Suppressing Diffraction Effect Using Kirchhoff Pre-stack Time Migration on 2D Seismic Multichannel Data at Flores Sea

Penekanan Efek Difraksi Menggunakan Kirchhoff Pre-stack Time Migration pada Data Seismik 2D Multichannel di Laut Flores

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(Received 20 May 2014; in revised form 28 October 2014; accepted 04 December 2014)

ABSTRACT : 2D seismic multichannel survey has been carried out by Marine Geological Institute to interpret imaging and sub-surface geological information in the Flores Sea. Seismic data processing starts from pre-processing until migration stage. Migration is an important stage in the seismic processing, because at this stage the effects of diffraction and oblique reflectors caused by fault, salt domes, wedging, etc. will be repositioned to the actual points. One example of diffraction effects can be seen on the seismic section of a conventional stacking that have not migrated, i.e. resulting in an apparent bowtie reflector. Geologists find difficulties in interpreting geological information from diffracted seismic section, so it needs further processing to overcome the effects.

By using Kirchhoff method and carried out during the Pre-Stack Time Migration (PSTM), this method turns out to produce migrated seismic section which is much better than conventional stacked one. This is due to the Kirchhoff method suppressed the identified diffraction effects, so that the geologist can interpret geological structure of the resulting migrated seismic section of the Flores Sea.

Keywords : 2D seismic multichannel, diffraction, Pre-Stack Time Migration (PSTM), Kirchhoff method.

ABSTRAK : *Survei seismik 2D multichannel dilaksanakan oleh Pusat Penelitian dan Pengembangan Geologi Kelautan untuk mengetahui gambaran serta informasi geologi bawah permukaan Laut Flores. Pengolahan data seismik dimulai dari pre-processing sampai tahap migration. Tahap migration merupakan tahap terpenting dalam pengolahan data seismik, oleh karena pada tahap ini efek difraksi dan reflektor miring yang diakibatkan oleh sesar, kubah garam, pembajian, dan lain-lain akan dikembalikan pada keadaan sebenarnya. Salah satu contoh adanya efek difraksi bisa dilihat pada penampang stacking konvensional yaitu "bowtie" yang mengakibatkan terjadinya reflektor semu pada penampang seismik. Efek difraksi "bowtie" sangat menyulitkan para peneliti dalam memperoleh informasi geologi, sehingga perlu adanya proses lebih lanjut untuk mengatasi efek tersebut.*

Salah satu metode migrasi yang berkembang saat ini yaitu metode Kirchhoff dan dilakukan pada saat Pre-Stack Time Migration (PSTM), menunjukkan hasil penampang jauh lebih baik daripada penampang stacking konvensional. Hal ini terjadi karena pada metode Kirchhoff Pre-Stack Time Migration, efek difraksi tersebut ditekan lebih awal sehingga penampang yang dihasilkan mampu menggambarkan struktur geologi permukaan Laut Flores Sea.

Kata kunci *:seismik 2D multikanal, difraksi, Pre-Stack Time Migration (PSTM), metode Kirchhoff.*

INTRODUCTION

Migration is a very important stage in the processing of seismic data. It is used when there is a slant reflector on seismic traces having a depth coordinates. Actual position of the reflector on the dipping layer is not in place as it is. This is because the image of seismic wave propagation using the assumption of SnellÊs law in the case of a flat plane. Thus, we need to apply correction for the case of an inclined plane, namely migration. Migration means to restore reflector point to its actual position.

The migration process can be carried out before the stage of stacking in the time domain, namely Pre-Stack Time Migration (PSTM) and after stacking or Post-Stack Time Migration (POTM). PSTM is rarely applied because it needs a lot of time-consuming, while POTM is commonly applied, but the results obtained are still dissatisfaction when compared with PSTM. One of the advantages to doing PSTM is a migration process is done at each shooting point thus increasing Signal to Noise Ratio (S/N) (Priyono, 2006). Stages of migration are also divided into several methods, namely Kirchhoff Migration, Finite Difference, Frequency-wave number method and Frequency-Space Migration (Yilmaz, 2001).

In this study the authors simply use Kirchhoff method, it was chosen because its formula can solve complex problems that include time, angles, and distances contained in the seismic section. In addition, Kirchhoff method can also overcome the reflector dip accurately to limit 90^0. This method is carried out during the Pre-Stack Time Migration (PSTM) or when combined with the so-called Kirchhoff Pre-Stack Time Migration.

The authors use the 2D marine seismic multichannel that was acquired during geological survey by using R/V Geomarin 3 in the Flores Sea. The raw data has some dipping layers and high S/ N so it can be processed with Kirchhoff method. Data processing ends at migration stage to obtain a 2D migrated seismic section with Kirchhoff Pre-Stack Time Migration (PSTM).

Diffraction

Seismic waves will experience diffraction when it strikes an irregularity plane. Figure 1 shows illustration of diffraction, where S is seismic source and R_N is receiver point. Diffracted wave will arrive first at the point right above the irregularity point. Diffraction is the apparent reflector resulted due to the scattering body wave hit major fault, unconformity, wedge, contrast of rock types, and others.

