Efficiency in multiple prediction, leveraging the CMP gather

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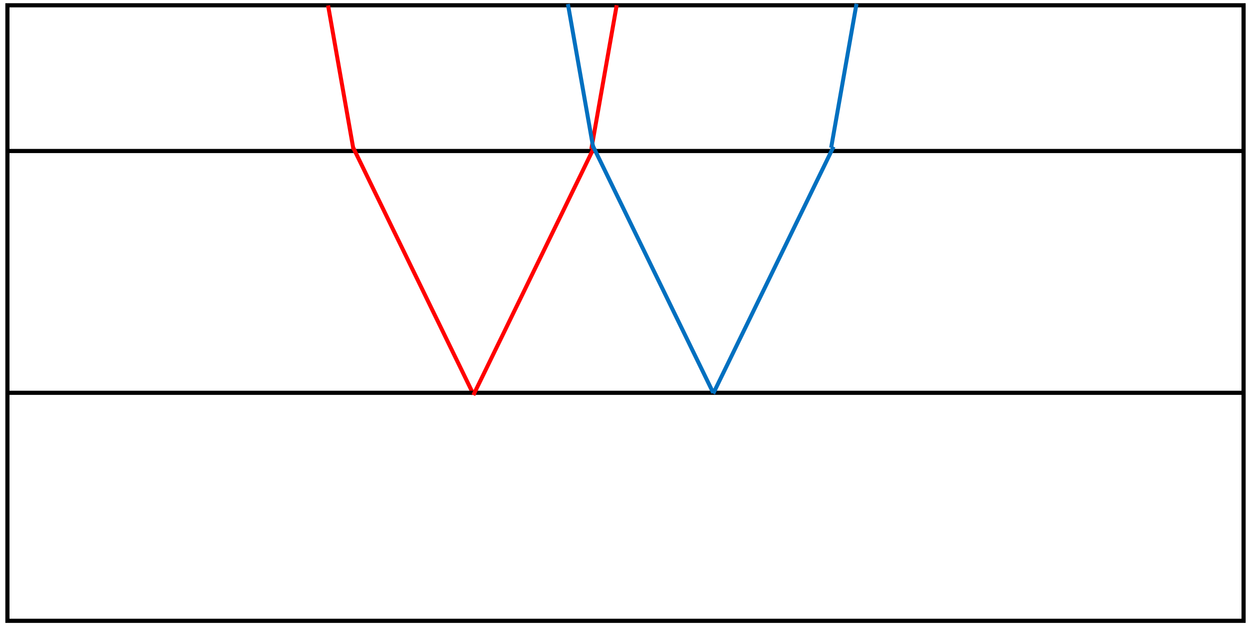
Talk Outline

1. Motivation
2. Review of multiple prediction based on the inverse scattering series
3. 2D versus 1.5D prediction algorithms
4. Traveltime equations, the CMP gather, and the impact on multiple prediction
5. Examples
6. Conclusions

Motivation

- 2D internal multiple prediction is a time consuming and computationally exhaustive process
- 1.5D algorithms are much more efficient, however, applying them to datasets acquired over 2D geology is typically a fruitless endeavor
- Our goal is to develop methods for successful application of 1.5D prediction algorithms to 2D datasets, improving efficiency, while maintaining a robust level of accuracy.

Review of Inverse Scattering Multiple Prediction



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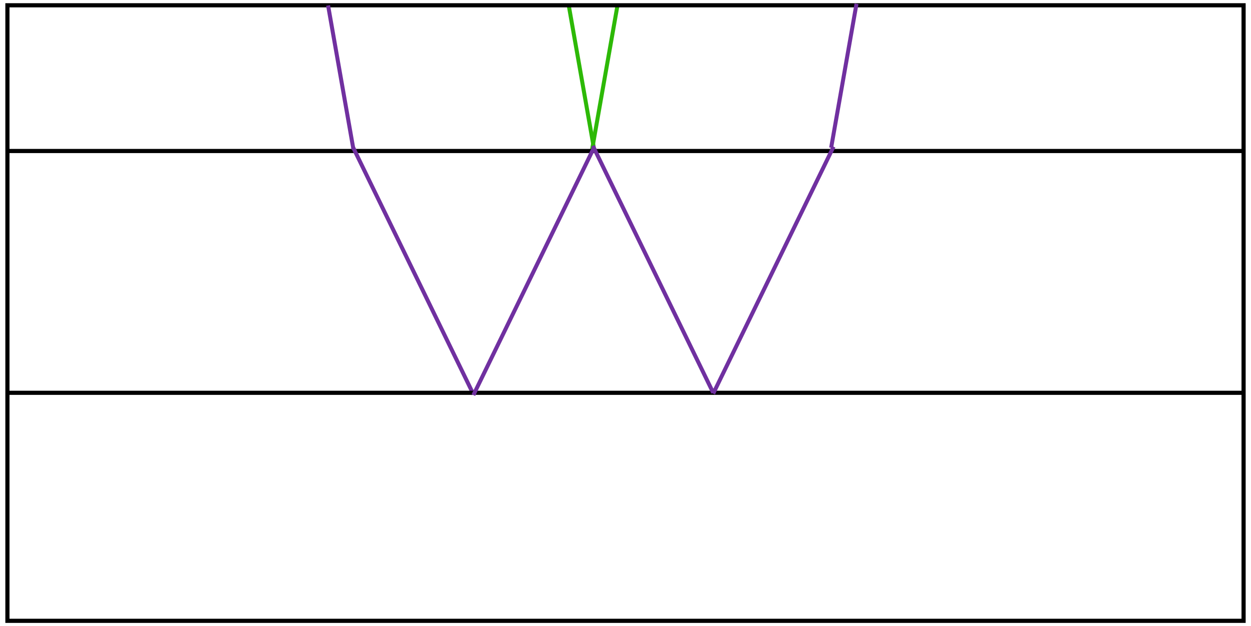

