# Seismic Imaging and Applications in Mountain Areas

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## Summary

Seismic imaging in mountain areas is very challenging due to dual complexities of near-surface and sub-surface conditions. Near-surface condition is dominated by heterogeneous proluvial fans which strongly scatter seismic waves and reduce the ratio of signal to noise. Sub-surface condition is complex structures including overthrusts, high-velocity conglomerates, and anhydrates of cap-rock, which cause irregular velocity interfaces and induce azimuth anisotropy. Meanwhile, it gives following four issues to us: low SNR data with strong interference, severe statics problem, complex velocity structure with rapid spatial variation and strong stratigraphic anisotropy. In order to solve these four issues, wide-azimuth and high-density acquisition of exploration has been conducted. In seismic processing, wavefield preservation, high-precision velocity model building with multi-information constraints and adaptive migration algorithms need be concerned. Practical cases including Kucha, Longmenshan and Yingxiongling verify these integrated techniques and significantly improve structural interpretation accuracy and minor faults imaging quality.

## Introduction

Seismic imaging in mountain areas plays a crucial role and is also a super challenge in oil and gas seismic exploration. The main issues are the complexities of the near-surface and sub-surface, which distort seismic wave propagation and reduces data quality (Liu et al., 2025).

Near-surface multistage proluvial fans show strong heterogeneity and anisotropy which scattering seismic waves, causing low SNR and severe statics problems (Wang et al., 2023). Sub-surface tectonic deformation forms overthrusts, high-velocity conglomerates, and anhydrates of cap-rock, which result in irregular velocity interfaces and azimuthal anisotropy (Zhang et al., 2025).

These issues cannot be properly handled with traditional approaches, such as narrow-azimuth acquisition, conventional de-noise methods, traditional first arrival tomography, and inaccurate velocity model building, which lead to insufficient subsurface illumination and inaccurately recognize high-velocity bodies (Chen et al., 2024), as well wipe out key anisotropy information (Liu, 2023).

## Methods

### 1. Wide-azimuth and High-density Seismic Acquisition

Seismic acquisition is a foundational step for the subsequent seismic imaging. Narrow–azimuth and low-density acquisition give rise to an insufficient illumination and low ratio of signal to noise data, which need to be optimized.

Wide-azimuth and high-density acquisition has been carried out, that is, the aspect ratio is increased from 0.6 to 1.0, and trace density is raised from 1 million/km$^2$ to 5 million/km$^2$. It significantly reduces the illumination shadow effect of deep structures and enhances the continuity of reflection events.

For areas in phase of development with highly developed overthrust structures, standalone surface seismic acquisition struggles to image clearly. So, surface seismic + VSP joint acquisition has been adopted to achieve full-azimuth illumination. As a result, the image of conglomerates boundary turns to be much clearer. Fig. 01 shows the scheme of surface seismic + VSP joint acquisition.

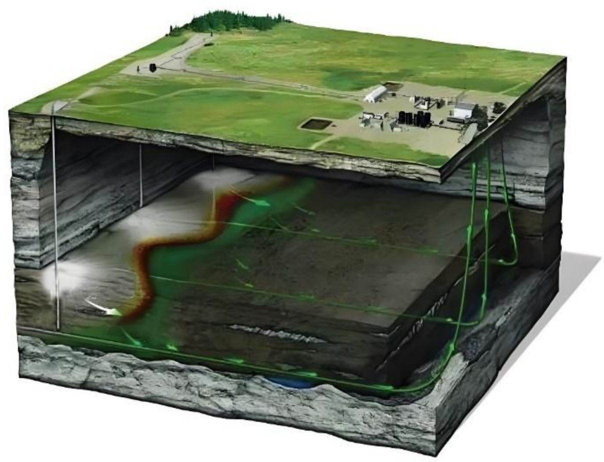

Fig.01 Surface seismic + VSP joint acquisition

**2. Wavefield Preservation in Seismic Data Processing**

Wavefield preservation is essential to image in mountain area. Complex wave fields with geological information in these regions cannot be correctly dealt with conventional processing methods that deteriorate image quality. To avoid incorrectly imaging, retaining both the kinematic and dynamic wavefield characteristics as a core processing principle needs to be followed.

