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Navigating through the Red Sea Subsalt Structures: A Look-Ahead VSP Case Study from Saudi Arabia

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ABSTRACT

Obtaining an accurate migration velocity model is an ongoing challenge in seismic exploration. Using a Zero-Offset Vertical Seismic Profile (ZVSP) survey, one can obtain a 1D time-depth profile at the well location. This velocity model can be sufficiently accurate to yield accurate migrated images in case the subsurface consists predominantly of horizontal layers. However, these images might be heavily distorted in the presence of lateral velocity variations, anisotropy, or fault events in the subsurface. The Red Sea basin is geologically quite complex due to the presence of inhomogeneous and complex-shape salt bodies. A look-ahead walkaway VSP (WAVSP) data was acquired while drilling through a salt body to predict the subsalt reflectors and navigate the drilling operation. Utilizing first-breaks traveltime tomographic inversion to update the migration velocity model is indispensable in order to detect lateral velocity variations in such basin. Therefore, we applied the tomographic inversion to the data. The dataset consists of equally-spaced 225 shots around the well from ~5000 ft to ~13450 ft, and 40 equally-spaced 40 receivers from depth of ~4560 ft up to ~6510 ft, directly below the wellhead. The shot and receiver spacing are 82 ft and 50 ft, respectively. The frequency range of the VSP data is limited to 100 Hz with a dominant frequency of 20 Hz. The first-break traveltimes were picked on all 9000 raw traces. Then, the upgoing P-wave reflections were separated from the recorded total wavefield using model-based separation techniques. An initial two-layer velocity model was constructed employing the nearest shot to the wellhead. Tomographic inversion was applied to the picked traveltimes and a smooth inverted velocity model is obtained after 10 steepest descent iterations. Subsequently, the upgoing P-wave reflections were imaged with the inverted velocity model using Kirchhoff migration. The migrated image is remarkable as it better delineates the subsalt reflectors. It also predicts their dip direction, which is consistent with the geological interpretation and the surface seismic. Least-squares migration was also used to further enhance the final VSP image quality by suppressing the migration artifacts and the acquisition footprint. We concluded that applying first-break tomographic inversion is an essential step prior to imaging VSP data to resolve subsalt structures in a geologically complex basin such as the Red Sea.