ISSN: 2579-5821 (Print)
ISSN: 2579-5546 (Online)
URL address: http://journal.unhas.ac.id/index.php/geocelebes
DOI: 10.20956/geocelebes.v8i1.24638

Jurnal Geocelebes Vol. 8 No. 1, April 2024, 11 – 25

2D Marine Seismic data Analysis Using Comparison of Kirchhoff's Migration Method and Finite Difference Method (Case Study: Nias Basin, North Sumatera)

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Manuscript received: 20 December 2022; Received in revised form: 6 September 2023; Accepted: 25 October 2023

Abstract

Seismic migration is one of the important stages in seismic data processing which aims to map seismic events to their actual positions. The migration process used in this study is post-stack time migration in the time domain using the Kirchhoff migration technique and the finite difference method to determine the results of subsurface imaging from the two migration techniques and then compare them to determine the accuracy of selecting the appropriate migration for the L08 basin trajectory research area. Nias basin, North Sumatra. The processing steps are carried out according to the preprocessing to processing stages in the Promax 5000 software. Based on the results of the study, the optimum use of aperture migration in Kirchhoff migration will produce good subsurface cross-sectional imaging. The aperture value used is 3000 ms. In the finite difference migration, subsurface imaging is much more focused with a time step variation of 10 ms, whose function is to focus the hyperbolic diffraction energy on the migration data.

Keywords: finite difference; Kirchhoff migration; reflection seismic.

Citation: Annisa, C. F. N., Muliadi., Ivansyah, O., & Subarsyah. (2024). 2D Marine Seismic data Analysis Using Comparison of Kirchhoff's Migration Method and Finite Difference Method (Case Study: Nias Basin, North Sumatera). *Jurnal Geocelebes*, 8(1): 11–25, doi: 10.20956/geocelebes.v8i1.24638

Introduction

The need for oil and natural gas in Indonesia continues to increase yearly, so oil and gas energy exploration activities continue to be carried out. Bearing in mind that oil and natural gas are still the dominating energy in national energy use, efforts to increase oil and natural gas reserves are made regularly. One of them is expanding the scope of the search for new oil and gas reserves, especially in the high seas (marine). The National Energy Committee (KEN) provided recommendations regarding biogenic gas research in oil and gas basins in several locations in 2016 and provided recommendations regarding biogenic gas research in 10 Indonesian basins, one of which is the Nias basin, North Sumatra.

The method used in this study is the seismic method, especially the use of the seismic reflection method which utilizes reflected waves from the injection of wave sources which are generally in the form of explosions using dynamite as a source in the reflector field (rock coating boundary) (Permana et al., 2015).

The seismic method is one of the geophysical methods of geophysical method by utilizing seismic waves seismic waves to produce vibrations on the waves are generated from a source and then recorded source and then recorded then recorded by the receiver. The farther distance between the source and the receiver, the longer the recording process (Nainggolan et al., 2019).

The seismic method has a wave source from dynamite and vibroseis (if the reflection is on land), air guns (if the reflection is at sea), and sledgehammers (if refraction) and has a receiver in the form of a geophone (if the survey is carried out on land) or hydrophone (if the survey is carried out at sea) so that the response from wave propagation can be received by the receiver or sensor. The influence of the reflector field when seismic waves bounce can cause one of them is the diffraction and smiling effect, both of which affect the results of the subsurface cross section during data processing. So, it is necessary to do a migration method which is a problem limitation in this study (Sea et al., 2017).

Migration is a process in seismic data processing that aims to improve the image of the subsurface cross section that has been processed from acquisition data that initially has reflectors that do not match the actual data (Sidiq et al., 2019). Migration aims to make seismic sections like the actual geological conditions based on the reflectivity of the earth's layers. The accuracy of the migration technique greatly affects the resulting seismic section (Nurlindah, 2017). The difference in amplitude anomalies seen between layers is due to the contrast in density of rocks in the subsurface and shows better reflectivity after migration (Asriani, 2020). Each method has its advantages and disadvantages and each has different sub-methods. All these migration methods have the same goal but with different approaches and processing steps according to the problems that exist in the data itself (Rasimeng, 2020).

The methods used in this study are the Kirchhoff migration method and the finite difference method. The working principle of each of these migration methods that produce the reflectivity image pattern will be considered. In Kirchhoff's migration, the problem is solved by using the sum of the amplitudes at the reflector points along the path at the actual location, and the range of the structure migrated by this method is wider, with the migrated angle reaching a maximum point of 90˚. The finite-difference migration method, on the other hand, is a migration that utilizes wave separation using the finite-difference numerical method. This method is often referred to as the wave equation method, seismic data processing looks for differential operators in the wave equation either explicitly or implicitly (Sheriff & Gerald, 1995) and has the advantage that it can be applied to data with a low signal-to-noise ratio (bad data).

Research related to seismic methods, specifically Kirchhof migration and Finite Difference data processing, has been conducted by several previous researchers. Sukmana et al. (2014), have conducted Finite Difference and Kirchhof migration studies on 2D reflection seismic data and can produce migration stack data showing the desired subsurface image. Chintia et al. (2017), have conducted research by analyzing the gap parameters in the predictive deconvolution stage, which works to reduce short-period multiples and increase the signal-to-noise ratio in marine 2D reflection seismic data processing. Anggary et al. (2015), has carried out a comparison between the post-stack time migration finite difference method and the Kirchhoff method with gap parameters deconvolution seismic data 2D line "SRDA". From the various studies conducted, the researcher realizes that migration with one method allows there to still be reflectors whose reflectivity pattern is not clear. Therefore, in this research, a comparison was made between the Kirchhoff migration method and the finite difference method in the Nias Basin research area, North Sumatra, to complement each other and to know the advantages and disadvantages of each migration to obtain better subsurface cross-sectional imaging results.

Materials and Methods

The field data used in this study are the GM3-BIO-NIAS-L08 data, which is one of the 2D seismic line on the detailed Singkel line (Figure 2), which has 26 lines with a length of 767.03 km, obtained from seismic acquisitions conducted by the Marine Geological Survey and Mapping Center (BBSPGL) using the Geomarine III vessel, which was carried out from 20 June to 13 July 2018 in the Nias Basin, North Sumatra, using the SEG-D data format (BBSPGL, 2018).