Two specific methods are used. The first is 5D-RNA de-noise method, which solves the limitation of traditional 3D de-noise filter and preserves azimuthal anisotropy signals. By constructing a 5D data cube, the continuity of valid wavefield events across dimensions can be leveraged to distinguish signals from raw data in 5 demotions. On OVT gathers, fluctuation reflect events respond subsurface anisotropy. 5D RNA method preserves these azimuthal anisotropy features while suppressing surface waves and random interference. After applying 5D RNA on OVT gathers shown in Fig. 02, reflection amplitude variation related to high-velocity conglomerates is preserved, and the conglomerate boundary turned to be clearly imaged, as shown in Fig. 03.

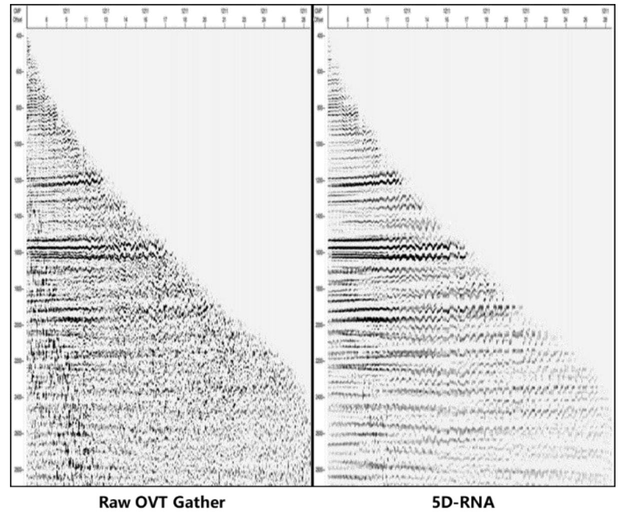


Fig.02 OVT gathers before and after 5D RNA

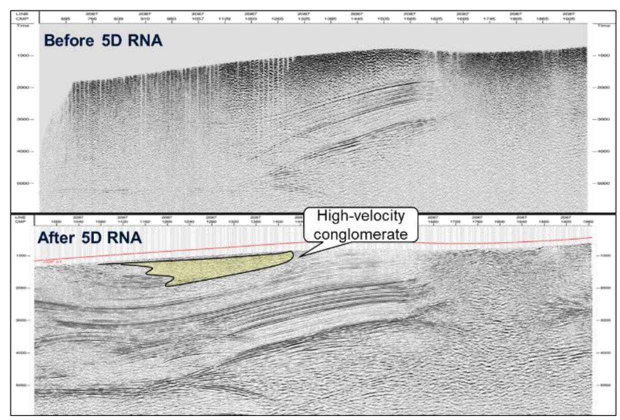


Fig.03 Stack sections before and after 5D RNA

The second is migration datum choosing. Time domain migration datum is at a spread-length smoothed surface which neglects detailed near-surface velocity variations, while the depth migration at a spread-length smoothed surface will lead to "smiling" artifacts. Because wavefield is recorded at ground surface, so depth migration datum should be chosen at an undulated surface that is closed enough to the ground surface. So, the input data for migration should be matched with migration datum, that is, undulated surface, as well, TORT-RTM PSDM algorithm has been chosen. Fig. 04 shows the synthetic data migration results and CIP gathers. Fig. 04(a) shows PSDM results at different migration datums. The undulate surface PSDM preserves the wave field's true propagation path and diffraction is collapsed, while smoothed surface PSDM appears to be "smilling" on migration section. Fig. 04(b) shows CIP gathers on different migration datums. Undulated surface PSDM events are flattened in CIP gathers.

