Practical Implementation of Multiple Attenuation Methods on 2D Deepwater Seismic Data : Seram Sea Case Study

Implementasi Praktis Atenuasi Multiple pada Data Seismik 2D Laut dalam: Studi Kasus Laut Seram

Tumpal Bernhard Nainggolan and Deny Setiady

Marine Geological Institute, Jl. Dr. Djundjunan No. 236, Bandung, 40174

Corresponding author : tumpalbn@mgi.esdm.go.id

ABSTRACT: Some deepwater multiple attenuation processing methods have been developed in the past with partial success. The success of surface multiple attenuation relies on good water bottom reflections for most deepwater marine situations. It brings the bigger ability to build an accurate water bottom multiple prediction model. Major challenges on 2D deepwater seismic data processing especially such a geologically complex structure of Seram Sea, West Papua – Indonesia are to attenuate surface related multiple and to preserve the primary data. Many multiple attenuation methods have been developed to remove surface multiple on these seismic data including most common least-squares, prediction-error filtering and more advanced Radon transform.

Predictive Deconvolution and Surface Related Multiple Elimination (SRME) method appears to be a proper solution, especially in complex structure where the above methods fail to distinguish interval velocity difference between primaries and multiples. It does not require any subsurface info as long as source signature and surface reflectivity are provided. SRME method consists of 3 major steps: SRME regularization, multiple modeling and least-square adaptive subtraction. Near offset regularization is needed to fill the gaps on near offset due to unrecorded near traces during the acquisition process. Then, isolating primaries from multiples using forward modeling. Inversion method by subtraction of input data with multiple models to a more attenuated multiple seismic section.

Results on real 2D deepwater seismic data show that SRME method as the proper solution should be considered as one of the practical implementation steps in geologically complex structure and to give more accurate seismic imaging for the interpretation.

Keywords : multiple attenuation, 2D deepwater seismic, Radon transform, Surface Related Multiple Elimination (SRME).

ABSTRAK: *Banyak metode atenuasi pengulangan ganda dikembangkan pada pengolahan data seismik dengan tingkat keberhasilan yang rendah pada masa lalu. Keberhasilan dalam atenuasi pengulangan ganda permukaan salah satunya bergantung pada hasil gelombang pantul pada batas dasar laut dan permukaan pada hampir seluruh survei seismik laut. Hal tersebut menentukan keakuratan dalam membuat model prediksi pengulangan ganda dasar laut dan permukaan air. Tantangan utama dalam pemrosesan data seismik 2D laut dalam khususnya struktur geologi kompleks seperti Laut Seram, Papua Barat – Indonesia adalah pada kegiatan menekan pengulangan ganda permukaan sekaligus mempertahankan data primer. Beberapa metode yang dikembangkan untuk menghilangkan pengulangan ganda permukaan pada data seismik seperti least-square, filter prediksi kesalahan dan transformasi Radon.*

Dekonvolusi Prediktif dan Metode Surface Related Multiple Elimination (SRME) digunakan sebagai solusi yang baik pada struktur kompleks dimana metode-metode lain gagal untuk memisahkan perbedaan kecepatan interval data primer dan pengulangan ganda. Metode tersebut tidak membutuhkan informasi bawah permukaan selain parameter sumber dan reflektivitas permukaan. Metode SRME terdiri dari 3 tahapan utama : regularisasi SRME, pemodelan pengulangan ganda dan pengurangan adaktif least-square. Regularisasi near offset diperlukan untuk mengisi kekosongan pada near offset yang disebabkan oleh adanya sejumlah tras terdekat yang tidak terekam selama akuisisi. Pemodelan maju digunakan untuk memisahkan data primer dan pengulangan ganda kemudian inversi dengan pengurangan input data dengan model multiple.

Hasil pada data seismik 2D laut dalam menunjukkan bahwa metode SRME layak diterapkan sebagai salah satu pengembangan metode atenuasi multiple permukaan serta untuk meningkatkan akurasi data seismik terutama untuk struktur geologi kompleks.

Kata kunci : *peredaman pengulangan ganda (multiple), seismik 2D laut dalam, transformasi Radon, Surface Related Multiple Attenuation (SRME).*

INTRODUCTION

Eastern Indonesia is a complex region located in the zone of convergence between Eurasian, Indo-Australian and Pacific plates. The major complex geological structure is Seram Trough which is located beneath Seram Sea at northern part of the Banda-Arc – Australian collision zone and currently the site of contraction between Bird's Head and Seram (Pairault et al., 2003). Seram Sea marks as a transition point within the Banda-Arc – Australian subduction complex, being stalled and sutured in western Seram and actively subducting Australian oceanic lithosphere in the Weber Basin to the southeast. The magnitude of uplift and shortening on Seram diminishes away from the western collision zone. Shortening is limited to the outboard region with strike-slip movement dominating the core areas of Seram (Figure 1). The Seram Trough separates Seram from the island of Misool, which is linked geologically to Semai, Western Papua. Seram island can be divided geologically into two parts; a northern belt, covering the north part of the island in the west and all of it in the east, consist of imbricated sedimentary rocks of Triassic to Miocene age whose fossils and facies resemble those of the Misool and New Guinea continental shelf; the southern belt is dominated by low-grade metamorphic rocks (Amiruddin, 2009). The island of Misool and Semai, Western Papua are the north and east flank of an anticlinorium plunging southeast towards Onin peninsula of Papua known as Misool-Onin-Kumawa anticlinorium (Figure 2). The Misool-Semai stratigraphy is similar to the northwestern Australia margin rift-drift sequence and was controlled by the breakup of northern Gondwana and subsequent spreading in the Indian Ocean (Pairault et al., 2003). The Triassic age similar in lithology to the Kanikeh Formation of Seram island and probably represents an Australian siliciclastic shelf/basin facies. In the Late Triassic, the sediment supply was diminished in part due to the renewed onset of extension along the New Guinea margin (Hill, 2012).

DATA AND METHODS

Seismic Data

The study area is situated on Seram Sea in between $130^030'$ – 133^0 E and $2^045'$ – $4^015'$ S (Figure 3). 2D seismic surveys shot along the Seram Trough were done by Marine Geological Institute in 2014. Line 37 was

studied in order to better understand the best multiple attenuation method which will be applied to all seismic lines in the surveyed area. Seismic data were acquired using Sercel Inc. 60 channels single-streamer and 850 cu. in. power pressure airgun at average 4 knot vessel speed. Seismic acquisition parameter obtained from observer report is used as input parameter in seismic processing software (Table 1).

