigraphy of the offshore/onshore Matruh Basin is currently based only on the extrapolation of the onshore well data sets from the Western Desert (Tari et. al, 2012).

The study area was covered by 3D Seismic survey acquired in 2008 and three 2D seismic lines acquired in 2007. These 2D seismic lines are part from a large 2D marine seismic survey covered many areas neighboring to Matruh Canyon. SRME technique is applied on the three 2D seismic lines located at the northern part of Matruh canyon. The acquisition parameters of the 2D seismic survey are; shot interval= 37.5 m, source depth=7 m, streamer length=8000 m, streamer depth= 9 m, channel interval= 12.5m. Record length is14 second with sample rate equals 2 msec.

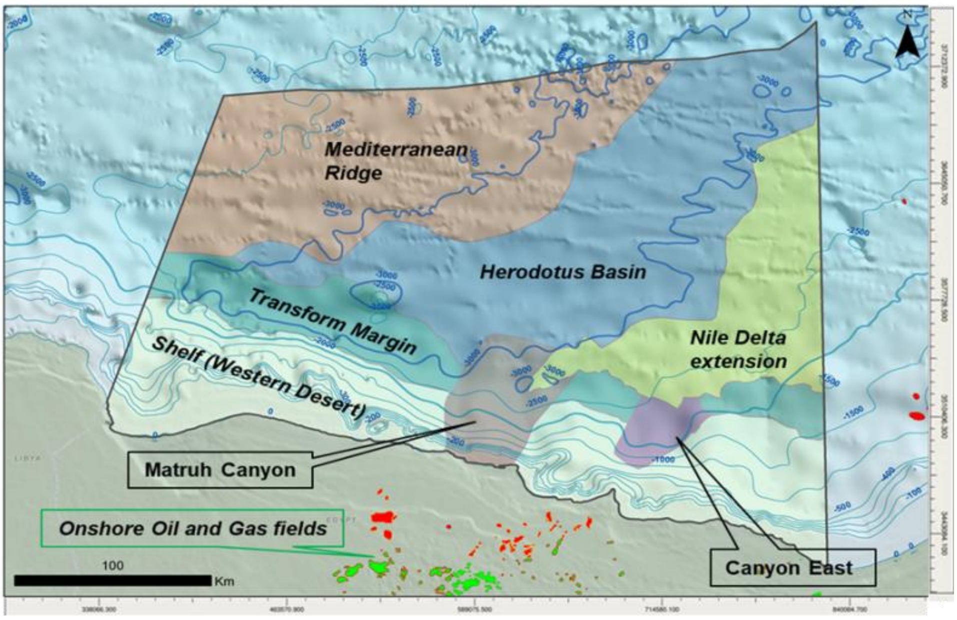

Figure (1): Location map of the study area (Mutruh Canyon).

THEORTICAL BACKGROUND OF SRME TECHNIQUE

The principle of SRME technique depends on subdivision of the near-surface multiple events into two sub-events that can be represented mathematically by using Kirchhoff summations (Spadavecchia, 2013) as the following.

The first order multiple ray-path (Xs, A, Xr) appears as a combination of the two primaries ray-paths (Xs, A) and (A, Xr) as shown in Figure (2).

i.e. the first order multiple $p * p = m_1 * -1$ Eqn.(1)

Where, "p" represents the primaries and m_1 is the first order surface multiples. The minus sign appears because of the amplitude reversal at free surface .

Second order multiples $+ p * p * p = m_2$ Eqn. (2)

Third order multiple $- p * p * p * p = m_3$ etc…. Eqn. (3)

The summation of the convolution can then be expressed as:

$$m_1 = - p * p \qquad = - p * p$$
$$+ m_2 = + p * p * p \qquad = - m1 * p \quad \text{replacing } (+ p * p) \text{ by } -m_1$$
$$+ m_3 = -p * p * p * p \qquad = - m_2 * p$$

Generally, $m = - d * p$ Eqn. (4)

Where, "m" represents the total multiple wave field, "d" represents the total data wave field (primary + multiple) and "P" is the total primary wave field.

