Common reflection surface methods in low fold coverage seismic data of complex marine geological structures

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Abstract. The primary objective of seismic data processing is to generate seismic cross-section with an optimum signal to noise ratio to model geological structures imaging as accurately as possible with the actual condition. However, we may look onto complex geological structures with less than adequate number of fold coverage seismic data. In this study, Common Reflection Surface (CRS) method is applied to generate 2D marine seismic cross-sections with better reflector continuity of 3 (three) real data seismic lines. It is based on obtaining the suitable aperture value along the attributes namely RN, RNIP, and α. Its results are compared to conventional Common Mid-Point (CMP) ones. The final products are presented in multiple-attenuated and time-migrated cross-section with Surface Related Multiple Elimination (SRME) and Kirchhoff Migration techniques, respectively. Comparison of final time-migrated both CRS and CMP stacks show the CRS method is more effective and reliable to model accurate complex marine geological structures with high signal to noise ratio based on reflector continuity and noise reduction.

1. Introduction
Seismic reflection is a method used in natural resource exploration such as hydrocarbons. There are three main solutions in seismic methods: data collection, data processing, and data interpretation. Seismic data processing aims to improve the quality of the signal to noise ratio (SNR) [1] without changing the shape of the reflection appearance so that a seismic profile is obtained that really imaged the subsurface geological conditions [2]. The value of coverage can affect the results of seismic cross section. Higher value of the folding coverage is higher of SNR value the more clearly the appearance of the reflector [3]. Common reflection surface (CRS) method can increase SNR in complex geological cross sections with low coverage value. This is because CRS performs geometry by substituting the angle attribute between light and normal lines (α), the radius of the curvature of the Normal Incident Point (RNIP) and the radius of the curvature of the normal wave (RN) on CDP [4].

In this research, we find long period multiple that is acknowledged as surface related multiple. Surface Related Multiple Elimination (SRME) method is a method that can eliminate all types of multiple waves whose propagation is related to the surface [5]. The final results of this study are comparing the seismic appearance that has been migrated with the SRME method without CRS and the SRME method with CRS.
1.1. Fold coverage
Fold coverage is the number or frequency of reflections concerning a field of reflection on a rock. Fold coverage is very important during the stacking process, which can strengthen the signal and eliminate noise. The more number of signal reflections in a field, the better the quality of the resulting data is expected.

1.2. Multiple
In seismic data acquisition process, not only the primary reflection that was recorded but also the reflection of multiple. Multiple reflections usually interfere with primary reflection and produce a poor seismic picture [2]. Multiple arises due to waves trapped in the seawater layer or rock layer due to the contrast of the very large propagation medium impedance. Waves cannot penetrate or pass through layers to get back to the surface, so they are reflected in the same layer.

![Figure 1. Propagation of primary (orange) and multiple (blue) waves below the earth's surface [5].](image)

The orange line shows the propagation wave of the primary reflection and the blue line of the multiple waves. Figure 1 shows that the primary reflection wave propagation only experiences one reflection below the earth's surface. Whereas multiple waves experience more than one reflection and have at least one reflection wave going below the surface of the earth.

1.3. F-K filter
F-K filter is one of the filters in seismic data processing which is done by changing the seismic data from time domain (t) and distance (x) to domain (f) and wave number (k) by using Fourier transform. Because events in seismic data have many slopes and frequencies (in this case what is meant by slope is even slope, in milliseconds per trace, not slope of geological structure), then each different slope in the t-x domain will change to a line with a slope differ in the f-k domain. Even horizontal in the t-x domain has a wave number value equal to zero, so in the f-k domain it will be plotted along the frequency axis. The greater the slope of an event in the t-x domain the closer the plot is to the wave number axis. A signal with a positive slope will have a positive wave number and a signal with a negative slope will have a negative wave number. Events with different slopes always indicate different slopes when mapped in the f-k domain [6]. As the value of f increases with constant k, the dip will decrease. And if it is reversed if f decreases with constant k, then the dip will increase (Figure 2).

![Figure 2. Dipping in f-k domain [7].](image)
1.4. Surface related multiple attenuation (SRME)
SRME is used to patent multiple surfaces contained in seismic data by utilizing reflections contained in seismic data to predict multiple surfaces. The three main stages in the SRME method are first to eliminate non-physical noise, regulation of data so that a constant source of reception is obtained, interpolation of the near intermediate offset is lost, eliminating direct waves. Then the second predicts multiple, this prediction is based on the observation that the multiple related to the surface can be predicted through the temporal and spatial convolution of the data itself. Finally, the input data is reduced by the multiple predicted in step two.

