# The Linear and Non-Linear Background Energy Approach in The Seismic S/N Ratio Enhancement

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**ABSTRACT** - Side-swept is often understood as a side sweep of seismic waves that occurs on the surface. This understanding creates confusion when considering that side-swept is a part of linear function, in fact side-swept could be in the form of sweeping waves from the reflector on the side, so side-swept is a non-linear function like a signal. The implications for noise reduction with the τ–p transformation becomes more complex. The elimination of side-swept in this study, relies on an application using an algorithm developed by (Hampson 1987). Initial data conditioning preparation should be needed to clarify the difference between linear and non-linear functions through static refraction correction and velocity analysis, then coherent noise elimination (ground-droll) is carried out through f-k domain transformation, as well as random noise through f-x domain transformation. Side-swept is eliminated in τ–p domain. Energy observation shows the remaining noise energy caused by coherent noise, random noise and non-linear side-swept functions. It proves that it is difficult to remove a non-linear function that overlaps the reflector signal. The best step is to minimize coherent (linear) noise and random noise by consistently using an amplitude correction indicator on the surface and performing velocity analysis especially for the suspected power spectrum as an effort to attenuate side-swept wave interference on the reflector signal. Finally, the signal restoration efforts due to non-linear noise attenuation, is carried out by surface consistent deconvolution.

**Keywords**: side-swept, coherent noise, random noise, f-k transformation, τ–p transformation, surface consistent deconvolotion

**How to cite this article:**

Imam Setiaji Ronoatmojo, Yarra Sutadiwiria, Muhammad Burhannudinnur, Dewi Syavitri, 2023, The Linear and Non-Linear Background Energy Approach in The Seismic S/N Ratio Enhancement, Scientific Contributions Oil and Gas, 46 (2) pp., 1-24, DOI.org/10.29017/SCOG.46.2.1572.

## INTRODUCTION

The increasing discoveries and researchs on an unconventional oil and gas accumulation have shown that the theory and practice of traditional petroleum systems, which built on studies of conventional oil accumulations are unlikely to be able to fully meet the current needs of hydrocarbon exploration and development in the recent years. Research on a continuous petroleum system requires reliable data to determine CWT and sweetness processing was applied to some sequences based on the old 2D data (Julikah et al, 2015), (Musu et al, 2015). Many seismic data lines are old vintage 2-D data, which at the time of acquisition did not consider the purpose of implementing elastic and mechanical attributes, as needed to model oil shale and gas shale properties. It is the motivation for our intention to reprocess old data for the latest use in the petroleum system

modeling. In this case, we will take an example of a data reprocessing activities to be able to display the required stratigraphic characteristics. Regarding to the previous processing result, it has lack imaging on the crest of a shallow structure, ultimately in Gumai Formation which was observed from the previous 2-D seismic lines. For this reason; the decision was made to enhance the existing 2-D seismic processing over the entire concession. There are some kind of problems related with the surface coupling, when it was acquired; including source and receiver impact, which it should be solved in the processing stage. This problems consist of source generated noise (ground-roll) and low coupling geophone generated noise such as random noise and also the vary of receiver response. The other problem is side-swept effect of outside structure has been recorded in their orientation. The purpose of this study is to enhance PSTM stack lines over the prospect, using any tests to make it better image than previous lines. The primary objective is Gumai which is present in the target window of 500 msec to 700 msec with a stratigraphic features and Baturaja carbonates with facies changing dominantly in the target window below Gumai formation up to 1,000 msec.

Acquired raw data and available stacked lines were reviewed previously; in order to estimate co-herency, energy penetration, frequency content and signal to noise ratio. Then, the following general observations were made. Ground-roll could be able to observe by raw data directly. It can not be eliminated by seismic survey parameters. Consequently, it also appears in any previous stack displays. Ground-roll in the previous processing and re-processing had not been handled yet optimally. Energy trapped in the shallow layers. If it is trapped in the weathering or sub weathering layers, then it can damage or destroy shallow reflections. Shot generated noise does not appear worrisome or warrant special consideration from a design perspective. The charge size variation may possible have a significant response on shot generated noise. Unfortunately, it can not be learned from any reports availability. Unless for a limited information originating from the source parameters of the new vintage survey, which used Daya Gell with charge of 3 kg and planted in average depth of 25 m. It is likely that will generate a large intensity of coherent noise. So, these might be caused by un-correct charge and depth of seismic sources. Basically, several types of seismic waves occur following surface disturbance. Each seismic waves have different velocities depending on the medium through and the energy is proportional to the medium characteristics. Seismic waves energy can be likened to a bulk energy value which is turned into data and noise, Woods (1968) mentioned each fractions are 67 % Rayleigh wave, 26 % shear wave and only 7 % compression wave (Figure 1a). An initial pulse energy will be transformed to become signal and noise in the linear system with varying proportions for each seismic waves. If we assume that every ray-path is in the linear system box, the output is the sum of each unique ray paths. Every coherent things will increase exponentially, while every incoherent things will eliminate each others. It is important to notify that coherency can occur in both signal and noise, meanwhile the linear system box itself represents the data recording system (Figure 1b and Figure 1c).

Based on the raw data observations (Figure 2); source generated noise has a variety of responses captured by geophones. The influence of noise is very strong affecting the signal in the target window (red box). By a number of shot point displays without using AGC; we may observe that a strong feature of surface energy is inherent in the appearance of the existing seismic environment. It causes the differ-ence of background energy levels which will make difficult to convince interpreter later, for example in terms of facies changing or gas cloud effects. The success of removing surface noise will be identified by the reduction of background energy difference. Also shown in the figure below is the presence of a side-swept effect due to recording of a reflection from the up-dip out-side structure.

By using coherent noise reduction techniques, the initial effort tried to bring a free of source gen-erated noise condition, but -in fact- it still appears a residual coherent noise that affects in-consistency surface energy. The presence of residual coherent noise generates the energy level difference of each shot points (Figure 4). It has been stated before, as much as possible, the surface energy diversity should be eliminated, so then all amplitude differences in the linear system due to subsurface events can be accurately observed. Similarly, the appearance of each traces energy also seems to vary. It arises as a result of the remaining surface energy that cannot be compensated when observed in a dynamic range of observation. If it does not compensate properly, an appearance of amplitude changes due to subsurface events is difficult to be revealed. This situation must be avoided as much as possible when we are going to image subsurface data.

**(a)**

**(c)**

| Wave Type | Per Cent of Total Energy |
|---|---|
| Royleigh | 67 |
| Shear | 26 |
| Compression | 7 |

(b)

**(b)**

*Recording System*

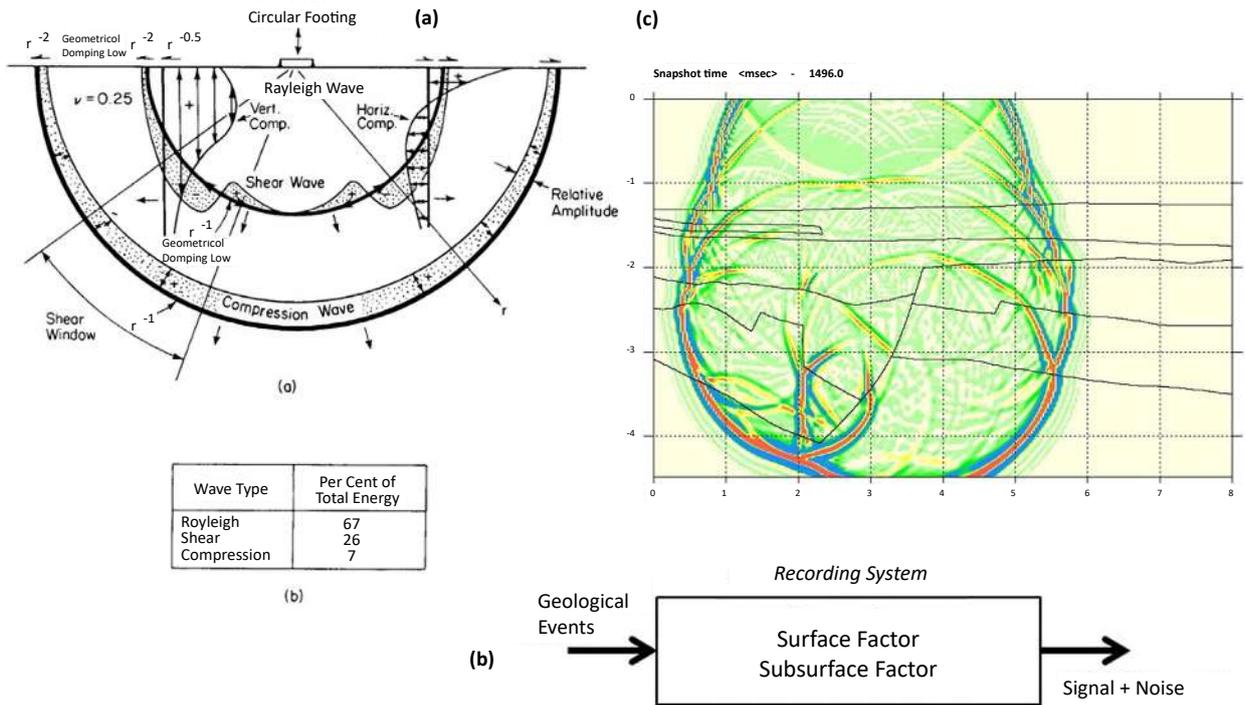Geological Events → Surface Factor / Subsurface Factor → Signal + Noise

Figure 1
(a) Distribution of the stress waves (Woods, 1968); (b) Seismic data acquisition as a linear system (Ronoatmojo, 2016); (c) Seismic waves propagate in a complex structure (Ronoatmojo, 2016).
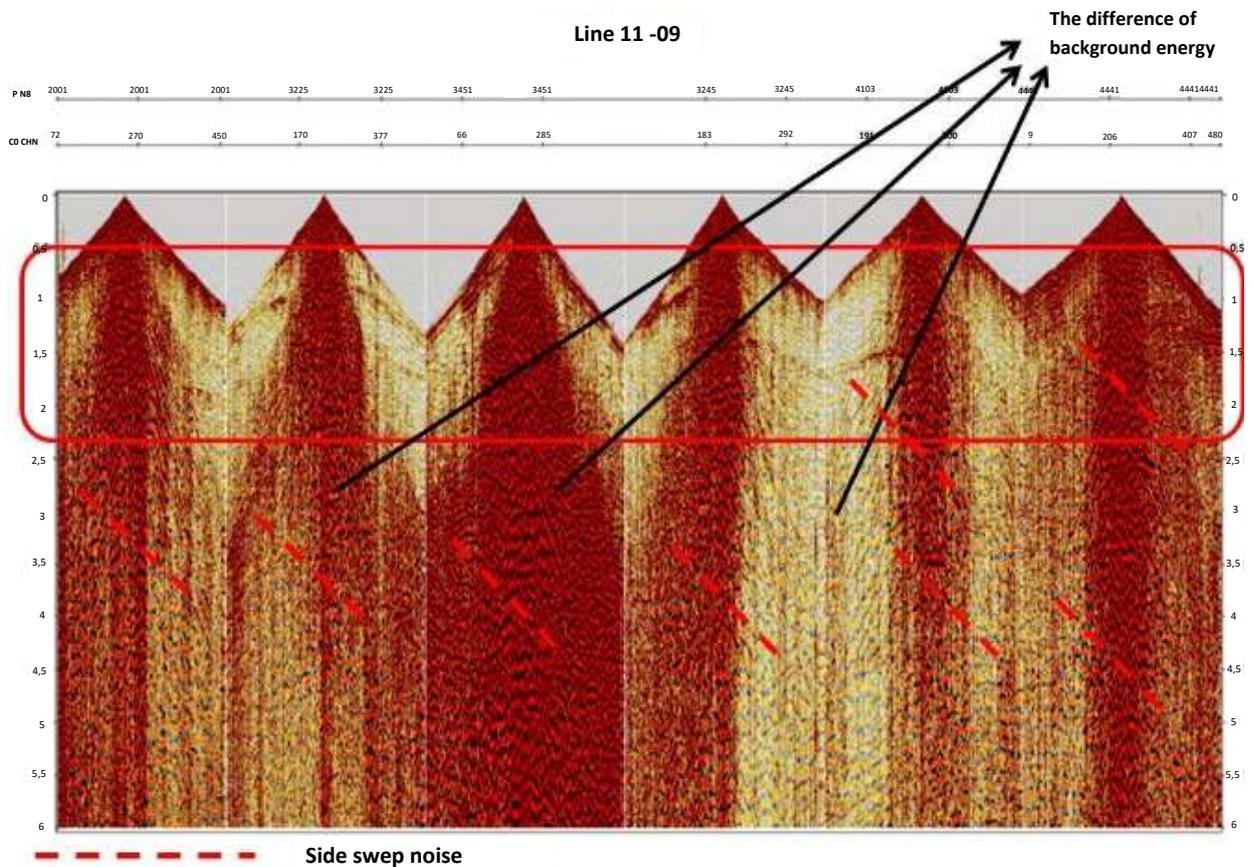
Figure 2
Shot point displays which showing the vary of background energy levels between them.
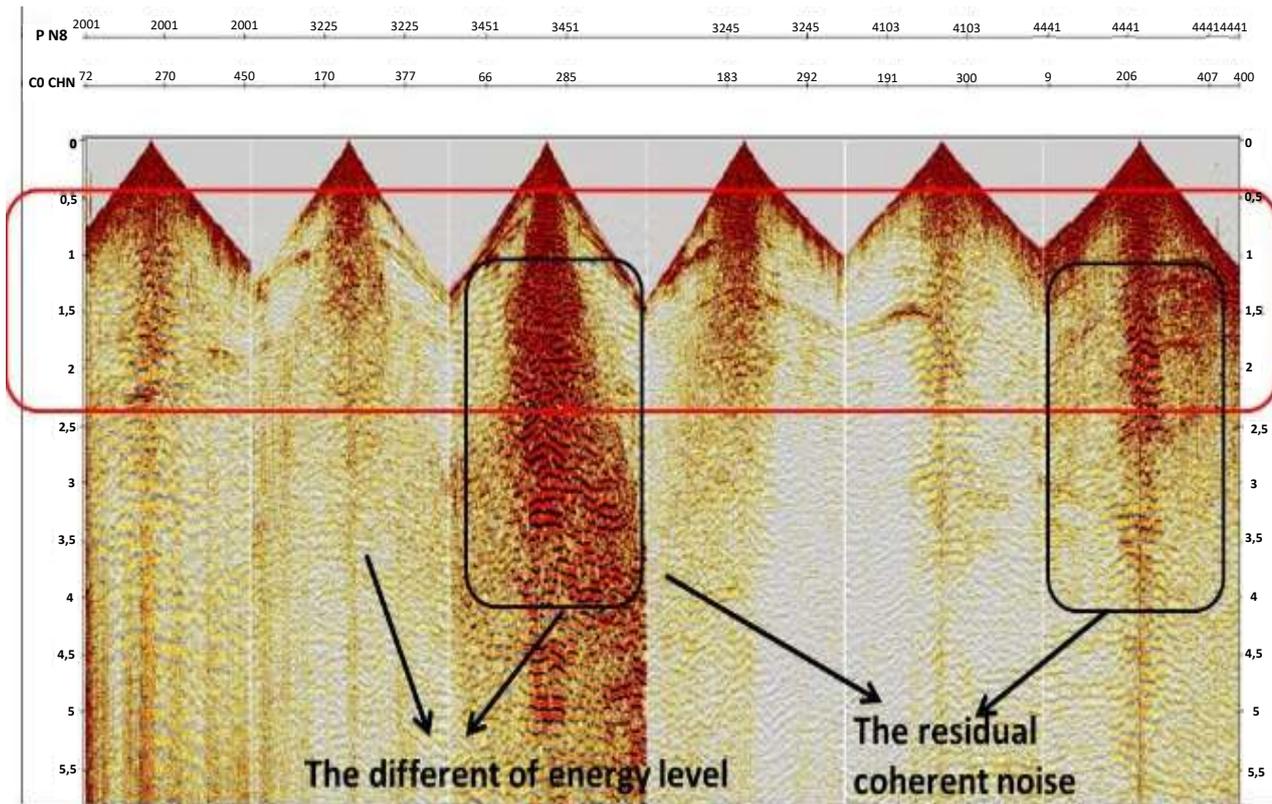It was due to the source generated noise.