Data processing was supported by the ProMAX 5000 2D software to successfully obtain the best seismic cross section by applying the Kirchhoff Post Stack Time Migration method and the Finite Difference method. Data processing begins in detail with the first stage being pre-processing, namely data input, geometry editing, filtering, and deconvolution (Figure 2). This data does not need to be reformatted, but the data used has not been added to the positional information and contains changes to it. The input data used in data processing are raw data in SEG-D format.

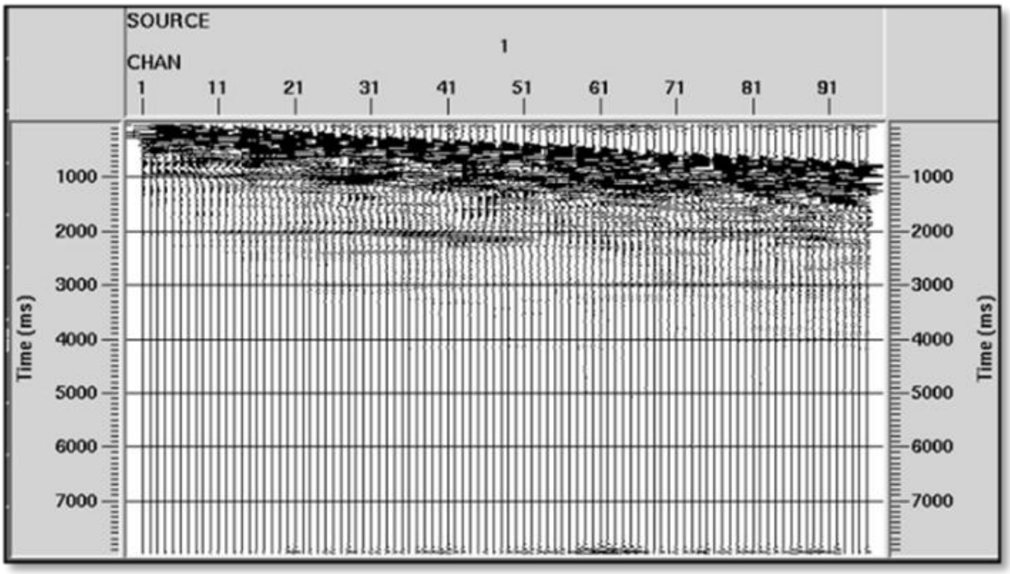


Figure 1. Shot gather with a bandpass filter.

Table 1. Table parameters

Configuration	off-end
Aktif Channel	96
Line Azimuth	345˚
Shot interval	25 m
Group Interval	12.5 m
Number of Shot	946
Near offset	50 m
Far offset	1137,5 m
Fold Maximum	24
Line Length	23,625 km
SR	2 ms
RL	8000 ms

Figure 1 shows an example of shot gather data with a bandpass filter applied. The shot gather is then combined with geometry parameters (Table 1) whose function is to match the survey geometry with the recorded seismic data, because the seismic data recorded in the field only contains SOU_SLOC data or station values, FFID which indicates the shot number and channel that is active in data acquisition. as the function of data acquisition in indicating hydrocarbon content in the subsurface, acquisition needs to be planned and calculated based on the target to be obtained based on what parameters are used (Banuboro et al., 2017). In addition, to facilitate data presentation in data processing, other acquisition parameters need to be added such as shot point coordinates, receiver coordinates, CDP coordinates, CDP numbering, offsets, and others.

