# Strategy Research on Improving the Imaging Efficiency and Effect of Converted Wave

**Xin Liu**

Department of Basic Course Teaching and Research, Guangdong Polytechnic College, Zhaoqing, 526100, China

**Keywords:** Converted wave; Imaging efficiency; Strategy

**Abstract:** Multi-wave seismic exploration can use converted wave information, and more underground geological information can be obtained compared with conventional P-wave exploration. Compared with the traditional acoustic wave reverse-time migration method, elastic wave reverse-time migration can provide more physical information of underground structures. However, the crosstalk noise and various non-physical noises in the migration seriously reduce the imaging quality. On the premise of accurate velocity model and other parametric models, the elastic wave reverse migration method is used to image the elastic wave data. The key technology in this process is to use Poynting vector to separate the wave field and calculate the angle, so that the elastic wave reverse migration can generate multiple sets of imaging gathers with dip angle as the index. The converted wave data in complex structural areas usually have low signal-to-noise ratio, and the static correction problem is very serious, so it is difficult to realize the correct imaging of converted wave. In this paper, the processing method of 3D converted wave is studied and applied, and the strategy of improving the imaging efficiency and effect of converted wave is put forward to realize the accurate imaging of 3D converted wave.

## 1. Introduction

Multi-component seismic exploration can comprehensively utilize P-wave, S-wave, converted wave and other seismic wave fields for fine exploration of oil and gas reservoirs, and reduce the multi-solution of P-wave exploration alone. More and more successful examples have been seen in gas cloud imaging, fracture detection and reservoir prediction [1]. To use converted wave to solve practical geological problems, we must first solve the problem of processing converted wave. Time migration adopts full-wave operator, which can deal with strong velocity change and steep dip imaging, and has gradually become an important means of imaging complex underground structures. Multi-component seismic data can better represent the physical law of seismic wave propagation, so elastic wave reverse-time migration can provide more geological information than acoustic wave reverse-time migration [2]. In recent years, the research using the information of seismic converted wave can stratify the crust and upper mantle, detect the shape of the plane, determine the location and distribution of faults, etc. according to the data of several seismic stations in the known velocity model, and it is not required to know the exact time of the earthquake and the location of the source [3]. As the converted wave has the characteristics of asymmetric propagation path, more sensitivity to anisotropy and low signal-to-noise ratio, the imaging difficulty of the converted wave is far more difficult than that of the longitudinal wave, especially in complex structural areas, and there are still many problems in the processing technologies such as static correction and velocity modeling of the converted wave [4].

Converted wave is different from longitudinal wave. It has the characteristics of low main frequency, low speed, asymmetric ray path and high sensitivity of single-point digital detector, which makes the interference waves of the received converted wave data develop and have many types, and the signal-to-noise ratio is low. Especially, the developed low-frequency interference waves coincide with the effective waves, which makes it more difficult to suppress the low-frequency noise [5]. Multi-wave exploration can effectively reduce the multi-solution of geophysical inversion, not only improve structural imaging, but also provide better solutions to key problems of oil and gas reservoir exploration and development such as lithology description, fluid prediction, fracture detection and anisotropy detection [6]. Peng et al. studied the post-stack migration algorithm of converted wave, and described how to establish the shape of converted wave diffraction scattered at points in horizontal layered media, so that a velocity function can be obtained for reasonable migration [7]. Liu used a marine converted wave data to calculate the converted wave prestack time migration, which shows that the converted wave prestack migration is beneficial to the imaging of gas-bearing reservoirs [8]. Li et al. have studied a new block pre-stack elastic migration algorithm for mixed system functions. For complex structures with longitudinal and lateral speed changes, the travel times of longitudinal waves and converted wave can be calculated by downward continuation of wave field [9]. How to effectively remove the noise existing in the original data, remove the false and preserve the true, improve the signal-to-noise ratio of the data, and meet the needs of high-precision imaging and interpretation, it is necessary to adopt various means to analyze and study the noise generation mechanism and types in the processing process, and adopt effective noise suppression methods.