Figure 3
Shot point displays after ground-roll attenuation but it still has residual coherent noise which also showing the vary of background energy level between them.

Re-learning of each coherent noise needs to be done, one of the efforts by using f-k display to determine the amount of wave number to be suppressed. It does not to be similar for all shot points, then so careful steps need to be taken. The difference of background energy in the stacking process will greatly complicate facies changing or a gas cloud effect imaging. It can be seen from the picture below that the residual coherent noise still appears and has a strong effect when doing energy compensation, so that is a bright and dark feature appear along the line. The near surface data also looks dark so that it still shows an energy compensation that is not yet effective. This compensation will be optimum if the near surface energy difference is minimized. It happens if coherent noise elimination being optimum and a random noise to be maximal reduced.

Random noise reduction should be carried out in a surface consistent to maintain preserved data. The reduction is carried out in the trace domain so that when the surface consistent amplitude correction can be optimized, which is carried out in 3 domains: shotpoint domain, trace domain and offset domain. The surface energy indication has been compensated

and it has become brighter eventhough a whole data still permits a bright-dark energy levels. Certainly, it is better to be done by integrating coherent noise and random noise reduction modules as well as the surface consistent amplitude correction and surface energy compensation modules. Good collaboration will produce an image that truly depicts an event underneath surface.

Side-swept could be able to observe directly either from shot point display or stack display. Side-swept is a reflection signal originating from tilt structure outside of the seismic line. It occurs due to the existence of a steep slope of up-dip oriented layer, in contrast to the down-dip, which the energy will go away from source (S) to receiver (R) (Figure 4). Seismic waves will be more easily reflected by the steep up-dip bedding plane outside the line than the gentle slope. The energy received by the geophone will appear as a signal rather than noise. Meanwhile in the down-dip direction the energy will disappear out of the line. In a three dimensional situation, this event is quite common considering that the shot point has a lay out away from the line orientation so that instead we will get perfect image of a plane.

Conversely in the case of two dimension, we actually get a defective image of a field. It is what we know as side-swept. Side-swept will be annoying if we expect a stratigraphic event, but It is not easy to eliminate, especially if we are in a state of complex structure, where planes with steep up-dip are obtained from any direction. One of methods that can eliminate this effect is by transform data from t-x domain to τ-p domain. Another way is to do a careful velocity analysis even though it feels naive, because the side-swept signal may overlap with the original signal. Eventually, it can only be optimized by reducing the effect carefully, so that the original signal is not disturbed, during the reduction of the side-swept effect.
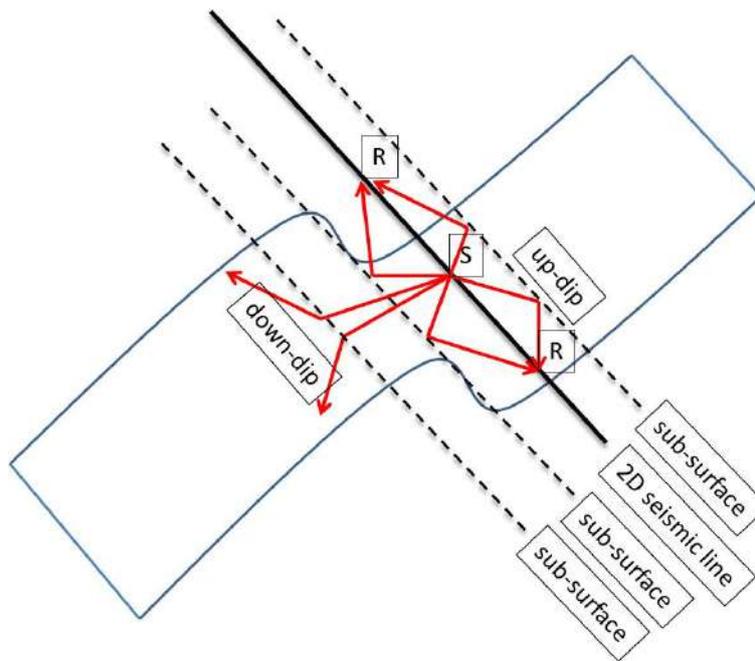


Figure 4
Schematic diagram of side-swept

## METHODOLOGY

### Methods

The Radon transform is a mathematical technique that has made its way into the processing and analysis of seismic data in recent years. Known as the τ-p transformation, the slant stacking technique, or the velocity stack method. Originally developed by Radon in 1917 (Deans 1983). A similar mathematical method is the Hough transform (Hough 1962). It has provided a mathematical basis for major issues of tomography, physics, medicine, astronomy, molecular biology, materials science, optics, nuclear magnetic resonance and geophysics. The initial concept of slant-stack processing for geophysical applications stems from Rieber's construction of a new reflection system with controlled directional sensitivity (Rieber 1936), which delays and adds recordings (analog sound tracks) at ten equally domaind locations on the surface to form traces. directed in various directions. A similar method called the directed controlled reception (CDR) method has been widely used and developed in Russia (Gardner & Lu 1991).

The general theory of Radon transformation can be found in (Deans 1983). The basic properties of the Radon transformation were later developed by (Durrani & Bisset 1984). For linear transformations, (Chapman 1981) presents the exact form of the generalized Radon transform pair for point sources in Cartesian or spherical coordinates, and for line sources in cylindrical coordinates. (Thorson & Claerbout 1985) imposed a least squares error constraint on the reconstructed data and developed methods for velocity-stack and slant-stack stochastic inversions. (Hampson 1986) implemented the Thorson-Claerbout method efficiently with a parabolic approach to residual displacements for NMO-corrected data in the f-x domain. (Hampson 1987) identified his method as a discrete Radon transform (DRT) which was explored by (Beylkin 1987). Then (Kostov 1990)

derived a fast and accurate algorithm to calculate the least squares inversion of the slant stack. The classical and discrete Radon transformations were examined by (Gulunay 1990). The development of interest in transformation in the mid-1970s, stimulated in particular by the efforts of the Claerbout geophysics group at Stanford University, led to several applications of the technique in seismic exploration. One of the main goals of transforming a 2-D seismic record to the τ-p domain is to segregate, within the altered domain, coherent events that normally interfere with each other in the original domain of the record (x-t domain) (Tatham 1989).

There are several ways to construct transformation pairs: first determine the forward transformation, then derive the inverse transform, in both the continuous (analytical) τ-p domain and the discrete τ-p domain; or first determine the inverse transform, then derive the forward transform formula. It can also work in both analytical (continuous) τ-p domains and discrete τ-p domains.

The determination of the forward τ-p transformation is as follows:

$$v_F(p, \tau) = \int_{-\infty}^{\infty} u_F\big((x, \tau) + px\big)dx \quad (1)$$

In the temporal-frequency (f-x) domain it becomes:

$$V_F(p, \omega) = \int_{-\infty}^{\infty} U_F(x, \omega)e^{ip\omega x}dx \quad (2)$$

In this case (x,ω) and (p,ω) are the Fourier transforms of the functions (x,t) and (p,τ), respectively. For seismic exploration applications, (x,t) can be considered as a common mid-point (CMP) or common shot-point (CSP); meanwhile (p,τ) is the slant stack of input gather with horizontal lag p (or beam parameter, Snell parameter, or inversion of horizontal phase velocity) and intercept time τ. Slant stack is an integral description in Equation (1). The integral is addition or stacking along the slope t= τ+px in τ-p domain and for wideband data, hyperbolic reflection events are mapped to ellipses and linear refraction events are mapped to point shapes (Schultz & Claerbout 1978); (Diebold &Stoffa 1981); (Treitel et al. 1982); (Tatham 1984). At a common midpoint (CMP) or common shot-point (CSP), seismic signals tend to function hyperbolic rather than linear (reflection and diffraction are hyperbolic, refraction and direct waves are linear). The standard linear transformation converts a hyperbola in the t-x domain to an ellipse

in the τ-p domain. Such transformations do little to dampen noise in multiples or to separate reflected P waves and S waves which also have a hyperbolic trajectory in x-t domain. Instead of linear transformations, hyperbolic transformations can be devised. Transform hyperbolic events on a seismic cross section into lines and in much the same way linear events into points. This energy focusing can increase the resolution of an object by separating the signal from the noise. In particular, multiples can be more easily isolated from the signal of interest. However, the direct hyperbolic transformation is too expensive to realize because the transformation is time variable (Hampson 1986). To make the transformation time-invariant. NMO corrections are performed on seismic data to make events parabolic (Yilmaz, 1989). Then a parabola transformation is applied to the NMO-corrected data, and a better part of focus can be obtained to suppress coherent noise. A generalized transformation that provides good resolution in the transformation domain by integrating/stacking data along a suboptimal hyperbolic surface (Foster & Mosher 1992).

**Materials**

Based on the shot-point display observation, it can be seen that side-swept is a signal that could be differed from the expected reflectors. The signal cuts the reflector in un-equal orientation (Figure 5). Side-swept effects can be occured in a row due to a complex structural condition. Reduction of this effect can be done in τ-p domain where τ is $T_o$ or intercept and p is slowness. The difference of reflector and side-swept functions in τ-p domain can be recognized so that side-swept attenuation can be carried out more easily than in t-x domain.