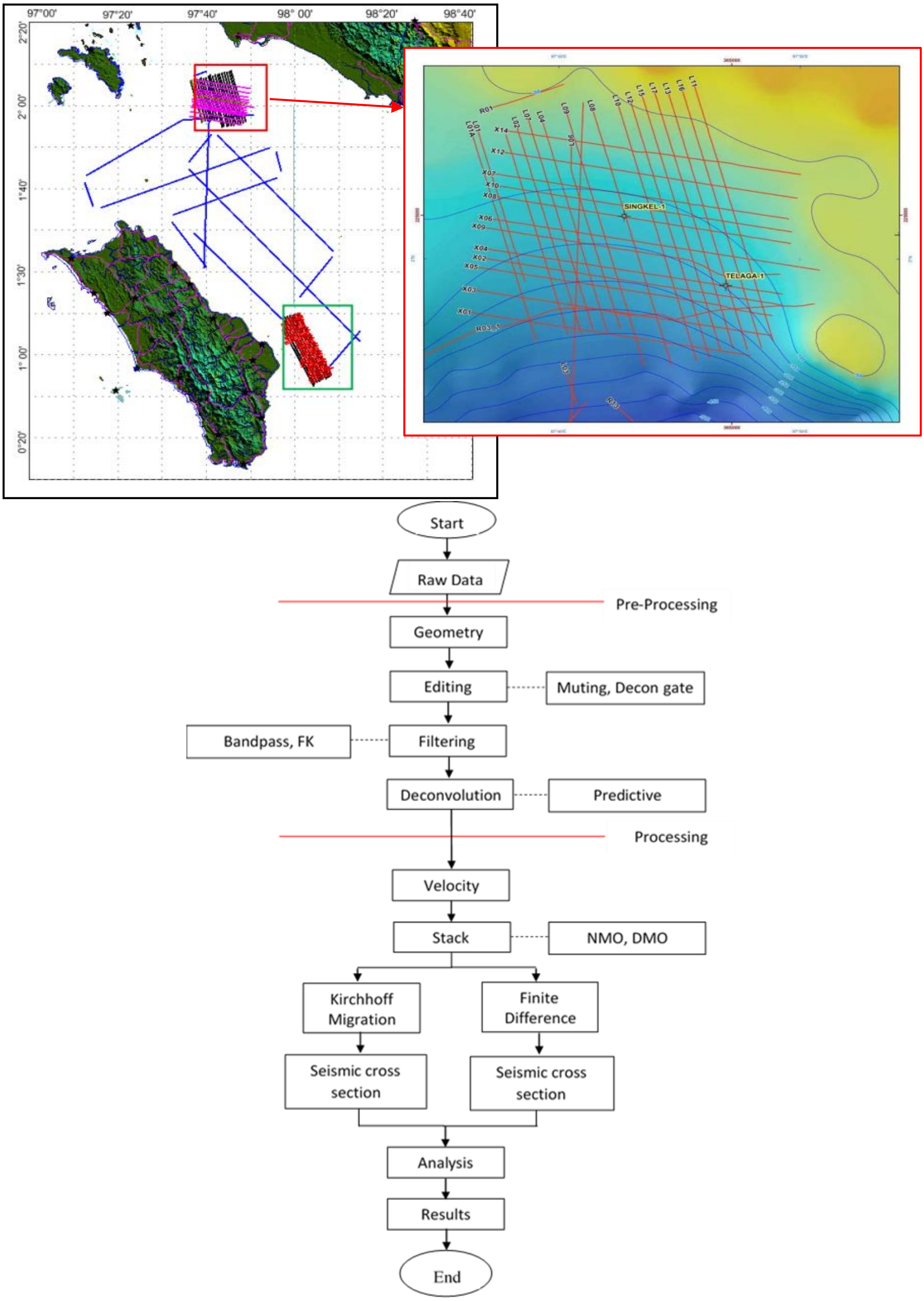


Figure 2. Research flowchart (below) and Location of the Nias Basin Biogenic Gas Survey, North Sumatra, with detailed research locations at the Singkel Site (red box) (BBSPGL, 2018) (left).

Geometry aims to match the file number (there is an observer report) to the file record of the seismic data recorded in 1 shot. Frequency filters such as bandpass and FK filters are applied to this data to separate the desired frequencies from the seismic waves and eliminate unwanted frequencies, so that the resulting image will be smoother and the layers are clearer (Permana et al., 2015). This process is enhanced by predictive deconvolution, which is used to predict the arrival of multiple reflection waves in the seismic traces by applying gap values, including the length of the gap and the length of the operator tested by the process, to the data. The selection of multiple gap values is also used to see how far the noise is reduced and the deflection width, which is the primary data, is still maintained. The gap value is reinforced by applying autocorrelation analysis to see how effectively predictive deconvolution is applied. This method can reduce multiple short period types of noise to increase the required signal-to-noise ratio (Chintia et al., 2017). The next stage is what is known as routine processing, which includes velocity analysis, stacking, NMO, DMO corrections and migration.

Velocity analysis uses the semblance method, where the velocity obtained is the root mean square (Vrms), which is the total velocity of the horizontal layering system in the form of square roots. The purpose of stacking the survey data is to increase the number of seismic traces in a CDP after NMO correction so that the signal-to-noise ratio (S/N) is higher because coherent signals enhance each other and incoherent noise cancels each other out. NMO and DMO corrections were performed to eliminate the effect of different offset distances for each receiver in the CDP format and to see the pattern of reflectivity at the zero-offset position of the CDP (Sukmana et al., 2014). Then, with the presence of complex geological structures that cause velocity variations with depth, causing problems in determining the position of the structure and problems at the time of the migration process. Therefore, velocity analysis is a very important process in the seismic data processing stage (Manrulu, 2016).

The stacking to migration stage can be referred to as the post-stacking stage, which aims to return the reflector to its true position. So that the migration stage has a function as eliminating the effects of diffraction at discontinuity points (faults) and moving the event layer obliquely in this position caused by oblique reflectors or faults. In a seismic cross section with zero offset, the waves received by the receiver are considered as a depiction of the shape of a layer directly below the source and receiver (Asrori & Santosa, 2015).

The cross section resulting from the migration process in the time domain called time migration can generally be applied to small to medium lateral velocity variations and the migration process in the time domain performed after the stack (post-stack time migration) is relatively faster and more efficient in processing seismic data (Anggary et al., 2015).

The migrations used are Kirchhoff and Finite Difference. The Kirchhoff migration process is carried out by adding the amplitude of a reflector point along a notch, which is the actual possible location in the form of a diffraction curve, while the finite difference migration uses a wave separation using the finite difference numerical method. An apple-to-apple analysis of the seismic section was then carried out on both methods to determine which migration gave the best results.

Results and Discussion

Preprocessing

The trace display shown in Figure 3 is a display of trace acquisition data that has been provided with geometry and bandpass filter information, and it is known that this data has multiple, which indicates the presence of a seismic event that experiences more than one reflection from the position of the primary reflector. The multiple is included in the coherent noise found in the collected trace, so the filter frequency applied to this data really helps to eliminate the existing noise.

The filters used include bandpass and FK filters. Prior to filtering, a spectral analysis is performed to identify the frequency content of the data so that the frequency design to be used can be determined. The frequency used is usually above 3 dB, and in this processing the frequency 10-15-45-60 is used (Figure 4). When selecting this frequency, it is important to consider whether the data used needs to be bandpass filtered, as seismic data typically has a frequency range of 10 to 70 dB, and anything below a frequency of 10 or above a frequency of 70 will be clipped or eliminated.

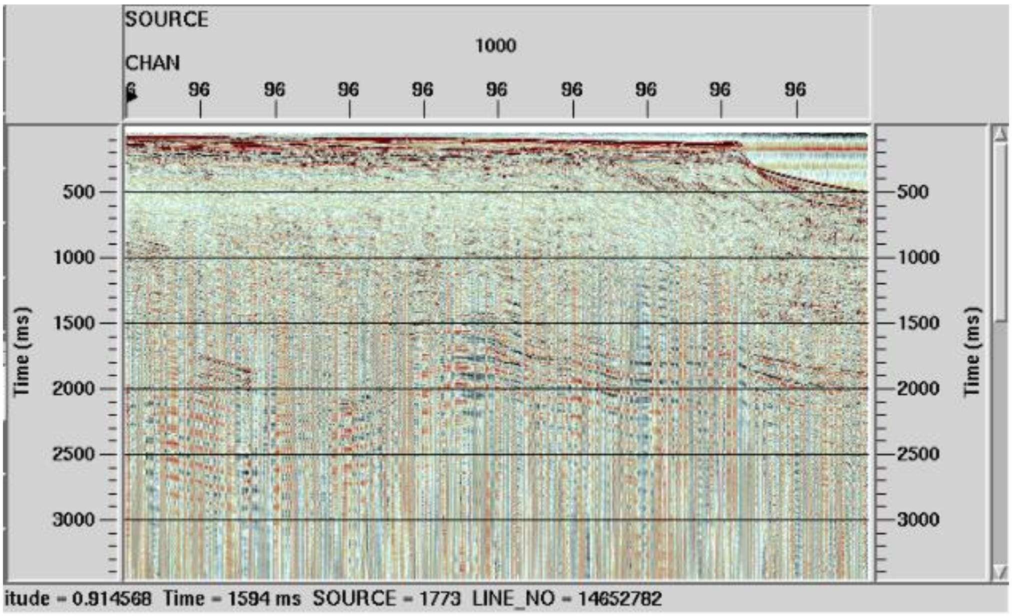


Figure 3. Brute-stack geometry.