Diffraction on seismic section would sometimes look like parabolic shape which causes apparent structure layer (Figure 2). This effect could interfere interpretation of seismic image; hence geological information will consequently be under expectation for further steps. Therefore, it is necessary to minimize diffraction through the migration process.

Normal Moveout (NMO) Correction

Prior to stacking, trace-trace at Common Depth Point (CDP) must be corrected for the time difference caused by differences in the source receiver distance. This correction is called Normal Moveout (NMO) in addition to the magnitude of the distance dependent source - receiver, it depends on the depth (record time) of a reflector. This correction is often also referred to as the dynamic correction. NMO correction is performed

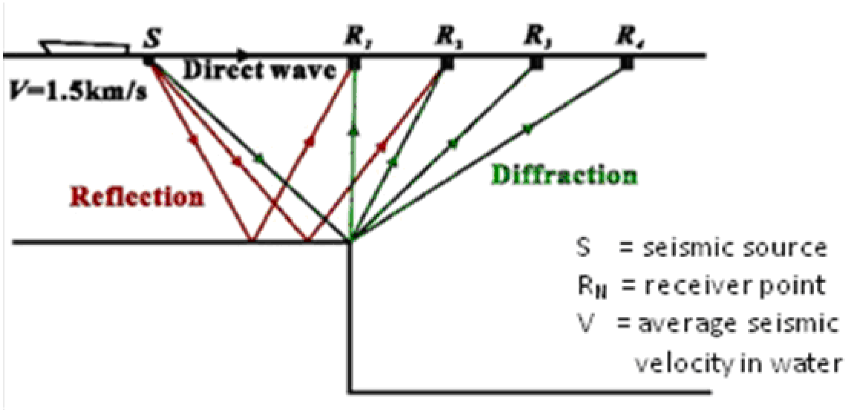

Figure 1. Illustration of diffraction of seismic waves (Priyono, A., 2006).

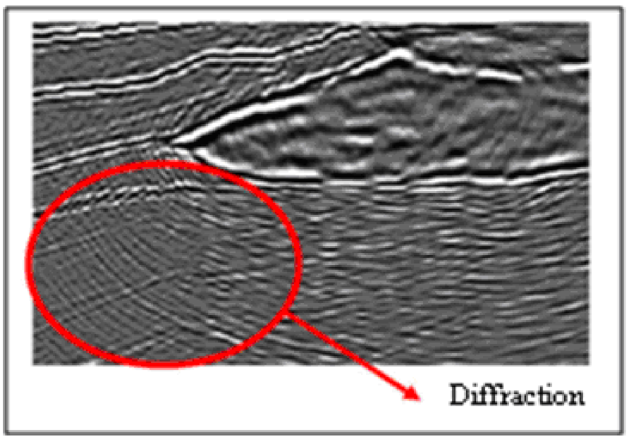

Figure 2. Example of the diffraction (Abdullah, 2011).

to eliminate the effect of distance or offset against the wave propagation time, or in other words made ??to address the effect of the acquisition geometry so that the trace was recorded as if the zero offset.

NMO correction is related to the analysis of the speed of the reflector or rock layers; resulting in the selection of the NMO correction velocity model is very important. It depends on velocity above the reflector, offset, two-way zero-offset time associated with reflection event, dip of the reflector, the source-receiver azimuth with respect to the true-dip direction, and the degree of complexity of the near-surface and the medium above the reflector (Yilmaz, 2001).

Figure 3 shows the simple case of a single horizontal layer. At a midpoint location M, we compute the reflection travel time t along the raypath from source position S to reflector point D then travel back to receiver position G. Using the Pythagorean Theorem, the travel time equation as a function of offset:

$$t_x^2 = t_0^2 + \frac{x^2}{v^2} \qquad (1)$$

where

x = offset between the source and receiver positions
v = velocity of the medium above the reflecting plane
t_0 = two-way traveltime along the vertical path MD
t_x = reflection traveltime along raypath SD then back to G

Note that vertical projection of depth point D to the surface, along the normal to the reflector, coincides with midpoint M. This occurs only when the reflector is horizontal. From equation (1), we see that velocity can be computed when offset x and t_0 and t_{TWT} are known (Figure 4-a). Once the NMO velocity is estimated, the travel time can be corrected to remove the effect of offset as shown in Figure 4-b. Traces in the NMO-corrected gather then are summed to obtain a stack trace at the particular CMP location. The NMO correction is given by the difference between t_x and t_0:

$$\Delta t_{NMO} = t_x - t_0 \qquad (2)$$

or by the way of equation (1) and (2)

$$\Delta t_{NMO} = t_0 \left[\sqrt{1 + \left(\frac{x}{v_{NMO}\, t_0} \right)^2} - 1 \right] \qquad (3)$$

Equation (3) shows the NMO correction depends on two variables offset and NMO velocity. Since we determine the offset of source and receiver from the seismic acquisition equipment, the correction depends on medium velocity variable (v_{NMO}).