Table 1. Seismic Acquisition Parameter

Configuration	Off-end
Active Channel	1-60
Line Azimuth	325^0
Shot Interval	25 m
Group Interval	12.5 m
Shot Number	5871
Offset	150 – 887.5 m
Maximum Fold	15
Total Seismic Line	14.68 km
Sampling Rate	2 ms

Both Radon transform and Surface Related Multiple Elimination (SRME) were applied to a 2D seismic line across the Seram Trough from Seram Sea, West Papua. Field data from the acquisition is known to be severely contaminated with multiples that were generated by a strong reflection coefficient at the sea-bottom resulted in a strong surface multiple problem. Strong internal multiples were also accumulating a severe problem to seismic data.

Forward/Inverse Radon Transform

The forward transform is commonly used to transform data to Radon domain in order to suppress multiples. The multiples are periodic in the τ-p domain and it can be recognized and identified as moveout errors. The periodic multiples energy can then be subtracted from the data to improve S/N ratio. The inverse transform is then run to convert the corrected data back to the time-space domain. Particularly, the slant-stack (or τ-p) transform integrates the data along planar surfaces where τ is the time intercept and p is the moveout (Latif and Mousa, 2015). Ibrahim and Sacchi (2013) applied NMO-correction to common midpoint (CMP) data and performes a Radon transform along parabolic stacking curve to suppress multiples. The CMP gathers after NMO-correction are modelled by a superposition of constant amplitude. The most curved parabola, assumed to be multiples (slower than the
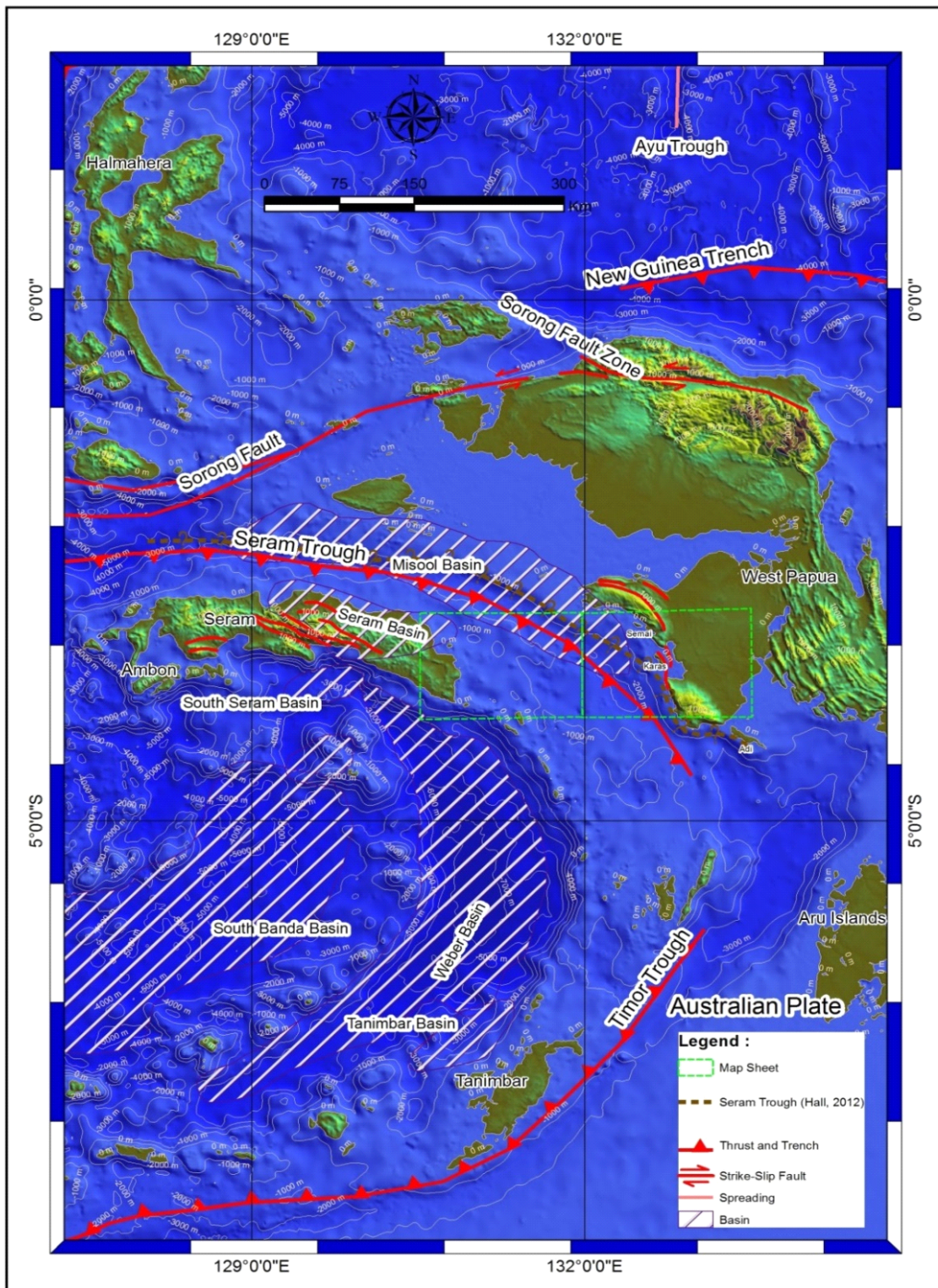
Figure 1. Tectonic Setting and basins of Eastern Indonesia (modified after Hall, 1996; Hall, 2001; Milsom, 2001)
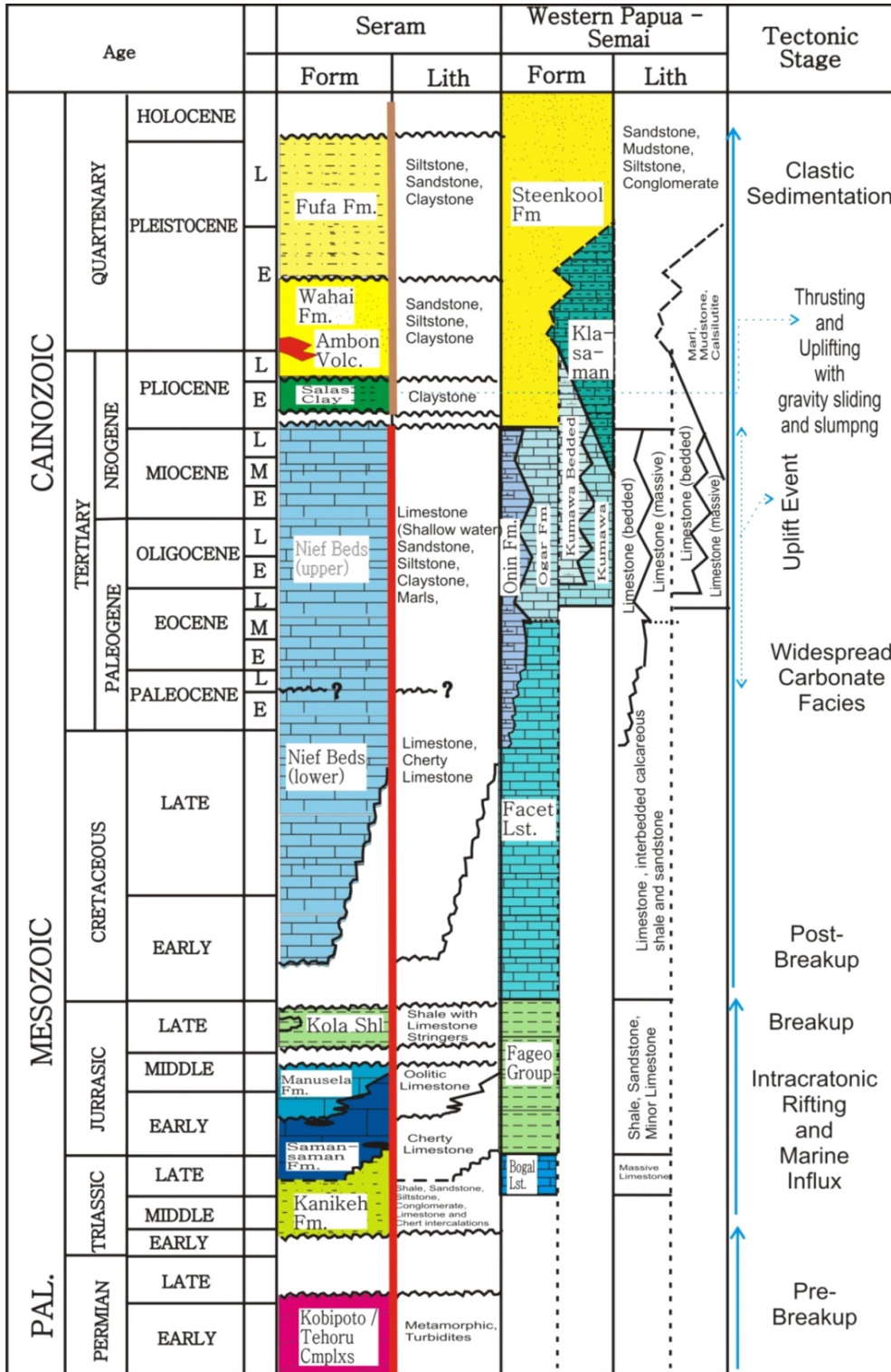
Figure 2.   Stratigraphy of Seram Island (modified after Kemp and Mogg, 1992; Pairault et. al., 2003) and Semai, Western Papua (modified after Tobing & Robinson, 1990; Pairault et. al., 2003).
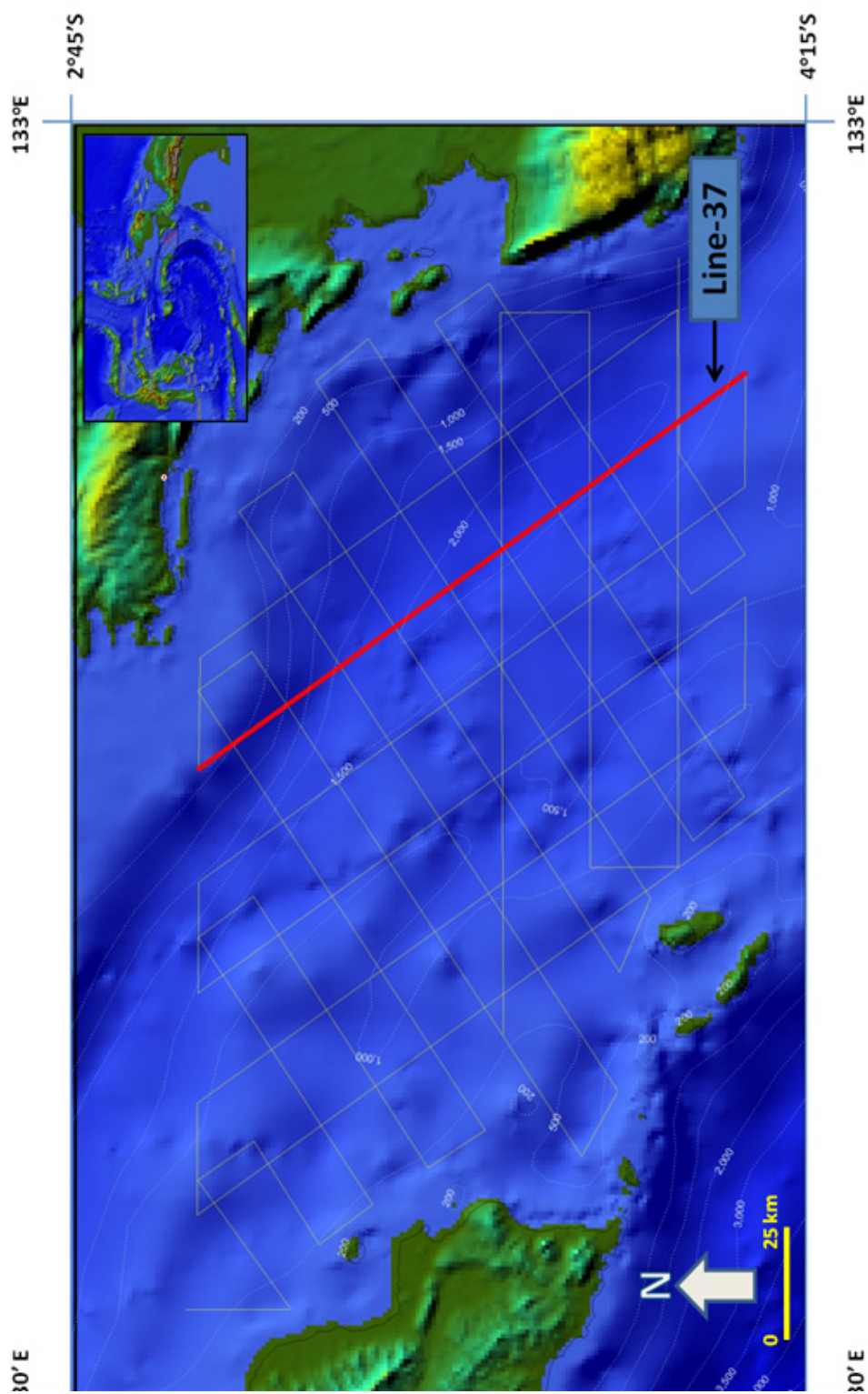
Figure 3. Seismic acquisition location (Nainggolan, 2014).

primaries), are retained and subtracted from data. Radon transform applied pre-stack either before migration in the common midpoint (CMP) domain or after migration within a common image point (CIG) to target multiples that have difference in moveout compared to corrected primary reflections of interest (Poole, 2015). Dutta (2016) explained the least-squares solution of the discrete Radon transform to regularize noisy or severely undersampled data.

