Submission code: YPKDM850LG

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Study and Application of Data-Driven Multiples Elimination Techniques for Land Seismic Data

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Summary

Complex multiples severely degrade seismic imaging, posing significant challenges for interpretation and inversion. This issue is prominent in Brazil's onshore Paleozoic basins, such as the Parnaíba, Solimões, Amazonas, and Paraná basins, where extensive volcanic coverage (primarily basalt and diabase) generates strong surface-related and interbed multiples. In this paper, we improved the Surface-Related Multiple Elimination (SRME) technique, which is widely applied in marine data, then proposed fully data-driven 3D Generalized SRME (GSRME) and 3D Interbed Multiple Elimination (IME) approaches for land data. Applied to a challenging land survey with heavy multiples and low S/N, these methods effectively suppressed complex multiples, significantly enhancing seismic imaging. The results demonstrate a robust solution for multiple attenuation, offering valuable insights for seismic data processing in Brazil's onshore basins and similar geological environments worldwide.

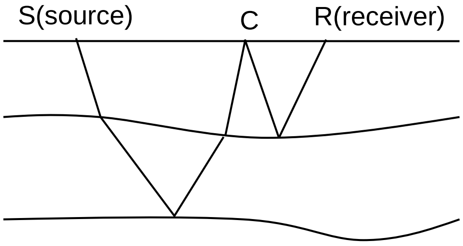
Introduction

De-multiple remains a significant challenge in seismic exploration and has not yet been fully resolved. Multiples introduce considerable uncertainty in interpretation and inversion, making effective de-multiple a critical aspect of seismic data processing.

Multiples are mainly divided into surface-related multiple and interbed multiple according to the generators. For surface-related multiples, Kennett (1979) proposed 1D medium attenuation method, but its practical effectiveness is limited [1]. Berkhout (1982) put forward the inversion algorithm, which shows a good effect in application, but it cost too much [2]. In the 1990s, Berkhout and Verschuur proposed the SRME method, which has been successfully applied to the marine streamer data in recent years [3]. However, for land data, due to the complexity of near surface, low S/N ratio, irregular geometry etc., it is a big challenge to attenuate surface-related multiples. For the interbed multiples, a lot of researches have been carried out by the predecessors, which are mainly divided into two categories: one is to use velocity discrimination between primaries and multiples or the period of multiples. Typical methods include predictive deconvolution, Radon transform etc. The other is based on the wave equation theory. They include inverse scattering series (ISS) [4] proposed by Carvalho (1991) and extended SRME proposed by Jakubowicz (1998) [5]. These kinds of methods are completely data-driven and do not need to know velocity and depth information. Mohamed S. A. N. (2008) [6] and Adel E. (2011) [7] studied and applied the practical data.

We investigated a land survey characterized by heavy multiples and a low signal-to-noise ratio. In this survey, carbonate and gypsum are well developed, and it is easy to form strong impedance interface. These interfaces and surface will produce strong reverberations, which are surface-related multiples. Serious interbed multiples will be generated between strong impedance interfaces. The surface-related multiple and interbed multiples are mixed together, which seriously affects the quality of imaging. This paper studied the multiples issue of survey S. Firstly, the generalized surface–related multiples elimination (GSREM) technique is used to suppressed the surface-related multiples, this method can overcome the influence of irregular geometry and complex near surface. Then 3D interbed multiple elimination (IME) is used to remove the interbed multiples, it is an extended algorithm of conventional SRME, the two methods achieved good results in survey S. Many onshore basins in Brazil share similar geological conditions, as widespread volcanic coverage (primarily basalt and diabase) formations contribute to strong multiple generation. Therefore, these two methods are also applicable and effective for multiple attenuation in Brazil's onshore basins.

Method



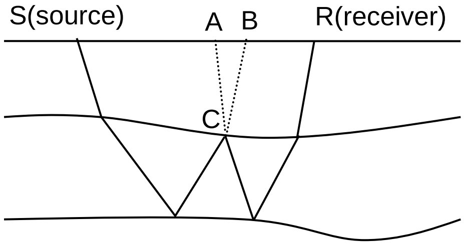


Figure 1: Theory of surface-related multiples **Figure 2:** Theory of interbed multiples

GSRME is an improved method for suppressing land surface-related multiples. Figure 1 shows the theory of surface-related multiples, it can be simulated by convolving two seismic traces. However, the determined downward reflection point C is usually unknown. Multiple model in f-x domain could be simulated by formula (1):

$$M(x_s, y_s, x_r, y_r, \omega) = \sum_{x_c}\sum_{y_c} P_0(x_s, y_s, x_k, y_k, \omega) P(x_k, y_k, x_r, y_r, \omega) \qquad (1)$$