## 2. Elastic wave reverse time migration processing

Cross-well seismic data processing is mainly divided into two categories: one is tomography, which mainly uses the arrival time of the direct wave in the received signal to obtain the cross-well velocity model; The other is reflected wave imaging, which is based on the velocity field obtained by tomography, and returns the reflected wave in the received signal to the correct position of the stratum. Compared with tomography, reflection imaging has higher vertical resolution and wider exploration area, which is an indispensable link in cross-well seismic data processing. Compared with the geometric theory, the wave equation theory is closer to the actual propagation situation of Apollo, and can image more complex stratigraphic structures. The migration method based on one-way wave equation can well describe the wave propagating in the near-vertical direction and adapt to the medium with sharp velocity change, but it is difficult to image the steep dip interface because of the phase change and amplitude weakening when describing the wave propagating in a large angle. Compared with these methods, the elastic reverse-time migration method based on two-way wave has the advantages of simple principle, accurate imaging, no limitation of reflection dip angle, and adaptability to any complex velocity model. The first-order velocity-stress equation of two-dimensional elastic wave is:

$$\frac{\partial v_x}{\partial t} = \frac{1}{\rho}\left(\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xz}}{\partial z}\right) \quad (1)$$

$$\frac{\partial v_z}{\partial t} = \frac{1}{\rho}\left(\frac{\partial \sigma_{xz}}{\partial x} + \frac{\partial \sigma_{zz}}{\partial z}\right) \quad (2)$$

$$\frac{\partial \sigma_{xx}}{\partial t} = (\lambda + 2\mu)\frac{\partial v_x}{\partial_x} + \lambda \frac{\partial v_z}{\partial z} \quad (3)$$

$$\frac{\partial \sigma_{zz}}{\partial t} = \lambda \frac{\partial v_x}{\partial x} + (\lambda + 2\mu)\frac{\partial v_z}{\partial_z} \quad (4)$$

$$\frac{\partial v_x}{\partial t} = \mu\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z}\right) \quad (5)$$

Where $v_x$ and $v_z$ are particle velocities, $\sigma_{xx}$, $\sigma_{zz}$ and $\sigma_{xz}$ are stress components, $\rho$ is density, and $\lambda$ and $\mu$ are Lame constants. Elastic reverse-time migration directly processes multi-component data and uses elastic wave equation to extend the wave field, which can keep the elastic and vector characteristics of the wave field and more truly simulate the propagation process of seismic wave field in underground media. Elastic reverse-time migration converted wave imaging is a systematic project, which needs to be supported from pre-processing, theoretical basis of forward modeling, imaging conditions, calculation and implementation, etc. In the process of seismic data preprocessing, it is necessary to effectively keep the converted wave information from being destroyed, which includes the preservation of its vector characteristics and the preservation of the relative relationship among multiple components.

## 3. Enhanced converted wave imaging efficiency

The elastic wave equation can more truly simulate the propagation process of seismic wave field in the real earth medium, so it has higher accuracy in theory. However, the elastic wave equation is extended to obtain the mixed wave field of P-wave and S-wave in the form of three-component vector, while what we need is the imaging results in scalar form for various reflection modes of P-wave and S-wave. In the processing of converted wave data, the extraction of common converted point gathers and the correction of dip moveout are the difficulties. However, the KeShikhov pre-stack time migration technology can realize the full-space accurate imaging of 3D converted wave data without the extraction of common converted point gathers, the correction of dip moveout and the post-stack migration. There is little difference in frequency and velocity between the low-frequency noise of converted wave data and the effective wave, so it is difficult to suppress it with conventional processing methods.

Set the gray value range of the original converted wave imaging $f(x,y)$ as $(g_{\min}, g_{\max})$, select a suitable threshold $T$, and:

$$g_{\min} \le T \le g_{\max} \quad (6)$$

The single threshold image segmentation can be expressed by the following formula:

$$g(x,y)=\begin{cases}1, & f(x,y)\ge T\\ 0, & f(x,y)<T\end{cases} \quad (7)$$

$g(x,y)$ is a binary image. The object can be easily exposed from the background by binarization. The key to binarization of converted wave imaging is the reasonable selection of threshold $T$.

Let the gray function of converted wave imaging be $f(x,y)$. The $r(r>0)$ domain of $(i,j)$ position pixels is defined as the following set:

$$N_r(i,j)=\{(k,l)|\max\{|i-k|,|j-l|\}\le r\} \quad (8)$$

The value defined below is called the degree of interest of $(i,j)$ bit pixels:

$$I(i,j)=\frac{1}{(2r+1)^2-1}\sum_{(k,l)\in N_r(i,j)}\left(f(i,j)+w(k,l,\sigma)f(k,l)\right) \quad (9)$$

Among them:

$$w(k,l,\sigma)=\psi(i-k,j-l,\sigma) \quad (10)$$

$\psi(x,y,\sigma)$ is a DOG function.

Determine the survey line position. If mobile observation is selected, mobile seismic stations can be arranged along the pre-designed survey line position. If the data of fixed stations are used, a certain number of fixed stations should be selected according to the needs, and the positions of these stations should be fitted into a straight line as the position of the survey line. Static correction of detection points needs to be carried out in two steps, that is, the calculation of long-wavelength static correction and short-wavelength static correction. The velocity ratio of surface P-wave and

P-wave in this area is calculated by multi-wave microlog data, and the long-wavelength static correction of converted wave detector is calculated by model method according to the static correction of P-wave detector.

