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Application of ZO-CRS Stack on Residual PP Removal of PS Component in Converted-Wave Seismic Reflection Processing

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ABSTRACT - A high-quality image of the PS component is needed since applying the converted-wave seismic method has increased significantly in hydrocarbon exploration, especially in interpreting the detail and complexity of structure or reservoir zones. The incident P-wave on a surface produces a reflected and converted P-S wave. Converted-wave seismic uses the multicomponent receiver that records both vertical and horizontal components. The vertical component is assumed to correspond to the compressional PP wave, and the horizontal corresponds to the PS converted-wave. To better understand how to image better the PS component, synthetic seismic data with the shallow gas and relatively complex model are constructed by the full-waveform modeling. This study aims to improve the imaging quality in the PS section to remove the residual PP events on the horizontal data refer to our previous study. In this study, to obtain the more reliable PS data, the residual PP reflections have been removed by applying the Zero Offset Common Reflection Surface (ZO CRS) Stack of the PS component. The results of this study, the imaging quality is better than that in the previous study.

Keywords: Converted-Wave, Complex Model, PP removal, ZO CRS PS stack.

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INTRODUCTION

Two basic seismic wave modes propagate through a solid medium: P or compressional and S or shear, each affected differently by the medium's properties. The seismic exploration method has traditionally relied only on P waves, detected by one component sensors, but the S-wave information content has been neglected. Since S-wave has a shorter wavelength, compare to P-Wave. Thus the vertical resolution is higher. However, it is challenging to generate the S-wave, and it is vulnerable to be absorbed by the deep layer.

A new seismic exploration method has been discovered, known as converted wave seismic exploration (Hardage, *et al.*, 2011). This method's main principle is to records the propagation of converted-wave derived from a down-going P-wave, which converted to an up-going S-wave at a reflector point.

The converted wave seismic survey uses multi-component receivers to record seismic signals both on vertical and horizontal components. S-waves can provide additional information about the medium, such as the sedimentary rock's stratigraphic model beyond those supplied by the P waves.

The S wave properties, such as high sensitivity to anisotropy and anelastic attenuation, can explain the deficiencies present in the P wave; thus, the converted wave (P-S) application appears to be in practice comfortable (Hardage, *et al.*, 2011).

However, in practice, P S-waves are applied less often than PP -waves since they require more effort for multicomponent acquisition. Their processing is more involved and laborious, and their interpretation appears less profitable (see, e.g., Cary, 2001).

The presence of PP events on PS data and vice versa exists in the seismic shot gather data. To get better quality of the PS component section to image detail and complex structure is then really needed. The purpose of this study is to present the other process as an improvement to obtain the more reliable and better PS image quality due to the existence of the residual PP events on the PS data.

METHODOLOGY

General

This study aims to improve the imaging quality on the PS seismic section and obtain the other seismic attributes for subsurface characterization related to removing a shallow gas cloud existence. This study is then divided into three main processes; full-waveform forward modeling and seismic basic processing with ZO CRS Stack (Mann, *et al.*, 1999; Jäger, *et al.*, 2001) seismic migration.

Full Waveform Modeling

To better understand before the real data acquisition, it is preferred to do the full waveform modeling to get the best result's framework parameter. The synthetic model is used in this study could be seen in the following figure (Figure 1). The configuration of shot geometry in this study refers to Viony & Triyoso (2018). It has 81 shot points and 181 geophone groups with split-spread geometry. Each group's interval and the shot interval is 100 m, and 25 m for the near offset with 4525 m far offset the Ricker wavelet with the dominant frequency of 15 Hz designs for the source wavelet.

The simulation used 2D elastic modeling to produce a full-waveform shot gathers data based on the above sources and the receiver's configuration. The synthetic shot gathers both vertical and horizontal particle velocity, normal stress, and stress shift. The vertical particle velocity is merged to obtain the compressional PP gather data. While to get seismic gather data of the converted-wave PS, the horizontal particle velocity is combined. After receiving the synthetic data, both conventional PP and converted-wave PS seismic data are then processed.

Common Reflection Surface (CRS) Method

The Common Reflection Surface (CRS) stack is a theoretically well-established method (Mann, *et al.*, 1999). It considers layers separated by curved reflectors. The reflection comes from a reflecting segment, and the second-order approximation of transmitted and reflected traveltime rays in the seismic system was developed (Bortfeld, 1989).