The generalized Radon transform $u(q,t)$ is defined as

$$u(q,t) = \int_{-\infty}^{\infty} d\big(x, t = \tau + q\phi(x)\big)dx \qquad (1)$$

where $d(x,t)$ is the original seismogram, $\phi(x)$ is a spatial variable such as offset, is the curvature based on which the transform curve is defined, q is the slope of the curvature, and τ is the intercept time (Fan et al., 2015).

Since the seismogram is digitally recorded, a discrete form of equation (1) is:

$$u(q,t) = \sum_{x} d\big(x, t = \tau + q\phi(x)\big) \qquad (2)$$

Then the inverse transforms of equation (1) and (2) are:

$$d'(x,t) = \int_{-\infty}^{\infty} u\big(q, \tau = t - q\phi(x)\big)dq \qquad (3)$$

or

$$d'(x,t) = \sum_{q} u\big(q, \tau = t - q\phi(x)\big) \qquad (4)$$

Also, we can express the Radon transform in velocity domain (Yilmaz, 2001) as follows:

$$u(v,\tau) = \sum_{x} d\big(x, t = \tau + q\phi(v,x)\big) \qquad (5)$$

$$d'(x,t) = \sum_{q} u\big(v, \tau = t - q\phi(v,x)\big) \qquad (6)$$

Theoretically, an event with linear moveout in the time-offset domain can be mapped to a point with the slant-stack transform. A primary or multiple event can be mapped to an ellipse as shown in Figure 4.

Surface Related Multiple Elimination (SRME)

Surface Related Multiple prediction by feedback iterative method based on wave equation does not depend on any assumptions about underground media nor does it need any prior geological structure information, or source characteristics (Li, 2014). For a given trace containing multiple, SRME must populate a well-sampled grid of downward reflection points where the multiple likely reflected off the free surface (Sanger et al., 2016). 2D SRME will predict all surface-related multiples, provided all the necessary sub-events were recorded within the aperture and azimuth of the acquisition line. The surface is assumed to be perfectly reflecting boundary and the input data are assumed to have been regularized prior to the application of 2D SRME. Shot and receiver regularization for 2D SRME will ensure the data are prepared correctly for 2D SRME multiple prediction. The implementation assumes zero azimuth acquisition. Sources and receivers must be sampled at equal increments, and near offsets must be extrapolated back to the source. The traces within the shot must be ordered from near to far offsets. Preprocessing usually involves swell noise attenuation and direct wave muting.

Considering a source-receiver pair for the 2D case, a multiple in the frequency domain is modeled by (Verschuur, 2006) :

$$M^i(x_r, x_s, f) = -\sum X_0^{(i-1)}(x_r, x_k, f)r_0 P(x_k, x_s, f) \qquad (7)$$

In order to isolate primary wave from the multiple, we simplify the Eq. (7) as

$$X_0^i(x_r, x_s, f) = P(x_k, x_s, f) - r_0 S^{-1}(f)P^i(x_k, x_s, f) \qquad (8)$$

where M^i is the iterative predicted multiple, X_o is the reflection coefficient, r_o is the earth's impulse response free of surface multiples and containing primary and internal multiple reflection, $P(f)$ and $P(f)$ are the total recorded field and wavelet respectively, is the source location, is the receiver location and the is the lateral coordinate over which the data are summed (Figure 5). The multiple is a combination of a shot gather of the P data and a receiver gather of the primary impulse response . These gathers are convolved and summed, generating the modeled multiple. The sum along means that all possible combinations of paths are considered. Only one event in and one event are considered. The minus sign in Eq. (7) represents the reflection at the interface. Regarding the periodicity of the surface-related multiples that might have appeared, the higher order of the time is recorded in the shot record, the higher order multiples can be collected, and wider fold and illumination range can be gained (Li and Wang, 2015). Abbasi and Jaiswal, 2013 explained that higher order multiples are mixed in seismic data in time and space, and each successive multiple estimation is prone to error, and it is difficult to accurately estimate the long periode multiples. Therefore, SRME needs to be run in an iterative way.
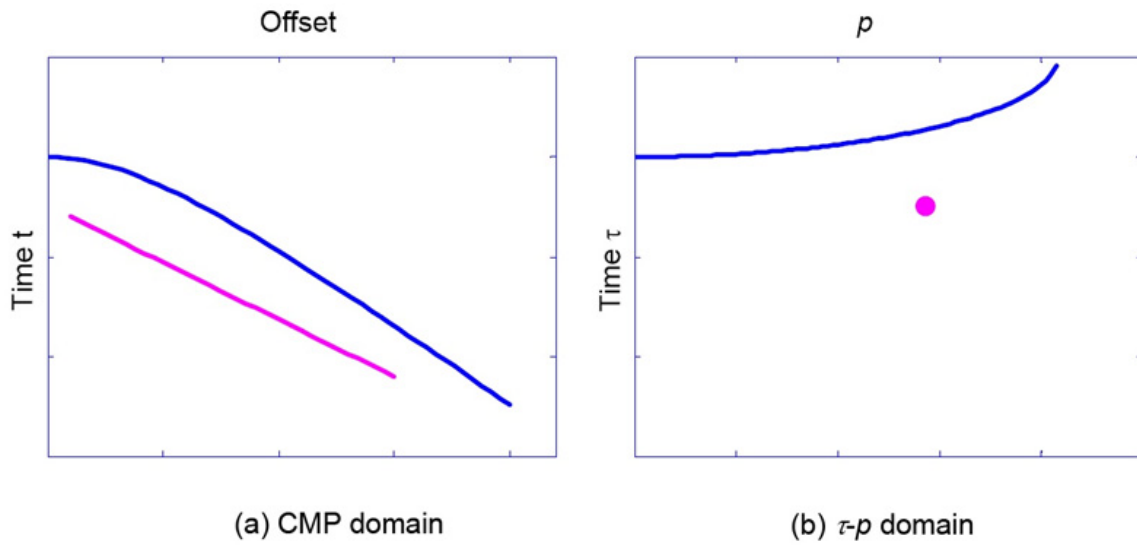
Figure 4. The linear and parabolic events in the CMP gather (a) and its slant-stack transform (b) (Cao, 2006)
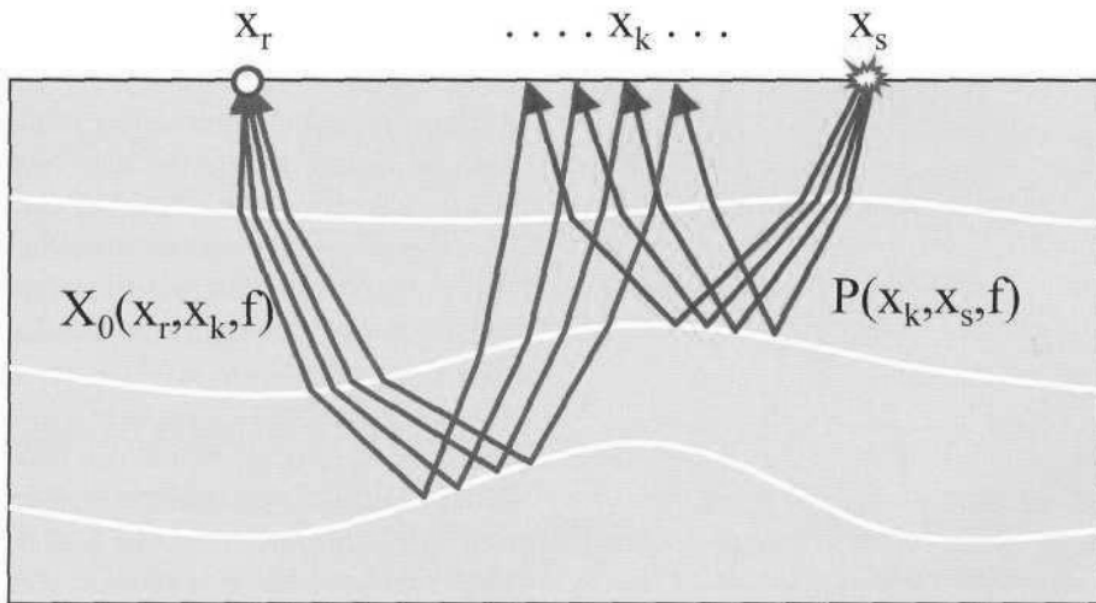