Meanwhile, from CDP gather observation before NMO, the side-swept effect appears as a relatively flat linear function (Figure 6). In this case it should be noted that side-swept can resemble a signal if it is on the cross-section between two stack lines. Furthermore, It will be easily seen when doing velocity analysis with intercept value almost as reflector value, but without similar NMO function, therefore the power spectrum tends to be nearly zero for NMO delta value, when it is transformed to τ-p domain, there could be separated.. As the obstacle. It is piled up on the reflector so rather difficult to separate or if muted will affect the reflector amplitude. It can be observed as two power spectrum is somewhat coincided. If side-swept function is nearly similar

to reflector function, so the elimination within the τ-p domain to be less effective. Different with source generated noise which is more likely to be suppressed, side-swept only can be optimized. The complicated geological structure, which is revealed both in strike and dip direction, will caused the number of side-swept as observed during velocity analysis. Such like there are visible spectrum in red box remaining signal after NMO correction. The side-swept appearance seems rather similar to coherent noise, but actually different because the intercept value is more deeper (Figure 7).
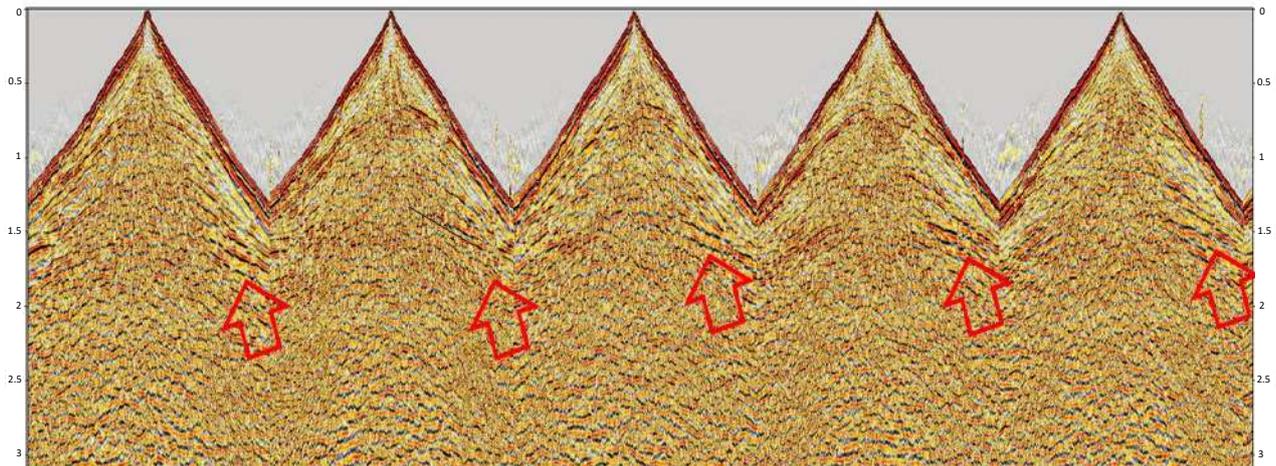


Figure 5
Shot point display shows the presence of side-swept on a function marked by an arrow.
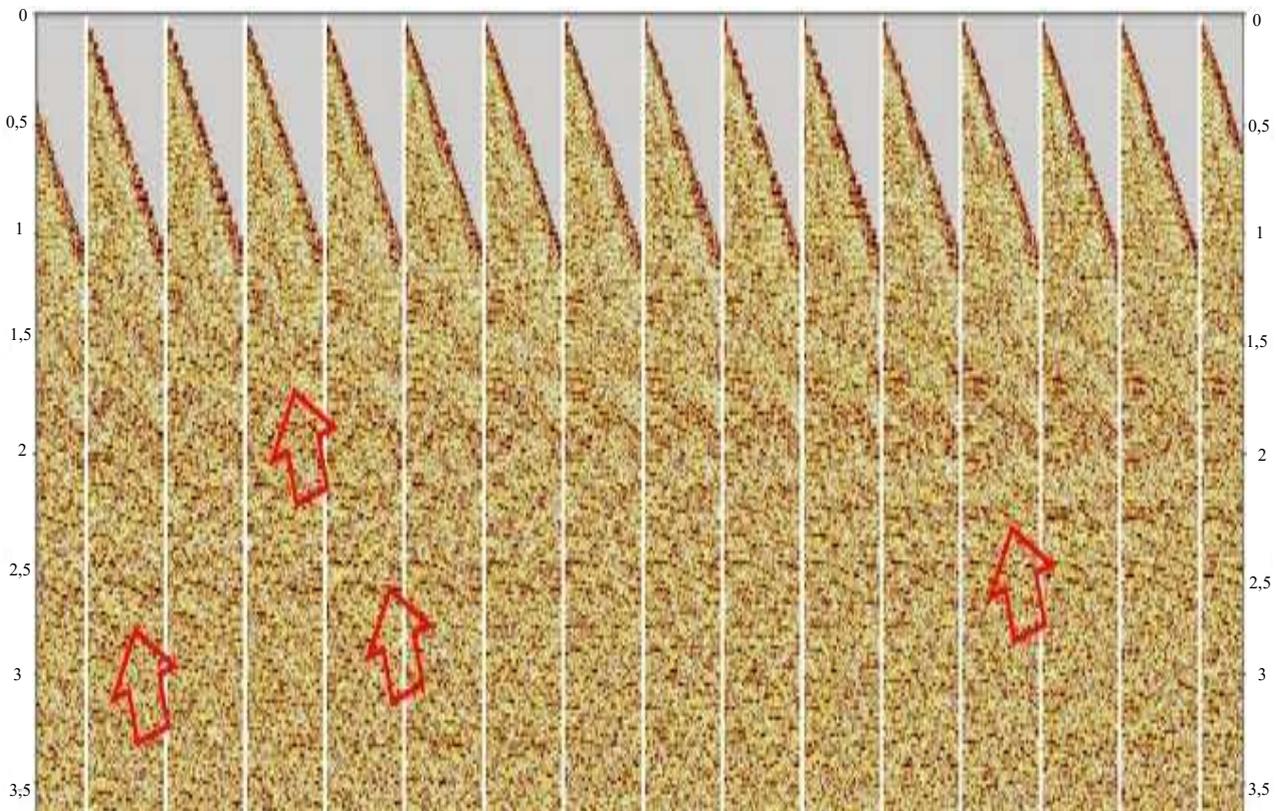


Figure 6
CDP gather display shows the presence of side-swept on a function marked by an arrow.

Before NMO correction, the side-swept appearance in the CDP gather domain tends to be flat but when it has been corrected by NMO, its appearance is tilted (Figure 8). Side-swept would be optimized by using some steps i.e velocity analysis accuracy and $\tau$-p domain attenuation.
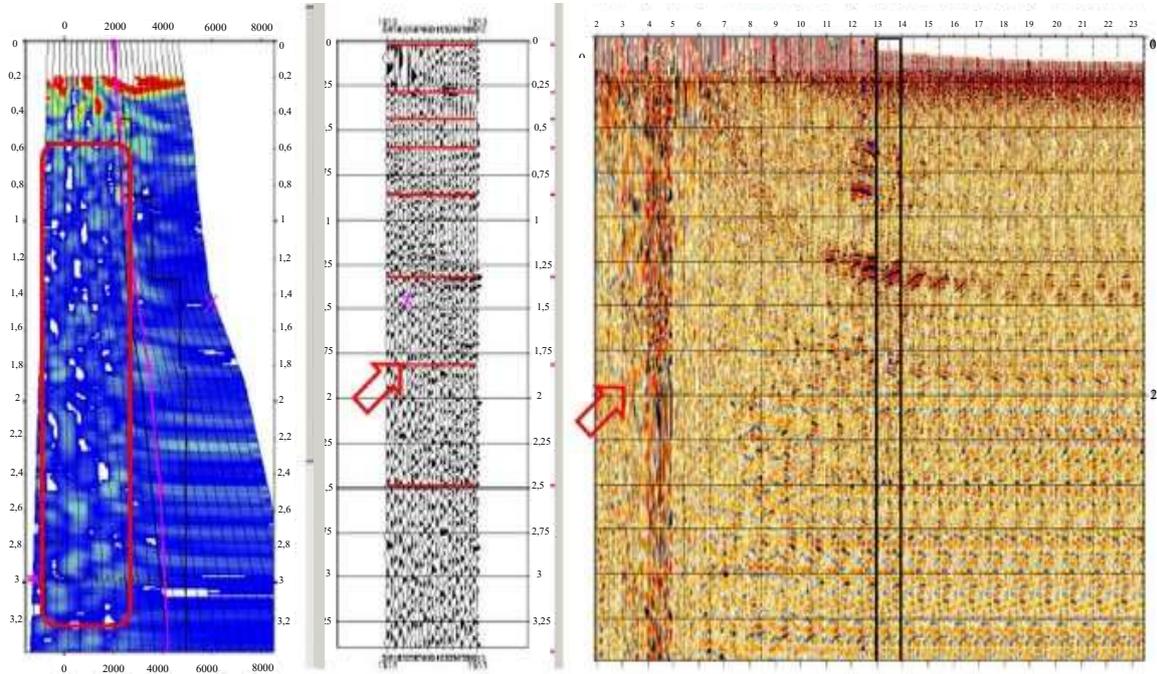


Figure 7
Velocity semblance in CDP gather shows the presence of side-swept on a function marked by an arrow and power spectrum semblance in red box
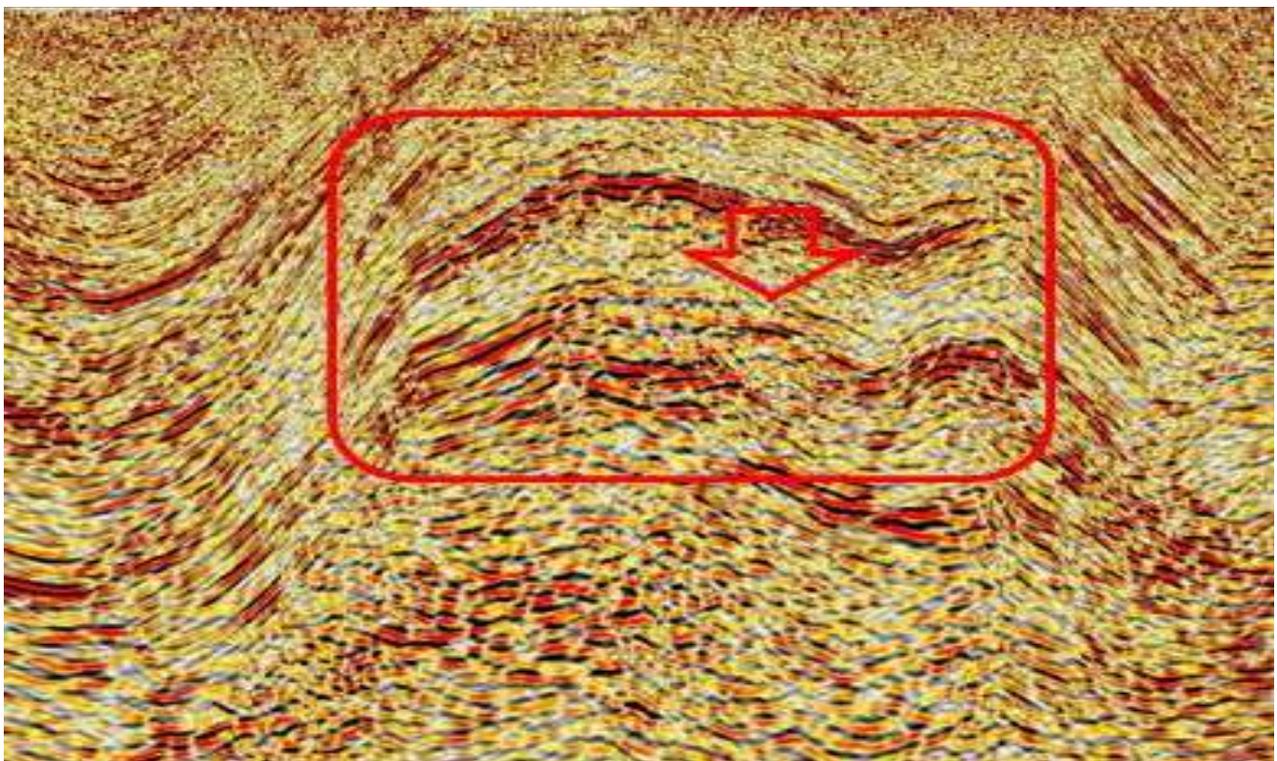


Figure 8
PSTM cross section that displays a side-swept in manifestation of relatively flat reflection.

Frequency content will affect data resolution. In this case, Gumai Formation and Baturaja Formation is a stratigraphic object or in another words that there are several events existing within Gumai Formation and Baturaja Formation. Such as Gumai Formation may be deposited, both on a slope or basin floor of marine environment, it depends on the event package size. So, the high frequency content necessity becoming very important. Generally, the 2011's seismic data frequency content is higher than the 1973, 1974, 1979 and 1980's seismic data. It may be due to difference of explossive types and more up-to-date recording system. Unfortunately, the result information of parameter test can not be obtained therefore frequency content learning is ultimately limited, just by the observation of shot point and stack display in the processing stage. It was found from new vintage shot point display that frequency content is approximately 35 Hertz regarding to the peak of amplitude spectrum, but most of signals appear in range of 15 Hz to 30 Hz, a little bit appear in higher frequencies, anyhow random noise can also appear in a higher frequencies (Figure 9).
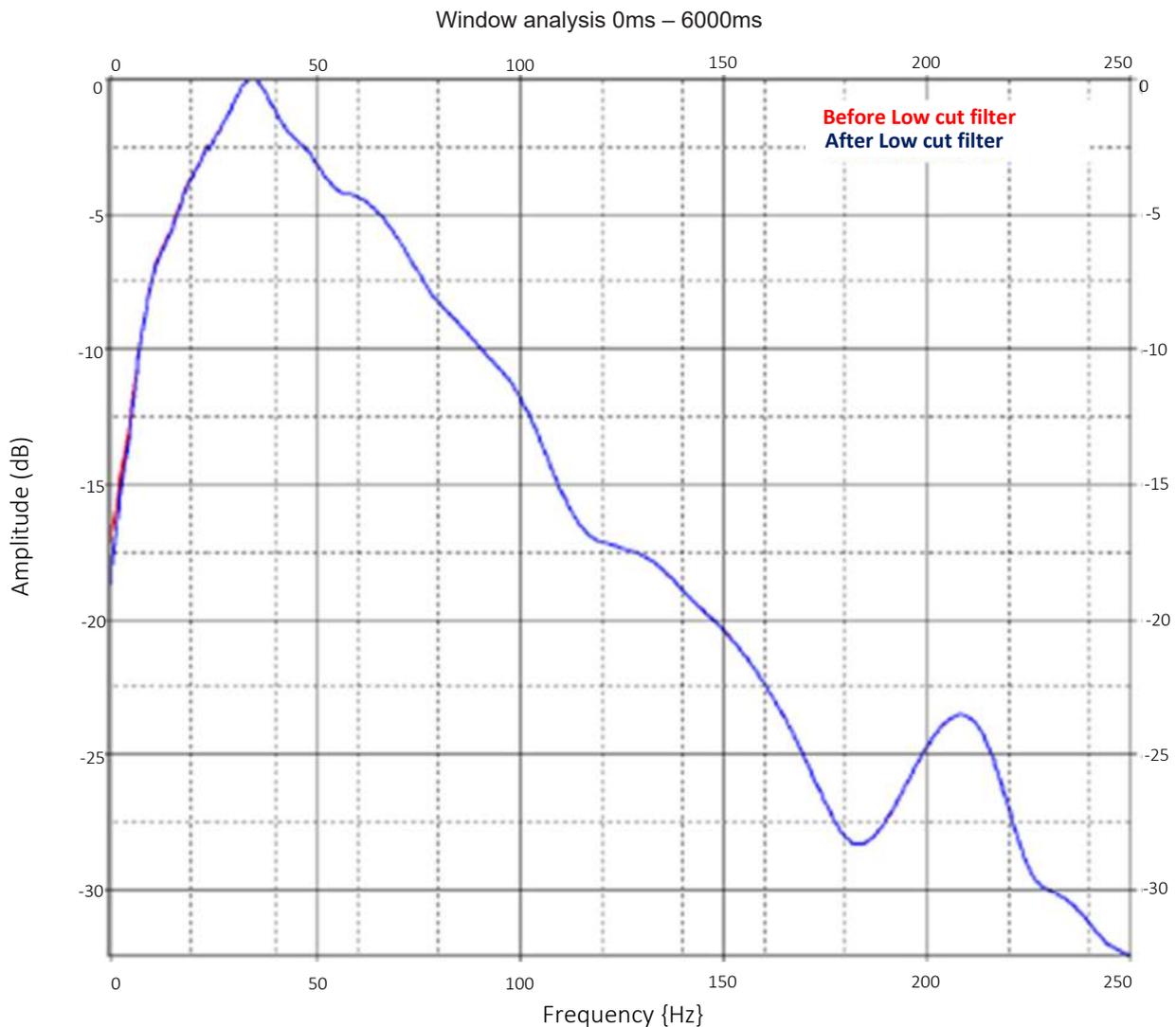