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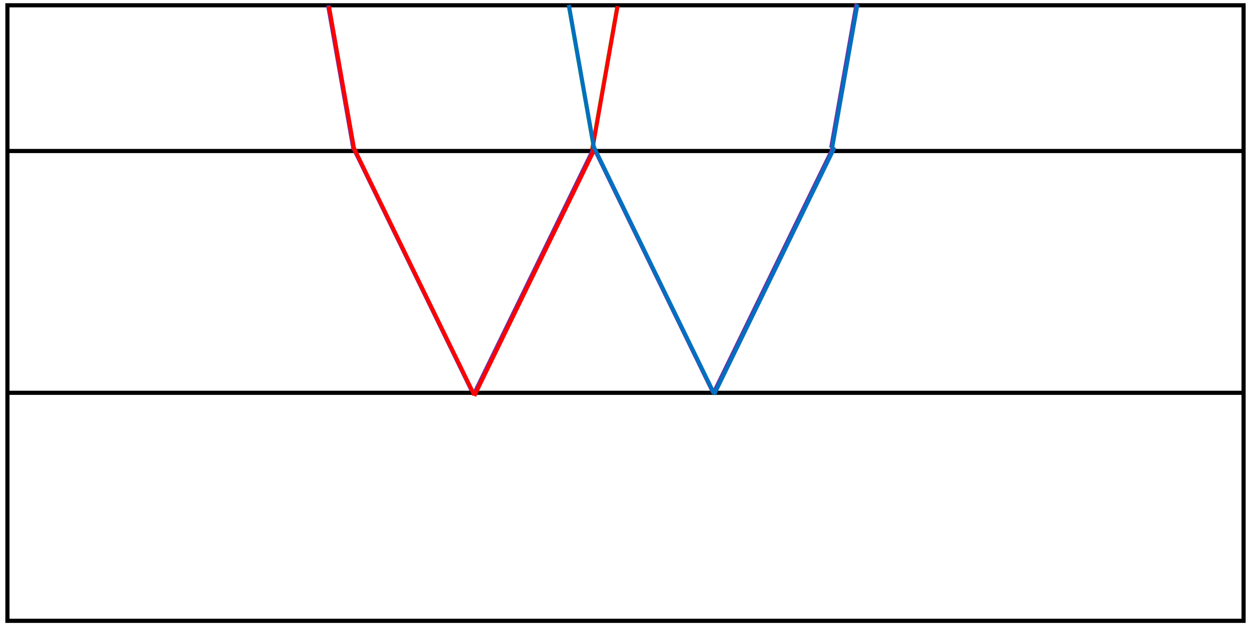