The illustration of the previous equations is represented in Figure (2). A surface- related multiple is recorded at receiver Xr due to a shot at location

Xs. This event can be considered as the composition of two events: one recorded at A due to a shot at Xs and a second recorded at Xr due to a shot at A. Both events XsA and AXr are recorded independently as two seismic traces. Now, if the position A (reflection of the surface multiple at the surface) is known, the multiple can be predicted by convolving the individual events which were recorded already. But the challenge is to find the position A before run the algorithm. To solve this problem, the algorithm performs convolutions of individual events for all possible locations between Xs and Xr. As shown in Figure (3), for a given source receiver pair, all possible combinations of ray paths are made and the total travel time of every event is calculated. According to Fermat's principle, the multiple for that source receiver pair is the event which has the least travel time. Thus the basic operation in SRME is spatial and temporal convolution of the original pre-stack data with itself. This gives the correct kinematics of the surface related multiples. Then, the estimated multiple models are adaptively subtracted from the input data.

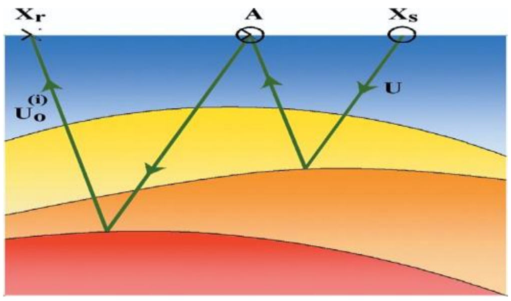

Figure (2): Theory of surface-related multiples (Berkhout and Verschuur, 1997).

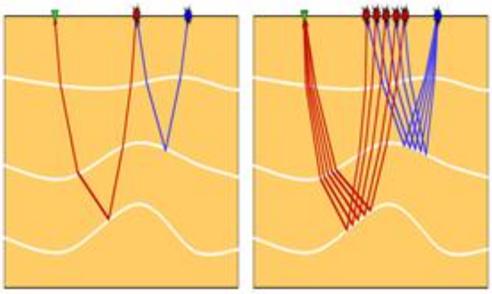

Figure (3): Combinations of all possible primaries to model a first order surface multiple for a given source receiver pair (Verschuur, 2006).

The great advantage of the algorithm is that no subsurface information is required, but it does have two requirements. The first requirement is that all the needed sub-events must be recorded or estimated to properly predict the multiples. The second requirement is that the source wavelet must be removed from the predicted multiple before subtraction them from the data. If sub-events are missing or contain errors, free–surface multiples that contain those sub-events will not be predicted accurately.

METHODOLOGY

SRME technique is applied in the study area on the 2D seismic data, before running the algorithm some pre-processing steps is applied. These steps are muting the direct waves out of the data and applying anti-aliasing filter "spatial and temporal" and tidal statics and swell noise removal.

Verschuur et al. (1992) pointed out that the near offset needs to be filled in before applying multiple prediction model. Dragoset and Jericevic (1998) demonstrated the dramatic effect of missing near offset could have on multiple suppression especially for shallow water setting. Therefore, a near offset interpolation has been performed to the data and thoroughly reviewed.

In this study, shot interpolation is applied to change the shot distance from 37.5 meter to 12.5 meter. Consequently the input data to the modeling stage has an equivalent shot and receiver spacing of 12.5m which help for proper and accurate modeling of the multiples. These interpolated shots are dropped after the modeling stage.

The first step: Prediction of the multiple models

After applying the above data preconditioning, the 2D SRME algorithm models the surface related multiples of the data. A 45 degree phase shift is applied to the multiple models to properly match the input data. A good result of the SRME is obtained as shown in Figures (4 and 5).

Figure (4) represents four shot gathers from a seismic line in the study area. These recorded shot gathers contaminated by heavy multiples events that indicated by red arrows in Figure (4A). The predicted multiple models for these shots are represented in Figure (4B). The predicted multiples (green arrow in Figure 4B matched well with the recorded multiples found in the shot gathers above.

