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Improving the Sub-Volcanic Image through Least-Squares PSDM with TLFWI

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Summary

Imaging deep targets underneath highly heterogeneous overburden using data from non-ideal acquisition is always challenging. In Block SC38, offshore Philippines, the seismic energy propagation is disrupted by a complex volcanic system in the overburden, leading to washed-out imaging beneath the volcano. The absence of diving waves further complicates velocity modeling, and heterogeneous velocity variations challenge depth imaging. An accurate velocity model and advanced migration approach are both crucial for deep target imaging in this area. This paper demonstrates how the combination of Dynamic-Resolution Time-lag Full-waveform Inversion (DR-TLFWI) and Least-squares PSDM (LS-PSDM) addresses these challenges. DR-TLFWI optimizes contributions from low- and high-wavenumber components, improving velocity model accuracy for deep targets beyond the reach of diving waves. With the improved velocity, Least-squares PSDM (LS-PSDM) further compensates for illumination loss and enhances amplitude fidelity in complex subsurface conditions. The results demonstrate improved event focusing and gather flatness in the target reservoir, highlighting the effectiveness of DR-TLFWI with LS-PSDM for sub-volcanic imaging.

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Introduction

Imaging deep targets underneath highly heterogeneous overburden using data from non-ideal acquisition is always challenging. In Block SC38, offshore Philippines, the seismic energy propagation is disrupted by a complex volcanic system in the overburden, leading to washed-out imaging beneath the volcano. The absence of diving waves further complicates velocity modeling, and heterogeneous velocity variations challenge depth imaging. An accurate velocity model and advanced migration approach are both crucial for deep target imaging in this area. This paper demonstrates how the combination of Dynamic-Resolution Time-lag Full-waveform Inversion (DR-TLFWI) and Least-squares PSDM (LS-PSDM) addresses these challenges. DR-TLFWI optimizes contributions from low- and high-wavenumber components, improving velocity model accuracy for deep targets beyond the reach of diving waves. With the improved velocity, Least-squares PSDM (LS-PSDM) further compensates for illumination loss and enhances amplitude fidelity in complex subsurface conditions. The results demonstrate improved event focusing and gather flatness in the target reservoir, highlighting the effectiveness of DR-TLFWI with LS-PSDM for sub-volcanic imaging.

Method

Full-waveform inversion (FWI), primarily driven by diving waves, is a powerful tool for seismic velocity model building and imaging. However, in Block SC38, where targets lie 3-4 km deep beneath a complex volcanic overburden, the streamer acquisition with a maximum offset of 4 km and with water depth exceeding 1000 m, diving waves penetrating of the subsurface is restricted. Consequently, the use of reflections becomes critical in FWI. Conventional reflection-based FWI updates often lack critical low-wavenumber components for kinematic corrections, which is a key to imaging improvement. In this work, we apply DR-TLFWI (Wang et al., 2023), which enhances full-wavefield utilization by dynamically weighting tomographic terms and compensating for scattering effects to optimize contributions across low- and high-wavenumber components. This approach provides effective velocity updates for both volcanic overburden and deep targets beneath the volcano. With the complex velocity variations well captured by DR-TLFWI, the conventional Kirchhoff depth migration (K-PSDM) engine struggles with lateral velocity contrasts and fails to compensate for the illumination loss. The single iteration curvelet domain LS-PSDM (Wang et al., 2017) is applied to better handle the illumination loss and imaging issues caused by strong velocity heterogeneity.

Examples

In this study, the legacy velocity model is derived from conventional FWI, tomography and interpretation-driven methods. It fails to capture the velocity variations associated with the volcanic overburden, as shown in Figure 1a. Consequently, the target region exhibited unfocused events and strong migration artifacts, particularly at greater depths, as shown in Figure 1b. By incorporating dynamic weighting into the FWI kernel, DR-TLFWI revealed features such as lava flows, volcanic conduits, and other geological characteristics and achieved effective kinematic corrections with flatter gathers and improved event focusing (Figures 1d, 1e, 1f).

Another challenge to revealing deep sections is the distortion of the wave propagation from the overburden, which causes unbalanced illumination in sub-volcano areas. Conventional K-PSDM struggles to image these areas leading to significant migration artifacts, amplitude imbalances, and poor focusing of the targeted structures, as shown in Figure 2a. With the improved DR-TLFWI velocity, LS-PSDM can effectively attenuate migration swings and artifacts, compensate for the illumination loss, improve reflector continuity, and produce more uniform amplitude distribution across complex geological settings beneath the volcano. This led to a high-fidelity image with better visualization of reservoir structures and improved interpretability of deep target zones (Figure 2b). These advancements demonstrate the superiority of LS-PSDM in delivering more precise images in challenging geological environments when supported by accurate velocity models.