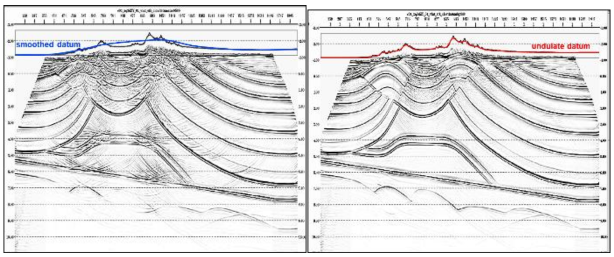


Fig.04 (a) PSDM sections comparison

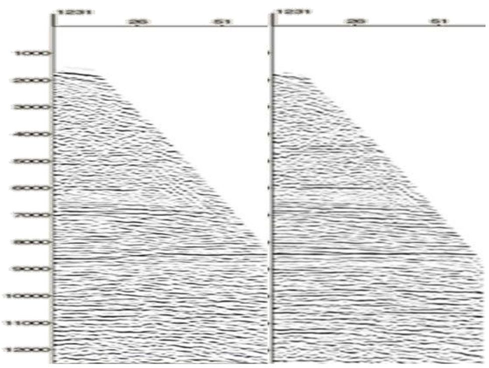

Fig.04 (b) PSDM CIP gathers

### 3. High-precision Velocity Model Building

Velocity model building is important to depth migration, and high-precision velocity model directly determines the position of deep structures and includes identification of special lithology bodies. To overcome the multi-solution problem of tomography inversion and the difficulty in description of high-velocity anomalies, following two methods are adopted:

3.1 Near-surface Velocity Model Building

Near-surface weathering layers exhibits rapid lateral velocity variations in mountain areas, where inaccuracies can significantly compromise deep structure imaging quality. In order to solve this critical issue, enhancing the quality of first arrival picking is necessary. By using FASTOMO software package, that is AI-assisted first arrival picking software package, made by BGP, near surface velocity tomography inversion constrained by upholes has been achieved. The AI module employs machine learning algorithms to analyze the waveform features of the first arrivals, enabling automatic identification of first break even in low SNR seismic data.

To solve the Eikonal equation of tomography inversion, upholes and digital outcrops are used as constraints of multi-solution issue to get velocity model. On one hand, uphole data provides direct measurements of near-surface velocity at well locations. On the other hand, the digital outcrops built for the Tarim basin in 2018 shown in Fig. 05 contains lithology and structure information of the surface. These constraints can demonstrate the lateral variation distribution of near-surface velocity. These multi-constraints significantly improved near surface velocity model reliability.

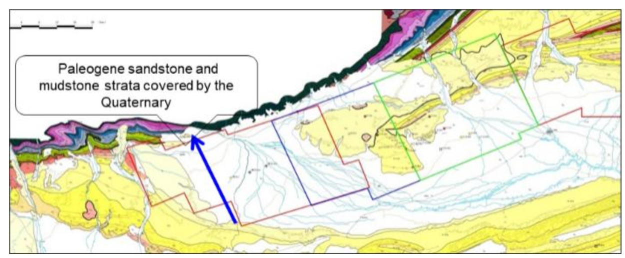


Fig.05 Digital outcrop

3.2 Special Lithology Body Identification

Deep subsurface layers are dominated by special lithology bodies such as Tertiary high-velocity conglomerates and layered anhydrates of cap-rocks with spatial variated distribution. The key challenge is to accurately describe Tertiary conglomerate boundaries and internal anhydrate velocity variation distribution.

Due to uphole drilling can hardly reach the depth of Tertiary conglomerates, TFEM data are used to interpret the boundaries of Tertiary high-velocity conglomerates and resistivity of TFEM can be converted to velocity of lithology bodies through experimental formula. VSP data are used as constraints.

Furthermore, a quantitative experimental relationship between seismic reflection energy and anhydrate velocity is established, which can help us to describe the boundaries of layered anhydrates and its inner gaps. Finally, full-azimuth tomography inversion has been conducted and a high precision velocity model building is completed, which fully describes the 3D distribution of these lithology bodies.

## Examples

### 1.Kucha Area

With the continuous upgrading of wide-azimuth and high-density acquisition, 5D-RNA de-noise methods, and multi-constrained velocity model building, structure interpretation of this area has been undergone significant refinement from 2005 to 2024. Early interpretation is only able to outline large-scale overthrust frameworks, whereas the 2024 results clearly depict minor faults, lithology interface spatial distribution, and the contacts between conglomerates and surrounding rocks. The interpretation based on new acquisition and processing data provides a reliable result for structure trap evaluation shown in Fig. 06.