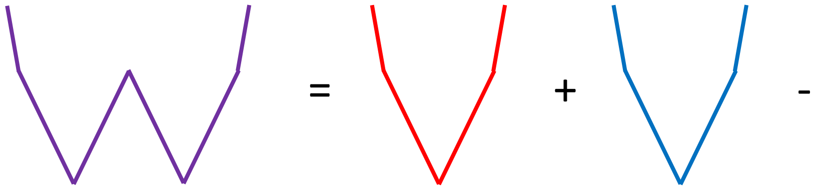

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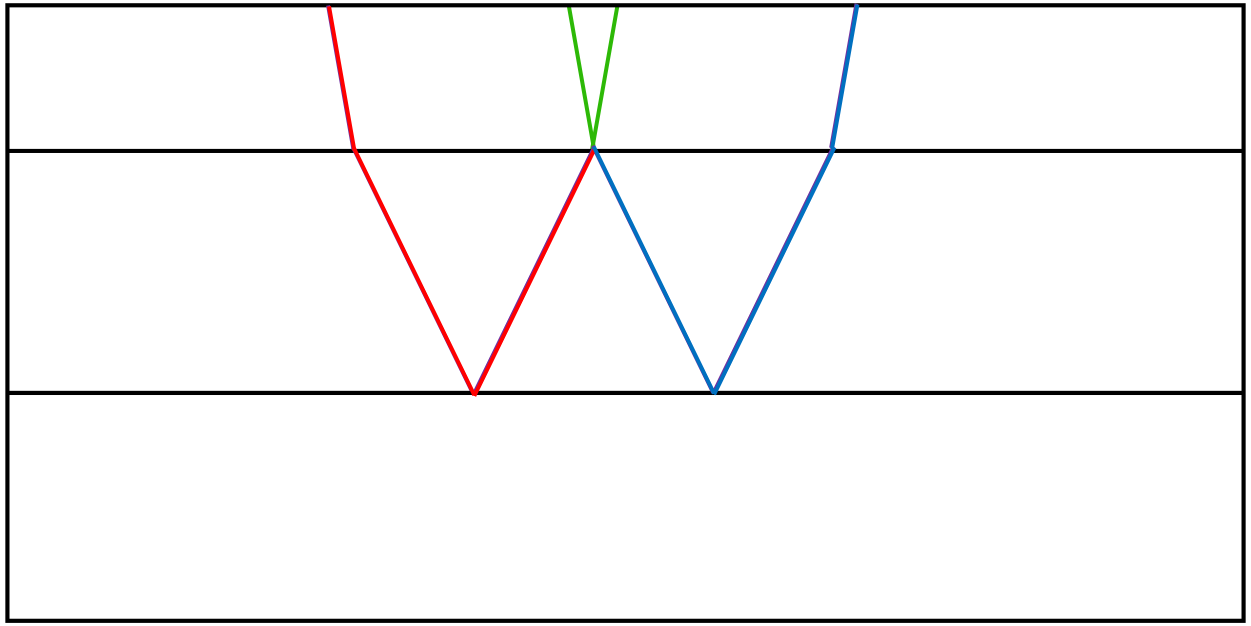
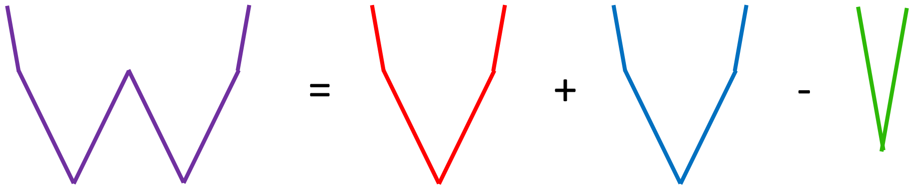
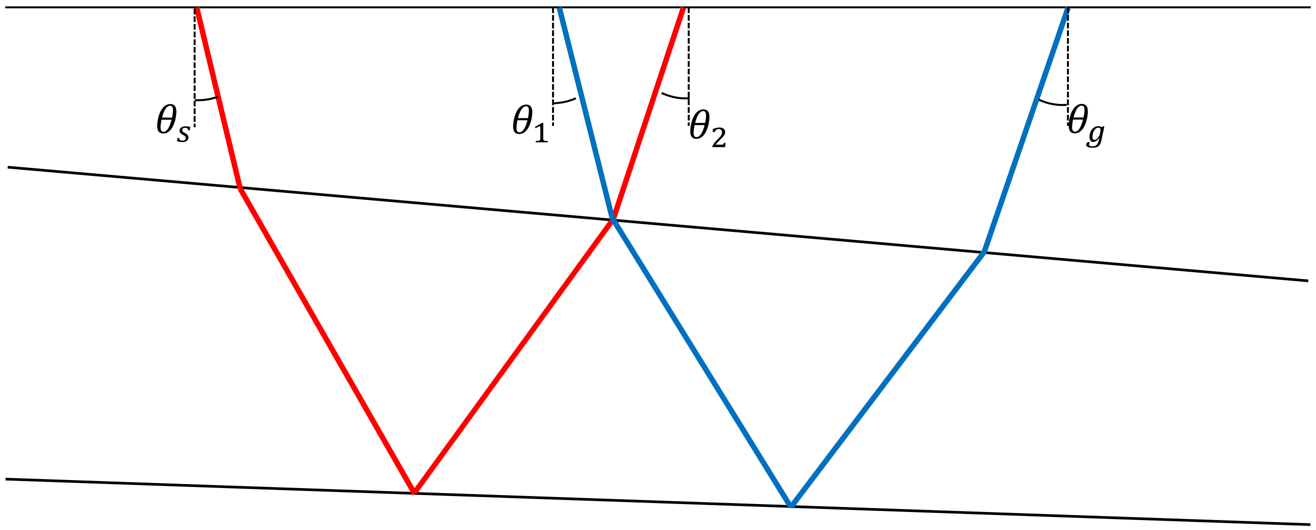




- Fully data driven algorithm for prediction all first order internal multiples in dataset with correct phase, and approximate amplitude

- Combines events in the data that obey a lower-higher-lower relationship to automatically predict internal multiples

