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Near-Seabed velocity model building and Inversion strategy in shallow water data Full Waveform Inversion

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Abstract Summary

A precise initial velocity model is essential for mitigating the cycle skipping phenomenon in full waveform inversion, ensuring that the velocity model converges correctly. Consequently, it is often necessary to optimize the initial velocity field using reflection tomography prior to conducting full waveform inversion. However, the geological conditions near the seabed in shallow water data are complex, and seismic data typically lack mid-to-far offsets close to the seafloor, rendering conventional reflection tomography ineffective for optimizing and updating the initial velocity field. To overcome this challenge, this paper presents a method that utilizes a first break tomography velocity model, constrained by micro-logging data, to develop the near-seabed velocity model. This approach yields a more accurate velocity model and helps avoid the cycle skipping phenomenon during full waveform inversion. Furthermore, ground roll noise generated near the seabed in shallow water data cannot be efficiently removed without adversely affecting the waveform of turning waves. As a result, full waveform inversion based on waveform matching struggles to effectively optimize and update the near-seabed velocity field. Therefore, it is crucial to employ a mask file during the full waveform inversion process to protect the near-seafloor velocity field, preventing incorrect updates that could adversely affect the velocity adjustments of deeper layers. By implementing the near-seabed velocity modeling technique alongside the mask protection strategy, full waveform inversion has achieved improved results in shallow water regions, enhancing the quality of depth migration imaging

Introduction

The full waveform inversion (FWI) technique is currently the most advanced and precise method for velocity inversion modeling (Pratt R. G., 2004). FWI refines the initial velocity model through iterative calculations, minimizing the discrepancy between the forward model data and the actual seismic data to produce an accurate subsurface velocity field necessary for high-precision pre-stack depth migration imaging (Torantola A, 1984). The input for FWI includes wavelets, the initial velocity field, and seismic data, while the output is the updated velocity field after iterations (Torantola A, 1986). If the error in the initial velocity field is excessively large, the waveform matching between the forward model data and the actual data may exceed half a cycle, resulting in a phenomenon known as "misalignment" or "cycle skipping." This can lead to the FWI-converged velocity field progressing in the wrong direction during iterations, yielding an inaccurate velocity field (Fichtner A et al, 1986). A common approach to mitigate this issue is to optimize the initial velocity field using reflection tomography techniques, ensuring it is as accurate as possible and maintaining the error between the initial forward model data and the actual data within half a cycle. This strategy helps prevent the "cycle skipping" phenomenon, allowing subsequent iterations of FWI to proceed in the correct direction and ultimately achieve an accurate subsurface velocity field (Hu et al, 2013) (Pratt R et al, 1996).

Shallow marine data often encounter complex geological conditions near the seabed due to their proximity to land, leading to significant variations in lithology and velocity fields. Furthermore, the original acquisition data typically lacks medium to long offset information near the seabed, rendering conventional reflection tomography techniques ineffective for optimizing the near-seabed velocity field. As a result, inaccuracies in the near-seabed velocity field can severely hinder the effectiveness and precision of full waveform inversion (FWI). To tackle this challenge, this paper proposes using a first break tomography inversion velocity field, constrained by micro-logging data, to model the near-seabed velocity. This approach facilitates the creation of a more accurate near-seabed velocity field and helps prevent the "cycle skipping" phenomenon, ultimately enhancing the effectiveness and accuracy of FWI.

Additionally, while FWI relies on waveform matching, shallow marine environments are often affected by well-developed ground roll noise. Near-offset ground roll noise can interfere with turning waves, significantly distorting their waveforms. Suppressing near-offset ground roll noise without compromising the integrity of the turning waves remains a challenge, resulting in unsatisfactory iterative outcomes for FWI at near offsets. Consequently, FWI is less effective than first break tomography for updating the near-seabed velocity field in shallow marine data. To address this during the iterative FWI process, this paper employs a masking technique to safeguard the near-seabed velocity field, ensuring it remains stable throughout the inversion process. This effectively prevents the near-seabed velocity field from being updated in the wrong direction, thereby maintaining the quality of updates for deeper velocity fields.

By utilizing near-seabed velocity field modeling techniques and implementing mask protection, this paper achieves improved velocity update results in FWI applications for shallow water marine data, enhancing the quality of pre-stack depth migration imaging.