Landa, *et al.* (2010) pointed out that a multi-covering and the multi-focusing of the seismic data acquired over a set of homogeneous and isotropic layers, with arbitrary velocities separated by smooth interfaces. It is suggested to handle such kind of phenomena, and the CRS method has been considered an attractive stacking method to provide improved zero-offset sections (Mann, *et al.,* 1999).

Seismic Data Processing

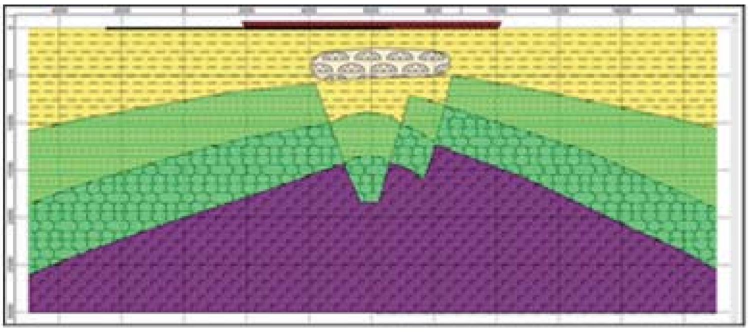
In this study, both vertical PP and horizontal PS converted-wave data processing are performed. Since the knowledge and the result of PP data are needed, the PP needs to be properly-processed first to get the RMS velocity value before processing the horizontal PS converted-wave data.

The development of the velocity analysis from PP data constructs the initial PS velocity in horizontal processing. In this study, the CRS method's advantage, especially Zero Offset (ZO) CRS stack, is used to remove the PS gather data's residual PP reflections. The flowchart for processing the seismic data is shown in Figure 2.

In general, both the seismic basis processing flows between PP and PS are similar. Those are geometry assignment, velocity analysis, etc. However, in PS processing, some additional flows such as ACP binning, constructing PS initial velocity, reversing the polarity, CRS analysis, and ZO CRS stack. Figure 3, an average Vp/Vs value, is estimated from the optimum ACP fold diagram to analyze the ACP binning. Furthermore, the Vp/Vs is used to construct PS initial velocity from the RMS Velocity from PP data.

Furthermore, the reliable RMS Velocity has resulted based on velocity analysis in which CRS semblance is used. The ZO CRS stack then does the best CCP mapping with the CRS velocity analysis result. Reversing polarity has to be done due to the acquisition configuration in this study is asymmetrical split-spread. Following Hardage, *et al.* (2011), the source's azimuth to the receiver of the negative and positive offset differs by 180^{o}, and the polarity of these two offsets should differ by 180^{o}.

In the PS section's residual PP events, the ZO CRS stack is then applied to remove the PS stack



No.	Colour	Vp(m/s)	Vs(m/s)	Density (kg/m^3)
1		2250	1300	2105
2		1802.21	1304.27	1780
3		2750	1590	2200
4		3000	1730	2200
5		4000	2310	2350

Figure 1
The subsurface model used in this study is a complex geological structure below the shallow gas zone.