Figure 5. Diagram of how first-order multiple for the 2D data are constructed (Verschuur, 2006).

RESULTS

The following standard conventional pre-processing steps were applied: Muting the direct wave arrival and water swell noise with amplitude preservation, anti-aliasing, filtering and autocorrelation of a single shot gather before the application of Radon transform and SRME. Simple predictive deconvolution was applied to remove consistent short period shot signature noise of primary reflector. The strong energy of both surfaced-related and internal multiples are still existed (Figure 6).

Figure 7a shows stack results of both significant surface and internal multiples. Radon transform method attenuates multiple with primary reflections distortion especially at near offsets stack Zone 1 and Zone 2. It was followed by slightly helpful method at far offset stack Zone 3 and Zone 4 to attenuate multiples (Figure 7c). SRME method effectively gains successful results on keeping primary reflectors intact as well as attenuating surface and internal multiples on some zones (Figure 7b).

Both Figures 8 and 9 display the effect of using SRME and Radon transform on primary reflectors of near stack CDP 1-800 (depth interval 3800-5000 ms) and of mid stack CDP 2000-3600 (depth interval 5200-6000 ms), respectively. Primary reflectors preservation is more difficult as the primary and multiple events come closer and eventually cross each other on many points. Radon transform causes severely loss of primary reflectors especially on near stack section (Figures 7c and 8c). SRME preserves most of primary reflectors and significant improvement of continuity of the primary reflectors (Figures 8b and 9b).

A very strong reflection coefficient at the water-bottom layer results in a strong surface multiple along with internal multiple problems especially in both far stack Zone 3 (Figure 10) and Zone 4 (Figure 11). Radon transform did unsuccessful job on removing strong multiples as shown in Figures 10c and 11c. It cannot remove the multiples at the steep reflectors plane (Figure 11c) caused by inaccurate internal velocities. SRME successfully removes most of surface multiples (Figures 10b and 11b). Modelled multiple on SMRE method never matched perfectly with the original multiples caused by under- or over-corrected NMO of parabolic approximation of the events. A second least-square iterative subtraction of the estimated multiples needed to enhance multiple attenuation.

DISCUSSIONS

Both SRME and Radon transform have difficulties with the short period multiple, however simple predictive deconvolution can be applied to remove the short period multiple because it simply predicts the reflector reverberations on near time gate. Radon transform shows poor result on near offset zone of the stack section because it has no enough time moveout difference between primary and multiple even by using the hyperbolic model to suppress the multiples. On the other hand, SRME method applies a precondition for successful multiple estimation of near offset interpolation. Combining predictive deconvolution algorithm before SRME improves ability to reconstruct the primary reflector reverberations in the near offsets accurately enough for SRME.

Furthermore, in case of Line-37 stack section, Radon filtering is unable to preserve primary reflectors. It can not suppress reflector reverberations generated on Seram Sea deepwater seismic data because it has small differential moveout compared to their own primaries on the $-p$ domain. Multiple attenuation by moveout discrimination is based on differences between primaries and long period multiples when there is substantial velocity gradient over depth. Apparent velocities in CMP gathers are depended on reflector's dip so it explains why moveout discrimination may fail if primaries and multiples have different dips. SRME is based on a data-driven approach using convolutions to predict multiples from shot gathers and provides better multiples estimation for long period multiples.

CONCLUSION

Predictive deconvolution algorithm before SRME improves ability to reconstruct the primary reflector reverberations in the near offsets accurately enough for SRME and attenuates consistent short period shot signature noise of primary reflector.

The principal advantages of SRME over Radon transform are that SRME makes no assumptions about moveout or periodicity, and it requires no subsurface information. The surface is assumed to be a perfectly reflecting boundary and the input data are assumed to have been regularized prior to the application of 2D SRME. It will predict all surface-related 2D multiples, provided all the necessary sub-events were recorded within the aperture and azimuth of the acquisition line.

Further research on enhancing multiple attenuation methods can be studied to use SRME method to obtain multiple prediction, then transform the SRME-modelled and NMO-corrected data into hyperbolic Radon domain.