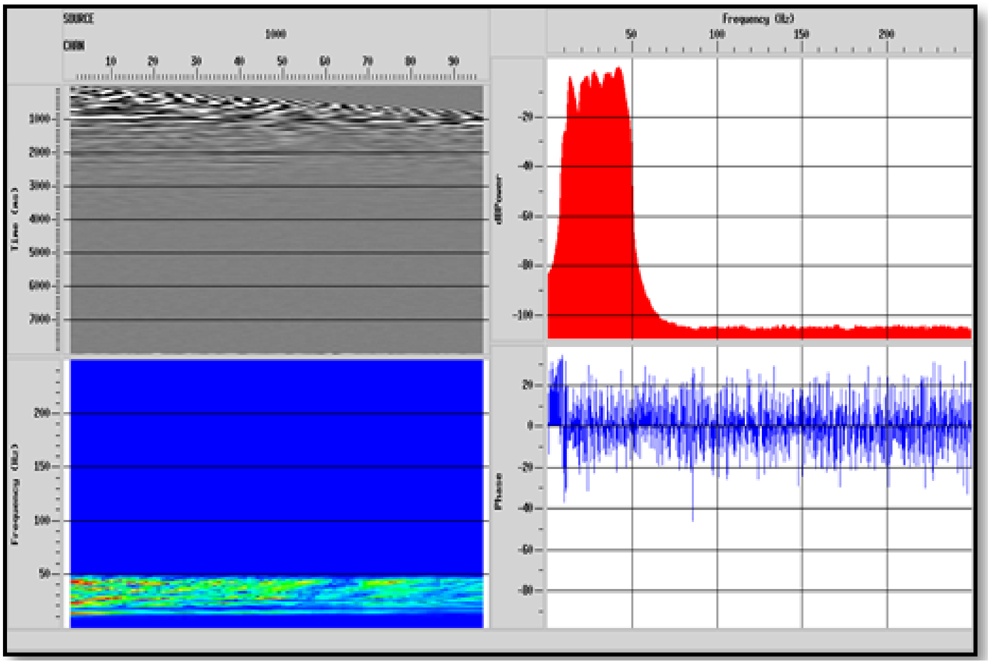


Figure 4. Interactive spectral bandpass 10-15-45-60.

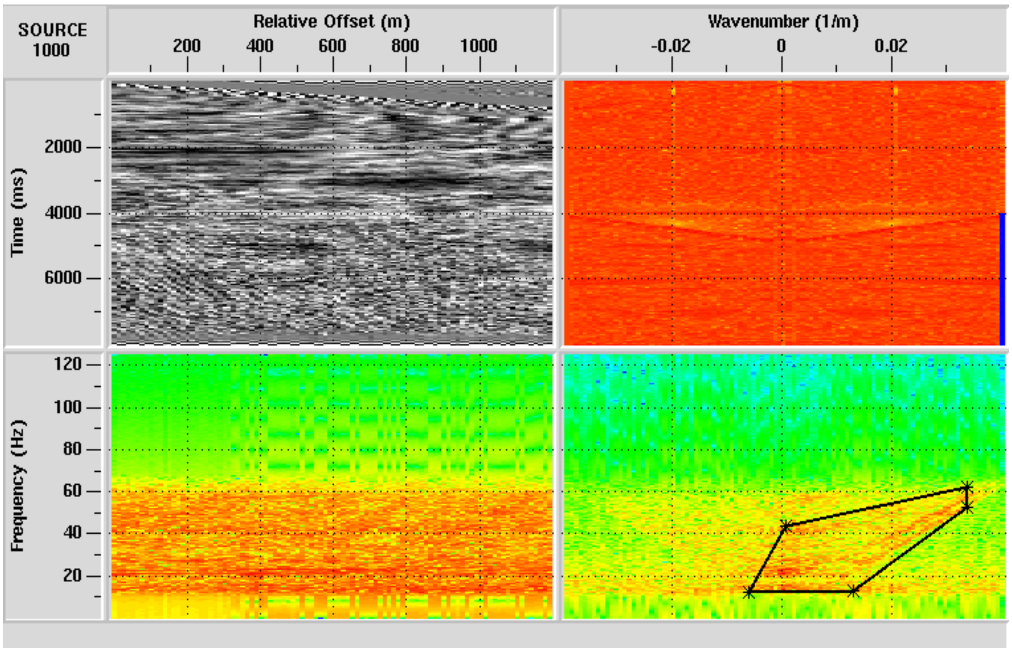


Figure 5. Picking results on FK analysis.