Kirchhoff Pre-Stack Time Migration

The common processing stage of PSTM is elliptical convolution with the impulse response then summation along diffraction response curve (Kirchhoff Migration). The first stage includes seismic data sorted into common-offset domain. Furthermore, it convoluted with elliptical impulse. Because PSTM usually have a smooth velocity variation, residual NMO

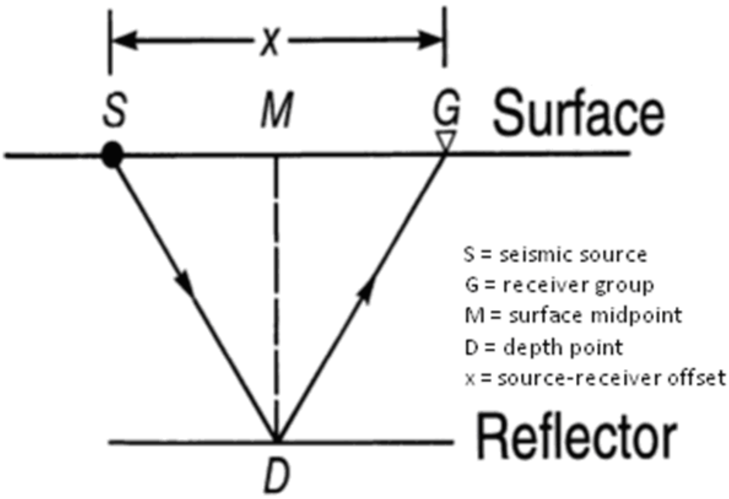

Figure 3. NMO geometry for a single horizontal reflector plane (Yilmaz, 2001).

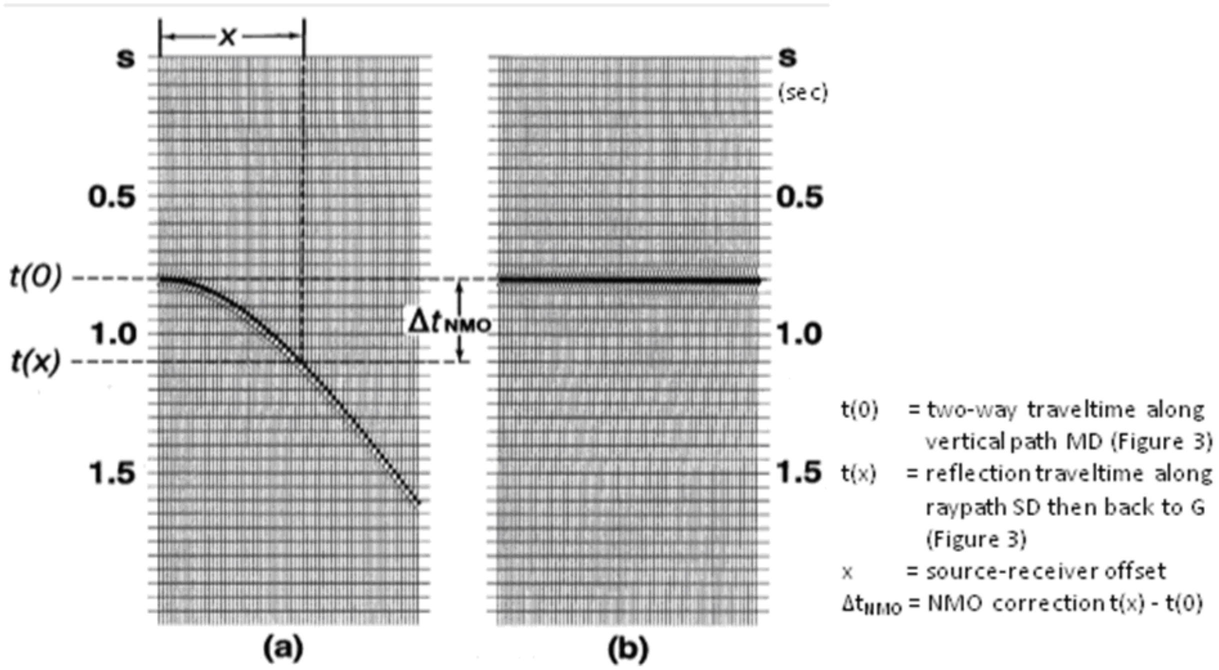

Figure 4. NMO correction involves mapping nonzero-offset travel time tx onto zero-offset travel time t0 (Yilmaz, 2001).

correction applied after primary NMO. PSTM is an attentive solution to the problem of conflicting dips with different stacking velocities by migrating each of the NMO-corrected common-offset section. We have the opportunity to update the velocity field and generate CMP gathers which can be used for analysis of amplitude variation with offset as well as to obtain an improved migrated stack (Yilmaz, 2001).