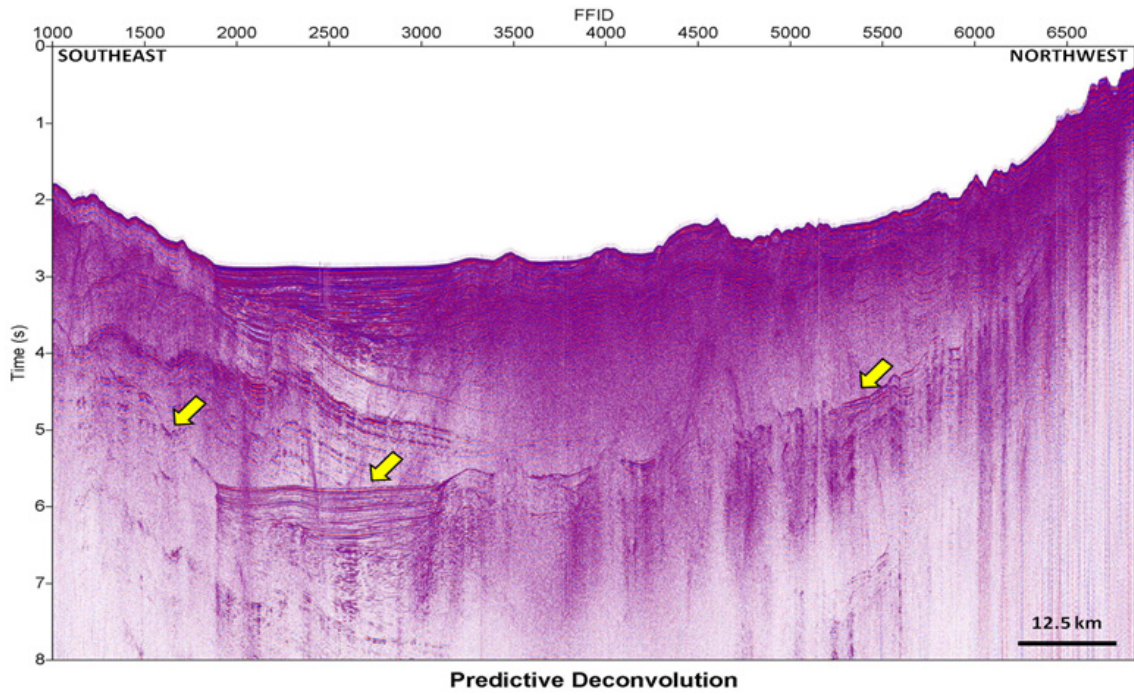**Predictive Deconvolution**

Figure 6. Single channel section after preprocessing.
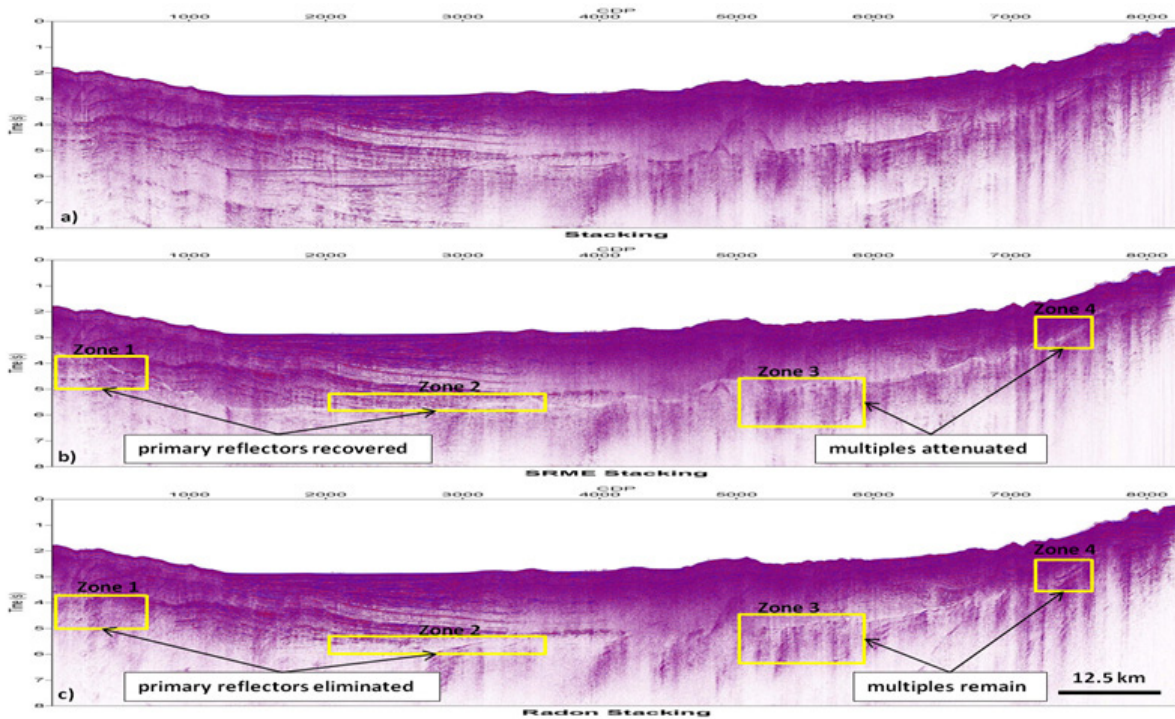

Figure 7.   Stacking section results using demultiple methods. (a) Conventional stacking. (b) After SRME.
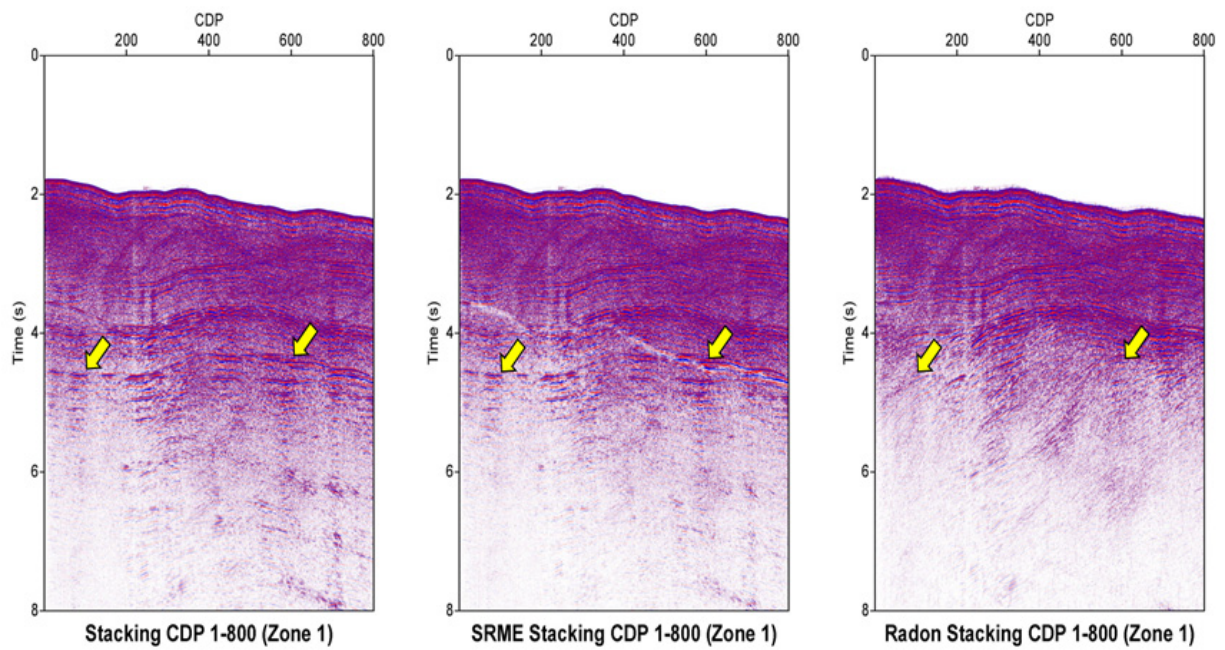(c) After Radon transform.