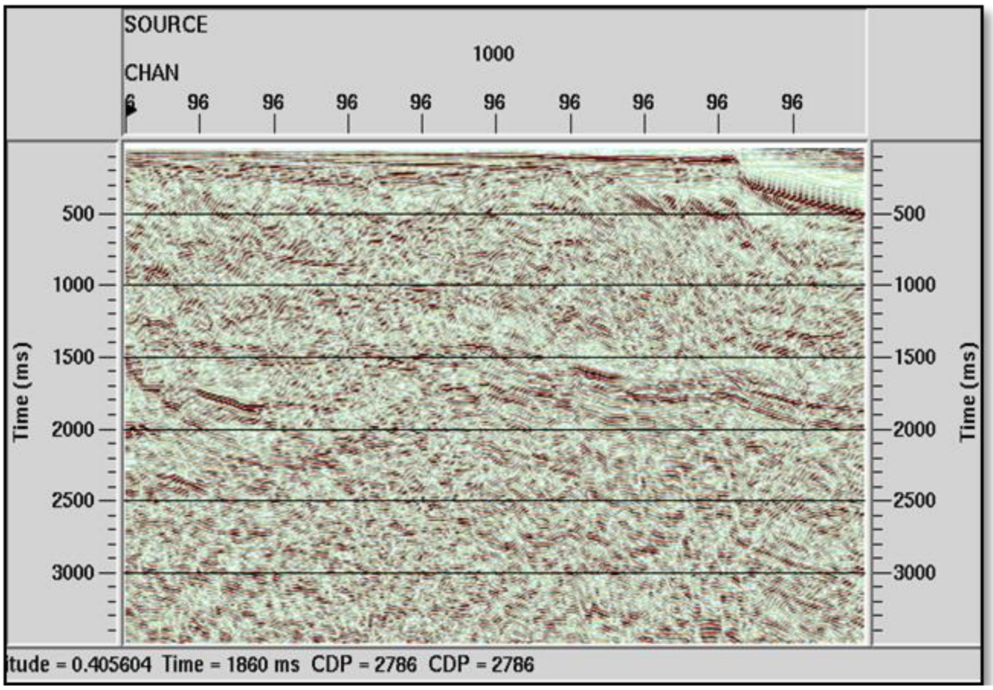


Figure 6. Brutestack after deconvolution.

The frequency filter used next is the FK filter, which functions as a linear coherence filter in the space-time domain wave equation (t-z), which is transformed into the wavenumber frequency domain due to the dip. The FK filter in this study is focused on the elimination of surface wave noise, direct waves, and bias waves that appear in the first reflection of seismic data. The modules used are F-K analysis and F-K filter. The selection results in the F-K analysis (Figure 5) correspond to the number selection with the noise data to be eliminated. Sub-sampling and automatic gain control are also applied to this data to display frequencies more clearly so that noise can be reduced. The noise to be reduced is the noise marked with a red bias (in the picking polygon in the figure), with the frequency domain and wavenumber used so that the recorded double noise can be attenuated and the picking performed is expected to match the actual data. In research conducted by Rasidin et al. (2022), that the use of F-K Filter is very powerful in removing noise contained in seismic data. The frequency of seismic data is difficult to separate if it only relies on a bandpass filter, so the polygon selection in the F-K filter is based on polygon selection. Polygons in the F-K filter is because coherent noise such as ground rollers and multiples will have. The velocity and frequency differences with the actual reflected wave thus have different slopes on the frequency spectrum and wave number. As can be seen in the figure above (Figure 6), the multiple has been well reduced, but the reflector trace is still somewhat abstract at times between 1000 ms and 2500 ms and its structure is not clearly visible, although good reflector seismic events are visible on the trace surface.

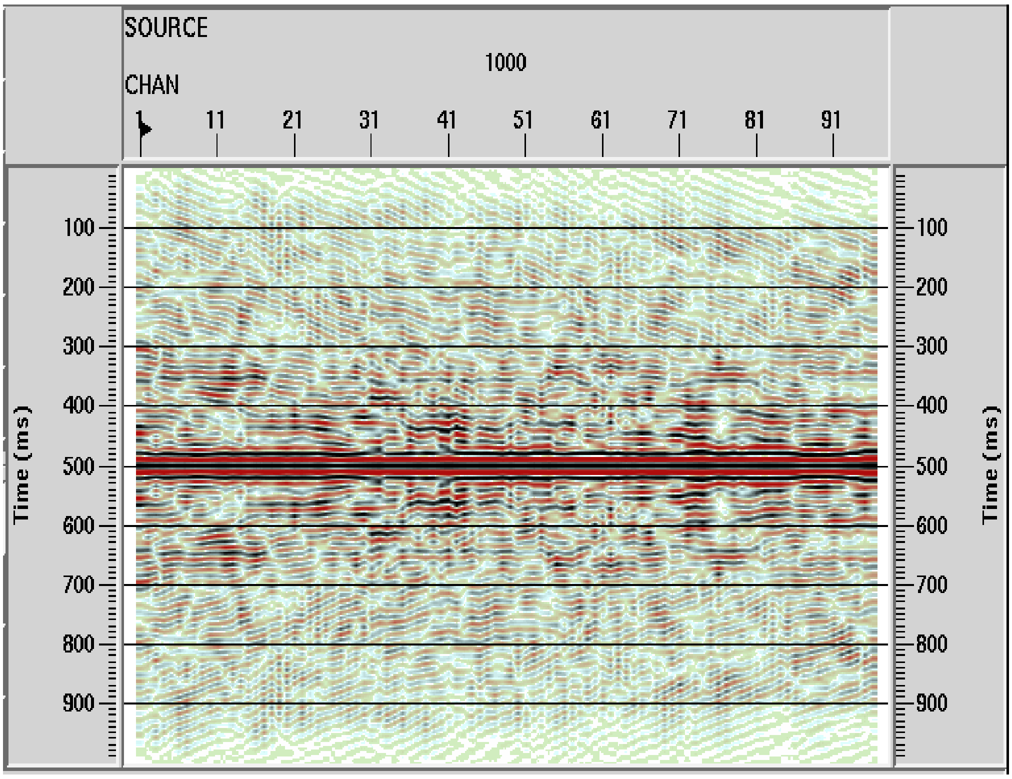


Figure 7. Autocorrelation gap 85-35 ms.

This process is enhanced by the selection of gaps in predictive deconvolution using the principle of a prediction error filter because multiples can always be predicted in seismic traces. The selection of this deconvolution is also based on research conducted by Romauli et al. (2016), that the spectral analysis of the predictive deconvolution is more effective at enhancing signal and suppressing noise than spiking deconvolution. Compared to spiking deconvolution. and of course, after try and error. This predictive deconvolution process uses a method of selecting several gap values to validate that the gap is close to the true value, characterized by reduced noise, and that the deflection width, which is the primary data, is still preserved (Figure 6). In autocorrelation, the width of the deflection indicates the presence of the primary data (black line), the rest is noise. So, in this study, a gap value of 85-35 ms (Figure 7) was chosen after trial and error in autocorrelation analysis, including using gap values of 80-12, 90-30 and 120-40.