Figure 9
Frequency content of shot point gather.

The next observations shows frequency content becoming 15-20 Hz in the range of 0-5,000 msec window. Notify that ground-roll placed dominantly in low frequency zone. The using of low cut filter is not able to suppress ground-roll (Figure 10). Therefore the effort to increase resolution is purely cleaned from ground-roll and random noise. So that this requirement will be inline with the efforts to

maintain surface consistency. It seems that if less energy can be penetrated, the intensity of the random noise content will relatively increase. Signal to noise ratio is very important in terms to measure sub-surface imaging quality. Learning about S / N ratio could be related to time window. In this case, we need to determine the optimal of S/N ratio characteristics so that background energy levels can be balanced and does not damage the existing image. Efforts to increase S / N ratio is done by reducing various noise. Based on the 2011's shot point and stack data observation, the S / N ratio is characteristically divided into 3 parts: 0 - 500 msec poor to fair; 500 – 2,000

msec fair to good; and > 2,000 msec fair. It is better in the range of 500 - 2,000 msec window because there are strong reflectors from Gumai Formation and Baturaja Formation (Figure 11). It appears that background energy is strongly influenced by coherent noise and random noise in the window 0 - 500 msec, consequently the shallow reflector cannot be observed properly. Meanwhile random noise is found in the window 500 – 2,000 msec and window> 2,000 msec. Regarding this explanation, it is necessary to clean the noise so that the signal can be observed. Noise cleaning should also consider keeping preserved amplitude.
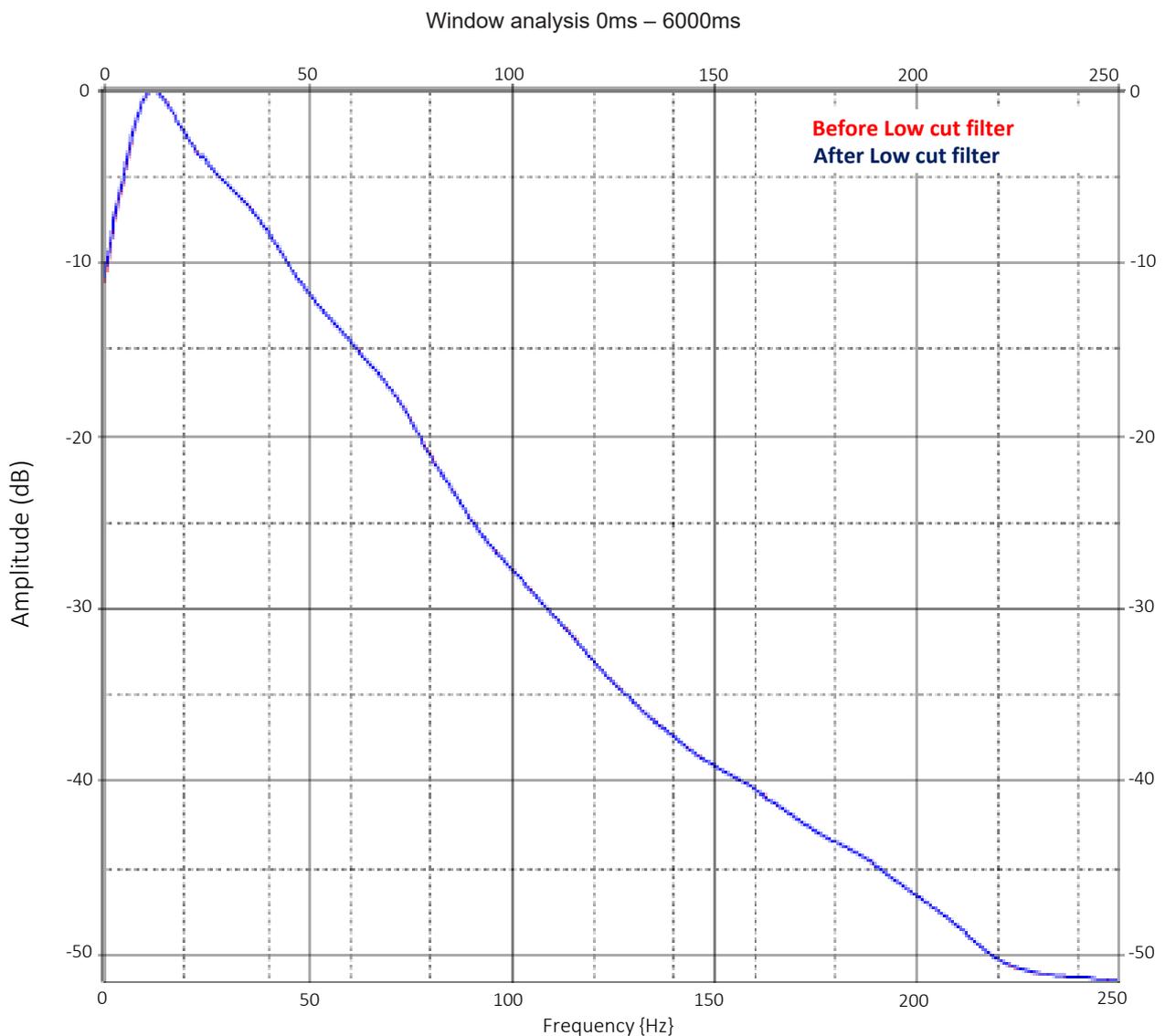

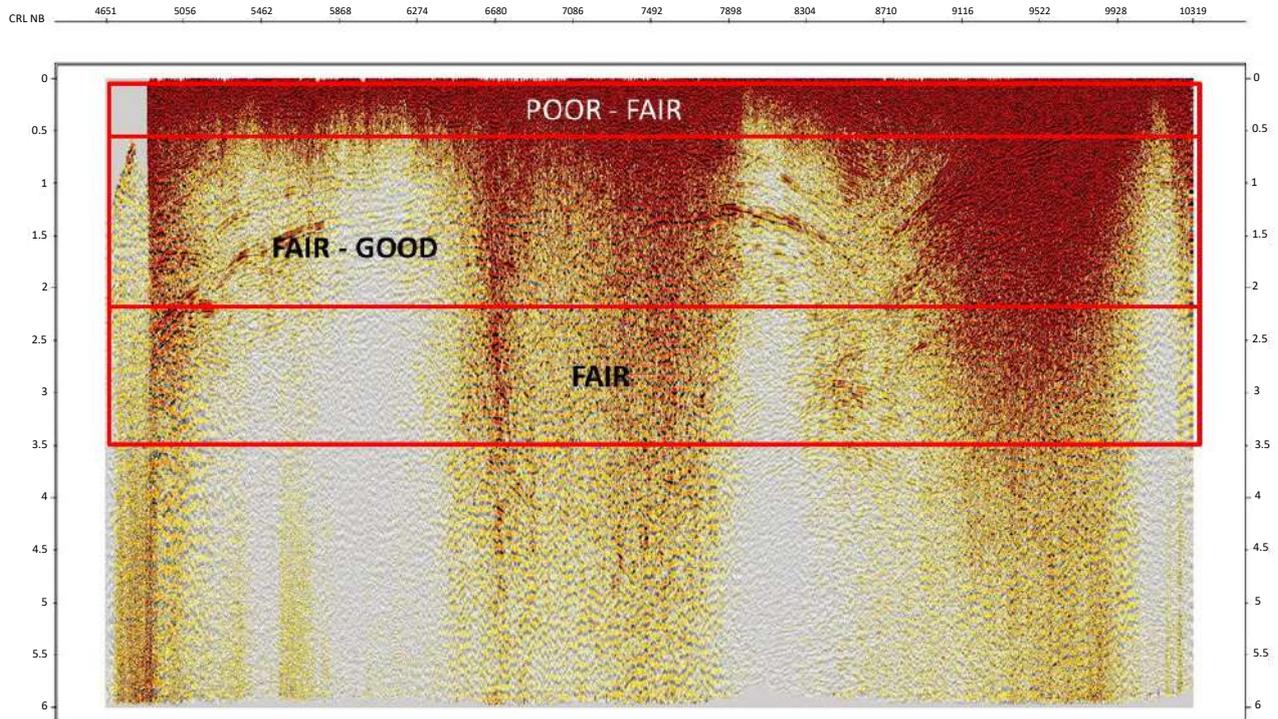
Figure 10
Frequency content of stack

Figure 11
S/N ratio over the window of stack section

## RESULT AND DISCUSSION

Enhancements are always done refering to the constraints which is faced by the data. It has been much explained above. Even so, standard normative matters are always taken into account, such as conducting static refraction or velocity analysis. Beside of this, of course, the main emphasis is on improving seismic data from all noise dominance, and there are following explanation of each steps.

### Refraction Static

Refraction static is used considering that the field conditions is arranged by bumpy hills, so it will be un-favorable if using only conventional method such as elevation static (CS-VT). The refraction static method allows us to know the variation of delay time values near surface which is obtained from tomographic model. Regarding to the obtained results, it will make easier to calculate residual static, so that any near-surface condition difference that cause velocity and delay time difference can be anticipated properly. Consequently velocity analysis result can be sharper. The following figures show a comparison between the stacking process without and with refraction static. It appears that the continuity of the reflector is sharper when done with refraction static (Figure 12a and 12b). The difference between before and after using refraction static mainly occurs when the regional static value is large. The continuity level becoming more higher after refraction static is applied. Noteworthy in applying this method is that when refraction velocity picking is done automatically, it is necessary to ensure that there is no disturbing noise when picking, if it is raw data, therefore it is necessary to re-inspect after picking. It is better to check the delay time value which is controlled by the refraction velocity value.