Method and/or Theory

The objective function of full waveform inversion is defined as the L2 norm of the discrepancy between the forward modeled data and the observed data, as illustrated in Equation (1). Through iterative adjustments to the initial velocity field, the algorithm refines the velocity field until it closely approximates the true velocity field, while minimizing the objective function (Virieux J et al, 2009). During each iteration, the velocity update is derived from the error between the original data and the forward modeled data, as indicated in Equation (2)

$$E = \frac{1}{2}\sum_s \sum_r \sum_t [P_{Cal}(s,r,t) - P_{Obs}(s,r,t)]^2 \quad (1)$$

In Equation (1), P_{Cal} represents the forward modeled seismic data, while P_{Cal} refers to the actual seismic data. The variable s denotes the shot point, r indicates the receiver point, and t signifies the propagation time.

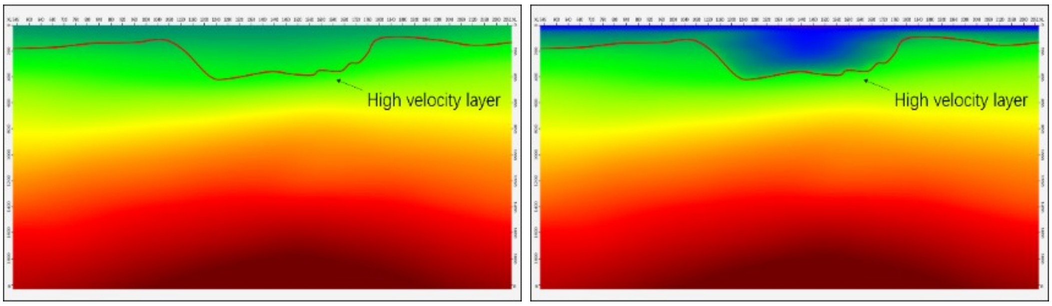
$$V_{n+1} = V_n + a \sum_s \sum_t \left[\left[\frac{\partial P_s}{\partial t}\right]_{prop} \cdot \left[\frac{\partial (P_{obs} - P_{cal})}{\partial t}\right]_{prop} \right] \quad (2)$$

In Equation (2), V_n represents the velocity model at the nth iteration, whereas V_{n+1} signifies the velocity model at the (n+1)th iteration, with P_s representing the source wavefield.

Throughout the full waveform inversion process, each iteration involves a forward modeling step followed by an inversion step. The forward modeling step computes the error between the modeled data and the observed data, while the inversion step updates the velocity. Consequently, the computational requirements for full waveform inversion are significantly high (Fichtner A, 2011).

Near-seabed velocity modeling technology

Using Block A in the South Caspian Sea as a case study, this area lies within a strike-slip fault zone featuring flower-like faults and shallow water depths, indicative of a shallow marine sedimentary environment. The lithology near the seabed is complex and includes widespread low-velocity mud volcano distributions, leading to considerable velocity variations. Traditional root mean square (RMS) velocity and reflection wave tomography techniques in the time-offset domain fail to produce accurate near-seabed velocity models. In contrast, only the first break tomography modeling method, constrained by micro-logging data, can generate a more precise near-seabed velocity model. To achieve this, we use the high-velocity top interface as the splicing interface, integrating the first break tomography velocity model with the initial velocity model. A 50-meter taper is placed at the splicing interface to prevent sudden changes in the velocity field. This process finalizes the near-seabed velocity modeling, as depicted in Figure 1.

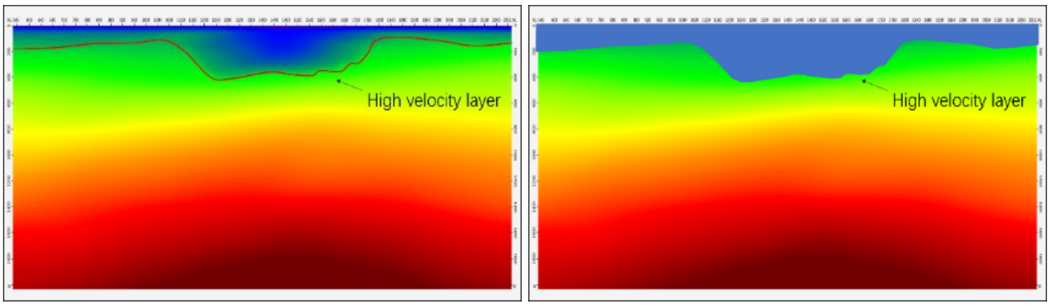


(a) (b)

Figure 1. Velocity model before (a) and after (b) splicing the first break tomography velocity model.