Figure 8.   Primary reflectors preservation at near stack CDP 1-800 at time depth 3800-5000 ms. (a). Conventional stacking. (b) After SRME. (c) After Radon transform.
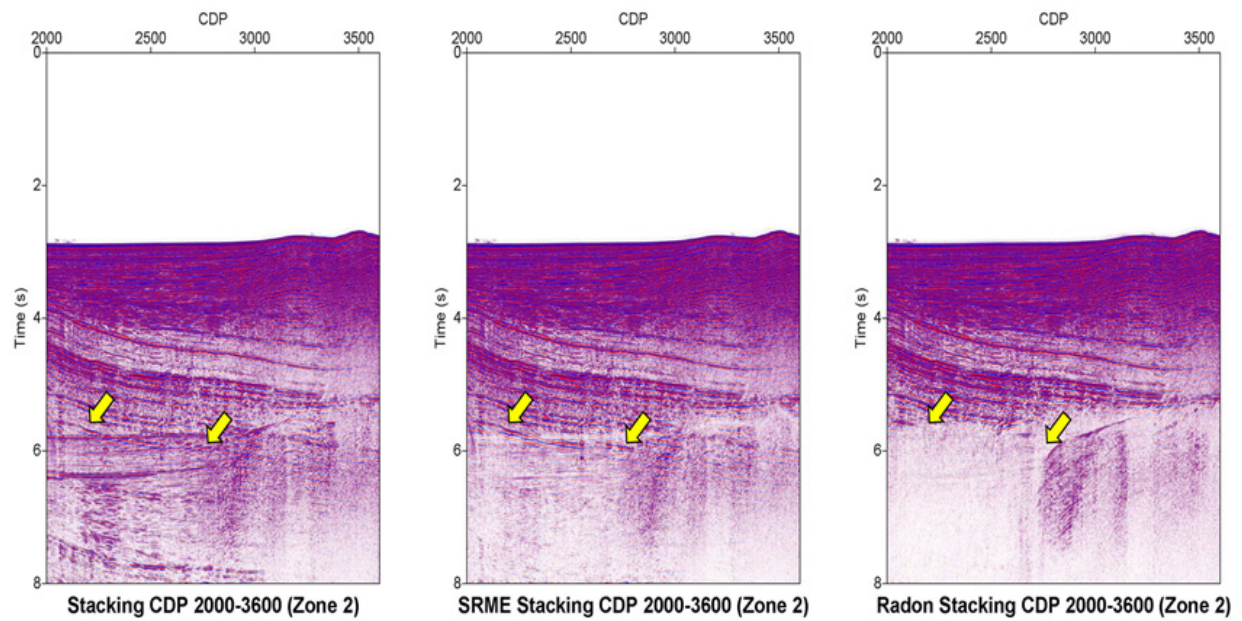

Figure 9.   Primary reflectors preservation at near stack CDP 2000-3600 at time depth 5200-6000 ms. (a). Conventional stacking. (b) After SRME. (c) After Radon transform
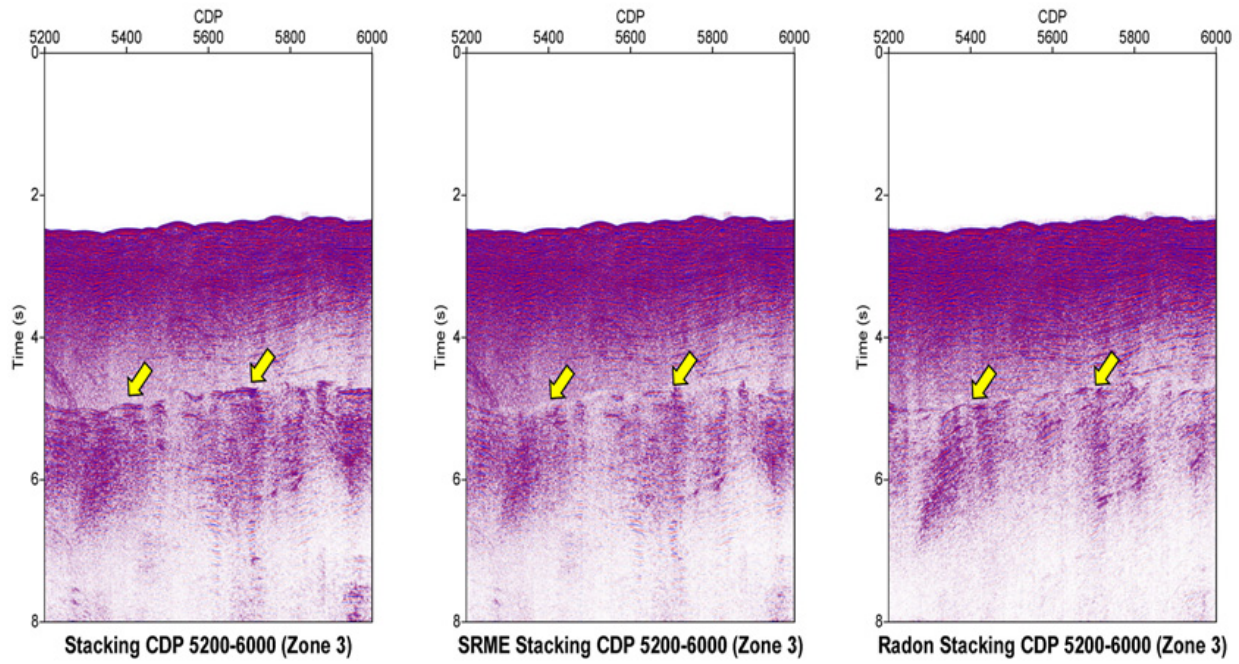
Figure 10. Multiple attenuation at middle stack CDP 5200-6000 at time depth 4500-6500 ms. (a). Conventional stacking. (b) After SRME. (c) After Radon transform.
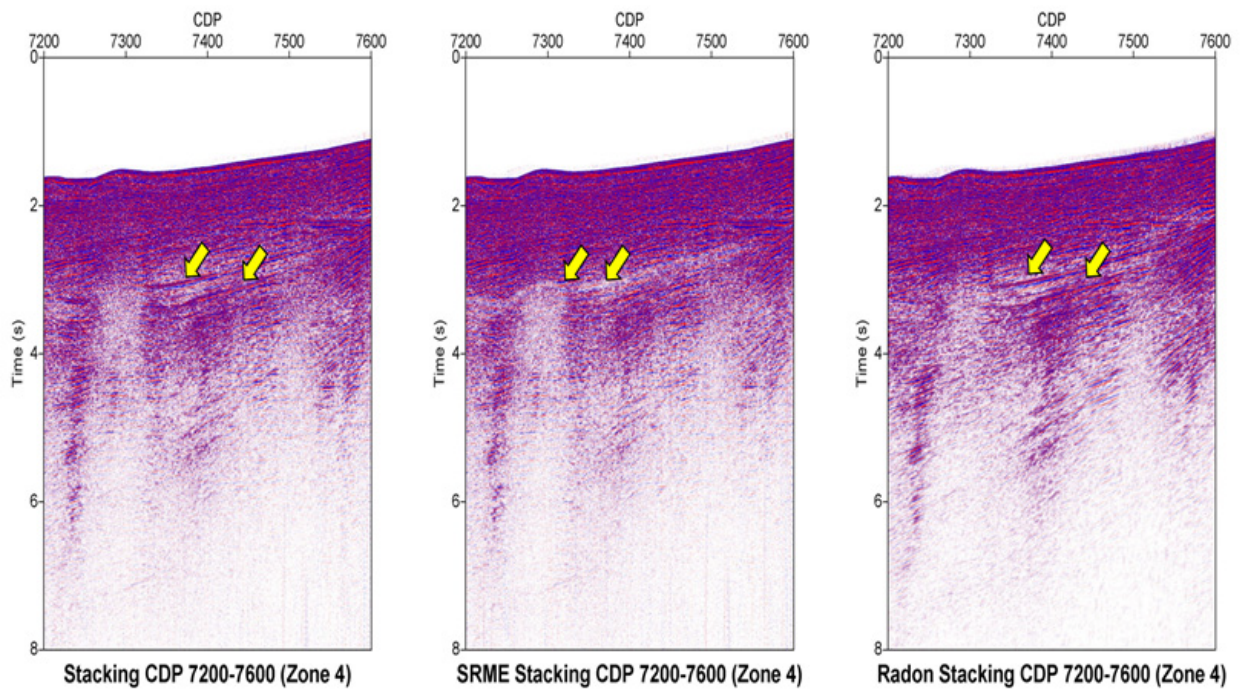