The existence of irregularities will be easily observed in both values. The next consideration is to consider the relationship between topography and delay time values. The greater the difference in elevation, the greater the delay time value. Furthermore, the number of layers near the surface will also affect the delay time variation. Some cases will show a variation of the number of near-surface layers that will appear as a refractive plane, but basically the depth of the layer to be calculated has a certain value with respect to the reference plane (datum).
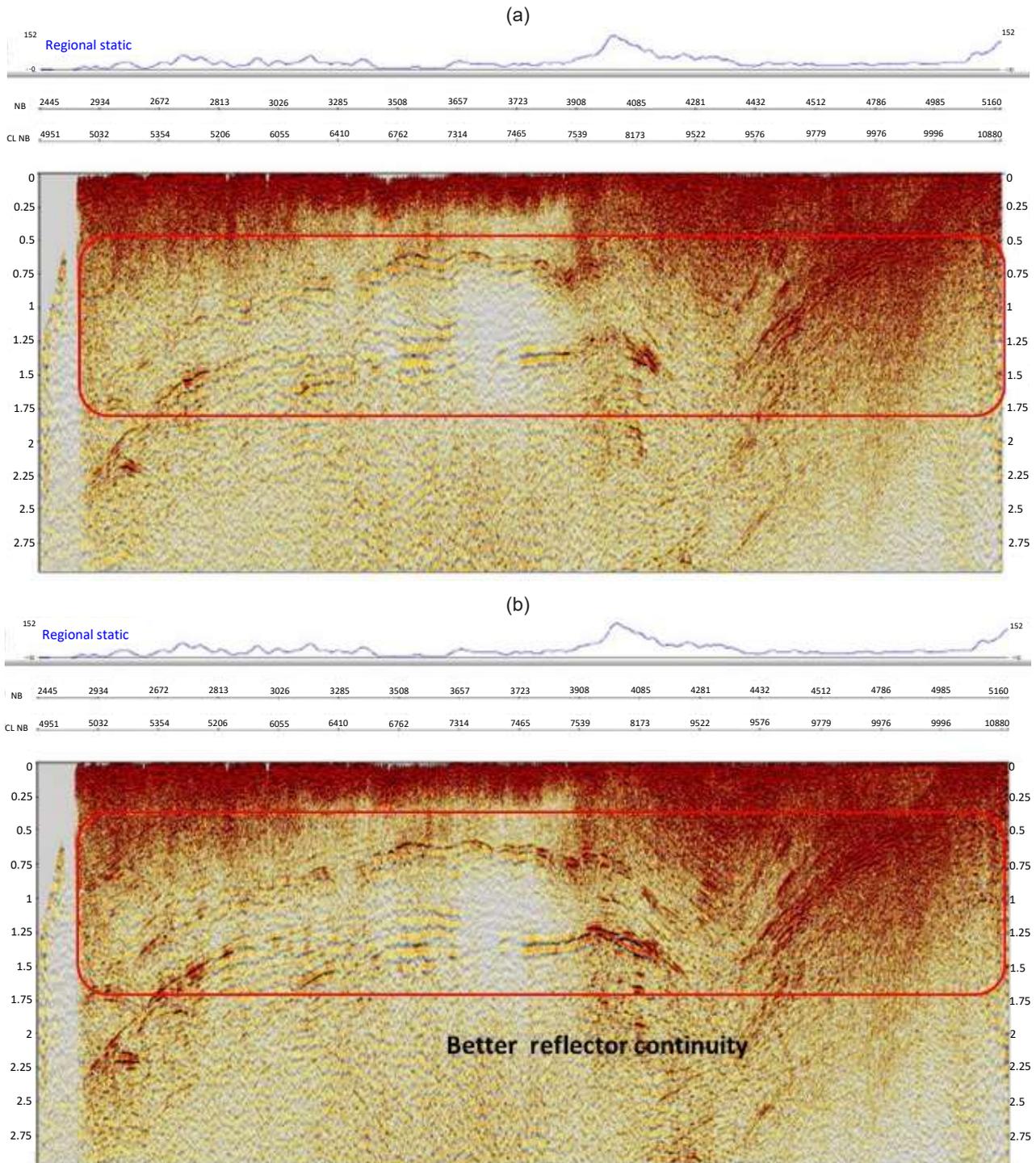
Figure 12
Stack line (a) before refraction static and (b) after refraction static

## Velocity Analysis

Velocity analysis is determined by choosing power spectrum (semblance) which is indicating an event marker. In this case, any power spectrum, as explained before, possibly are un-expected power spectrum such as side-swept, residual static step is necessary for solve this problem. For an example, velocity analysis on common dept point, it appears a lot of power spectrum, the choice is on the black solid line (Figure 13a). After static residuals, there will be obtained in Figure 13b, then the velocity and analysis secondary static residuals were re-done, thereafter Figure 13c and 13d were obtained.

Based on the observation of Figure 13d, it can be seen that the appearance of the stack line is quite striking compared to Figure 13b, where the coherence of the reflector signal is more pronounced than before the velocity and residual static corrections were performed. It indicates an attempt to further sharpen the reflector signal. Furthermore, it can be used to further identify the the power spectrum of side-swept by comparing the 1st velocity analysis and 2nd velocity analysis. The identity of the power spectrum from the side-swept, will be important used as an input when carrying out side-swept elimina-tion on the τ-p domain. The character of the side-swept will be different on the τ-p domain, when it compared to the reflector multiple. The multiple will have similar velocities but different intercepts, while the side-swept is recognized as a signal with the same intercept but different velocities. This characteristic allows that multiple removal is easier than side-swept. In fact, the side-swept can interfere with the signal in such a way that if it is attenuated in the τ-p domain, the signal is also affected. This is what makes the implementation of velocity analysis iterated together with the residual refraction statics.
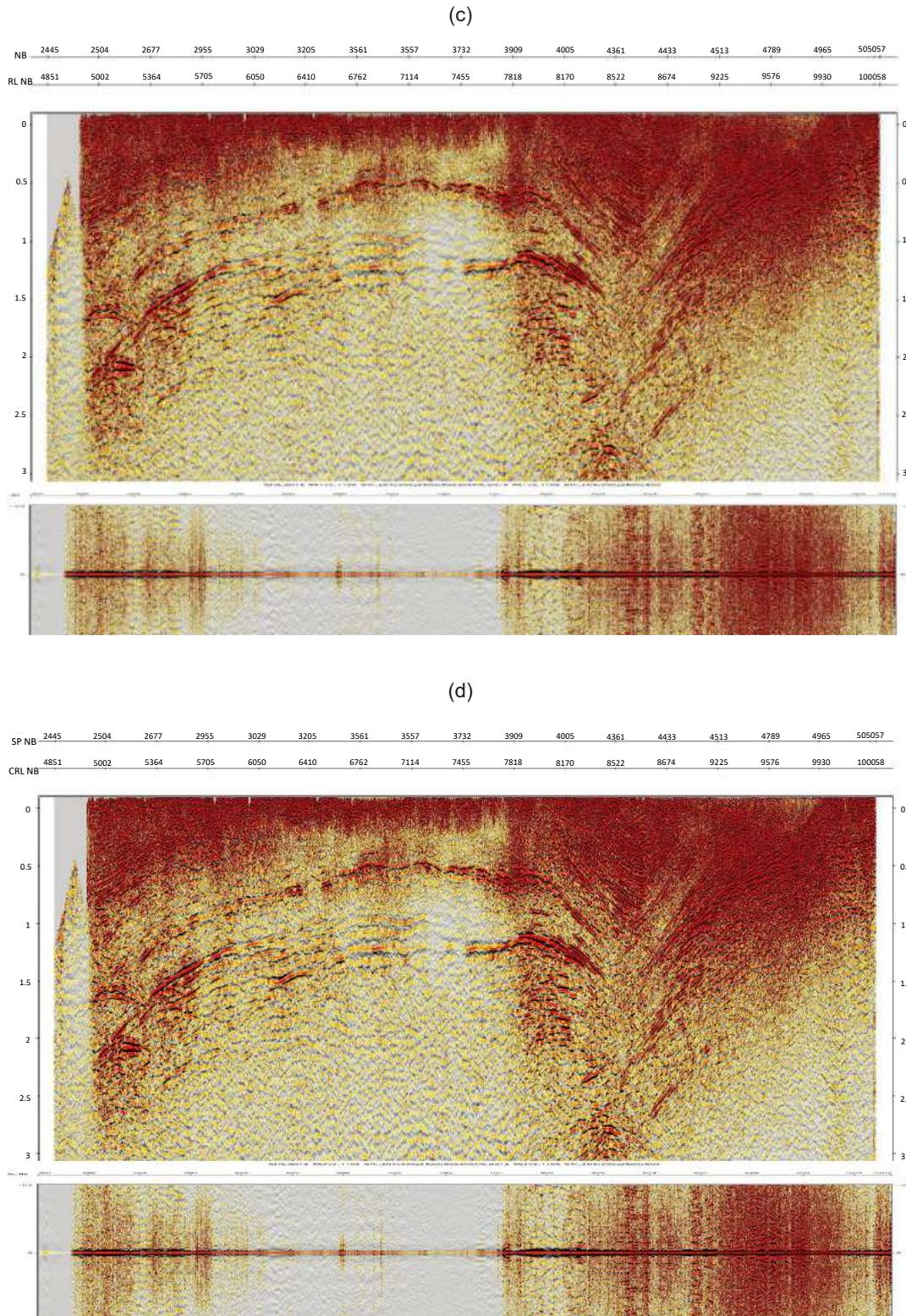
(a)



(b)

(c)



(d)
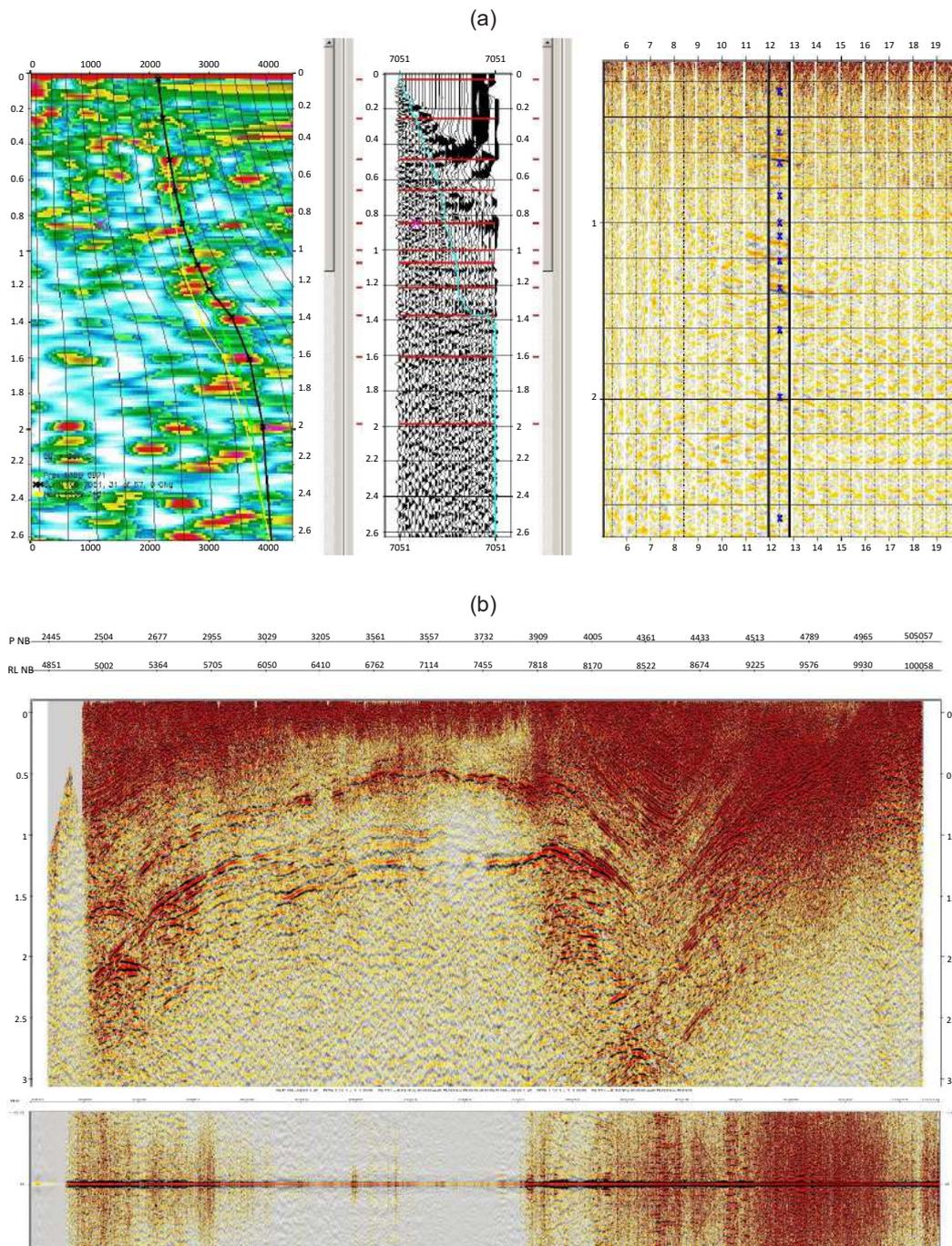


Figure 13
(a) Velocity analysis on cdp gather. (b) Stack line  after 1st velocity analysis, (c) after 1st velocity and 1st residual static
and (d) after 2nd velocity analysis and 2nd residual static