Where, $P_0(x_s, y_s, x_k, y_k, \omega)$ is the wave field from source S to down reflection point C, $P(x_k, y_k, x_r, y_r, \omega)$ is the wave field from down reflection point C to receiver point. (x_c, y_c) is the coordinate of C. However, the accurate wave field at C may be missing due to the irregularity of geometry and trace density in acquisition, so wave field at C should be rebuilt. Regular processing and anti-regular processing are applied in conventional processing, but this greatly increases the calculation cost. In this paper, missing traces are reconstructed by adjacent trace search and partial NMO correction technique, it can greatly increase the adaptability to conventional geometry.

The downward reflection point of interbed multiples is below the free surface, which is different with surface-related multiples. Theory of IME is shown in Figure 2. It can be simulated by convolving two seismic traces and cross-correlating one seismic trace. The interbed multiple model in f-x domain can be expressed by formula (2)

$$M(x_s, y_s, x_r, y_r, \omega) = \sum_{x_a, y_a}\sum_{x_b, y_b} P_0(x_s, y_s, x_b, y_b, \omega) P(x_a, y_a, x_r, y_r, \omega) P^*(x_a, y_a, x_b, y_b, \omega) \qquad (2)$$

Where, $P_0(x_s, y_s, x_b, y_b, \omega)$ is the wave field from source S to point B, $P(x_a, y_a, x_r, y_r, \omega)$ is the wave field from A to R, $P^*(x_a, y_a, x_b, y_b, \omega)$ is conjugate wave field of AB. C is downward reflection point. Points A and B can be searched in an aperture just as GSRME. Interbed multiples may be generated by many layers. This method can simulate multi-layers' interbed multiples. Simultaneous ls-square subtraction is used for these layers' multiples. It shows an excellent result than conventional subtraction. Generally, surface-related multiples are first removed and then interbed multiples second. On one hand surface-related multiples' energy are much stronger and more easily to identified, on the other hand the hypothesis of IME is that surface-related multiples are free. Precondition processing before de-multiple is important. Static correction should be solved for complex near surface. The signal-to-noise ratio of data should be high, otherwise the effect may be greatly reduced.

Examples

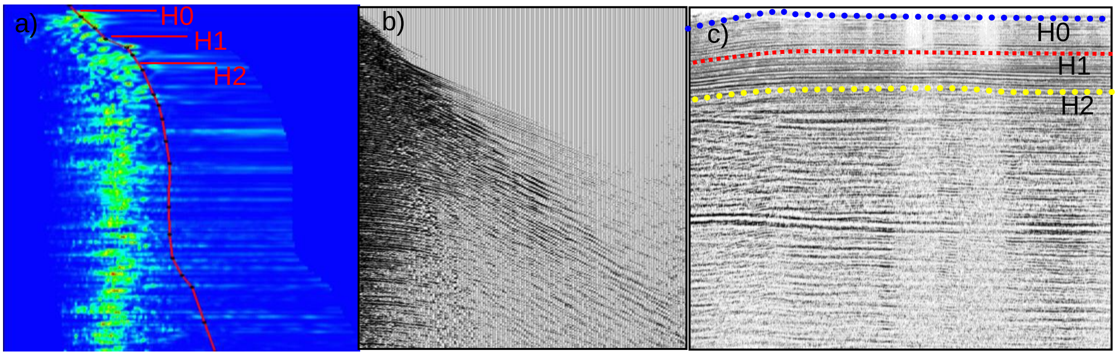


Figure 3: velocity semblance, gather and stack section

Figure 3 shows the data characteristics of land survey S. Strong multiples are concentrated in the near-offset range and mainly in the middle to deep areas below H2. The velocity distinction between multiples and primaries is minimal, rendering conventional methods ineffective in this area. Furthermore, the amplitude, frequency, and dip angle of multiples closely resemble those of primaries, posing a significant challenge for seismic data processing. Identifying multiples and their generators is a crucial first step in seismic data processing. In practice, well data are typically used to calibrate multiples; however, the absence of well data in this survey introduces additional challenges. From Figure 3a), it can be determined H1 and H2 are primaries which have strong energy. The S/N ratio of the section below H2 is low and multiples are seriously developed, making it difficult to identify multiples and primaries. By referencing adjacent wells, we identify H1 as the limestone interface, H2 as the salt interface, and H0 as the surface, which also represents a strong impedance interface. Based on these characteristics, it can be inferred that surface-related multiples are generated by H0 and interbed multiples are mainly generated by H1 and H2.

