Application of Pre-Stack Time Migration (PSTM) Using Kirchoff Method on Marine Seismic Data 2D in Sulawesi Sea Waters

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Abstract. To see the potential of weak zones, subduction zones and geological structures below sea level, research phases are needed based on geological and geophysical approaches. Geological approaches include regional geology and stratigraphy studies, while geophysical approaches include the depiction of underground structures using reflection seismic. The purpose of this study was to process 2D marine seismic data until the Pre-Stack Time Migration stage of the Kirchoff method and to interpret the underground surface structure of the Sulawesi Sea waters based on the Pre-Stack Time Migration using Kirchoff method in the Sulawesi Sea Water. This process can move the position of the reflector to the actual position, which is conducted by adding up the amplitude of a reflector point as long as a position is estimated at the actual location. The results of the interpretation of Pre-Stack Time Migration in the Line 22 crossing of the Sulawesi Sea waters have the presence of reflectors, Sulawesi ditch, faults and horizon layers of sedimentation. While the existence of low velocity zones can be analyzed by reading Root Mean Square (RMS) velocity in the cross section of this track, the lowest velocity zone distribution is found in CDP 7,350.8 with a depth of 11,860 ms to TWT depth of 10,967 ms having a constant velocity amounting to 2,291 m/s, and the estimated presence of weak rock structures.

1. Introduction
Sulawesi Island is one of islands located in Indonesia that includes in the Ring of Fire zone and it is flanked by three tectonic plates, those are Indo-Australian, Eurasian and Philippine plate, which often results in natural disasters caused by shifting plates [1]. One area on the island of Sulawesi that is crossed by the Ring of Fire zone is Sulawesi Sea Waters. To see the potential weak zone in the field, geophysical and geological studies are needed in interpreting the underground structures and the search for low velocity zones using reflection seismic, so that the vulnerable locations causing earthquakes in the area are obtained. The weak zone in the subsurface structure can be modeled by using seismic reflection method based on the wave propagation properties that can reflect in a certain critical angle in its propagation time, the wave through the boundary field which separates a layer with another one by the bigger velocity waves [2].

In order to interpret the earth's surface form by using seismic data, it is necessary to conduct processing steps. In the migration processing step is carried out some correction to get a high seismic section with S/N (signal to noise ratio) without changing the shape of reflection appearance, in other words, reducing noise and amplifying the signal [3]. Migration in seismic data aims to map seismic events in their actual position, which means moving the reflection point from the recording point to the actual reflector ones. This migration is executed by stack way (pre-stack migration), with the
advantage that it is able to carry out at each shooting point so that it can increase the S/N of the data [3].

This research will analyze the cross-sectional results in the Pre-Stack Time Migration stage by utilizing Kirchoff method because this calculation can solve the problems that include the time, angle and distance domains found in the seismic section [4].

2. Migration On Seismic Data
Seismic data migration is a seismic data processing that has the aims to map a seismic event in its actual position [5]. Seismic data migration as part of the seismic data processing attempts to eliminate the diffraction and reflector tilt effects. There are many migration methods that are used to produce seismic sections that approach the subsurface of geological structure. Migration is carried out to move the reflector tilted to the actual position and the surface can be described in detail, for example, fault areas or large zones. Pre-Stack Time Migration is a seismic data migration technique that is applied before the stacking process. Compared to Post-Stack Time Migration, this stacking process provides better results especially to be conducted in imaging complex structures such as conflicting dips structure and energy reduction from reflection points due to side swipe [6].

The methodology commonly used to process PSTM is: firstly, convolution with elliptical impulse response, secondly, by summarizing along the diffraction response curve (Kirchoff migration). For the first methodology, seismic data is sorted into common offset domains. Furthermore, the data is convoluted with elliptical impulse, because the PSTM usually has a smooth velocity variation, so the residual NMO correction is applied after the main NMO. Elliptical impulse response is built based on the ellipse equation as follows:

\[
\frac{x^2}{L^2} + \frac{z^2}{d^2} = 1
\]

\[L_2 = h_2 + d_2\] (1)

Where :
- \(h = \) offset/2
- \(L = T/2\)
- \(z = \) depth = \(v*T/2\)
- \(x = \) offset
- \(t = \) time (TWT)

The second way for PSTM is to summarize the diffraction response curve (Kirchoff migration). Diffraction response curves can be constructed based on equation (2) as follows:

\[T = \sqrt{(y-h)^2+z^2} + \sqrt{(y+h)^2+z^2}/v\] (2)

Where \(T\) is travel time, \(z\) is \(v*T/2\), \(h\) is offset/2, \(y\) is aperture, \(z\) is depth and \(v\) is RMS velocity while \(T_0\) time is at velocity \(v\).