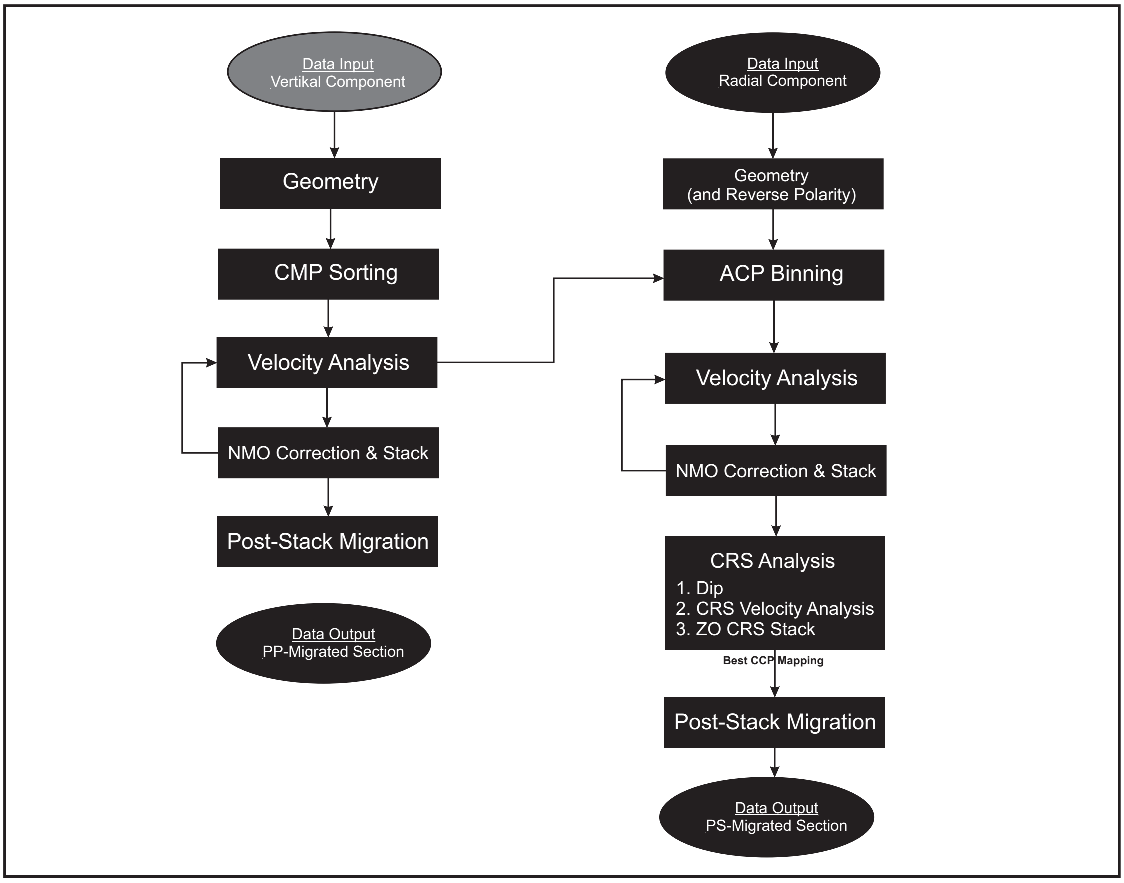


Figure 2
The workflow of the PP and PS seismic data processing (modified Guevara, 2000).

section's residual PP. The better quality of the PS stack section results based on the ZO CRS stack application in which velocity analysis based on CRS semblance is used. The ACP binning with a constant value of Vp/Vs is still used in this study, and it is proposed of using PS CRS gathers the next step of our research. It is a depth variant stacking step (Thomsen, *et al*., 1997).

Referring to the previous study (Viony & Triyoso, 2018, 2019), the residual PP reflections removal in PS data is also tested using f-k filtering. The result is compared to that ZO CRS stack. Figure 4 shows the PS stack effect, PS stack with f-k filter application, and ZO CRS stack section. ZO CRS stack has a better tendency to result in a better PS image with better Common Conversion Point (CCP) binning.

RESULTS AND DISCUSSION

PP and PS Migrated Stack Section

The result of the PS section compare to the PP section could be seen in Figure 5. It shows a time delay very clearly in the PS converted wave image. It is because S-wave takes a longer time to propagate through the layers than the P-wave. So, the same reflector occurred at different two-way-time in both PP and PS sections. The gas anomaly response (bright spot) in the PP section does not appear in the PS converted wave image. It is because S-wave is not sensitive to fluids.

Moreover, the PS section can image the base gas properly in the position's sense, while the PP section affects the so-called push-down phenomenon, while the PS section is not affected. In terms of the multiple, the PP section contains so many multiples compare to the PS section. It is because most wave energy is transmitted as P-waves rather than S-waves. PS seems to respond to lithology and structure only, while PP responds to lithology, fluid, and structure. It may indicate that PS is better used to image lithology and structure geometry compared to PP.

