Integrated Interpretation for Upholes and Small-refraction Data Based on Tomography Inversion

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Summary

An analysis of the poor reliability of current interpretation results for upholes and small-refraction data led to the proposal of a comprehensive interpretation method based on tomography inversion. This method applies the integrated interpretation results to constrain the first arrival tomography inversion, establishing a higher-precision shallow velocity model. The application of this comprehensive interpretation method to a 3D data processing in the southwestern Tarim exploration area improved inversion accuracy, effectively addressing static correction issues in the working area.

Introduction

Upholes and small-refraction are two technical means for investigating the distribution of near-surface velocities in onshore oil and gas exploration surveys. The results of these surveys are primarily used for field well depth design. In recent years, with the development of first arrival tomography inversion technology, the near-surface velocity information obtained from small-refraction or upholes data has been utilized to compensate for the limitations of conventional first arrival tomography inversion in shallow velocity modeling. This aims to improve the accuracy of near-surface velocity modeling, achieving an integrated modeling effect for static correction and pre-stack depth migration. Consequently, higher demands have been placed on the interpretation results of small-refraction and upholes.

Currently, interpretation results for upholes or small-refraction data typically provide information on three layers. When the low-velocity layer is thin, only information on the low-velocity layer and high-velocity layer is provided. While these results meet the requirements for well depth design, their accuracy is insufficient for constraining first arrival tomography inversion. Firstly, the near-surface is generally composed of sediment with a continuous increasing trend, rather than a layered distribution. Secondly, the interpretation methods for both types of data rely on the time-distance scatter plot of first arrivals, where turning points are determined interactively, inevitably introducing human errors. Additionally, for small-refraction, the conventional interpretation method using the delay time approach theoretically cannot obtain the thickness of the last layer, failing to fully explore the detection depth of small-refraction data. For upholes, the use of trigonometric functions to convert non-zero-offset first arrival times to zero-offset times introduces errors due to the gradual variation of velocities in the shallow layers.

To address these issues, this paper proposes a comprehensive interpretation method for upholes or small-refraction data based on tomography inversion. This method enhances the reliability of interpretation results for upholes or small-refraction data, facilitating the establishment of a higher-precision velocity model and subsequently improving the accuracy of constrained inversion modeling. The application of this comprehensive interpretation method to 3D data processing in the southwestern Tarim exploration area has enhanced inversion accuracy and effectively resolved static correction issues in the working area.

Conventional Interpretation Methods for Upholes Data and Associated Issues

The left diagram in Figure 1 illustrates the schematic diagram of a upholes observation system, where shot points are in the well, and receivers are on the ground, with offset distances of 0.5 meters, 1 meter, and 2 meters, respectively. Initially, the first arrival times are picked from upholes records. Subsequently, the non-zero offset first arrival times are converted to zero-offset times, generating the first arrival time versus offset plot as shown in the middle diagram. Then interactively delineate layers and determine velocities based on the trend of the time-offset plot, obtaining velocity-thickness layer information as depicted in the right diagram of Figure 1.

This interpretation method introduces errors in two aspects. Firstly, the conversion of non-zero offset observation times using trigonometric functions to zero-offset times assumes a uniform velocity distribution in the shallow layers, implying constant velocities both laterally and vertically. This assumption is required for the ray paths of zero-offset and non-zero offset first arrival waves to conform to the trigonometric relationship. However, in reality, the velocity of the shallow subsurface generally increases with depth, and the propagation path of the first arrival wave is not a straight line. As the offset distance increases, the error also increases. Secondly, when interactively determining turning points on the time-offset plot, there is inevitably human error since the distribution of first arrival times rarely exhibits clear turning points. Figure 2 presents two different outcomes of a conventional interpretation method for the first arrival times of a upholes dataset, emphasizing the inherent uncertainties in the results.

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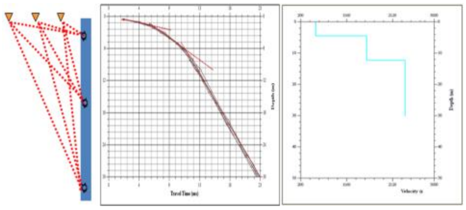

Figure 1: Schematic diagram of conventional interpretation method for upholes

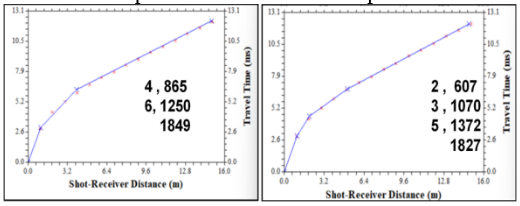

Figure 2: Illustration of human-induced errors in conventional interpretation results

Furthermore, the conventional interpretation methods for upholes do not provide the thickness of the last layer, as demonstrated in Figure 3, which presents an interpretation result for a specific upholes dataset. Although the velocity of the last layer is given as 1865 m/s the thickness is not provided, making it challenging to use for constrained inversion.