Velocity analysis is also guided by geological knowledge i.e the existing formation characteristics and the over-pressure zones that can be confirmed by velocity interval cross-section such as shown in Figure 14 where it appears an inverted velocity.
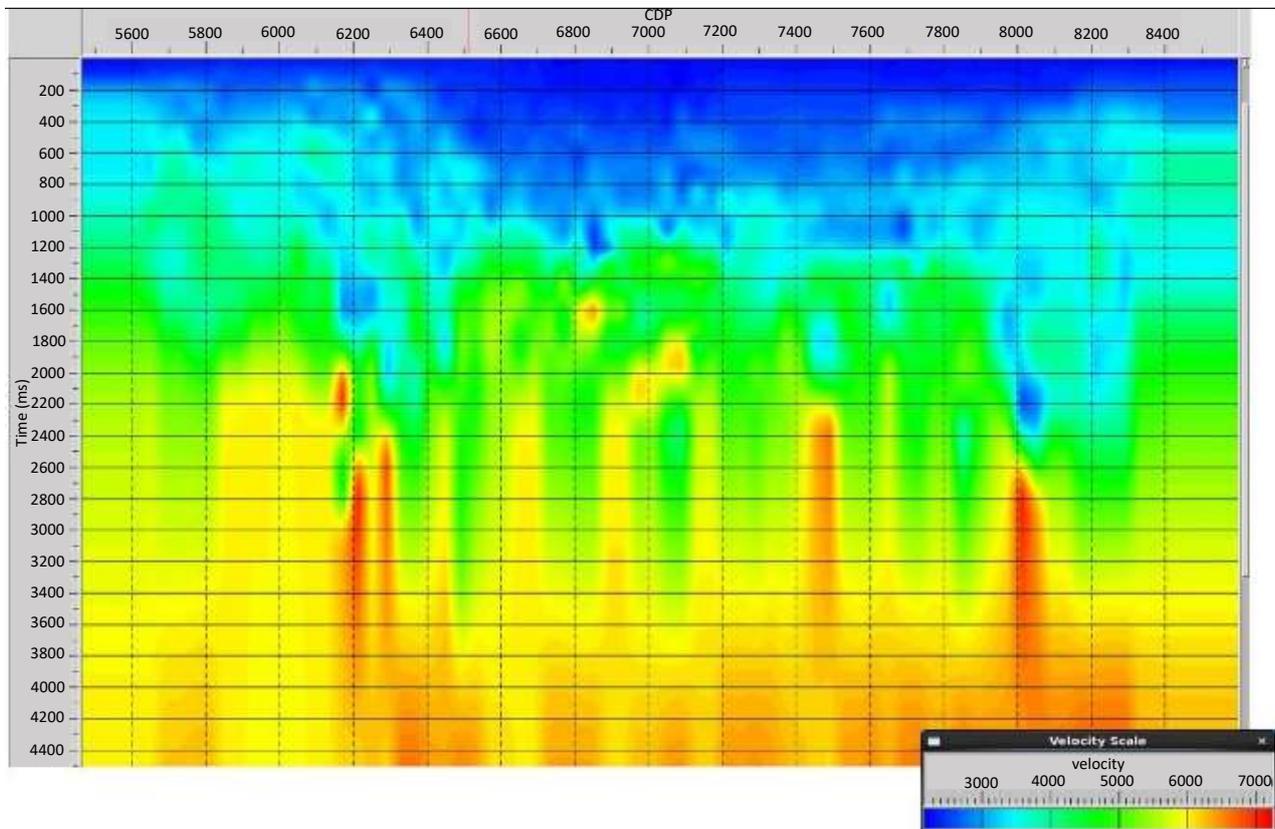


Figure 14
Interval velocity section after 2nd velocity analysis . This figure shows several inverted velocity such as occurring in dark blue and bright blue

**Coherent Noise (Ground-roll) Attenuation**

As stated on previous page, ground-roll or commonly mentioned as Rayleigh wave is a surface wave that takes up a lot of seismic energy, consequently the greater the ground-roll is generated, the lower the seismic energy that becoming the reflector signal. Ground-roll is largely avoided in seismic surveys by looking appropriate coupling of detonation, as well as the choice of charge and depth. Ground-roll appears to be more dominant than previous seismic survey data, it might be due to a poor source coupling, a good lesson learnt for the survey afterwards, to emphasize more clutch problem so that no blow-out and energy penetration is optimally downward.

The maximum effort to eliminate ground-roll must be done so that the background energy level can be balanced as well as energy compensation is not disturbed when true amplitude recovery or surface consistent amplitude correction. This effort includes two steps, first noise attenuation and second its remaining attenuation. The noise attenuation is not yet optimal, it still shows a background energy difference, for this reason it is necessary to eliminate residual ground -roll. Figure 15a shows a receiver gather display where is a residual ground-roll attenuation, which affects background energy, but in Figure 15b it can be clean up.

However, it must be considered the possibility of signal loss in the reflector. As shown in Figure 16, which depicts residues were eliminated in this process. There is a possibility part of signal will be also eliminated, therefore itmust be done carefully. Elimination of linear noise such as ground-roll is not sufficient in the f-k domain, but optimization of the residual linear noise in the f-x domain together with random noise.
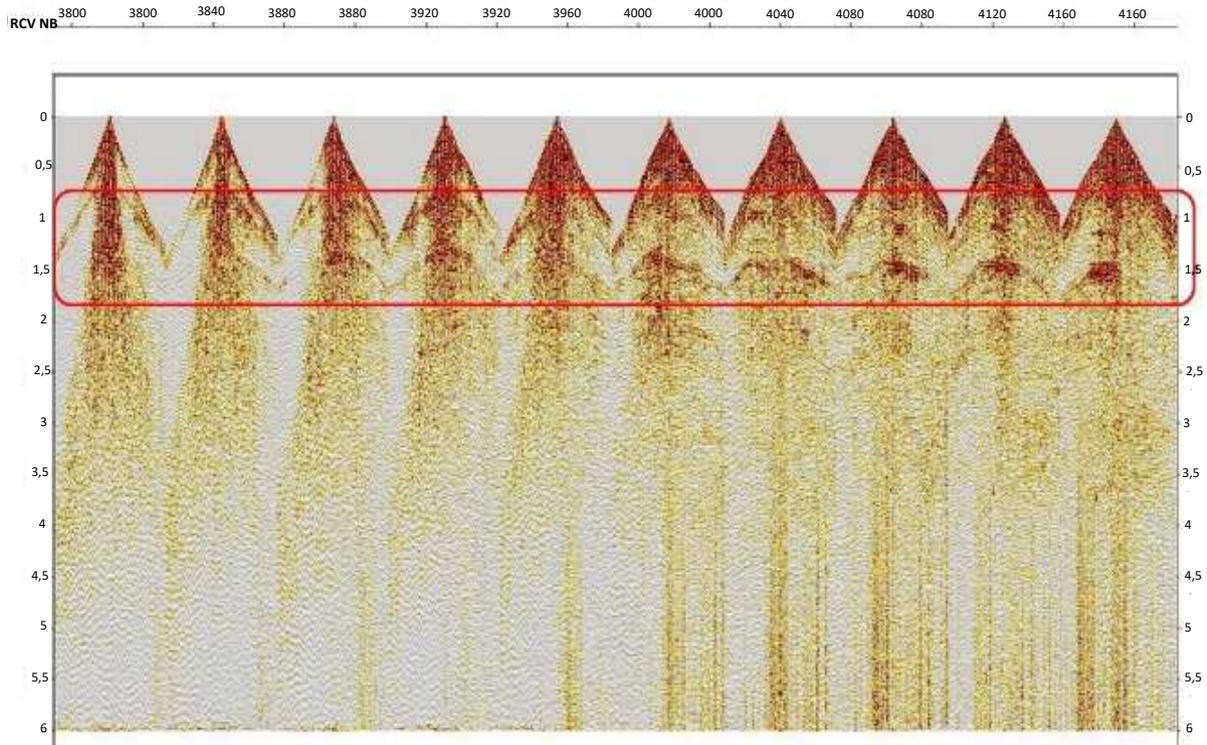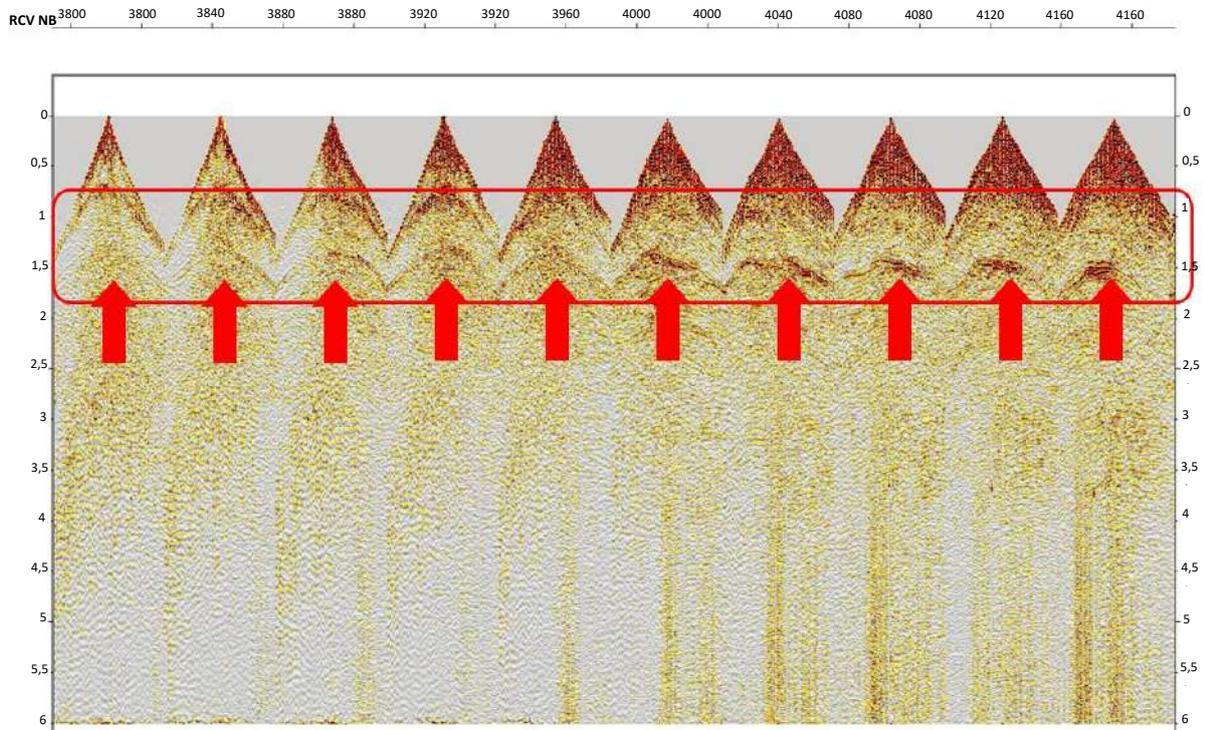
Figure 15
Receiver gather  before denoise (a) and after denoise (b)

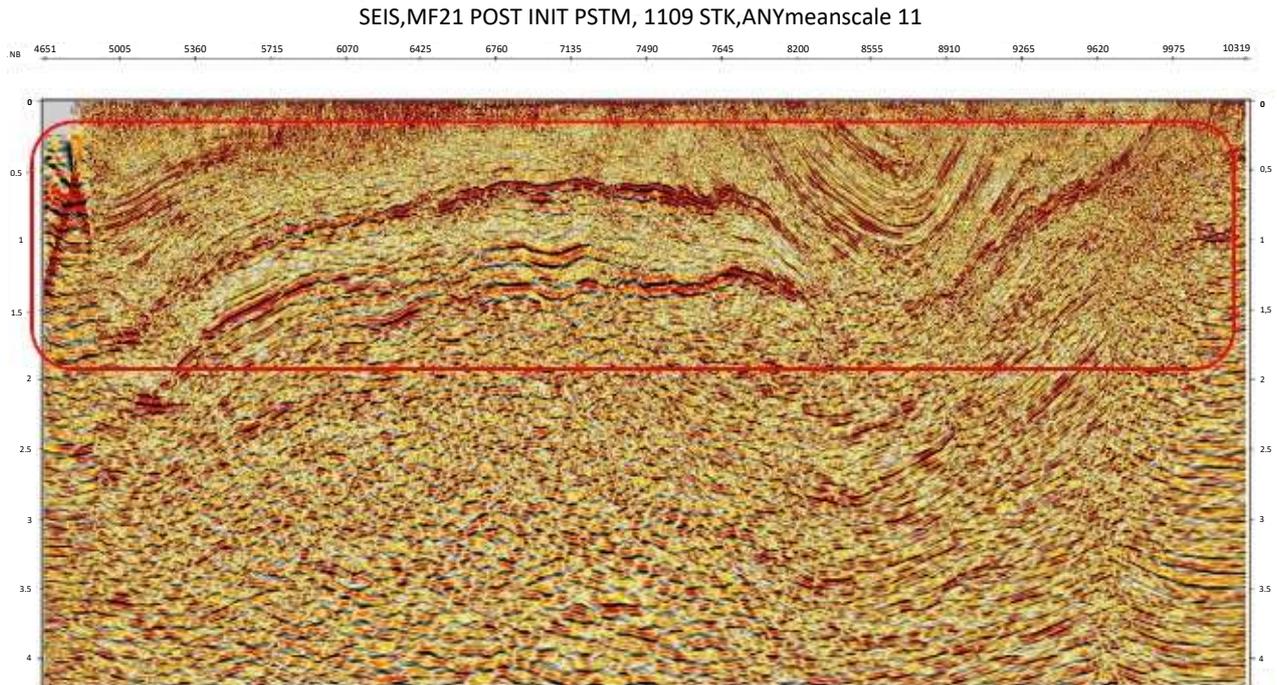SEIS,MF21 POST INIT PSTM, 1109 STK,ANYmeanscale 11



Figure 16
The difference of before and after denoising from shot gather, it appears signal removal effect

## Surface Consistent Amplitude Correction

One of ultimate requirement so that the surface consistent amplitude correction process governs acceptably is noise elimination, therefore it can be run appropriately. However, if signal is not completely clear from noise disturbance such like shown in Figure 15a, it is be scared that the calculation process of correction is not optimal, so that it still leaves a possible inaccurate correction value. But otherwise if it is clear of noise such like pointed-out in Figure 15b, the expected correction value will be truthful. For example, Figure 17a illustrates the residual ground-roll that has not been maximized. As a result of residual ground-roll and the energy is still strongly affected by background noise. So that when carrying-out surface consistent amplitude correction, this job is ineffective, there is background energy level difference (Figure 17b). It must be done to clean noise in the receiver domain.

## Deconvolution

The deconvolution process is expected to cancel-out earth filter, as if it is a really convolution between wavelet and reflection coefficient. Regarding to this occurrence, a more stable wavelet is desired because it is no longer affected by variations of the wave propagation. Align in a process that maintaining a consistent surface, the deconvolution process is carried-out on the surface domain so that the data remaining preserved. It works in two phases, namely filter estimation phase and deconvolution of raw traces phase. The deconvolution process is done by using a gap parameter that will be changed starting from 12 msec to 48 msec. Based on the results, it appears that the lower the gap parameter will produce a wider frequency spectrum results, but the wavelet becomes more unstable, it appears from a better continuity when the gap parameter is wider. Figure 18 illustrates the comparison between the 16 msec and 36 msec parameter gaps, where it appears that in the 36 msec parameter gap, the event package on the top of Gumai is more clearer, but in Baturaja, the 16 msec parameter gap is more better.