Horizon Interpretation

In the previous PS stack section, PS still contains some of the residual PP data events in the horizontal component. After applying the ZO CRS stack, the PS section is relatively clear from the residual PP events. It provides a reliable image that can ease better horizon interpretation and gas characterization. It

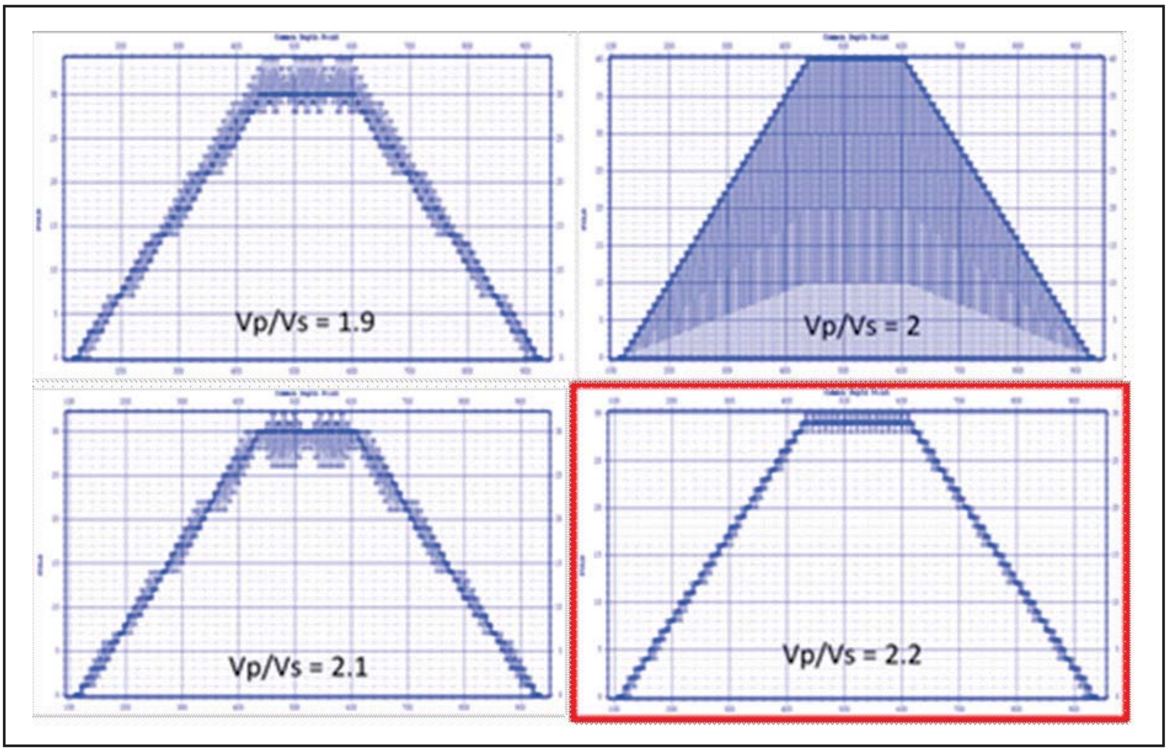


Figure 3
Shows the ACP fold diagram of each Vp/Vs.
The red square shows the Vp/Vs value, which is used in this study.

may imply that lithology geometry and structure's correct shape could be defined better using converted wave (PS) imaging (Sun & Innanen, 2014).

CONCLUSIONS

This study shows that the ZO CRS stack tends to produce a better PS image with better Common Conversion Point (CCP) binning.

The converted wave can image the reflector properly, while the PP section affects the fluid existence very much. PS seems to respond to lithology and structure only while PP responds to lithology, fluid, and structure.

PS is better used to image the geometry of lithology and structure compared to PP. It may imply that the correct shape of lithology and geometry of structure could be defined better using PS converted wave imaging.