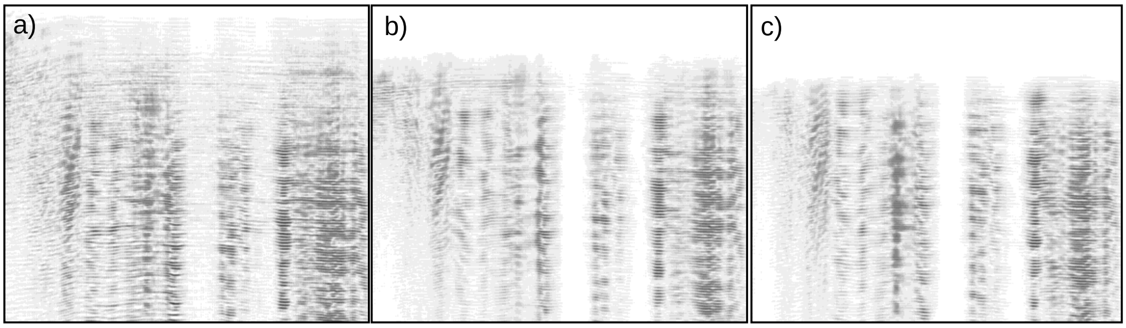


Figure 4: multiple models, a) surface-related, b) interbed by H1, c) interbed by H2.

The data preconditioning process begins with static correction and S/N enhancement. Then surface-related multiples are modeled using the GSRME technique. Figure 4a) presents the stacked section of the modeled data. Its feature is similar with original section, indicating the accuracy of this method. Interbed multiples are predicted using the IME technique, where Figure 4b) is the model generated by H1, and Figure 4c) corresponds to the model generated by H2, which all reflect the characteristics of multiples. Finally, adaptive subtraction is used to attenuate the multiples. All the above processes are pre-stack 3D algorithms that are fully data-driven and independent of velocity information, ensuring a robust and flexible multiple attenuation workflow.

Results

It can be found most of multiples are well eliminated by two-step method from Figure 5. The continuity of reflections is significantly improved and the structural features are clearer. Additionally, the smiles caused by multiples are greatly weakened and false fault disappear. However, there are still some residual multiples. Generally, it can be further attenuated on the migrated CRP gathers.

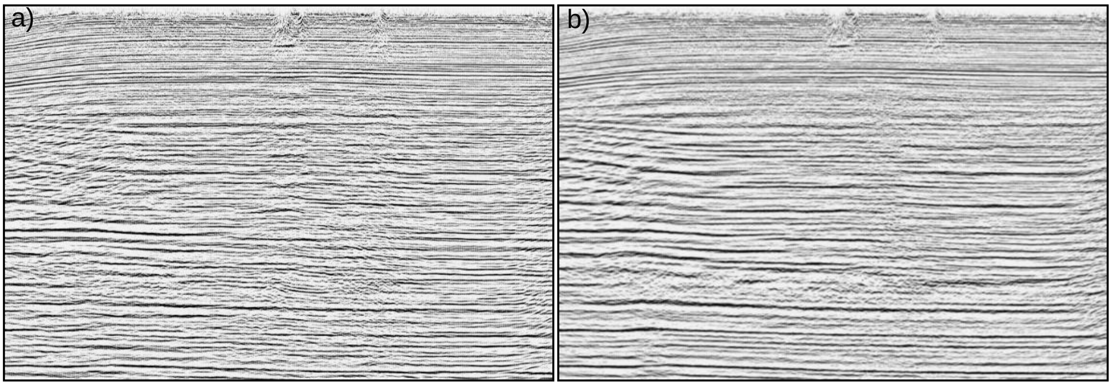


Figure 5: Migration section with AGC, a) before，b) after

Conclusions

Based on the conventional SRME, we developed 3D Generalized SRME (GSRME) and 3D Interbed Multiple Elimination (IME) techniques tailored for land seismic data. These methods serve as powerful tools for suppressing complex multiples with minimal reliance on velocity discrimination between primaries and multiples. This paper presents remarkable results in land survey S, where both surface-related multiples and interbed multiples are well eliminated, leading to a significant improvement in data quality. The results demonstrate a robust and practical solution for multiple attenuation, providing valuable insights for seismic data processing in Brazil's volcanic-covered basins and other similar geological environments worldwide.

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