Based on several trials it can be clearly observed that there is an event packages from Gumai Formation and Baturaja Formation. It can occur after background noise level can be compensated properly when surface consistent amplitude correction. A major disturbing aspects are the presence of noise and the geophone coupling instability in the acquisition stage.
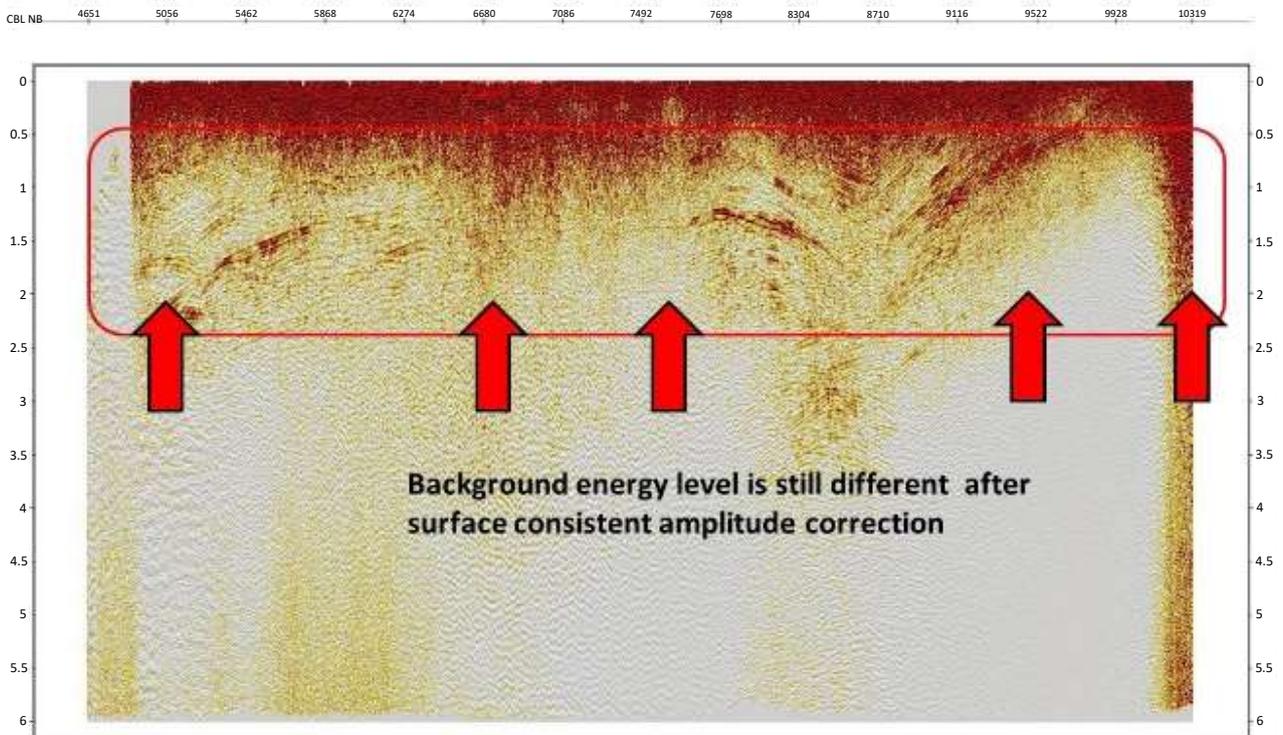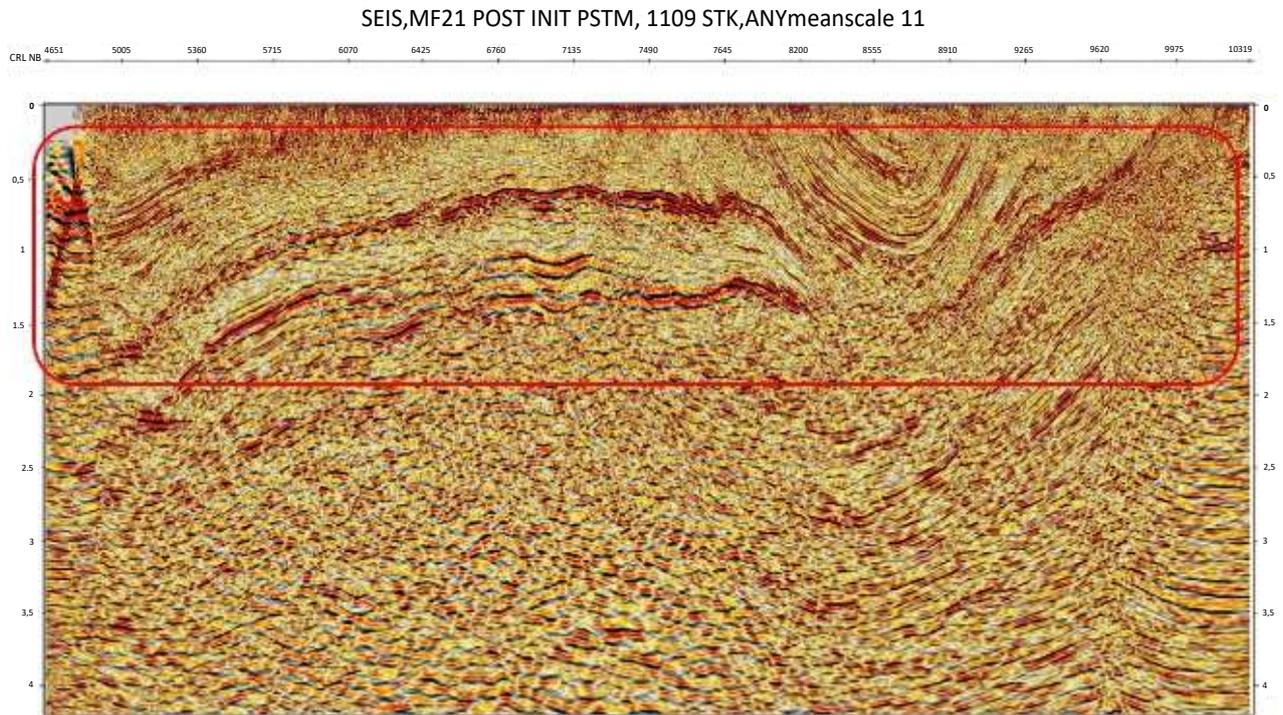
(a)
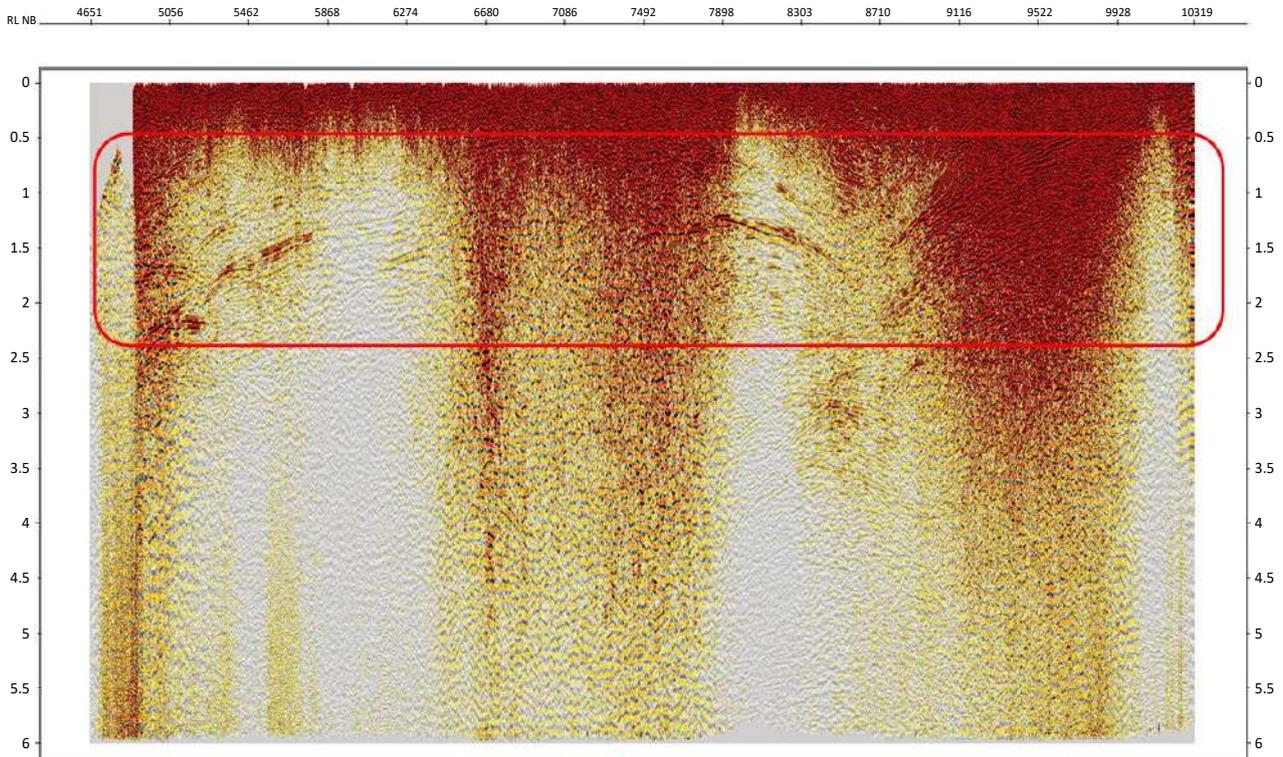


(b)



Figure 17
Stack line (a) before surface consistent amplitude consistent  and (b) after surface consistent amplitude correction, but remaining background energy difference, it appears with brighter and darker zone

(a)

SEIS,MF21 POST INIT PSTM, 1109 STK,ANYmeanscale 11



(b)

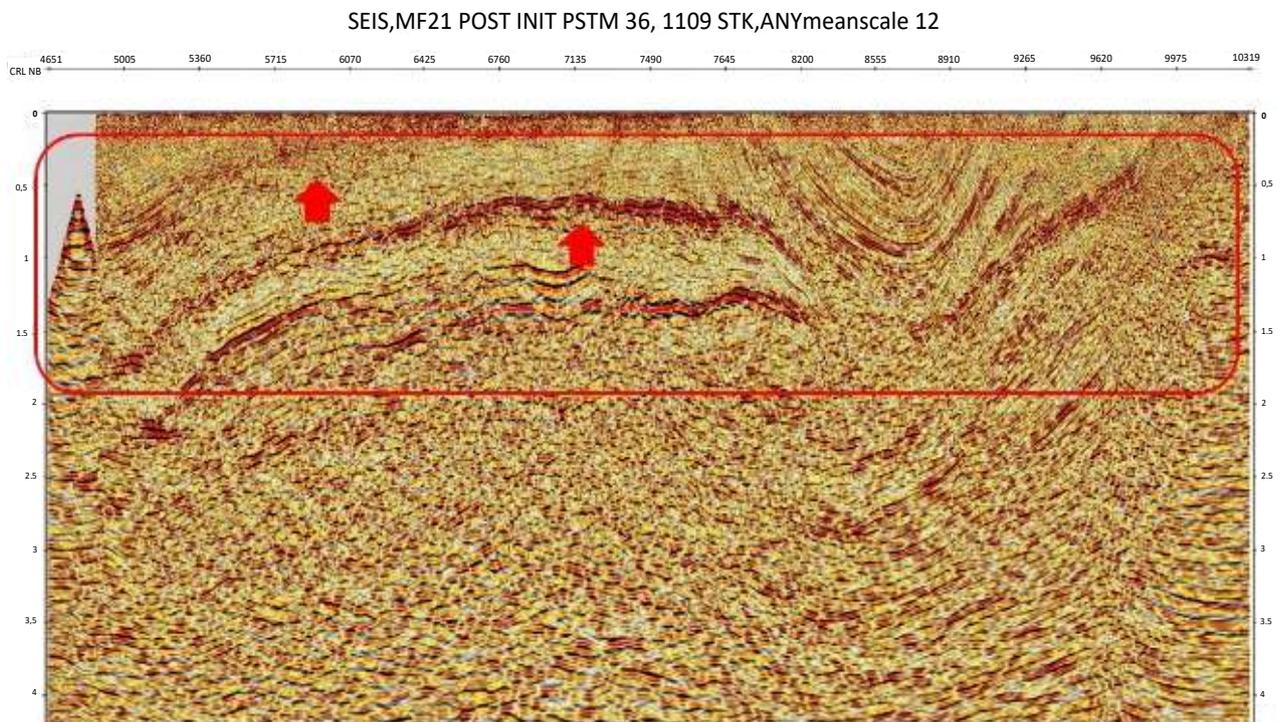SEIS,MF21 POST INIT PSTM 36, 1109 STK,ANYmeanscale 12



Figure 18
Stack line  (a) with gap deconvolution 16 msec and (b) gap deconvolution 36 msec