Conclusions

For deep target imaging in areas with strong velocity contrasts using data from non-ideal acquisitions, we propose the integrated approach of DR-TLFWI and LS-PSDM. DR-TLFWI effectively leverages reflections to update low-wavenumber velocities to better solve complex lateral velocity contrasts beyond the reach of diving waves. LS-PSDM addresses illumination loss, producing high-quality seismic images. This combined methodology represents a significant advancement in imaging capabilities, which can potentially reduce exploration uncertainties in future projects.
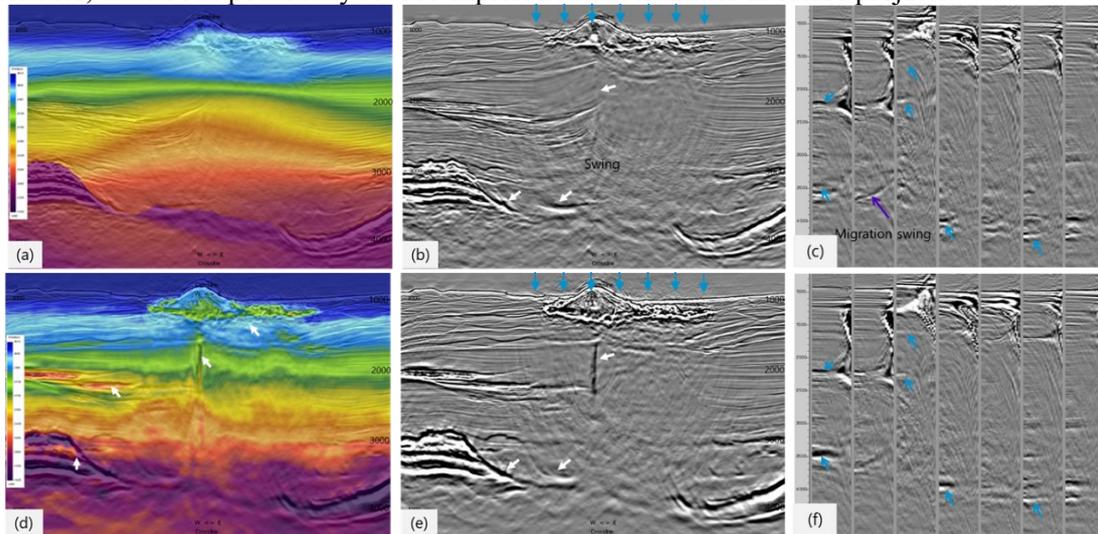

Figure 1 *a) Legacy PSDM overlaid with legacy velocity model; b) Legacy PSDM stack with unfocused volcano base and indistinct conduit; c) Common Image gathers (CIGs) with legacy velocity; d) final DR-TLFWI velocity model shows more details and conforms with structure; e) PSDM Stack using DR-TLFWI velocity model, showing enhanced imaging of the volcanic and deep section; f) CIGs with DR-TLFWI velocity, demonstrating improved alignment and focus.*
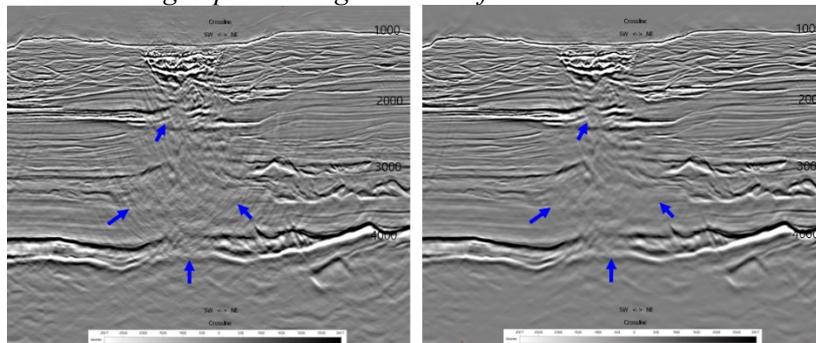

Figure 2 *LS-PSDM produced cleaner reservoir images with improved event continuity, reduced migration artifacts, and enhanced amplitude fidelity: a) K-PSDM stack; b) LS-PSDM stack*

Acknowledgments

References

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