## 4. Result analysis and discussion

On the basis of traditional separation of P-wave and S-wave in wave field, the scalar potential and vector potential are processed by gradient and curl respectively, and vector P-wave and vector S-wave are obtained. Finally, using the polarity characteristics of the vector P-wave and S-wave, considering the deep energy compensation, the normalized inner product imaging conditions are used to perform reverse time migration imaging on different wave patterns. Figure 1 shows the precision results of different algorithms.

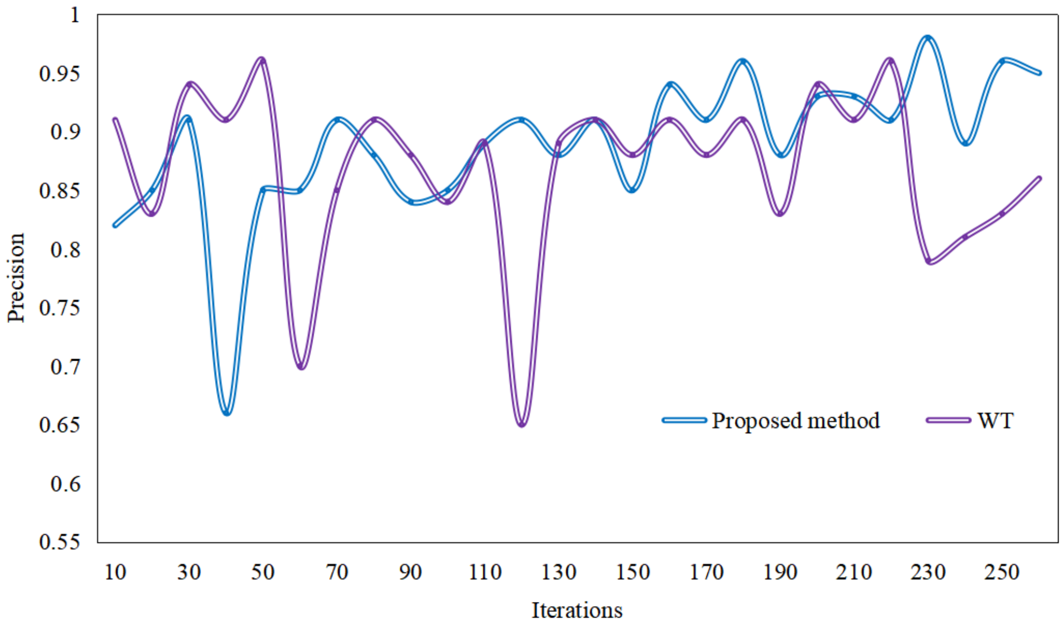


Figure 1 Accuracy results of different algorithms

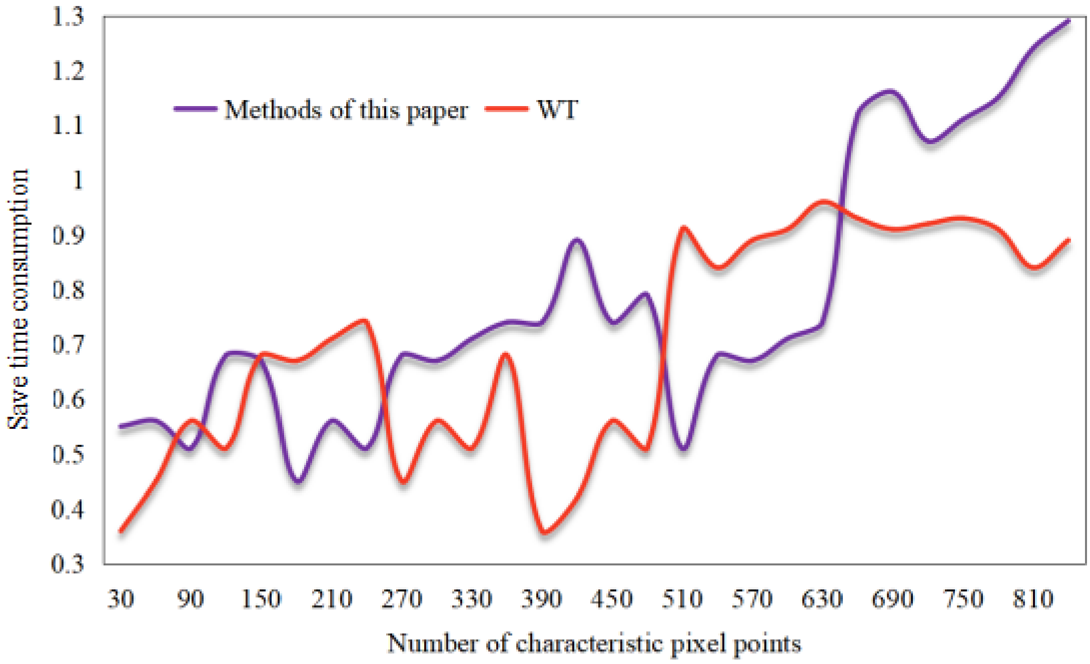


Figure 2 Time-consuming comparison results of converted wave imaging enhancement processing with different methods

The design method of converted wave imaging enhancement model proposed in this paper can effectively solve the problem of unclear image. Compared with the comparison algorithm, the highest accuracy is improved by 28.85%. Compare and analyze the time-consuming of converted wave imaging enhancement processing by different methods, as shown in Figure 2.

The application example shows that the method described in this paper can effectively improve the imaging accuracy of converted waves in complex structural areas, and provide high-quality data basis for joint interpretation of P-wave and converted waves. Sort out the waveform records recorded by each station. If the seismic source is far from the survey line, necessary distance correction is required. When selecting local and near earthquakes as observation data, the phase difference of seismic waveform caused by different sources must be considered, which may affect the stacking effect in migration stacking.

## 5. Conclusions

The converted wave is different from the longitudinal wave, because of its low main frequency, low speed, asymmetric ray path and high sensitivity of single-point digital detector, which makes the interference waves of the received converted wave data develop, have many types and have low signal-to-noise ratio, especially the developed low-frequency interference waves coincide with the effective wave bands, which makes it more difficult to suppress the low-frequency noise. Multi-component seismic data can better represent the physical law of seismic wave propagation, so elastic wave reverse migration can provide more geological information than acoustic wave reverse migration. In this paper, the 3D converted wave processing method is studied and applied, and the strategy of improving the