Mask Protection Technology for Near-Seabed Velocity Field

Full waveform inversion (FWI) operates on the principle of waveform matching, while first break tomography focuses on first break times. In shallow marine datasets, the waveforms of turning waves at near offsets can become distorted due to interference from ground roll noise. In contrast, first break times remain unaffected by this ground roll noise interference. Consequently, for the near-seabed velocity model in shallow marine environments, first break tomography algorithms yield greater accuracy than FWI algorithms. Once the modeling of the near-seabed velocity field is completed, it is essential to utilize a mask file during the FWI process to safeguard this velocity and prevent incorrect updates during iterations. This approach ensures that the velocity field located beneath the high-velocity interface is adjusted in the proper direction. Figure 2 shows the near-seabed velocity model with and without the application of the mask file.

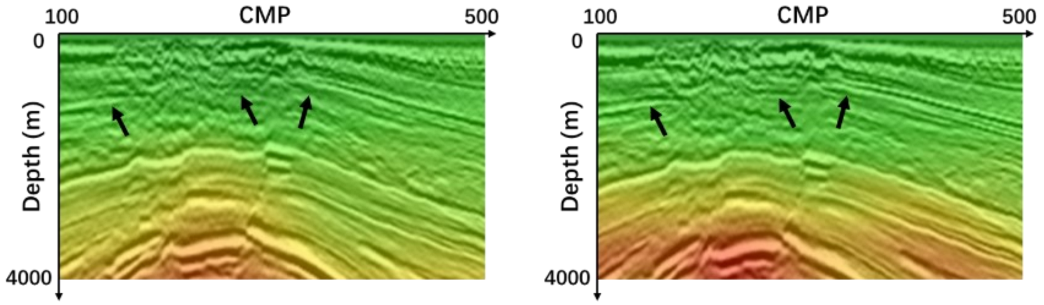


(a) (b)

Figure 2. Near-seabed velocity field without (a) and with (b) the application of mask file.

Results

By applying the near-seabed velocity modeling technique and the near-seabed velocity protection strategy introduced in this study for full waveform inversion, the pre-stack depth migration section has shown marked improvement, featuring clearer events and a higher signal-to-noise ratio, as demonstrated in Figure 3.



(a) (b)

Figure 3: Pre-stack depth migration section overlaid with velocity before (a) and after (b) full waveform inversion.

Conclusions

This study uses Block A in the South Caspian Sea region as a case study to tackle the challenges presented by the complex near-seabed velocities and substantial ground roll noise interference in the original seismic data for shallow marine datasets. Utilizing the near-seabed velocity modeling technique and the near-seabed velocity mask protection strategy for full waveform inversion resulted in a more accurate velocity model, significantly enhancing the pre-stack depth migration imaging. The methods introduced in this paper are highly applicable for imaging other similar shallow marine datasets.

References

Fichtner A, Trampert J., 2011, Resolution analysis in full waveform inversion. Geophysical Journal International, 187(3): 1604-1624.

Hu G H, Jia C M, Xia H R, et al., 2013, Implementation and validation of 3D acoustic full waveform inversion. Geophysical Prospecting for Petroleum, 52(4): 417-425.

Pratt R, Sams M., 1996, Reconsolidation of crosshole seismic velocities with well information in a layered sedimentary environment. Geophysics, 61(2): 549-560.

Pratt R G., 2004, Velocity models from frequency-domain waveform tomography: past, present and future. Expanded Abstracts of 66th Annual Internat EAGE Mtg, Z99.

Torantola A., 1984, Inversion of seismic reflection data in the acoustic approximation. Geophysics, 49(8):1259-1266.

Torantola A., 1986, A strategy for nonlinear elastic inversion of seismic reflection data. Geophysics, 51(10):1893-1903.

Virieux J, Operto S., 2009, An overview of full waveform inversion in exploration geophysics. Geophysics, 74(6): WCC17-WCC52.