1.5. Common reflection surface (CRS)

1.5.1. CRS stack operators. CRS stack method utilizes multi-coverage seismic data to perform the stacking process. If the conventional method only selects a number of CMP gather for stacking process, then this method uses information from all traces in the seismic record. The figure below shows the difference between conventional stack operators and CRS operators:

![Figure 3. Stacking operator of the NMO / DMO stack [8].](image)

![Figure 4. Stacking operator of the CRS stack [9].](image)
1.5.2. Wave field kinematic attributes. The wave field kinematic attribute is a parameter that describes the location, orientation, and shape of the reflector, which in this CRS case the parameters are $\alpha$, $RN$, $RNIP$ [10]. They provide a physical interpretation of the definition of the CRS attribute in the form of two wave front generated by the source in the form of a point on the reflector and the source along the reflector segment (exploding reflector) as shown below:

![Figure 5. Attributes in Common Reflection Surface [11].](image)

Green indicates normal wave curvature and red indicates NIP wave curvature. The blue color shows the magnitude of the incident angle formed from the wave front towards the normal line. NIP waves (Normal Incident Points) are defined as waves generated by a source point (called a NIP point) that radiates from the reflector to the surface. This wave front cones into a single point on the reflector, assuming there is no energy lost during wave propagation. Assuming a constant speed, the parameter $RNIP$ can be used to determine the distance from the reflector to point $x_0$. Whereas $RN$ is a wave that travels in the normal direction. The N wave is generated by the source in the form of exploding reflector around the NIP point. This parameter carries information about the shape of the curvature of the reflector. The two waves generated by the source at the NIP point and the reflector segment around this NIP point will propagate the wave energy in the path that coincides with the zero offset ray path and has a receiver angle at the $x_0$ point on the surface. The angle of arrival is a parameter $\alpha$ or emergence angle. This parameter is closely related to the slope of the reflector.

1.5.3. Fresnel zone. By using information from the reflection response around the Z normal line along the Fresnel Zone, we will get one surface stacking for each S point. By doing the sum along the surface area of the stacking the CRS stacking section will be obtained. The stacking operation in the CRS stack is determined by the width of the segment of the reflector or the aperture of the reflector, so the Fresnel Zone is within the optimum aperture for CRS stacking.

![Figure 6. Fresnel zone [12].](image)
AA’ and Z represent depth and λ is the dominant wavelength. The Fresnel Zone concept is in the depth domain, while the data is in the time domain. First interface of Fresnel Zone in identical time domain with first interface projection of Fresnel Zone in depth region. This relationship can be utilized to get the optimum CRS operator aperture. Seismic sources are fired to produce a Fresnel Zone of AA’.

By using all points around the reflector, the Reflector Zone can be derived from one S point.

1.6. Post-stack time migration (PSTM)

Migration is a process to move the position of the reflector that is not right at the actual position and time of reflection [13]. Migration can move the apparent reflectance position (the results of the recording) to the actual reflecting position (geological reflection) and collect diffraction points to the top of the diffraction curve. Migration by type is divided into pre stack migration and post stack migration. Post stack migration and pre stack migration can be done with time and depth domains [14]. Post-stack Time Migration is a seismic data migration technique that is applied after the stacking process.

2. Methods

2.1. Study area

The acquisition was carried out by Bandung geology research and development center, Bandung in 2018 in Waipoga Waters, Papua. The material of this research is the acquisition data in the form of raw data with the SEG-D extension on three tracks namely C06, L05, and L31 (Figure 7).

![Seismic acquisition map, Waipoga Waters, Papua.](image)

2.2. Data processing methods

The processing sequences are started by de multiplexing the field data, then processing the data to obtain seismic cross section free from noise multiple and has a high signal to noise ratio quality so that result can be analyzed and interpreted. The flow chart of seismic data processing can be seen in Figure 8.
Figure 8. Flow chart of seismic data processing.

Seismic data processing is carried out in several stages in ProMAX. Starting with data input geometry, editing, pre-processing, speed analysis and the SRME process, CRS or a combination of both. Processing is meant to eliminate noise and increase SNR. This is conducted while the data is processed exactly like the real situation in the field. Acquisition parameters in lines C06, L05 and L31 can be seen in Table 1.
Table 1. Acquisition parameters in lines C06, L05 and L31.