2.1. Root Mean Square (RMS) Velocity
Root Mean Square (RMS) Velocity is the total velocity of the horizontal coating system in the form of average rotation. If the vertical creep time is \(\Delta t_1, \Delta t_2 \ldots \Delta t_n\) and the velocity of each layer \(v_1, v_2 \ldots v_n\) then the RMS velocity for layer \(n\) is written with equation (3) below:

\[v_{rms}^2 = \frac{\sum_{i=1}^{n} v_i^2 \Delta t_i}{\sum_{i=1}^{n} t_i}\] (3)

The process of velocity analysis is the most important process in the processing of seismic data, because in the velocity analysis will get a velocity value that is accurate enough to determine the thickness, depth and slope of a reflector [7].
2.2. Kirchoff Migration Method
Kirchoff migration or often referred as Kirchoff addition migration is one of migration methods based on the sum of diffraction summation curves. This method uses statistical approach where the position of a point below the surface can only come from various possible locations with the same probability level. Practically, Kirchoff migration utilizes in adding up the amplitude of a reflector point as long as a position is a possible real location.[8]

3. Study Area
The field data collection process was carried out by The Center of Marine Geology Research and Development (PPPGL) Bandung, on 2 May - 3 June 2016 located in the Sulawesi Sea Waters, North Sulawesi, Indonesia. Data acquisition was carried out on 22 paths stretching at coordinates 127º0’0” E and 1º0’0” N to 122º0’0” E and 2º0’0” N. Data processing was processed in April - June 2017 at the ProMAX Laboratory in The Center of Marine Geology Research and Development, Ministry of Energy and Mineral Resources, Bandung.

4. Data and Methods
The method used in this research is multichannel Seismic Reflection. The device is used in the form of computer hardware with a Linux operating system with ProMAX 2D R5000.0 © 1989-2008 Landmark Graphics Corporation software. The material used is secondary data with the excites SEG-D which can generate magnetic tape recording on the acquisition of seismic data by Geomarine Research Ship 3. The seismic data processing itself uses several steps such as follow [9]:

4.1. Data Input
The inputted data is in the form of SEG-D data, this raw data is basically composed of waves that represent distance series. This demultiplexed seismic data that can be used in processing seismic data, which has been arranged according to the time series and the waves are arranged in a time sequence.

4.2. Geometry
This stage aims to input the value contained in the observer report table in the form of XY, FFID coordinate data and station data which is intended, so that the data is processed exactly with the actual position in the field.

Figure 1. Line Map Marine Seismic L-22 (red line)
4.3. Editing
This process aims to cut and remove damaged trace data in order to obtain a good seismic section before the next process, at this stage also determined the limit value for the autocorrelation and deconvolution process.

4.4. Preprocessing
There are several processes at this stage. The Band Pass filter aims to reduce the noise found in seismic data by using the Ormsby bandpass type [10], the filter in which uses four frequencies. True Amplitude Recovery (TAR) is an effort to restore lost energy due to geometrical spreading and energy attenuation due to the further distance traveled while the frequency of the waves is getting higher [10]. Next, the autocorrelation functions to calculate the specified trace limits. While on deconvolution attempts to reduce the effects of multiple or repeated signals regularly.

4.5. Velocity Analysis
The process in velocity analysis is by selecting a velocity that has a high Semblance value and red energy approaching or according to the color scale used.

4.6. Migration
The final stage of this research is migration correction which attempts to increase the slope angle, shorten the reflector, move the reflector towards up to dip and improve lateral resolution [11].