imaging efficiency and effect of the converted wave is put forward to realize the accurate imaging of the 3D converted wave. Compared with the contrast algorithm, the precision of the proposed converted wave imaging enhancement method is increased by 28.85% and the efficiency is increased by 22.98%. The imaging method in this paper does not need polarity correction, and the correctness and adaptability of the method in this paper are verified by imaging flat layers and complex models. Therefore, the design method of converted wave imaging enhancement model proposed in this paper can effectively solve the problem of unclear images.

## Acknowledgements

Science and Technology Project of Guangdong Polytechnic College“Study on two dimensional acoustic wave and elastic wave reverse time migration imaging”(2022GKJZK009)

## References

[1] Hou D M, Xu G J, Shen L, et al. Velocity field detection method using the elastic wave of a damaged bolster[J]. International journal of comadem, 2019, 22(3):15-18.

[2] Liu Wei, Villi, Zhang Wei. Comparative study of elastic wave reverse migration based on two wave field separation methods [J]. Advances in Geophysics, 2020, 35(3):10.

[3] Zhang Hao, Feng Xingqiang, Fu Chang, et al. Noise suppression method of elastic wave reverse time migration in dip domain based on convolutional neural network [J]. Geophysical Exploration of Petroleum, 2021, 60(3):9.

[4] Cai Zhicheng, Gu Hanming, Cao Jingjie. First-order equation elastic wave reverse time migration based on energy norm imaging condition [J]. Petroleum Geophysical Exploration, 2020, 59(1):9.

[5] Li Mengzhen, He Xiao, Chen Hao, et al. Numerical simulation of seismic wave field between wells and reverse time migration of elastic waves [J]. Applied Acoustics, 2021, 040(003):335-342.

[6] Zou Qiang, Huang Jianping, Li Qingyang, et al. Finite difference numerical simulation of elastic waves in pseudo-depth domain and reverse time migration [J]. Petroleum Geophysical Exploration,

2020, 55(2):11.

[7] Peng Kefeng, Cui Shitang, Pan Hao, et al. Simplified model of elastic wave propagation in cylindrical shell chain under impact load and its analytical solution [J]. Explosion and Impact, 2021, 41(1):11.

[8] Liu Xueyi, Cheng Jiu-bing, Wang Tengfei. Inversion method of wave travel time from multi-component data conversion of seabed considering acoustic shock in water layer [J]. Journal of Geophysics, 2021, 64(9):17.

[9] Li Zhijun, Ren Huayu, Yang Deyi, et al. Application of three-component microlog method in converted wave statics [J]. Petroleum Geophysical Exploration, 2021, 60(1):9.