Figure (5) represents near-trace stack section (zoom display) from a seismic line in the study area. This part of the section is contaminated by heavy multiples events that indicated by red arrows in Figure (5A). The predicted multiple model section for the pervious section exhibits a good representation of the recorded multiples in the seismic data (Figure 5B). This result indicates that SRME algorithm is run accurately on the seismic data.

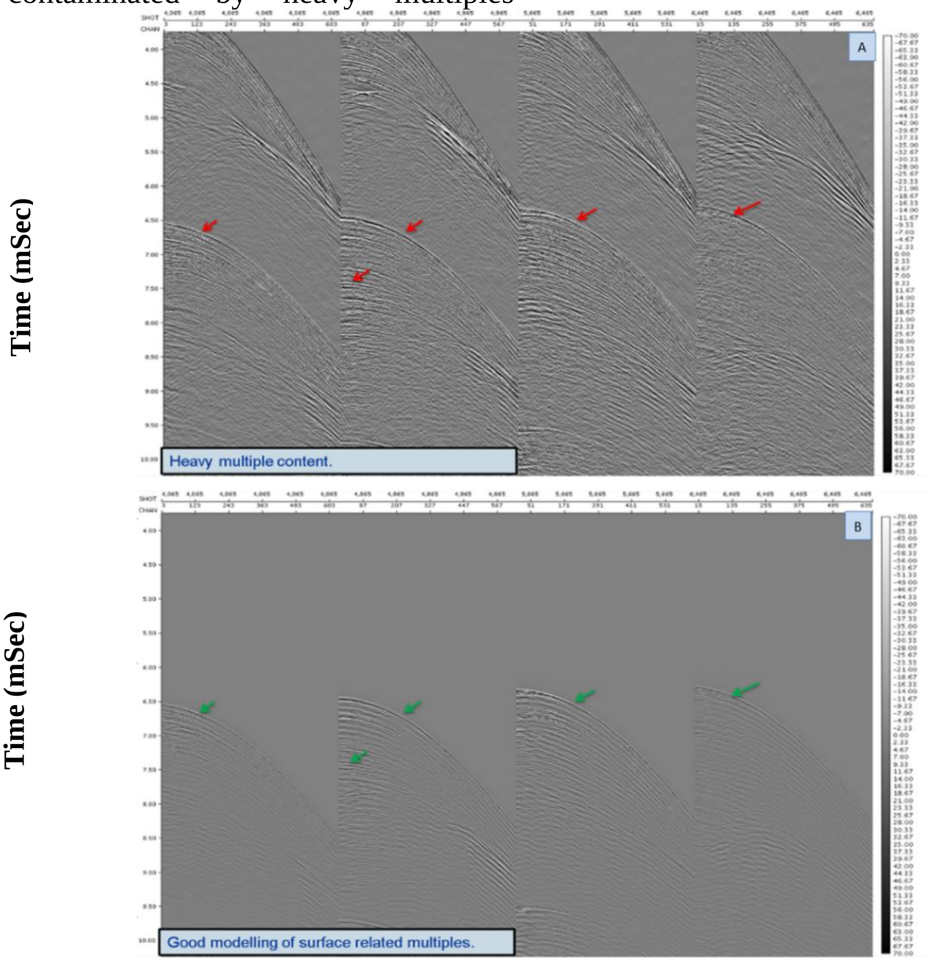

Figure (4): "A" Shows four shot gathers representing the input recorded seismic data and the 2D predicted multiple models for the recorded data “B” (zoom display).