The curvature of the hyperbolic trajectory for amplitude summation is governed by the velocity function. The equation for this trajectory can be derived from the geometry of Figure 5-a. Assuming a horizontally layered velocity-depth model, the velocity function used to compute the travel time trajectory is V_{rms} at the apex of the hyperbola at time . From the triangle COA in Figure 5-a, we note that:

$$t_x^2 = \tau^2 + \frac{4x^2}{v_{rms}^2} \quad (4)$$

Having computed the input time t_x, the amplitude at input location B is placed on the output section at location A, corresponding to the output time at the apex of the hyperbola. The diffraction summation that incorporates the obliquity, spherical spreading and wavelet shaping factors is called the Kirchhoff summation, and the migration method based on this summation is called the Kirchhoff migration. To perform this method, multiply the input data by the obliquity and spherical spreading factors. Then apply the filter with the above specifications and sum along the hyperbolic path that is defined by equation (4).

Seismic Data

The study area is situated on Flores Sea in between 121^0 30Ê– 123^0 30ÊE and 05^0 30Ê– 08^0 30ÊS (Figure 6). It is a continuation of the east-west oriented structure along 800 km to the east of Sunda back arc from Bali Basin, Flores until South Banda. They have been

Table 1. Seismic Acquisition Parameter

Configuration	Off-end
Active Channel	1 - 48
Line Azimuth	180^0
Shot Interval	37.5 m
Group Interval	12.5 m
Shot Number	2898
Offset	75 – 662.5 m
Maximum Fold	8
Seismic Line	10.86 km
Sampling Rate	2 ms

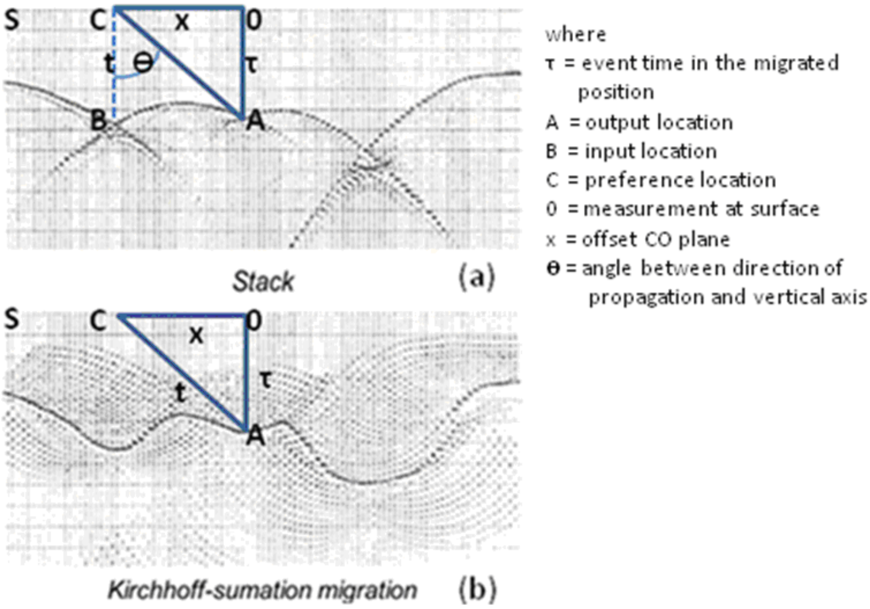

Figure 5. Stacking section (a), responses to Kirchhoff migration (b) (Priyono, 2006) (Yilmaz, 2001).