Internal Multiple Prediction in 2-Dimensions



$$p_g = \frac{sin\theta_g}{v_0}$$

$$p_1 = \frac{sin\theta_1}{v_0}$$

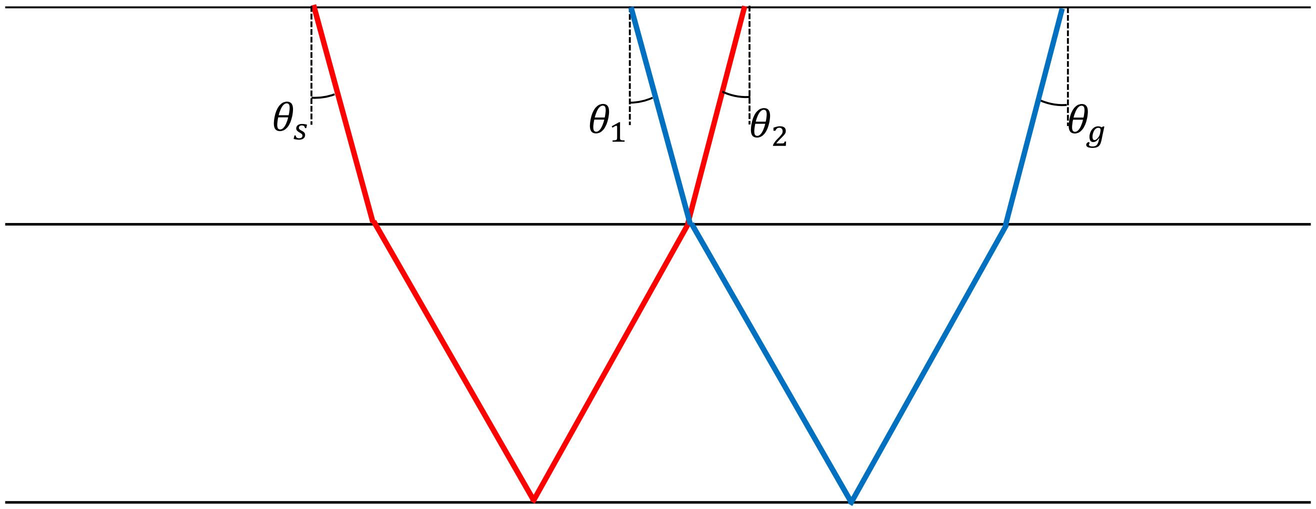
$$p_2 = \frac{sin\theta_2}{v_0}$$

$$p_s = \frac{sin\theta_s}{v_0}$$

$$b_{3_{IM}}(p_g, p_s, \omega) = \frac{1}{(2\pi)^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} dp_1 e^{-i\omega\left(\tau_{1_g} - \tau_{1_s}\right)} dp_2 e^{-i\omega\left(\tau_{2_g} - \tau_{2_s}\right)} \times \Omega(p_g, p_1, p_2, p_s|\epsilon)$$

$$\Omega(p_g, p_1, p_2, p_s|\epsilon) = \int_{-\infty}^{\infty} b_1(p_g, p_1, \tau) e^{i\omega\tau} d\tau \int_{-\infty}^{\tau-\epsilon} b_1(p_1, p_2, \tau') e^{-i\omega\tau'} d\tau' \int_{\tau'+\epsilon}^{\infty} b_1(p_2, p_s, \tau) e^{i\omega\tau''} d\tau''$$

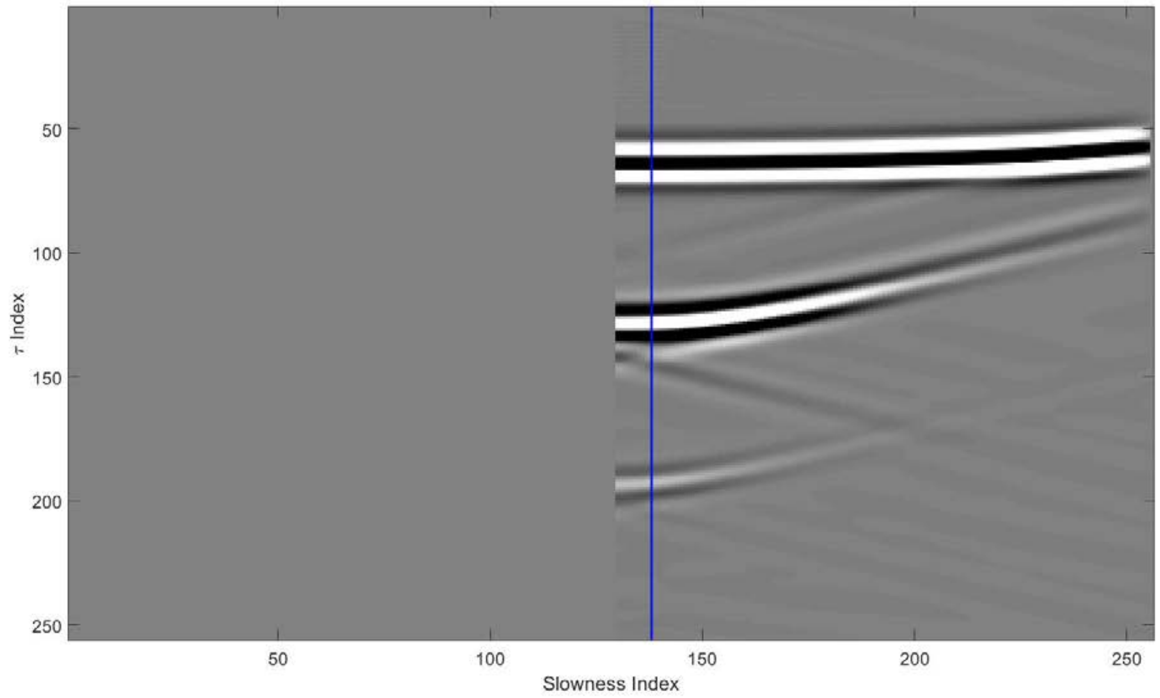
Reduction to 1.5D



When flat layers exist in the subsurface, and $p_g = p_s = p_1 = p_2$ the problem reduces to 1.5D, and the resulting prediction equation simplifies to:

$$b_{3_{IM}}(p_g,\omega) = \int_{-\infty}^{\infty} b_1(p_g,\tau)e^{i\omega\tau}d\tau \int_{-\infty}^{\tau-\epsilon} b_1(p_g,\tau')\, e^{-i\omega\tau'}d\tau' \int_{\tau'+\epsilon}^{\infty} b_1(p_g,\tau)e^{i\omega\tau''}d\tau''$$