Processing

The velocity analysis method used on this data is the velocity semblance method or amplitude plot, which is a plot of velocity signal similarity versus two-way zero offset time (TWT). This method displays the Semblance and CDP gather sections simultaneously.

The semblance display is shown as color contours, generally with the maximum color coherence being red and the minimum coherence being blue, and when using semblance panels, it is usually chosen by ensuring that the signal amplitude does not differ from the offset. If the seismic amplitude is evenly distributed along the displacement curve, the horizontal semblance of the semblance will be maximized by the gather as the event progresses.

In the Figure 8, the retrieval speed starts at 1000 m/s and the retrieval should have increasing speed values as the TWT (Two Way Travel time) increases, thus avoiding retrieval at multiple speed values. The CDP collection shown has a range of 100 between other CDPs when picking and NMO has been applied. Picking is done on CDP as much as approximately 3358 data. but not all CDPs are picked, the rest that are not picked will be interpolated from the speed picking results on CDP. and the data created has been applied smoothing using the velocity manipulation module. this is also applied in research conducted by Jamaludin et al. (2020).

After the velocity analysis is obtained, the next step in this study is to divide the data into two treatments, namely the stack to which DMO correction is added and the stack to which DMO correction is not added. This is done with the aim of checking which data is close to the actual data to be sent to the migration stage, so that the final data is in accordance with the appearance of the desired subsurface image by looking at the seismic shaping reflectors in the data.

The subsurface section using the DMO data stack before migration shows a firmer structure (Figure 9b) compared to the results of the stack without DMO (Figure 9a). In this figure can be seen that the resulting section is not very good because the resulting geological conditions are not very clear, making it difficult to distinguish between seismic horizons, especially in complex areas such as those marked with a red circle in Figure 9. Also, this migration has not been applied to the data in the flow stack, so the signal position is not at the true position and the visible reflector is still affected by diffraction effects.

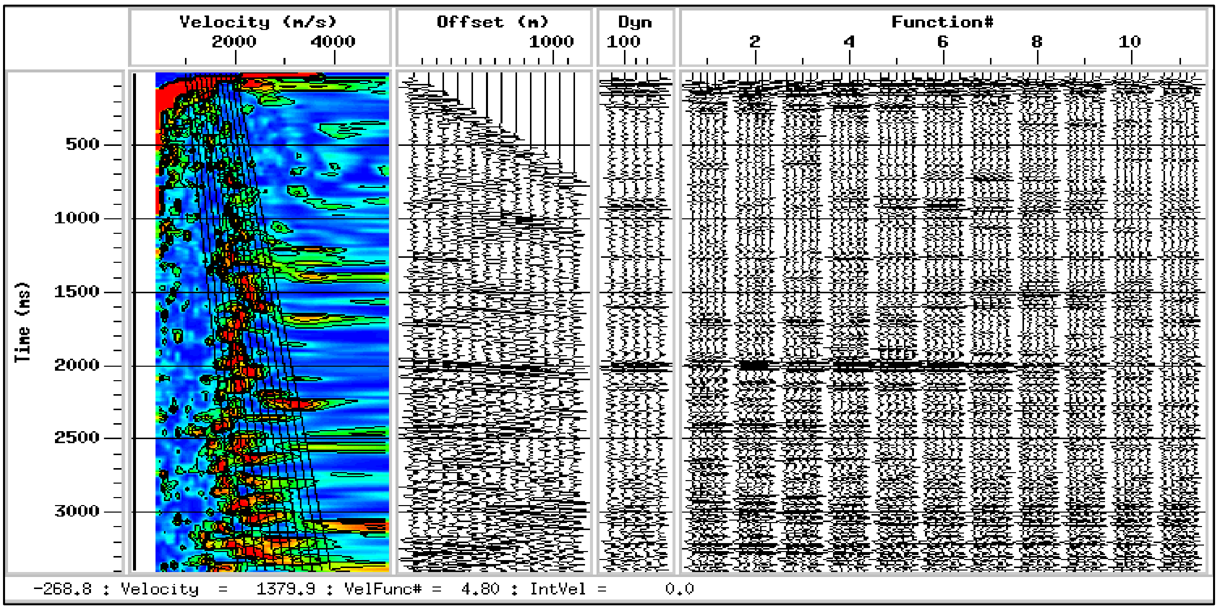
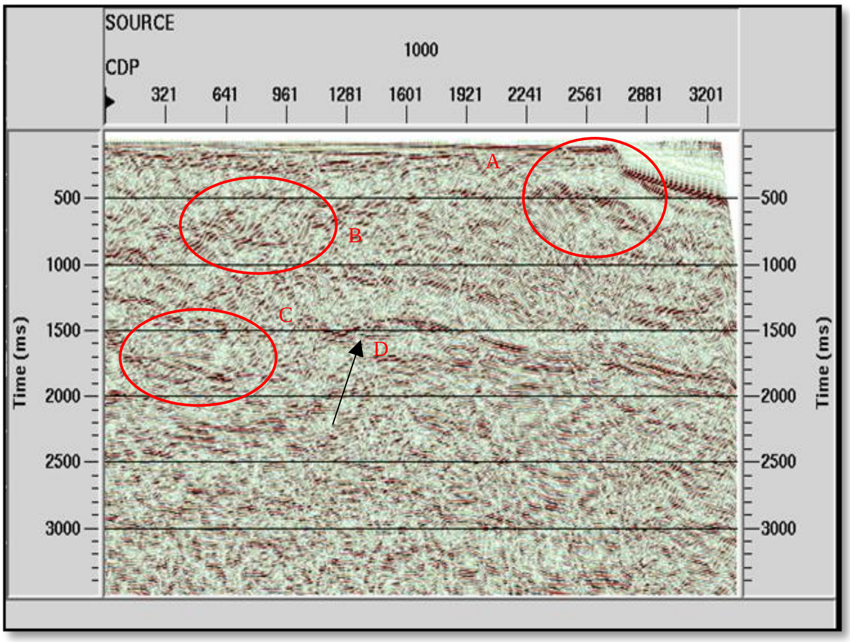
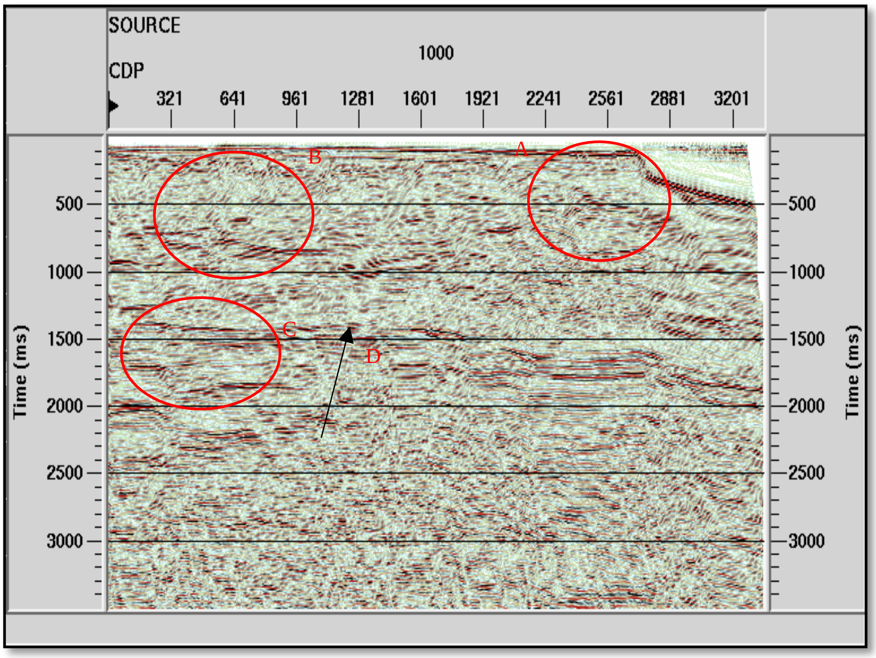