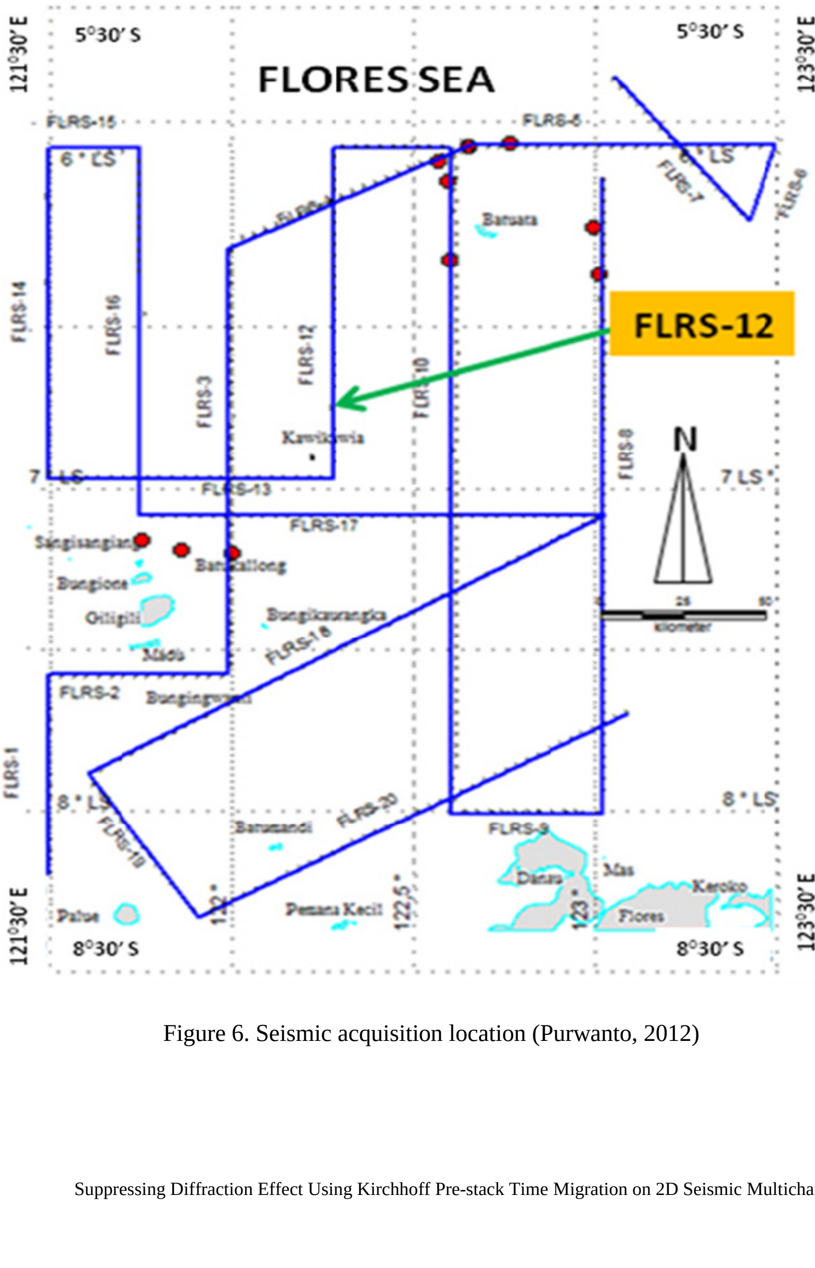

Figure 6. Seismic acquisition location (Purwanto, 2012)

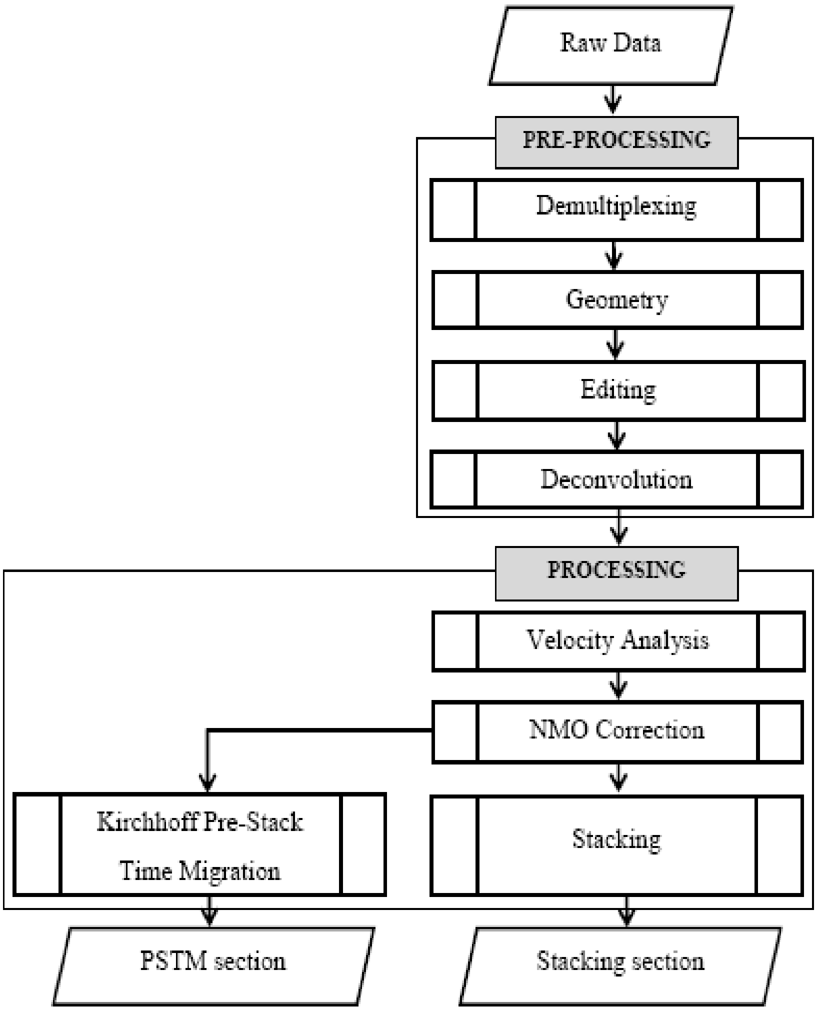

Figure 7. Stacking and PSTM flowchart

providing uniformity towards convergence direction between Indo-Australian and Eurasian. Transition to the north of Banda volcanic arc (Banda Orogen) shows a back arc thrusting that formed a well-defined accretionary wedge of reduced numbers of shortening. Seismic data was acquired using 48 channels streamer type Sercel and 400 cu in power pressure airgun at average vessel speed 4 knot. Seismic acquisition parameter obtained from observer report is used as input parameter in seismic processing software (Table 1).