Figure 11. Multiple attenuation at far stack CDP 7200-7600 at time depth 2500-3500 ms. (a). Conventional stacking. (b) After SRME. (c) After Radon transform.

REFERENCES

Abbasi, S., and Jaiswal, P., 2013, Attenuating long-period multiples in short offset 2D streamer data: Gulf of California, *SEG Houston 2013 Annual Meeting*, 4201-4205.

Amiruddin, 2009, A Review on Permian to Triassic Active or Convergent Margin in Southeasternmost Gondwanaland: Possibility of Exploration Target for Tin and Hydrocarbon Deposits in the Eastern Indonesia, *Jurnal Geologi Indonesia*, Vol. 4, 31-41.

Cao, Z., 2006, *Analysis and Application of the Radon transform*, University of Calgary, 88p.

Dutta, G., 2016, Least-squares reverse time migration with Radon preconditioning, *SEG International Exposition and 86th Annual Meeting*, 4198-4203.

Fan, J., Li, Z., Song, X., and Zhang, K., 2015, Application of anisotropic high resolution Radon transform for multiple attenuation, *SEG New Orleans Annual Meeting*, 4580-4584.

Hall, R., 1996, Reconstructing Cenozoic SE Asia, Tectonic Evolution of SE Asia, *Geological Society of London*, 153-184.

Hall, R., 2001, *Cenozoic reconstructions of SE Asia and the SW Pacific: changing patterns of land and sea, Faunal and Floral Migrations and Evolution in SE Asia and Australasia* - Swets & Zeitlinger, 35-56.

Hill, K.C., 2012, Tectonic and Regional Structure of Seram and the Banda Arc., *Indonesian Journal of Sedimentary Geology*, Vol. 23, 5-16.

Ibrahim, A., and Sacchi, M.D., 2013, Simultaneous source separation using robust Radon transform, *SEG Houston Annual Meeting*, 4283-4288.

Kemp, G., and Mogg, W., 1992, A re-appraisal of the geology, tectonics and prospectivity of Seram Island, Eastern Indonesia, *Proceedings Indonesian Petroleum Association*, 21st Annual Convention, Vol. 1, 521-552.

Latif, A., and Mousa, W.A., 2015, Efficient under-sampled high resolution Radon transform, *SEG New Orleans Annual Meeting*, 4574-4579.

Li, Y., Shi, Y., Jing, H., and Song, Y., 2014, Multiple suppression method by combining wave-equation prediction and hyperbolic Radon transform, *CPS/SEG Beijing 2014 International Geophysical Conference*, 253-256.

Li, Z., Wang, P., and Li, Z., 2015, Separation of primaries and different order multiples based on focal transform and SRME, *SEG New Orleans Meeting*, 4590-4594.

Milsom, J. 2001, Subduction in eastern Indonesia: how many slabs?, *Tectonophysics*, Vol. 338, 167-178

Nainggolan, T.B., 2014, Pemetaan Geologi dan Geofisika Kelautan LP 2812 dan LP 2912 Perairan Laut Seram, Papua Barat. Pusat Penelitian dan Pengembangan Geologi Kelautan, *Internal report,* Unpublished, 62p.

Pairault, A.A., Hall, R., and Elders, R.F., 2003, Tectonic evolution of the Seram trough, Indonesia, *Proceedings of Indonesian Petroleum Association 29th Annual Convention*, Vol. 1, 355-370.

Poole, G., 2015, Radon modelling with time-frequency sparseness weights, *SEG New Orleans Annual Meeting*, 4510-4514.

Sanger, W., Bloor, R., Kostov, C., de Melo, F.X., Espinoza, C., Moldoveanu, N., Miers, G., Slaton, S., and Thompson, J., 2016, Coil Demultiple Improvement through Reduction of Input Location Error, *SEG International Exposition and 86th Annual Meeting*, 4493-4497.

Tobing, S.L., Robinson, G.P., 1990, *Peta Geologi Lembar Kaimana, Irian Jaya Geological Map of The Kaimana Sheet*, Pusat Penelitian dan Pengembangan Geologi.

Verschuur, D. J., 2006, *Seismic multiple removal techniques: past, present and future*, EAGE publications, 174p.

Yilmaz, O., 2001, *Seismic Data Analysis : Processing, Inversion, and Interpretation of Seismic Data. Vol. 1*, Society of Exploration Geophysicists, 998p.