Slant Stack and 1.5D Data Preparation



$$\Psi(p_g, \tau) = \int \Psi(x_g, \tau + p_g x) dx$$

- Inputs to the 1.5D algorithm are simply created by a standard slant stack over receiver side horizontal slowness
- Each trace is the response of a single plane wave component traveling with horizontal slowness p_g.
- The prediction algorithm then searches for events to combine in vertical travel time τ.

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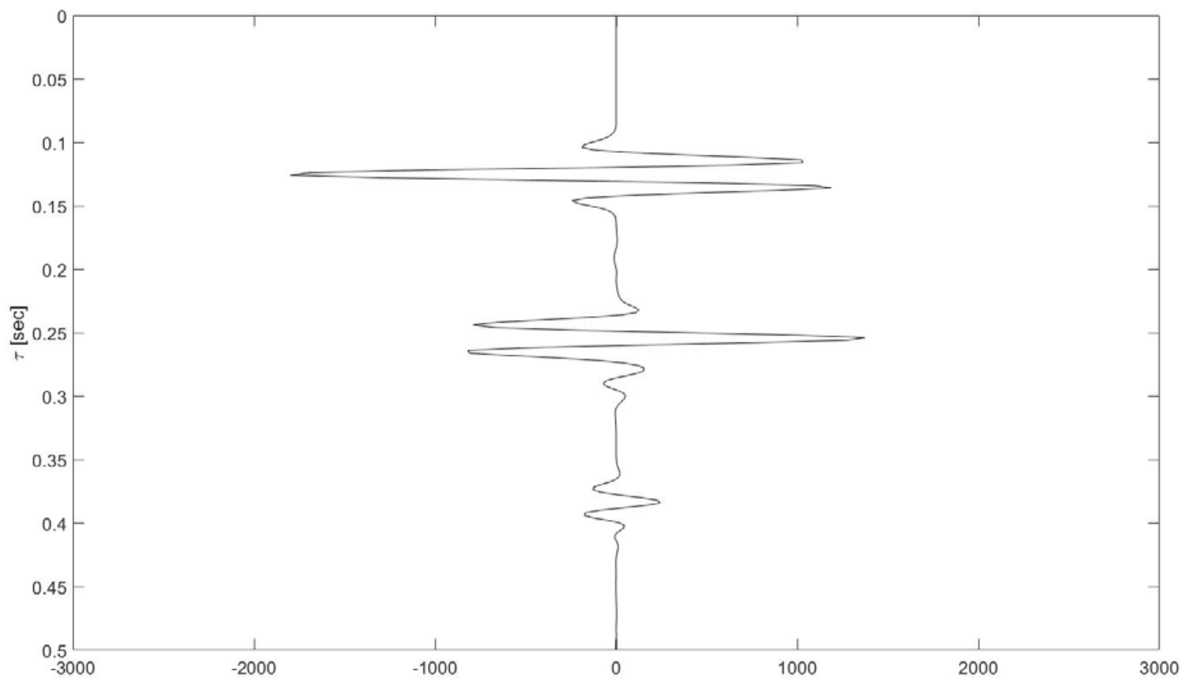