METHODS

Integrated seismic processing is applied to 2D marine raw seismic data in this research, such as demultiplexing, geometry assignment, and deconvolution for pre-processing stage and velocity analysis, NMO Correction, and Stacking/PSTM for processing stage (Figure 7). Advanced predictive deconvolution has been done together with input data from autocorrelation to predict multiple close to surface reflector of seabed (short period multiple), by determining through position of shot signature noise wavelet. It is important to avoid the ambiguity of boundary layer of reflector plane by suppressing or eliminating multiple events that appear after the primary events. Comparison between conventional stacking and Pre-Stack Time Migration (PSTM) has been added to conclude better method in suppressing diffraction effect.

RESULTS

Figure 8 shows the comparison between seismic sections resulted from stacking section and Kirchhoff Pre-Stack Time Migration (Kirchhoff PSTM) section. The stacking section indicates diffraction effect at t_{TWT} 1300 ms. In Kirchhoff migration section, the diffraction hyperbola is collapsed by summing the amplitudes, then placing them at the apex.

The effect of diffraction to the stacking section is shown clearly in Figure 9, as the diffraction bowtie point is noted at CDP 16324. The edge of discontinuities blocks acts as point sources and typically give rise to strong diffracted phases, represented by series hyperbolic patterns of diffraction bowtie events in the stacking seismic section. The Kirchhoff method in Pre-Stack Time Migration (Kirchhoff PSTM) suppresses the diffraction bowtie into continuous reflection line trough adjusting amplitudes for obliquity and divergence before summing along diffraction curves.

Using more accurate image from migrated seismic section from Figure 9, we can conduct interpretation of FLRS-12 to determine rock units (Figure 10). It shows stratigraphic sequence of complex geological structure based on reflection coefficient of seismic horizons.

DISCUSSION

Discontinuous block shifted the angle of receiving signal onto several acquiring channels. We find that reflectors in the subsurface can be visualized as being summation of many points that act as secondary sources. We also find that the zero-offset NMO section