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Figure 3: Example of conventional interpretation result for a specific upholes dataset

Conventional Interpretation Methods for Small-Refraction Data and Associated Issues

Figure 4 illustrates an example of a small-refraction observation system (bottom diagram) and first arrival times (top diagram), typically with a distribution of shot-receiver offsets that is denser at both ends and sparser in the middle. Small-refraction interpretation commonly employs the delay-time method, as depicted in Figure 5. The first arrival times are displayed as a time-distance scatter plot, and turning points are determined interactively to calculate velocities and thicknesses for each layer.

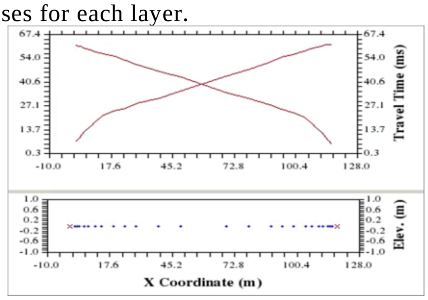

Figure 4: Example of a small-refraction geometry and first arrival times

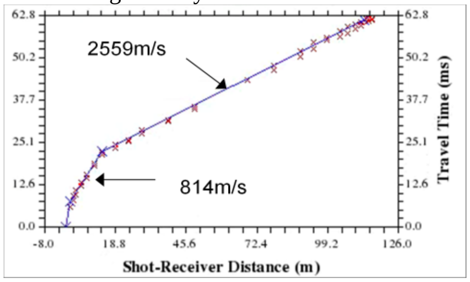

Figure 5: Schematic diagram of conventional interpretation for small-refraction data

Theoretically, the delay-time method cannot provide the thickness of the last layer, only the velocity. Therefore, similar to upholes, it is challenging to use for constrained inversion.

Integrated Interpretation of Upholes and Small-Refraction Data Based on Tomography Inversion

Treating upholes or small-refraction data as a 2D seismic line, near-surface tomography inversion is performed. Subsequently, combining upholes or small-refraction data for integrated interpretation enhances the reliability of interpretation results. Figure 6 presents an example of integrated interpretation results for upholes data. The left two graphs show ray density and inversion results, indicating reduced reliability with increasing depth due to decreasing ray density. The middle graph overlays tomography inversion results with conventional interpretation results, demonstrating that tomography inverted velocities vary gradually in the shallow section with high resolution, while disturbances appear in the deep layers. Therefore, velocities from tomography inversion are adopted in the shallow part, and velocities from conventional interpretation are used in the deep part. The integrated interpretation result is represented by the pink curve in the right graph of Figure6.

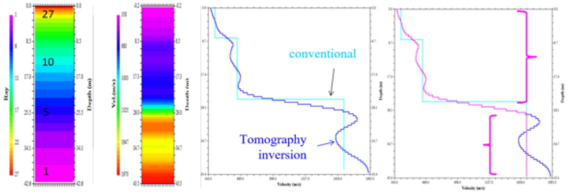

Figure 6: Example of integrated interpretation method for upholes data

Figure 7 displays ray density and velocity distribution obtained through tomography inversion of a small-refraction dataset, vividly showing the maximum detection depth of small-refraction.

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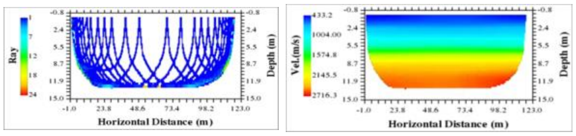

Figure7: Example of tomography inversion results for small-refraction data

Figure 8 combines tomography inversion velocities with conventional interpretation results. Similar to upholes, the inverted velocities are gradual with high resolution in the shallow section, while instability arises in the deep section due to a single ray angle. Therefore, velocities from the inverted results are used in the shallow part, and velocities from conventional interpretation are used in the deep part. The integrated interpretation result, depicted by the pink curve in the right graph of Figure 8, provides a thickness of 17 meters, revealing the full detection depth potential of small-refraction data compared to the conventional interpretation result, which only provides a thickness of 4.6 meters.

