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Application of serial offset technique in full waveform inversion

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Abstract Summary

In the modeling process of subsurface velocity fields, the importance of the shallow velocity field far exceeds that of the deep velocity field. The accuracy of the shallow velocity field has a more sensitive impact on depth migration imaging, and errors in the shallow velocity can affect both shallow and deep imaging. Full waveform inversion (FWI) is an ill-posed problem characterized by multiple solutions. During the FWI process, the low ray density of the shallow velocity field and the influence of far-offset data often lead to inaccuracies in the inversion of the shallow velocity field, significantly impacting the overall accuracy of velocity modeling. To address this challenge, this paper proposes a serial offset full waveform inversion technique, which involves iteratively inverting near-offset data to specifically update the shallow velocity before gradually expanding the offset range to update the deep velocity model. In practical data applications, this method yields superior inversion results compared to direct inversion using full-offset data, with better matching between the final synthetic data and the original data. This demonstrates the advantages of the proposed method and provides an effective technical strategy for the application of full waveform inversion techniques.

Introduction

Full waveform inversion technology is a precise modeling technique for velocity inversion that is becoming increasingly vital in high-accuracy depth migration imaging (Virieux et al. 2009). In the process of velocity modeling, shallow velocities are especially sensitive to depth migration imaging, and inaccuracies in these shallow velocities can impact both shallow and deep imaging results (Bian et al. 2010). If the shallow velocity is not accurate, assessing the accuracy of the deep velocity field loses significance. Thus, modeling shallow velocities is crucial. Full waveform inversion modeling is typically an ill-posed problem with multiple solutions (Tarantola A, 1984). During the data modeling process, the low ray density in shallow layers and the effect of far-offset data on shallow velocity can result in inaccuracies during the iterative inversion of shallow velocities, ultimately compromising the overall accuracy of the velocity model (Pratt R G, 2004). To tackle this challenge, this paper introduces a serial offset full waveform inversion iterative technique, known as the serial offset technique. Unlike traditional methods that directly use full-offset data for inversion, this technique first focuses on inverting near-offset data to refine the shallow velocity model. Once the shallow velocity is confirmed to be relatively accurate, the offset range is gradually expanded to further improve the deep velocity model. This method updates the velocity model by moving from near to far in offset range and from shallow to deep in depth. In practical applications, the synthetic data generated using this new technique shows better alignment with the original data compared to results from traditional approaches, illustrating the advantages of the proposed method. The strategy outlined in this paper offers a strong technical framework for enhancing the application of full waveform inversion technology.

Method and/or Theory

Full waveform inversion (FWI) iteratively updates the velocity model to minimize the error between synthetic data and observed field data, ultimately yielding an accurate subsurface velocity model (Fichtner A et al. 2011). The error functional for full waveform inversion can be expressed as follows:

$$E(m) = \frac{1}{2}\|L(m) - u_{obs}\|^2 \quad (1)$$

In this equation, m represents the subsurface velocity model, L is the forward operator, L(m) denotes the synthetic data generated from the velocity model, and u_{obs} refers to the seismic data collected in the field. The objective function E is defined as the squared L^2 norm of the difference between the synthetic data and the observed field data.

Strategy of serial offset technology

The study area is located in Block A of the Southern Caspian Basin, characterized by shallow marine OBN data with an average water depth of 30 meters and a maximum offset of 6000 meters. This paper employs both traditional Full Waveform Inversion (FWI) iterative strategies and serial offset updating strategies for iterative updates, comparing the results obtained from each approach.

The traditional updating strategy directly utilizes data across the entire offset range for FWI iterative updates, as illustrated in Figure 1, with a total of 20 iterations. Conversely, the serial offset iterative updating strategy initially uses offset distance data ranging from 0 to 2500 meters for FWI iterative updates, which yields a relatively accurate shallow velocity model. Building upon this initial result, the strategy continues to update using data from 0 to 6000 meters of offset distance, with both phases consisting of 10 iterations each, maintaining a total of 20 iterations 2.

Results

Figure 1 presents an overlay view of the velocity fields and depth migrated sections obtained from the traditional FWI iterative strategy (a) and the serial offset updating strategy (b). The latter demonstrates superior imaging quality, with stronger energy along the events and greater continuity of the events, proving the advantages of the serial offset FWI iterative strategy.

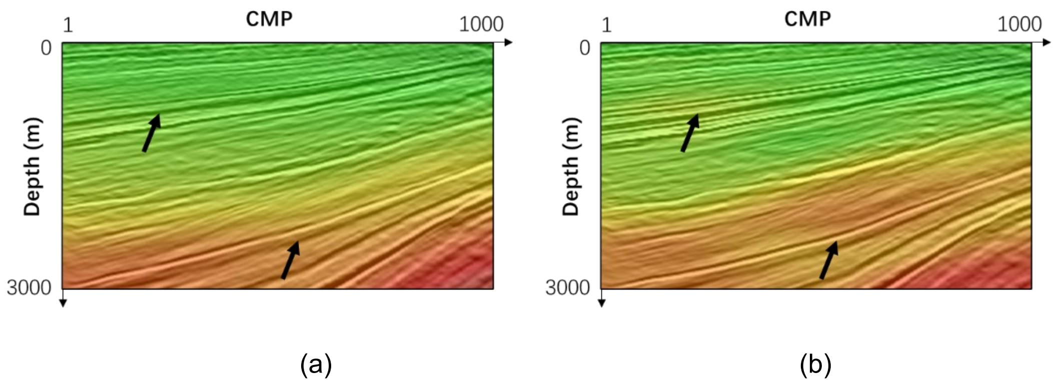

Figure 1: Overlay display of the velocity field and depth migrated section obtained from the traditional FWI iterative strategy (a) and the velocity field and depth migrated section obtained from the serial offset updating strategy (b).

Conclusions

This paper compares the traditional FWI iterative strategy and the serial offset FWI iterative strategy using actual seismic data from Block A in the Caspian Sea region. Compared to the traditional FWI iterative strategy, the serial offset FWI iterative strategy achieves better matching between the forward modeling data and the original data, results in velocities closer to well log data, and provides better imaging quality for depth migration sections. The effectiveness of the serial offset FWI iterative strategy surpasses the traditional strategy.

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