Figure 8. Picking velocity analysis on CDP 106.



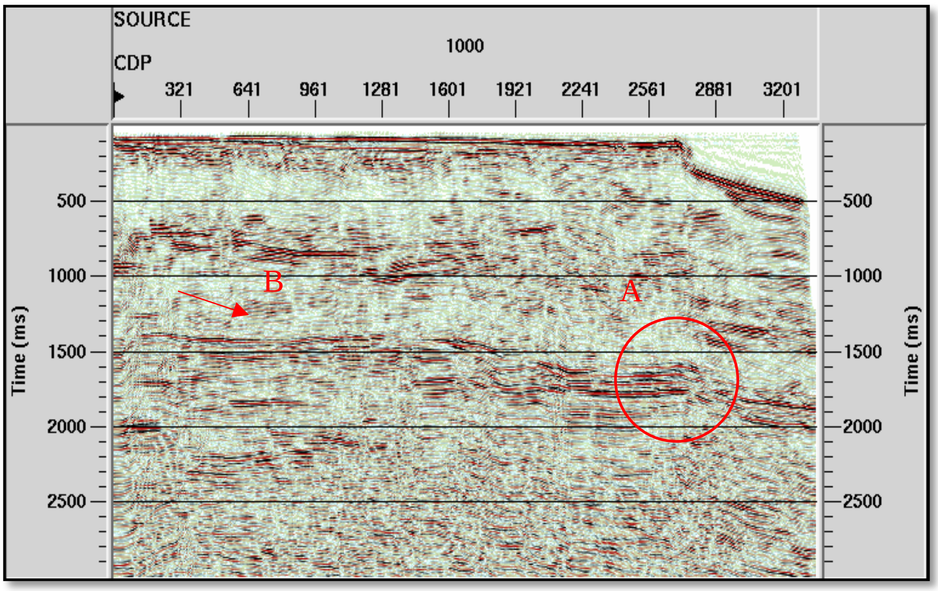
(a)



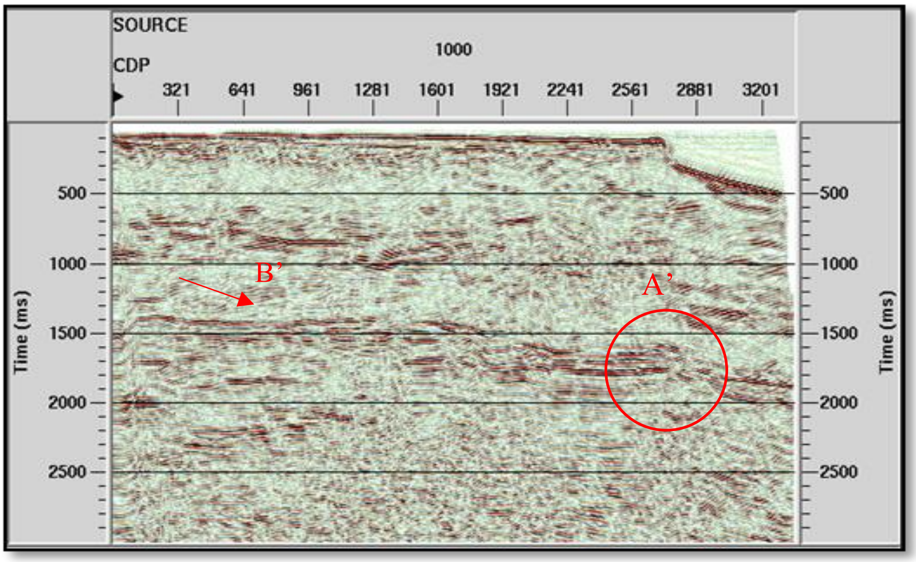
(b)

Figure 9. Brute Stack without DMO (a) and with DMO (b).

The two figures show a seismic cross section propagating in TWT (two-way travel time). In Figure 9a there are reflectors that are not continuous at points A, B, C and D. This is because the stack method used is based on a travel time parameter that is highly dependent on the velocity and trace model in the CDP survey, which must first be corrected by NMO to remove the effect of offset distance. While the results of the brute stack cross section with DMO (Figure 9b) show that the reflector has increased S/N, as indicated by more solid reflector lines, especially at points A, B, C and D, because the DMO stack uses more CDP gather, resulting in a better cross section. At 1500 ms or point D there is clear continuity, although it does not look good for imaging the seismic section.