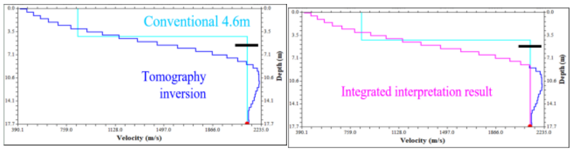

Figure 8: Integrated interpretation result for small-refraction data

Application of Integrated Interpretation Method in a Southwest of Tarim Working Area

The integrated interpretation method was applied to model the near-surface in a working area in the southwestern Tarim exploration region. The modeling results, as shown in Figure 9, compare the establishment of shallow velocity models using conventional interpretation results (left) and integrated interpretation results (right). Clearly, the model based on integrated interpretation is more stable, eliminating many anomalies and abrupt changes. The constrained inversion velocity model based on integrated interpretation results is depicted in Figure 10, showing a reasonable velocity distribution and high inversion accuracy.

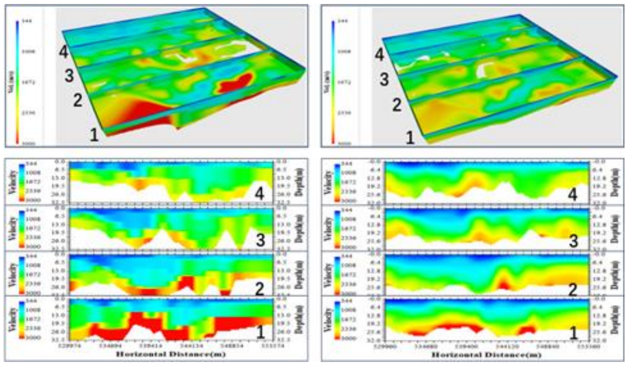

Figure9: Shallow near-surface models

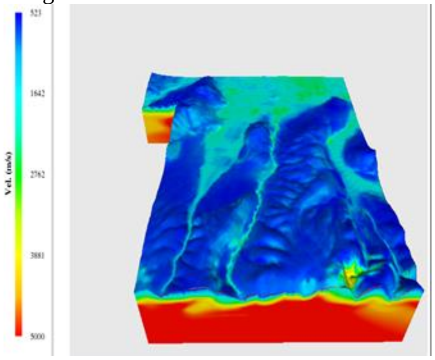

Figure 10: Constrained tomo-inversion result

Figures 11 and12 present stack section of field statics and tomo-statics, respectively. It is evident that tomo-statics effectively addresses static correction issues, providing a stable and clear boundary in the loess layer, significantly improving imaging quality.

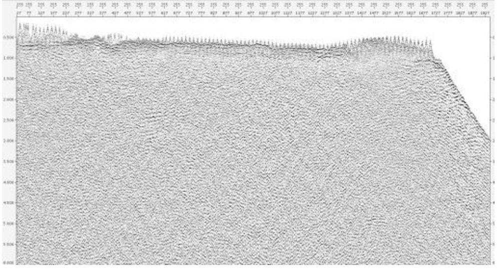

Figure 11: stack section with field statics

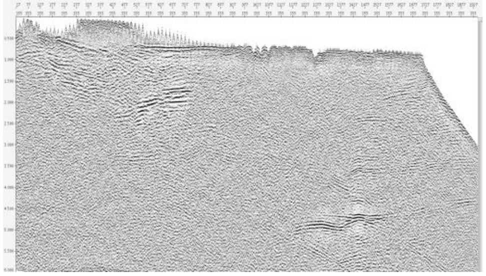

Figure12: stack section with tomo-statics

Conclusion

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The method described in this paper integrates the advantages of high precision in the shallow section from tomography inversion and stability in the deep section from conventional results. It overcomes the inversion anomalies in the deep section of upholes caused by low ray density and the single angle of small-refraction ray paths. Additionally, small-refraction, based on ray density, accurately determines the detection depth. The modeling of the near-surface in the southwestern Tarim exploration region demonstrates a more rational and stable shallow layer model, eliminating anomalies, achieving high inversion accuracy, and showing a significant improvement in static correction effects.

Keywords: Small-refraction, Upholes, First arrival tomography inversion, Constrained inversion

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