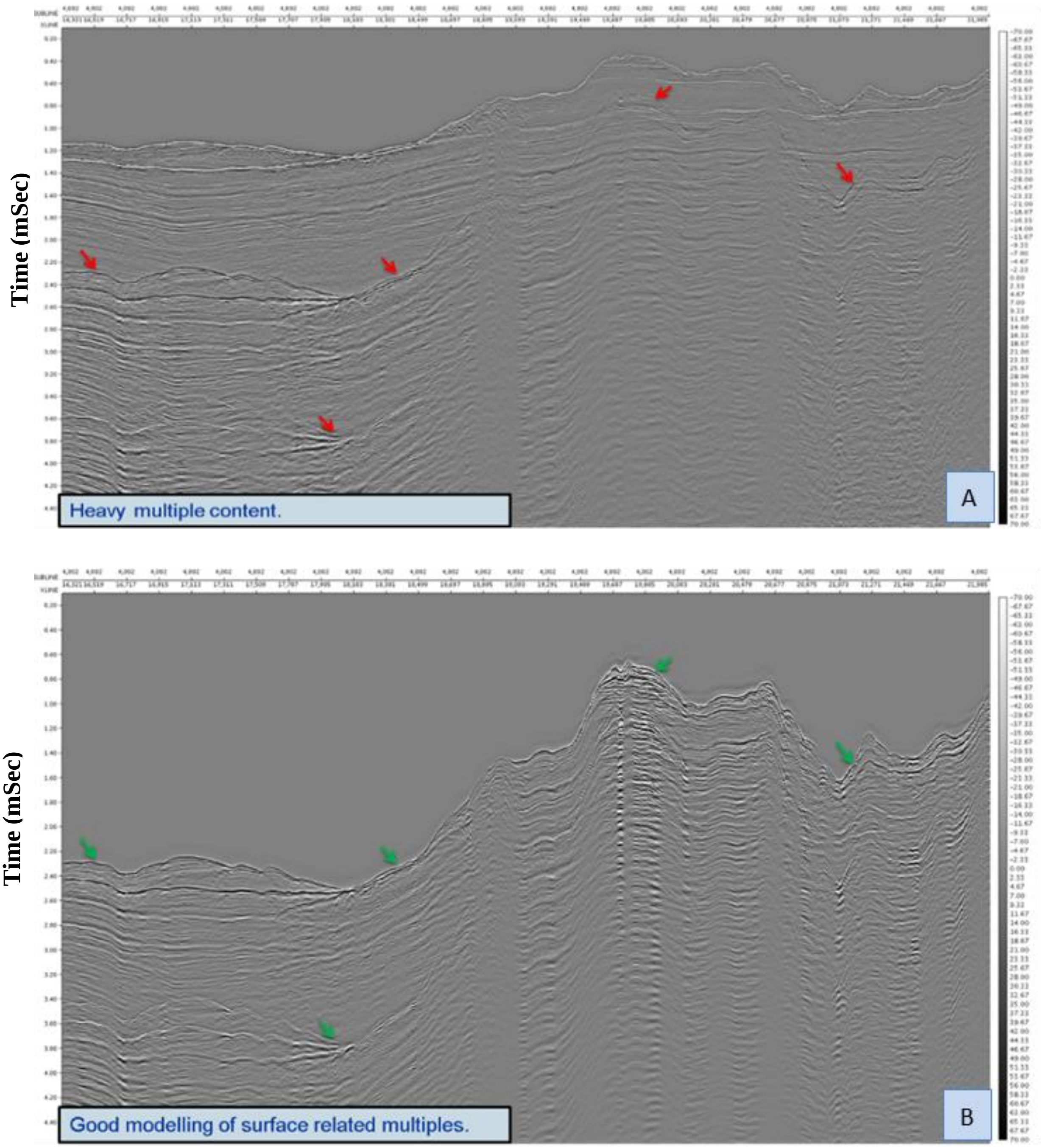

Figure (5): "A" shows near trace stack section for the input recorded data and the 2D predicted multiple model for the recorded data "B" (zoom display).

The second step: Model adaptive subtraction

The model adaptive subtraction process is aiming to subtract the multiple models generated by SRME from the input data. In the previous step the objective is focus on the prediction multiple models. The next important step is the subtraction of predicted multiples from the input data. In the multiple prediction process the amplitudes, phase and arrival times are usually not perfectly predicted due to different reasons as follows.