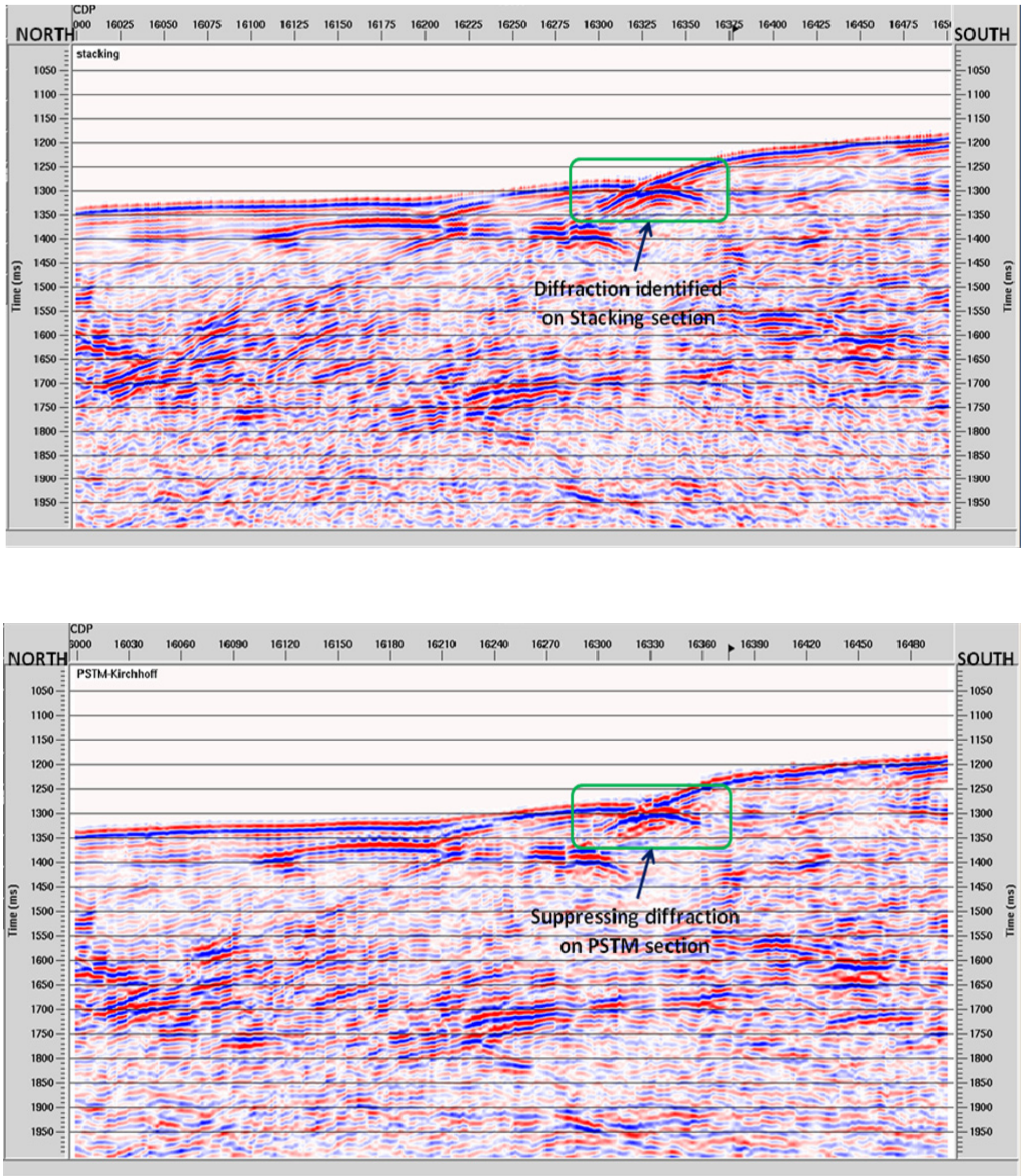

Figure 8. Comparison of diffraction events from stacking section (top) and Kirchhoff Pre-Stack Time Migration (Kirchhoff PSTM) section (below) of seismic line FLRS-12.

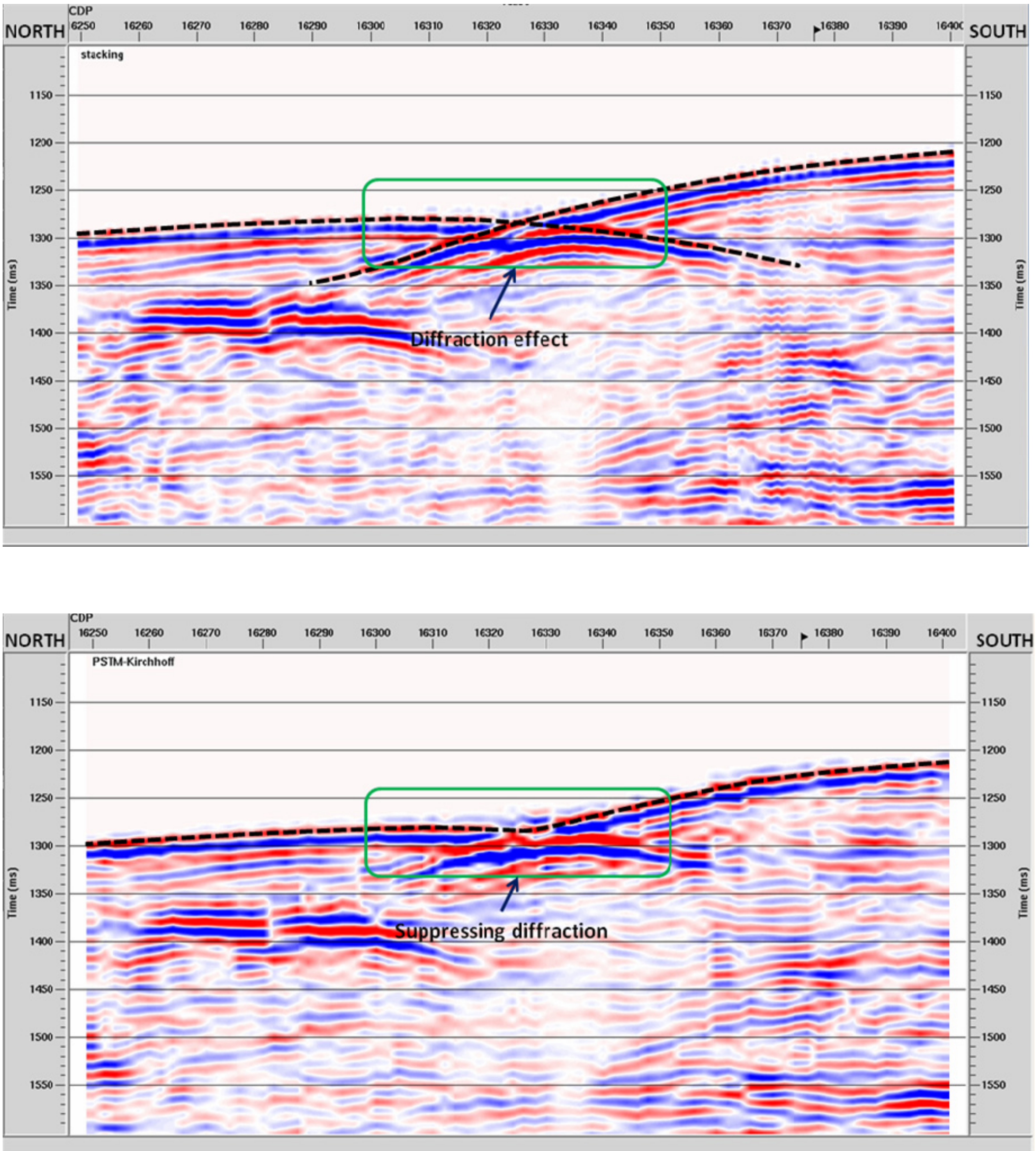

Figure 9. Reconstruction of diffraction bowtie events (top) and Kirchhoff summation (below) of seismic line FLRS-12.