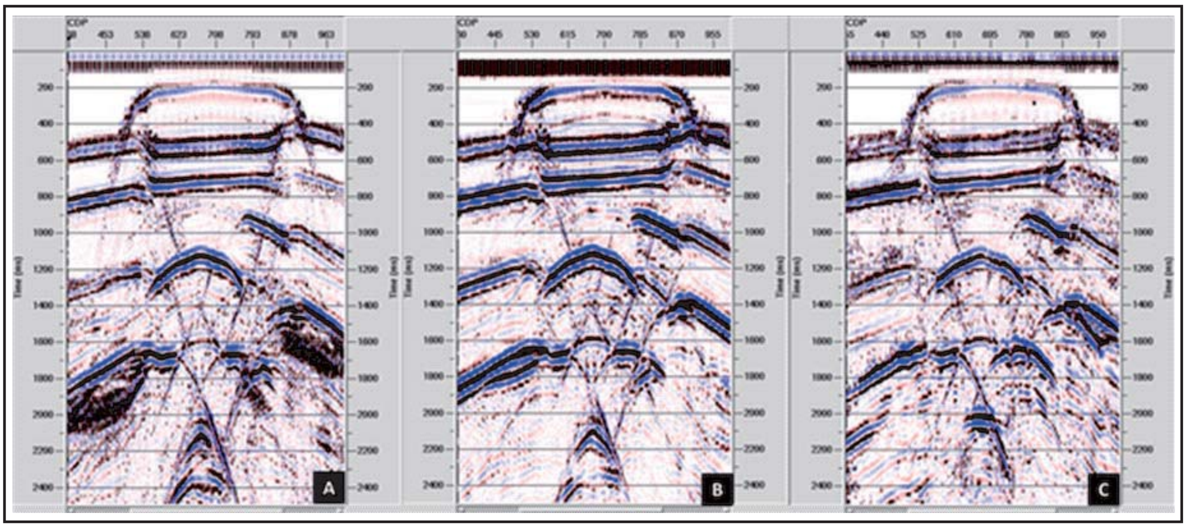


Figure 4
The result of the PS stack (A), PS stack with f-k filter (B),
and ZO CRS stack section (C). ZO CRS stack has a better tendency to result
in a better PS image with better Common Conversion Point (CCP) binning.

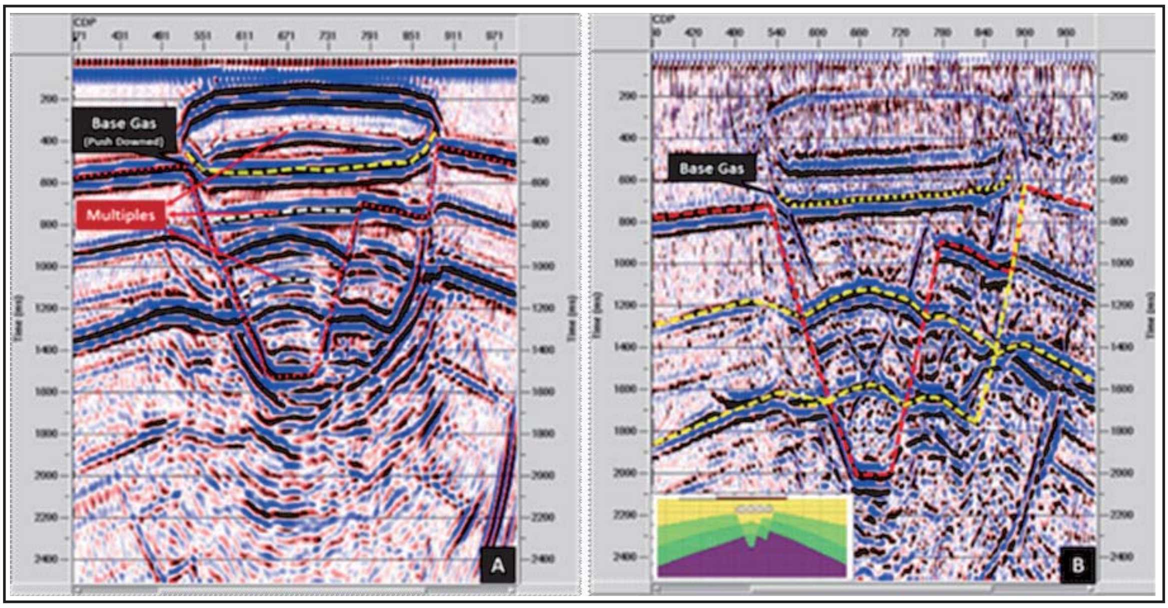


Figure 5
The PP (A) and PS (B) migrated sections. PS seems to respond to lithology
and structure only, while PP responds to lithology, fluid, and structure.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
ZO CRS	Zero Offset Common Reflection Surface	
CRS	Common Reflection Surface	
CCP	Common Conversion Point	
P3MI	Program Penelitian Pengabdian kepada Masyarakat dan Inovasi	
LPPM	Research and Community Services	

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