The predicted multiples contain the source wavelet twice due to the auto- convolution process, which make the predicted multiple amplitude differ from the actual multiple amplitude . Furthermore, in order to obtain the multiple model for one source and receiver pair several traces are convolved and summed (stacked), which enhances the error further (attenuation of high frequencies in the multiple model). This stacking of the multiple contribution gathers introduces a phase shift that needs to be corrected.

Spitz (1999) presented a pattern-based algorithm, which is based on the popular assumption that the primaries and multiples are predictable in frequency-distance (f-x) domain. It uses the prediction error filter (PEF) of the primaries as the constraints of minimization to reduce the freedom of the subtraction. This algorithm has proved to be particularly efficient when attenuating the multiples in the most complex structure areas where the multiples strongly interfere with the primaries.

In the study area, the adaptive subtraction designs an operator which compensates for all these differences between modeled and actual multiples by minimizing the energy in the difference between input and multiple model in a least squares sense. This procedure works in a local window defined after intensive testing, for each window a matching filter is estimated. Then, the window is shifted in time and / or in space and a new matching filter is calculated (Figure 6). The adapted multiples from each window are blended after tapering in time and space such that all tapered windows add up to unity. The matching filters aim to change the multiple models by modifying the phase, timing and amplitude of each window to match the input data.

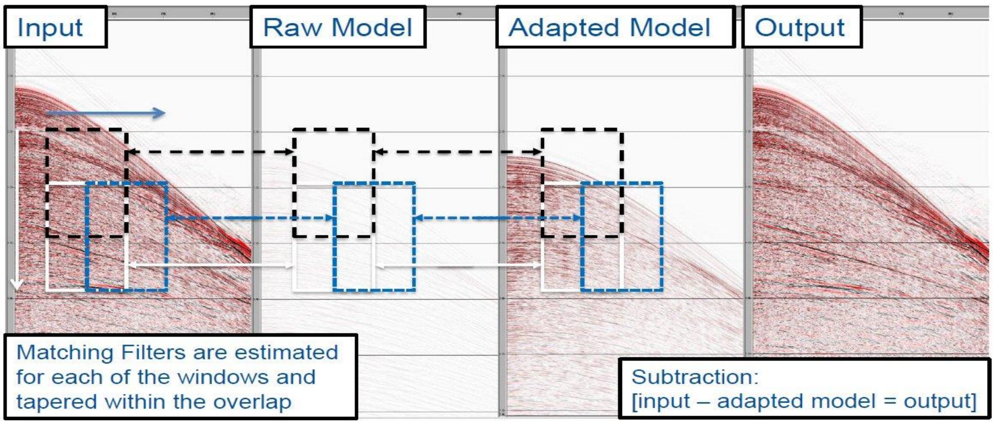

Figure (6): Least square adaptive subtraction windows (Verschuur, 2006).

Various parameters for the adaptive subtraction are tested. All tests are done using two passes of adaptive subtraction (Global + Local). The Global pass is necessary in order to better match the multiple models with input data. While, the local pass is needed to perform the residual matching and subtraction process. Good multiple elimination results (Figures 7 and 8) are achieved through the application of adaptive subtraction in the shot domain with 5 stationary wavelet transform (SWT) frequency bands using the following parameters.

Global pass

Filter length: 40 msec.

Time window length: 2000 msec.

Space window length: 640m.

Local pass

The parameters are shown in Table (1) below

Frequency (HZ)	62-125	32-62	16-31	8-16	0-8
Filter Length (msec.)	20	20	40	40	40
Time window length (msec.)	800	800	200	150	150
Space window length (m)	50	50	25	25	25

Figure (7) shows the input recorded seismic data in shot gathers contaminated by numerous multiples events that indicated by red arrows (Figure 7A). Figure (7B) represents the same shot gather after elimination of the multiples. The eliminated multiples (difference) are indicated in Figure (7C).

Figure (8) represents near-trace stack section from a seismic line in the study area. This part of the section is contaminated by numerous multiples events that indicated by red arrows in Figure (8A). Elimination of the multiples from this section is represented in Figure (8B) that indicates the seismic data free from multiples (green arrows pointed to primaries after elimination of multiples that interfered with them). The eliminated multiples (difference) are indicated in Figure (8C). This result indicates that SRME technique is a successful processing step that enhances the seismic data without any effects on the primaries.