consists of superposition of many hyperbolic travel time responses. Therefore, when there are discontinuities (eq. faults) along the reflection, diffraction hyperbolas often stand out. To carry out diffraction-stack migration, diffraction curves are calculated for each point on the seismic section. The data on the unmigrated seismic section ling along each diffraction curved are summed to give the amplitude at the respective point on the migrated section (Sheriff, 1995).

Interpretation of the seismic cross section from north to south of Flores Sea shows the presence of 4 rock units in complex lithologies. Unit 1 is Paleo-Mesozoikum Rock as basement of Buton micro-continent and East Sulawesi region. The second unit is accretionary prism (Plio-Pleistocene to Resen) as part of back-arc thrusting Flores formation. The third unit is inactive seamount (Plio-Pleistocene) after arc reversal polarity. The fourth unit is clastic sediment (Neogen to Resen). Harris, 2011, stated that the age of Buton - Tukang Besi, Banggai Sula, Seram and other islands as

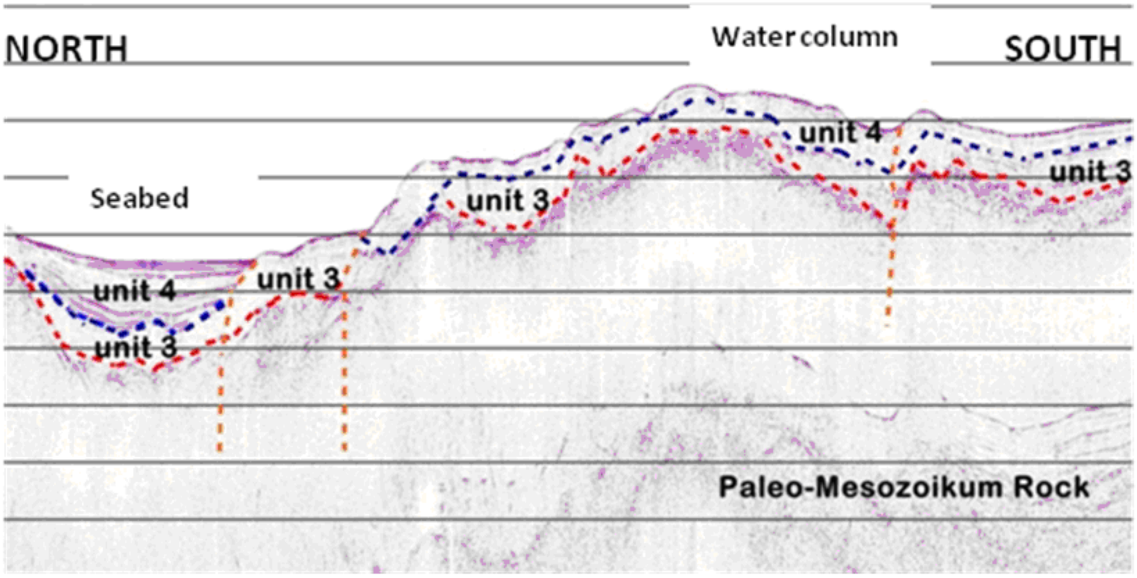

Figure 10. Interpretation of migrated seismic section

part of a micro-continent of Australia is 35 Ma - 67.8 Ma Mesozoic-Paleozoic, assuming Banda oceanic basin of the Late Miocene. Banda orogen formation (volcanic Banda Arc) is estimated of the 8 Ma (Late Miocene upper), followed by arc polarity reversal which formed Flores back-arc thrusting of the 4 - 5 Ma (Lower Pliocene) and volcanic activity as a single magmatic arc in northern Flores island < 2.4 Ma (Lower Pleistocene) or faster than seamount in the northern part of Wetar island (about < 0.4 Ma, Pleistocene).

CONCLUSIONS

Stacking is ineffective in suppressing diffractions because it sums both energy and diffraction events in an image of reflection points. The diffraction events interfere to form coherent events and superposition of diffraction events may be visible at discontinuities such as faults. It causes ambiguity in interpreting geological information from the seismic section.

Kirchhoff PSTM is somehow very effective in suppressing diffraction events but is expensive and time consuming because the many more data have to be migrated. Although the objective of migration before stacking is to obtain a more accurate image of reflectors at their correction location, the velocity required is usually not known accurately and the result of migration is usually migrated time section.

ACKNOWLEDGEMENTS

Appreciation and thanks to honorable Head of Marine Geological Institute for the trusting and supervising to the authors. Our truly appreciation to Mr. Catur Purwanto as Chief Scientist of Flores Sea Team.

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