![Flow data processing with ProMAX](image)

**Figure 2.** Flow data processing with ProMAX

5. Result and Discussion
Migration which is carried out before stacking or commonly referred as Pre-Stack Time Migration (PSTM) is a process to provide better results on seismic crossings especially on fairly complex structural imaging, the Pre-Stack Time Migration process is considered as a better stage than Post-Stack Time Migration [12], because the data used is the result of deconvolution that have not been processed yet on the stack gather, so the final result of this process will be better than the Post-Stack Time Migration. The migration process in this research using Kirchhoff addition method, in Kirchhoff method usage there are several parameters that are very influential in seismic cross section results in the form of velocity model, maximum slope, window width and frequency in the migration process.
The migration process greatly utilizes diffraction events based on the Huygens principle that each wavefront can be considered to produce a new wave. If the wave is reflected in a flat plane, each point of the migrated result will show a flat plane. The results of the diffraction itself can show the appearance of seismic cross sections such as faults, arches, bowtie diffraction effects, reflector continuity and weak velocity zones. Therefore, migration is very dependent on the value of the velocity used, if the velocity is weaker than it should be then the result of migration will leave a diffraction trail due to undermigrated.

Migration is very good in removing diffraction effects so that it can clarify detailed subsurface structures. A good reflector continuity appearance is seen during migration compared to stacking in figure 3. Because in the migration before the stack can focus the energy of the seismic event, the process data becomes simpler and can correct the inaccuracy of the position of the reflector so that the reflector position can be placed in the actual position.

![Figure 3](image1.png)

**Figure 3.** Comparison the continuity of reflector in seismic cross section (1) After Stacking, (2) After migrated before stacking time Kirchoff at the depth of 8.100-8.600 ms.

From the results above shows the cross-sectional reflectivity with strong wave penetration at TWT 8,100-8,600 ms, where from the reflectivity shows the seismic cross-sectional stratigraphy is quite clear because in the PSTM process can further sharpen the position of the reflector.

![Figure 4](image2.png)

**Figure 4.** (A) Basin Stratigraphy Interpretation on Sulawesi Trench after Pre-Stack Time Migration (PSTM), (B) Seismic Cross Section Line L-22 taht displays the interpretation of seismic stratigraphy in the field of Sulawesi sea water.
The final result of the Pre-Stack Time Migration (PSTM) is shown in the figure above which can be interpreted by the seismic appearance structure. The seabed of North Sulawesi is located at a depth 6,500-7,300 ms which is the deepest area in this zone. The black line shows the presence of a fault at a TWT depth from 7,300 to 8,500 ms which is due to the activity of tectonism and the fault moves dominantly towards the foot wall.

In addition, at the same depth can also be interpreted as in (4B), the L-22 trajectory seismic crossing at a TWT depth of 6,400 to 8,700 ms shows several reflectors with various features. The green horizon is the result of the first reflection of seismic waves to the earth's surface, this line is drawn based on the level of the reflector's continuity and high frequency level. Moreover, in the lower horizon are green, yellow and orange lines where there are visible sediment deposits from seismic wave reflection events. Furthermore, the red horizon has a reflector discontinuity when the curvature of the surface that occurs due to differences in acoustic impedance, it is estimated to have a fault, (1) is part of the foot wall and (2) part of the hanging wall. Small arrows leading to the subsurface are the direction of the tectonic dynamics of the earth's surface. Low velocity zones in these seismic crossings are seen in certain CDP zones due to amplitude values which also decrease with increasing velocity. The weak zone is formed due to lithological problems so that the velocity in the area decreases.

![Common Depth Point (CDP) 7,350.8](image1.png)  ![Common Depth Point (CDP) 9,814.8](image2.png)

**Figure 5.** (A) The Graph of Low Velocity Zone at CDP 7.350.8 and (B) High Velocity Zone at CDP 9.814.8

As a comparison, there are also known differences in velocity values in the low and high zones in CDP 7,350.8 and 9,814.8 which are contained in the graph.

6. Conclusion

The Kirchoff Pre-Stack Time Migration method is a migration method to move the position of the reflector to the actual position, which is done by adding up the amplitude of a reflector point as long as a position is estimated to be the actual location using the Root Mean Square (RMS) velocity. The results of the interpretation of Pre-Stack Time Migration are in the form of seismic stratigraphy, with the presence of continuous reflectors, Sulawesi trenches, fault discontinuities and horizon layers of land sedimentation from the L-22 in the Sulawesi Sea waters. The existence of low velocity zones can be analyzed in velocity analysis, by reading the root mean square (RMS) velocity in the cross section obtained, in this path the lowest velocity zone distribution is at the common depth point (CDP) 7,350.8 with depth TWT 11,860 ms to TWT depth of 10,967 ms has a constant velocity of 2,291 m/s, and it is estimated that there is a weak rock structure.

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