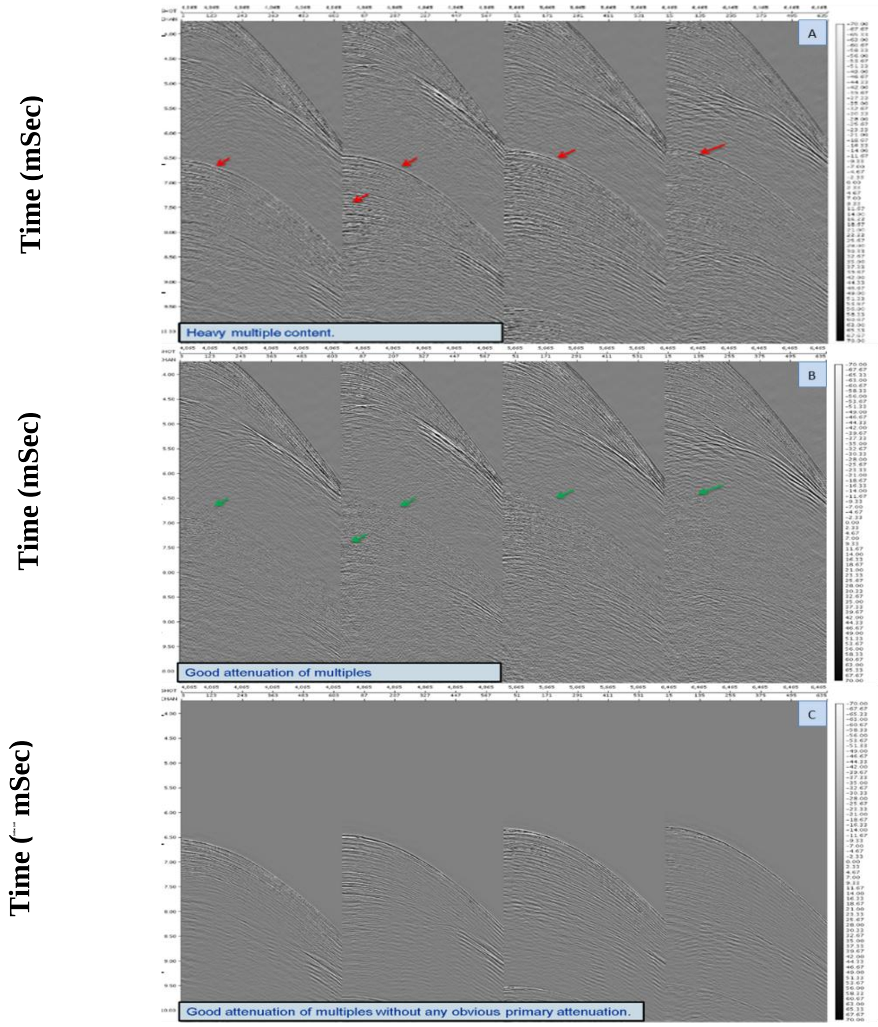

Figure (7): "A" Shows four shot gathers representing the input recorded seismic data and the same shots after subtraction of the predicted multiples "B". While, "C" shows the difference between them (zoom display).