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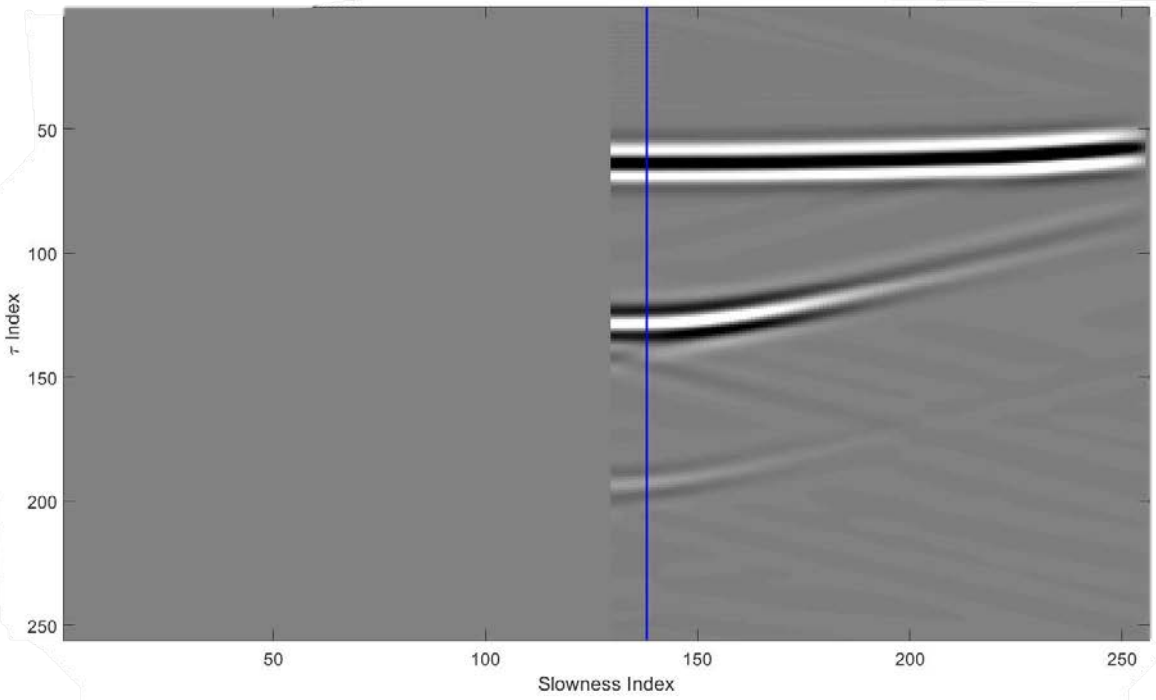
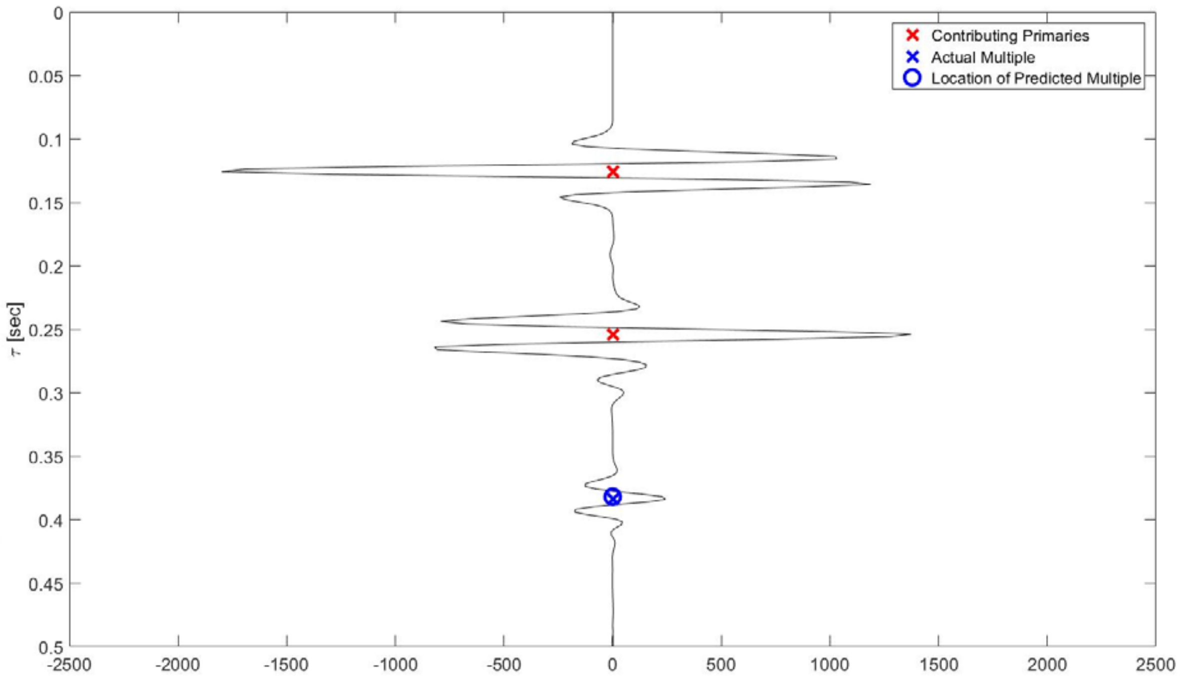
Issues Associated with Applying 1.5D Algorithms to 2D Data