| Line Name                  | Unit | C06     | L05     | L31     |
|----------------------------|------|---------|---------|---------|
| Shot Point                 | -    | 2133    | 2121    | 2139    |
| Shot Interval              | m    | 25      | 25      | 25      |
| Group Interval             | m    | 12.5    | 12.5    | 12.5    |
| Active Channel             | -    | 1-120   | 1-120   | 1-120   |
| Interval Channel           | m    | 12.5    | 12.5    | 12.5    |
| Near / Minimum Offset      | m    | 75      | 75      | 75      |
| Far / Maximum Offset       | m    | 1562.5  | 1562.5  | 1562.5  |
| Nominal Source Depth       | m    | 8       | 8       | 8       |
| Nominal Receiver Depth     | m    | 9       | 9       | 9       |
| Distance Between CDP       | m    | 6.25    | 6.25    | 6.25    |
| Fold Coverage              | -    | 30      | 30      | 30      |
| Sail Line Azimuth          | °    | 304     | 36      | 304     |
| Total Length               | km   | 53.30   | 53.00   | 53.45   |

The initial stages of seismic data processing include data input, de multiplexing, geometry, trace editing, True Amplitude Recovery (TAR), surface wave attenuation, and deconvolution. Data input is the process of entering field data that has been combined into shot gatherings into ProMAX. Geometry is the process of combining and matching field acquisition parameters with the seismic data used. Trace editing is the process of removing data that can interfere with the data processing. This can occur due to damaged and noise data. The steps of trace edit are trace muting, trace length and band pass filter. The next step is True Amplitude Recovery (TAR) and denoising. TAR is done to obtain the amplitude of seismic waves lost due to the attenuation of wave energy during propagation in the earth's layers. The Surface Wave Attenuation stage is used to attenuate noise emanating from surface waves by forming a low frequency array. The next process is deconvolution which is used to recover high frequencies, weaken multiple, equalize amplitudes, and produce zero-phase wavelets.

The next stage is speed analysis, FK filter, CRS, SRME, and post-stack migration. Speed analysis is done to eliminate the lag time due to the separation of the source (Gun) and receiver (Streamer) on the surface. This process uses semblance velocity which is a plot of signal coherence in the velocity field with Two Way Travel (TWT) time, then displayed in the form of a contour with a color with a semblance cross section. FK filter is used to convert seismic data from time and distance (t-x) domains to frequency and wave number (f-k) domains.

The Common Reflection Surface (CRS) stack is used to build a ZO stack or gather with increasing SNR using slope (dips) and sound speed. The stack aperture parameter in this stage plays a role in determining the size of the data radius to be stacked with the correct reflector points in the CDP domain that affect the reflector resolution. Surface Related Multiple elimination (SRME) is used to attenuate multiple surface noise found in a seismic cross section. Migration is a process to move the position of the reflector that is not right at the actual position and time of reflection [13]. Post-stack Time Migration is a seismic data migration technique that is applied after the stacking process.

3. Result and discussion

SRME method produces a seismic cross section that is clean from multiple noise to obtain better seismic cross section results, especially at low fold coverage, CRS method is very appropriate to be used to see the complex marine geological structure. Seismic cross section with the SRME method is then compared with seismic cross section of SRME and CRS results to see which cross section is better in showing the marine geological structure. In addition, addition, the conventional stack operator method is used only at velocity, while the CRS operator stack method is used dip (α), radius of the curvature of the normal wave (RN) and radius of the curvature of the Normal Incident Point (RNIP) [15].
Figure 9. Post-stack SRME time migration results in line C06 without CRS (a) and with CRS (b).

Figure 10. Post-stack SRME time migration results in line L05 without CRS (a) and with CRS (b).
Figure 11. Post-stack SRME time migration results in line L31 without CRS (a) and with CRS (b).

Changes of reflector quality are indicated by a black circle, where in SRME method continuity of reflector is not clearly visible. The continuity of the reflector in the CRS method can be caused by used of multi-coverage data when adding the wavelet seismic, so as to produce a reflector cross section that is clearer than the method without CRS [16]. Cross section results by CRS method show less noise and high-quality signal to noise ratio [17]. CRS aperture value used in C06 seismic line is 0-50, 600-75, 1000-100, 2000-150, 3000-175, 4000-200, L05 seismic line is 0-50, 1000-75, 2000-100, 3000-150, 4000-200, and L31 seismic line is 0-30, 300-50, 1000-75, 2000-100, 3000-150, 4000-200. Aperture is a parameter that greatly affects the results in CRS stack process. The right aperture is able to give a good picture especially on complex marine geological structures.

4. Conclusion
Post-stack migration seismic cross section with a combination of Surface Related Multiple Elimination (SRME) and Common Reflection Surface (CRS) method shows the best results compared to SRME method without CRS. Seismic cross section results have a high signal to noise ratio and are free from multiple noise.

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