(a)



(b)

Figure 10. Kirchhoff migration results (a) and Finite Difference (b).

Migration result and final analysis

Based on the results of the stacking performed, the subsurface image used in the migration and final analysis is a data process corrected by NMO and enhanced by DMO correction, because NMO correction itself is only effective when used on a flat reflector, and if it is not flat then CDP point shifting or so-called reflector point smearing occurs. DMO takes the slope of the reflecting plane in the data, so that the dispersion of the reflected points disappears and the signal-to-noise ratio increases. This is because DMO modifies the results of the reflection point stack, which is at the zero-offset point of a reflector, and corrects for the sloped layer by creating the seismic trace within the CDP (Susanti et al., 2020).

The results of this research migration data have been operated with the optimum stack and have been attempted by providing NMO correction, CDP interval of 6.25 m, frequency 50 Hz, maximum dip 180 and Vrms in time migration, as well as providing sub-sampling trace display with f-k decon, dip scan stack and automatic gain control (agc) whose function is to clarify the appearance of the cross-section reflector. Once the stacking results have been compiled, the migration results then apply the DMO correction up to the analysis stage.

Figure 10a shows the results of the Kirchhoff migration test with an aperture of 3000m using the DMO correction. The aperture used in the Kirchhoff migration is an important parameter to show its relationship with the noise generated. Previous tests have been carried out with apertures of 0 m, 1000 m, 3000 m and 6000 m, but for the data to be used for the migration, an aperture of 3000 m was chosen. This was chosen based on changes in aperture affecting the range and changes in angle can determine the level of tilt of the reflector, so that the more tilted the reflector value, the greater the angle value, this has also been proven by Handani et al. (2015) in their research. However, there are several things that need to be considered before choosing an aperture width, such as not using an aperture width that is too small, this will cause damage to tilt events and changes in amplitude that will vary and generate random noise, especially in deeper parts as the dominant event. Then, using an aperture that is too large can reduce the quality of the migration with a low signal to noise ratio and cause random noise in good shallow data.

The migration stack finite difference results (Figure 10b) appear to be no different from the Kirchhoff migration results, but at the migration horizon line the finite difference is not as clear as the Kirchhoff migration. And at the boundary of the strata, which is marked with a white line at 2000 ms to 2400 ms, seismic events can be seen that are more clearly continuous.

The finite difference migration applied to this data is conceptually physical, the method used is the same as Kirchhoff migration. This migration uses a maximum frequency of up to 80 Hz, with input data parameters in the form of final stack and time domain interval velocity. The method used in the finite difference migration itself is fast explicit Finite Difference (FD) time migration, which has previously been carried out FD migration data processing with the implicit FD algorithm with the parameters analyzed in this migration is the time step to be migrated before being compared with Kirchhoff migration. The time steps used are 5 ms, 10 ms, 20 ms, and 40 ms. The time step is used to concentrate the diffraction energy of the hyperbola. In this data, the time step used is 10 ms, when using 20 ms and 40 ms the seismic event on the imaging fades, this can occur because the hyperbola diffraction energy has begun to weaken. In contrast to Rahman et al. (2023) who in their research stated that the use of the Implicit FD Time algorithm is better, in this study Fast Explicit FD Time is better at processing data, this has also been proven by Jamaluddin et al. (2019) who stated that explicit finite difference migration succeeded in maintaining frequency data in accordance with the desired target. This can occur possibly due to the acquisition data model obtained or differences in reflectors and noise contained in the research data. Migration is performed in post-stack time migration. The post-stack time migration is performed in the time domain after the stacking process. The advantage of this technique is that it can produce high resolution subsurface sections on steep reflector planes. Based on the reflector analysis, it is shown that the continuity of the Kirchhoff migration results is clearer than the FD migration results.

The Kirchhoff migration in Figure 10a between CDP 2561 and 3000 at point A produces continuous reflector continuity and a clearer image. This also highlights the importance of the migration aperture parameter in Kirchhoff's migration, as selecting the correct aperture affects the resulting subsurface cross section. The Kirchhoff migration was able to minimize the diffraction effect in the subsurface image data. While the finite difference migration in Figure 10b produces a better focus and a firmer reflector at its zero offset point than the Kirchhoff migration. However, the appearance at the same CDP, which is between 2561 and 3000 CDP at point A' of the reflector, is not very clear. And the seismic events shown at point B' are much weaker compared to the results of Kirchhoff's migration at point B.

The results of this migration are good for use with data that has a high signal-to-noise ratio and a steep slope, because the finite difference migration concept allows predictions to be made about possible reflectors, the slope constraint can avoid smoothing non-coherent data and amplifying noise, and the migration is relatively more accurate, although the handling of the slope of this migration is limited. Meanwhile, Kirchhoff migration can be used for a variety of steep slope data, but because of its general nature, it is possible that the reflector from data with high S/N will not focus too much on the reflection, is able to handle steep slopes, and break in when summing can work to suppress noise. However, this may have different results for other data types or when using other seismic data corrections such as SRME (Surface-Related Multiple Elimination) corrections and Radon transformation, as well as the pre-stack time migration method, whose function is to correct for NMO errors in the return traces. Seismic to zero offset position.

Conclusion

Based on the results of this study, it can be concluded that the use of optimum aperture migration in Kirchhoff migration produces subsurface cross sections with clearer reflector appearances and the use of time steps in finite difference migration. Kirchhoff. Therefore, the best subsurface imaging on GM3-BIO-NIAS-L08 Site Singkel data after migration analysis is performed using Finite Difference migration.

Acknowledgements

The author would like to thank all those who have helped in carrying out this writing so that it can be completed properly specially the Marine Geological Survey and Mapping Center (BBSPGL) Bandung, which provided the author with the opportunity to directly experience the internship process and final project supervision (TA) independently of COVID-19.

Author Contribution

Each author has a task in completing this research. Reference collection, data processing, and analysis were conducted by Cindy Fatika Nur Annisa and Subarsyah as field supervisors. The recorded discussion was guided by Muliadi and Okto Ivansyah. All authors reviewed the manuscript.

Conflict of Interest

In this research, all authors have no financial or personal relationships with other people or organizations, so the author can account for the research results.

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