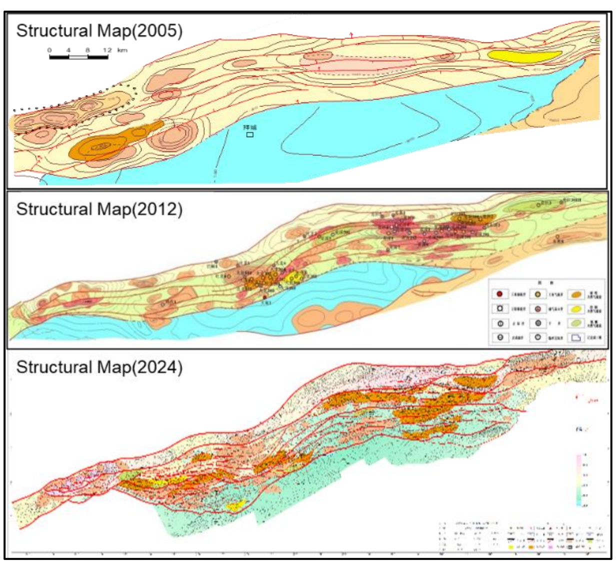


Fig.06 Structural maps

### 2. Longmen Mountain Area

The Longmen Mountain area is characterized by highly developed high-steep thrust faults, where vintage seismic data are poorly imaged and blurred faults can be seen. By applying the progresses of acquisition and processing of BGP, the newly processed seismic data exhibits significant improvement in minor fault imaging shown in Fig. 07. Faults on vintage PSDM section cannot be identified clearly, while faults on new PSDM section can be clearly delineated and the spatial extent and connectivity of faults are accurately imaged. This advancement provides critical support for the analysis of hydrocarbon migration pathways.

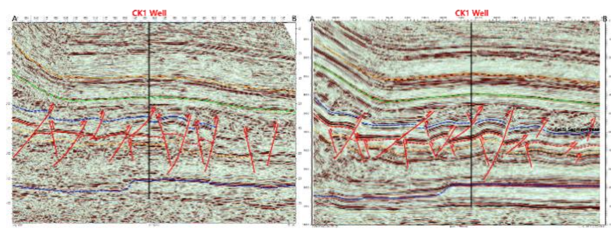


Fig.07 left: vintage PSDM section, right: new PSDM section

### 3. Yingxiongling Area

In this area, geology features an extremely thick near-surface weathering layer, which causes severe statics and absorption issues, directly leading to low resolution of deep structures image. To deal with this challenge, by using optimized migration datum and implementing high-precision velocity model building constrained by upholes and outcrops, the newly processed seismic data image quality has been significantly improved. Minor faults can be clearly recognized shown in Fig. 08. This refined image provides strongly support of exploration well drilling.

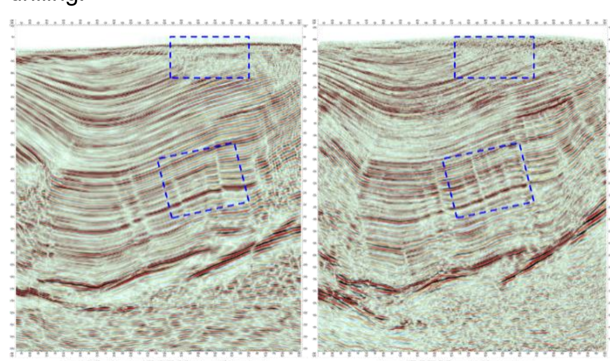


Fig.08 PSDM section comparison

## Conclusions

1) Weathering layer velocity accurate description is essential for PSDM image.
2) High-velocity anomaly identification of velocity model building plays an important role in PSDM imaging.
3) Choosing a suitable undulated surface for migration datum is a crucial step.
4) Migration algorithms should be adapted to the sub-surface media in mountain areas.

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