### Side-swept optimization

Side-swept -as explained earlier- is not noise but an un-wanted signal, because it comes from a reflector that originating from outside of the orientation. If not correctly identified it can lead to a mis-interpretation or even more fatal to mis-modeling. The solution used to eliminate side-swept is in the τ-p domain or radon, so the input are τ (intercept) and slowness p is 1/velocity); there both becoming very important to recognize side-swept characterization which disturbing seismic data. But, unfortunately, as it can be seen from Figure 9, there are a lot of power spectrum showing the existence of side-swept, it is thought to be triggered due to complicated structural geology, so that if done in surveys, it will experience quite serious obstacles. Ironically, the side-swept appears precisely, after noise removal effort optimally. In the moment of coherent noise and random noise still dominated background energy, the side-swept was still faintly mixed with the reflector. But, after these noise can be eliminated, the side-swept becoming easy to observe but not easy to remove. Figure 19 shows an effort to eliminate side-swept, but from these efforts there are still side-swept residuals as shown in Figure 19b. Meanwhile, Figure 19c illustrates how far it works to do elimination. Side-swept is not easy to remove, but its existence can be traced back from the mechanism of its genetic.
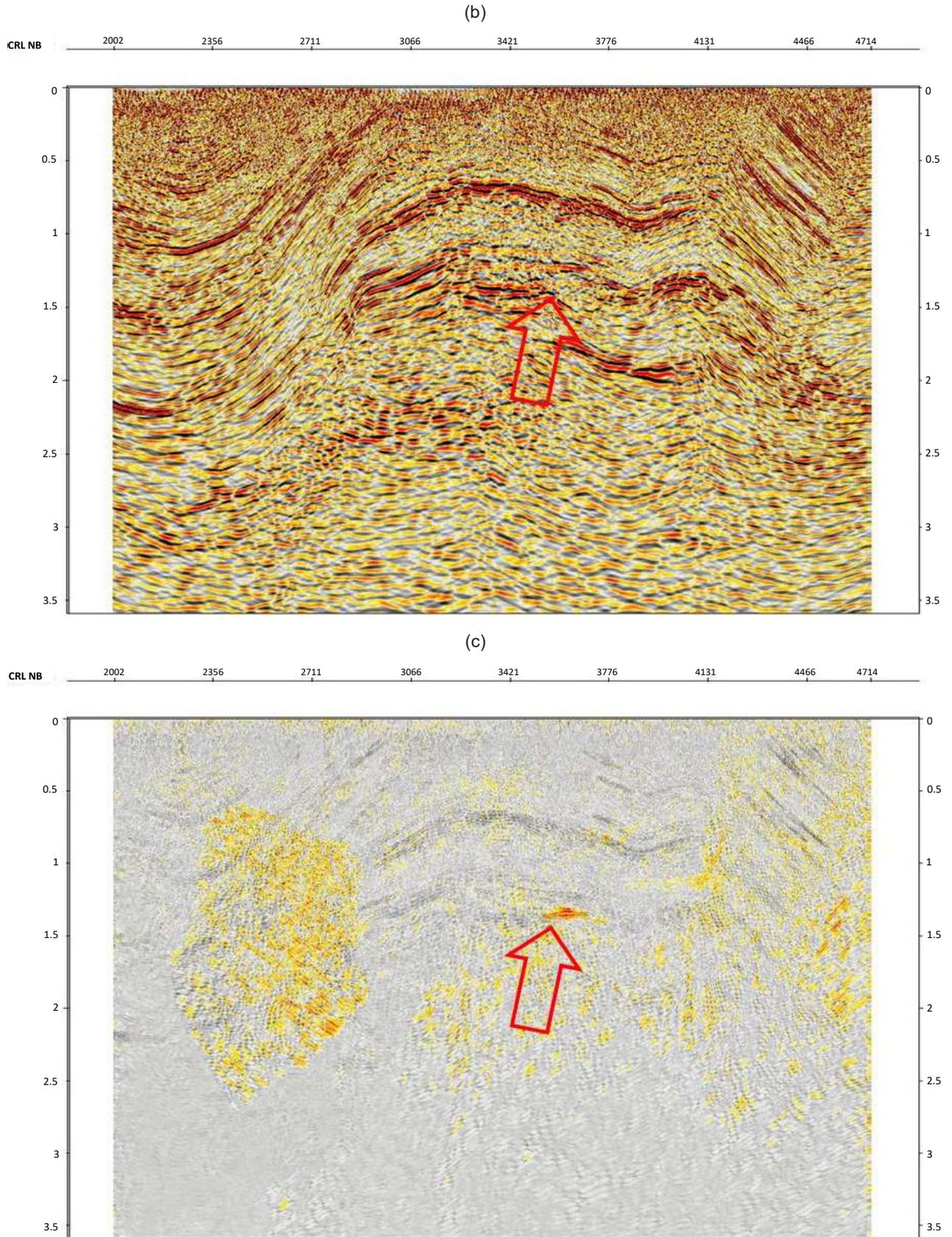
(a)

(b)



(c)
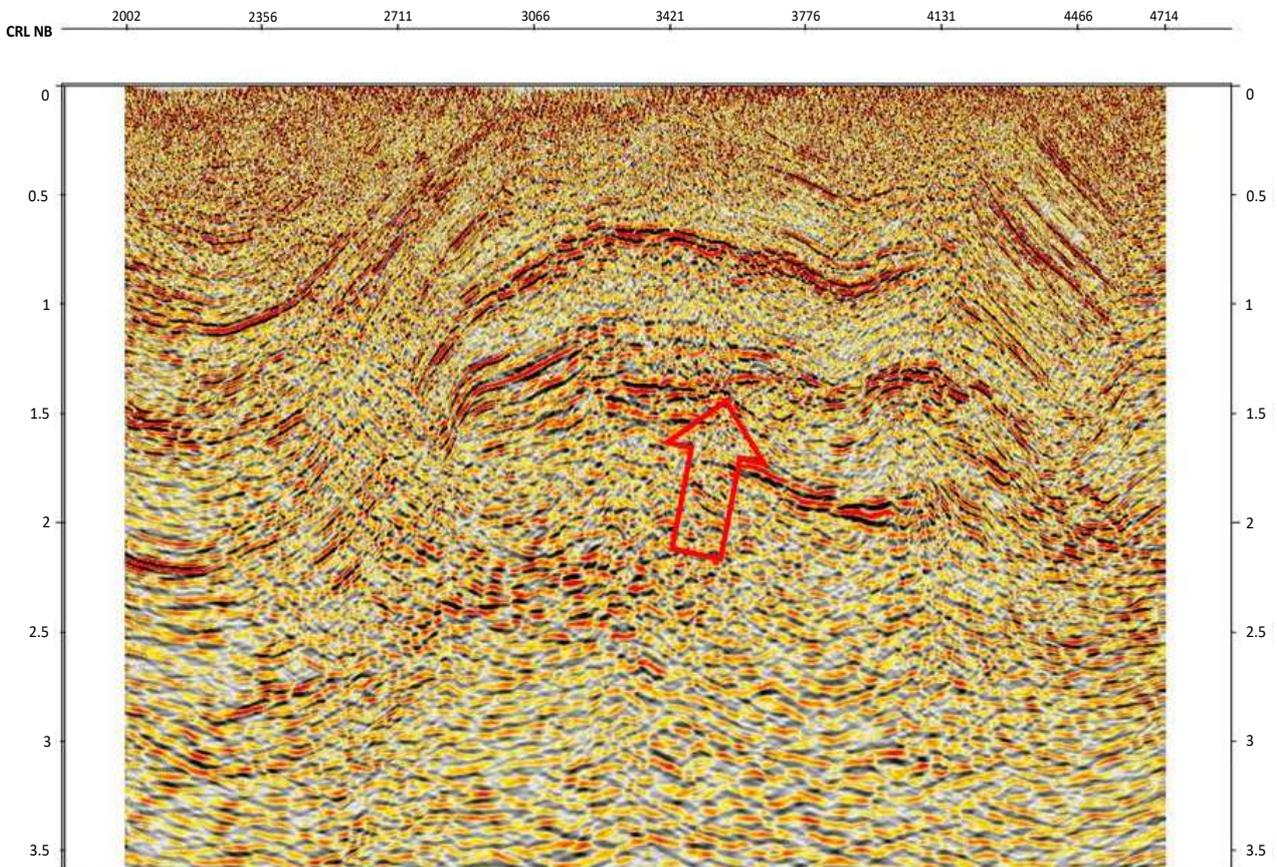


Figure 19
Side-swept elimination  of stack line; (a) before elimination;  (b) after elimination  and (c) the difference between before
and after elimination

It appears in Figure 19b that the side-swept residuals still exist in an event package that is in the Baturaja Formation, which has not been removed properly, especially those that are in interference with the actual reflector. We need to be careful in applying this solution, considering that if it is too far away it can affect the amplitude value of the actual reflector, as a result the data is no longer preserved. Therefore, we cannot eliminate side-swept completely, because it has been recorded along with the actual signal, but we can work on optimization steps, so that the existence of side-swept can be recognized and relatively reduced from what actually happened.

## Discussion

Background energy is the energy which is behind of the signal needed in the subsurface geological interpretation. Unfortunately, the signal energy decreases with increasing depth, therefore the background energy will seem to dominate the existing energy. If the background energy is relatively clean from noise, amplitude normalization will work more effectively. Conversely, if noise dominates the background energy, normalizing the amplitude of the signal will be ineffective, because it is hindered by noise that has a stronger amplitude or energy. Thus, the identification of noise characteristics needs to be done through a velocity semblance as shown in Figure 7, or a power spectrum as shown in Figure 9. The most basic identification is whether the noise has a coherent or random pattern, which is then quantified for each energy percentage. After energy allocation, we will determine the next strategy.

Observation of random noise was carried out at the receiver gather, it appears that random noise is very dominant appearing at high frequencies, thereby increasing its amplitude. Good attenuation is done by changing to the f-x domain and then choosing the right noise frequency, so as not to eliminate the amplitude of the signal. Random noise needs to be eliminated in order to reduce the "black and white" contrast on the background energy (Figure 9). This contrast can actually only be caused by the existence of the signal, beyond that it is not allowed.

Attenuation of random noise is relatively easier than non-linear coherent noise. The second work to improve the background energy is attenuation of linear noise, which seems easier to understand than non-linear noise. For linear noise, the most ideal attenuation is carried out at the shot point gather, the attenuation is carried out on a linear function which

is the variation of the amplitude of the seismic waves propagating on the surface relative to the surface offset. The choice of attenuation is in the f-k domain, where k is the wave number and f is the frequency. In this domain the separation is very clear between signal and noise, so we don not need to worry about the effect on the signal, because both the frequency and wave number of the two have different operating areas (Figure 15).

Basically, attenuation of the two noises above is needed to reduce the dominance of noise in the background noise, and is a preparation of data so that the optimization process of the attenuation of non-linear side-swept noise can run effectively. We know that the side-swept effect of subsurface objects, such as sideways reflections from an unwanted layering plane on 2D seismic data, will produce a signal-like hyperbolic function. Thus, static correction along with residual static is needed, as well as velocity analysis beforehand so that the signal appears more clearly in a power spectrum. This is a preparation for a transformation process to the τ-p domain.

Attenuation of the non-linear function side-swept starts with identification of the power spectrum at the time of velocity analysis repair after the refraction static residual correction is carried out as shown in Figure 13a. The sharpening of the reflector signal which is continuously iteratively carried out after the refraction static residual correction is carried out will reduce the amount of background energy from the side-swept. And during the elimination in the t-p domain, the risk of loss of reflector signal energy that overlaps with side-swept will be minimized. As previously explained, the side-swept appearance in the t-p domain, the intercept of the reflector signal and the side swept may be similar but the velocity is different.

No matter how much better the noise suppression solution, finally it still leaves an attenuation effect on the signal, for example in the case of attenuation of linear coherent noise (Figure 16), besides the presence of residual non-linear noise after the inversion process of the attenuation results in τ-p domain (Figure 19). It was happened due to within seismic data recording, there is an overlapping area between frequency, phase velocity and amplitude of signal and noise. So far, we can not get rid of the noise but reduce its effect on the background energy, so that its dominance does not appear at a higher level than the energy signal. The best step is to strengthen it again by performing surface consistent deconvolution, it

is a restoration step for a signal which is in a passion due to the removal of background energy.

## CONCLUSION

The term background energy is very appropriate to be used as a noise management approach that must be tested to amplify signals above the noise energy level or background energy, hence the attenuation is not applied in the separate treatment, but exercising from each noise behavior in the background energy. Noise processing remains residuals after attenuation which need to be analyzed continuously.

Noise attenuation is carried out not in the t-x domain and is carried out at appropriate gathers, such as receiver gathers for random noise, cdp gathers for side-swept effects and shot point gathers for linear noise.

Side-swept due to subsurface structures is a non-linear function and it might be a similar frequency content and intercept with reflector signal. The attenuation is accomplished by strengthening the reflector signal through coherent noise and random noise elimination as well as carrying out the iterations of velocity analysis, residual refraction static correction and surface consistent deconvolution, before the attenuation will be done in the t-p domain.

Signal amplification is still needed after all the attenuation processes have been carried out, either through velocity analysis, surface consistent amplitude correction and surface consistent deconvolution.

## ACKNOWLEDGEMENT

## GLOSSARY OF TERM

| Symbol | Definition | Unit |
| --- | --- | --- |
| τ−p | Intercept and Slowness | msec; sec/m |
| f-k | Frequency and Wave Number | hz; cycles/m |
| f-t | Frequency and Time | hz; msec |
| CMP | Common Mid-Point | none |
| CDP | Common Depth Point | none |
| CSP | Common Shot Point | none |
| NMO | Normal Move-Out Correction | msec |
| CWT | Continuous Wavelet Transform | none |
| PSTM | Pre-Stack Time Migration | none |
| DRT | Discrete Radon Transform | none |

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