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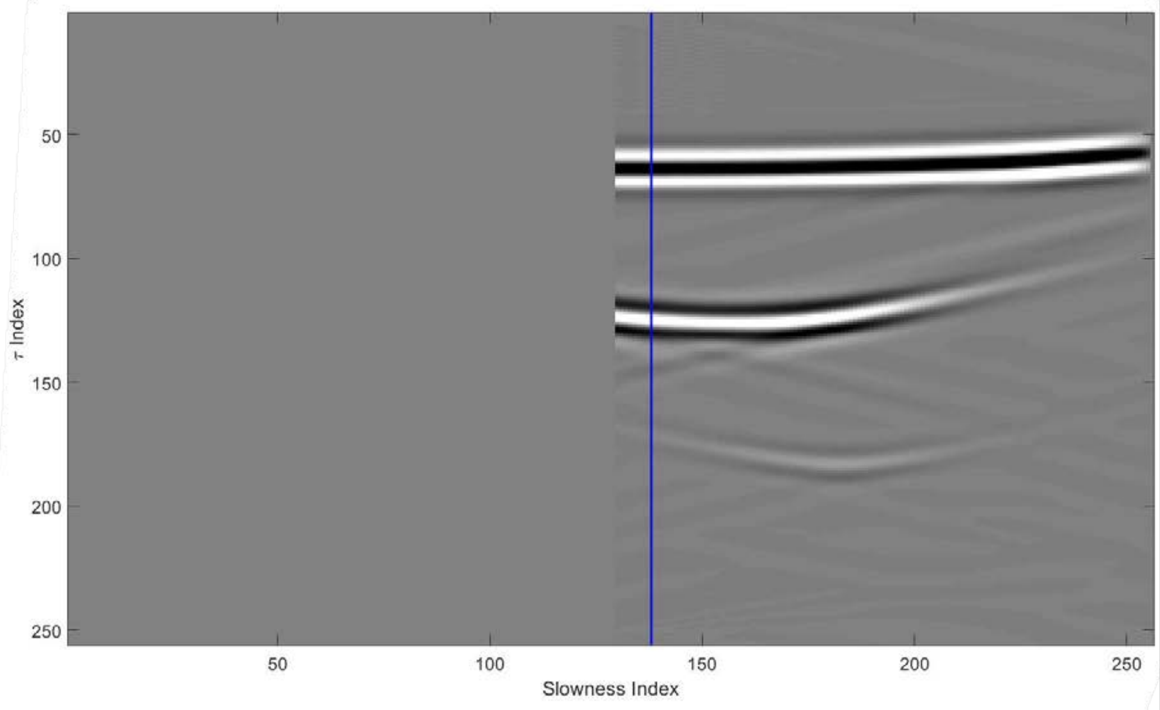
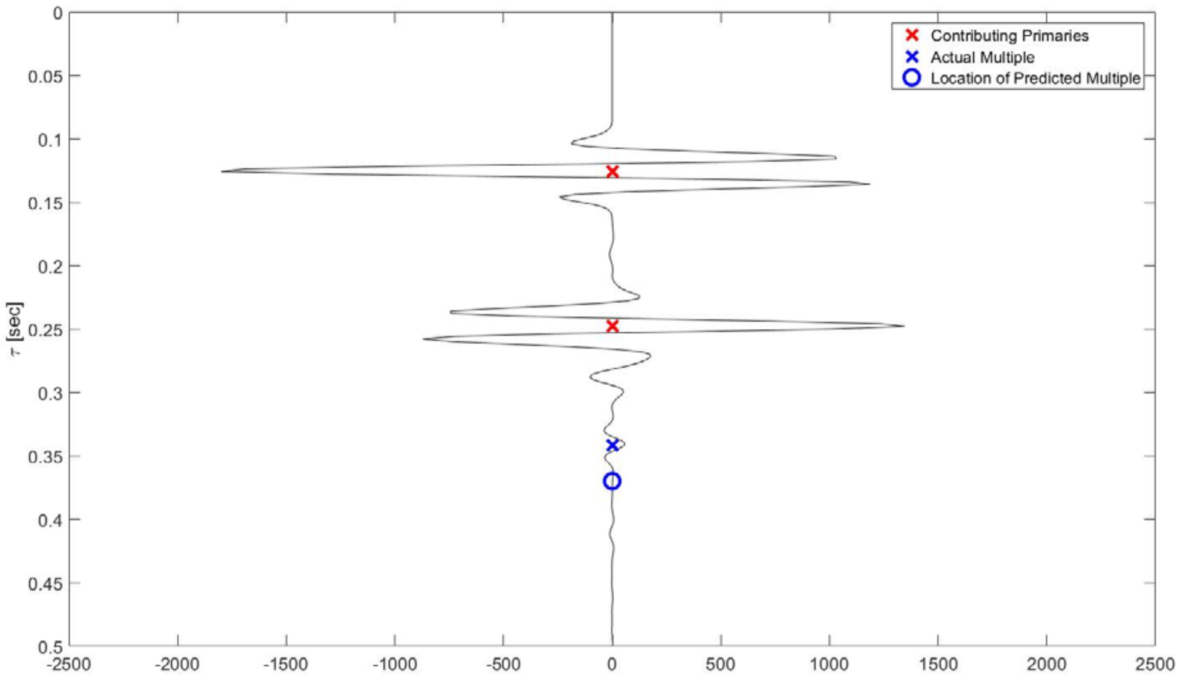
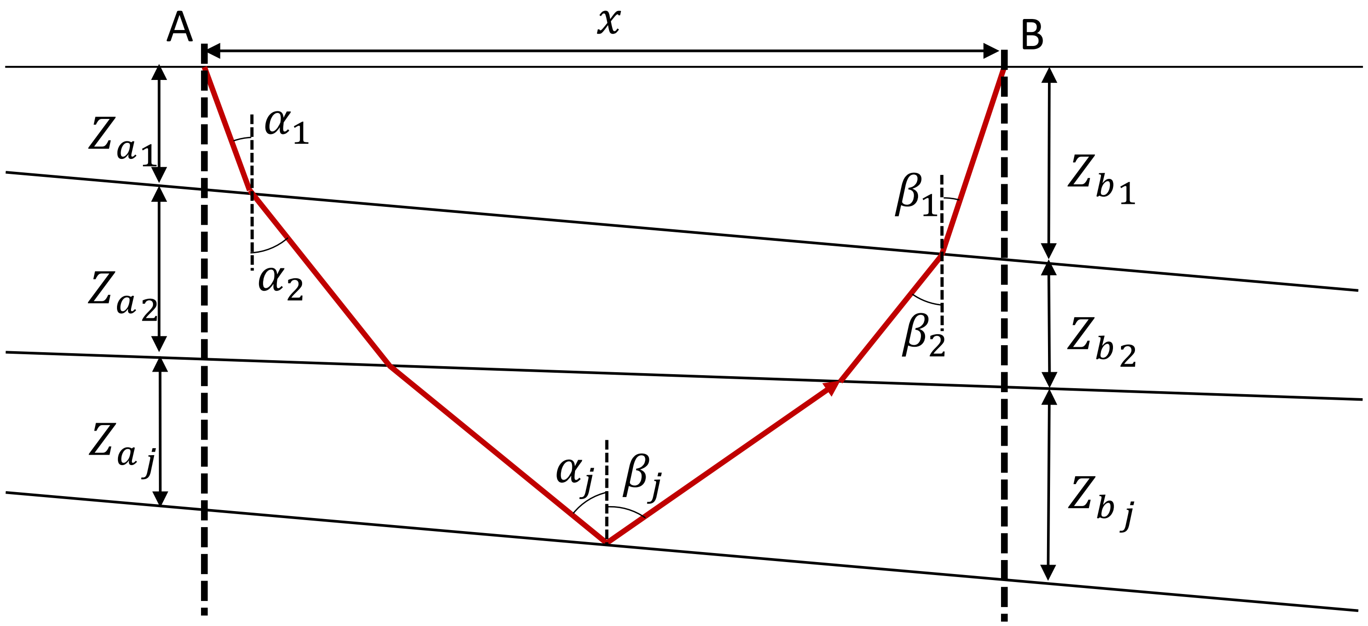