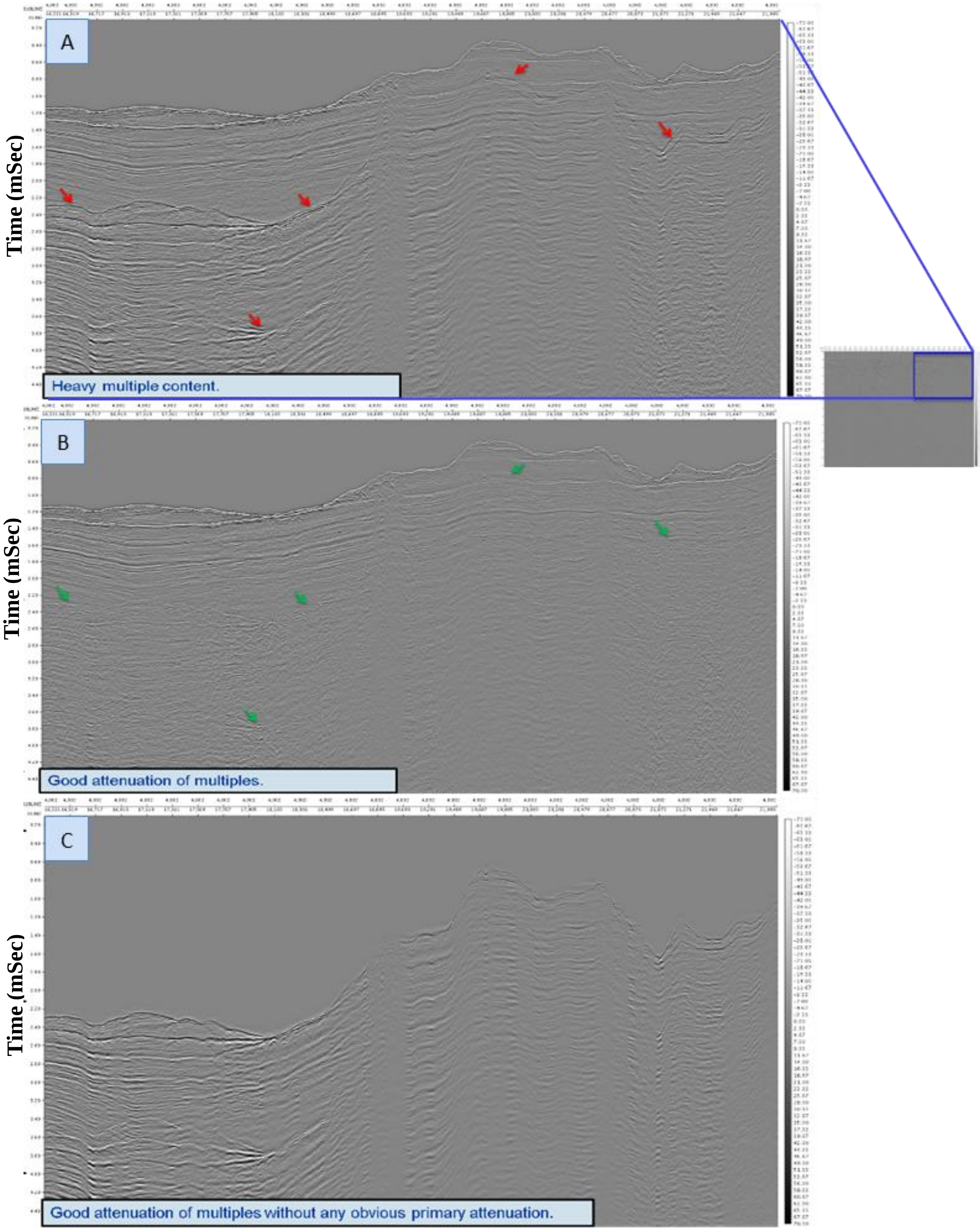

Figure (8): "A" Shows near trace stack section representing the input recorded seismic data and the same stack section after subtraction of the predicted multiples "B". While, "C" shows the difference between them (zoom display).

CONCLUSION

For successful seismic data processing, it is important to eliminate multiples for seismic data enhancement. Surface-related multiple elimination (SRME) technique is wave-field prediction and subtraction method that is a reflectivity–based multiples suppression method. It mainly suppresses surface–related multiples generated at water layers.

Surface-related multiple elimination technique is proposed for removing multiples from 2D marine seismic data in Matruh Canyon. This is quantified by selecting a common source gather and the measurements from a common receiver gather and combining them by convolution process. Repeating this process for all receivers multiples is estimated and then adaptively subtracted from the data.

This technique is applied successfully since surface related multiples are removed from the data without any attenuation on the primaries that make a great enhancement on the data for further seismic data processing or interpretation.

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