Traveltime Equation in Dipping Strata



Modified from Mota (1954) and Ocola (1972)

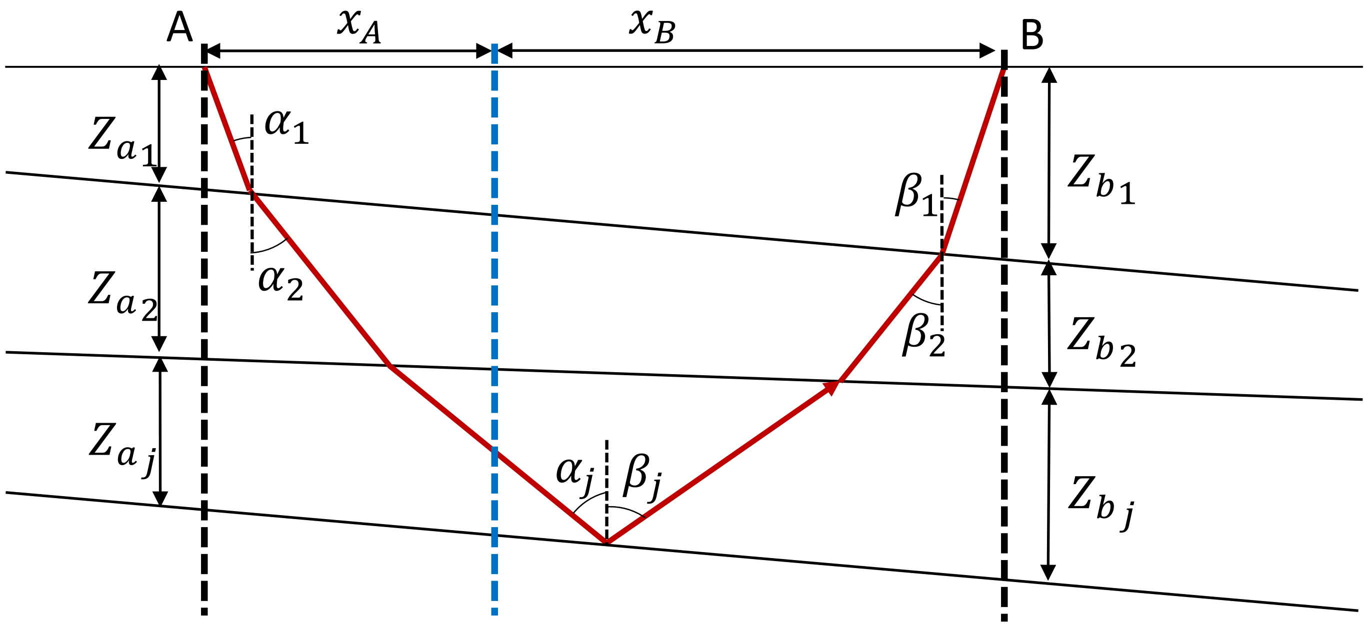
For a fixed source (or receiver) at location A, the travel time of the ray shown is:

$$T = p_B x + \sum_j Z_{a_j}\left(q_{a_j} + q_{b_j}\right)$$

Or for a fixed source (or receiver) at location B,

$$T = p_A x + \sum_j Z_{b_j}\left(q_{a_j} + q_{b_j}\right)$$

Traveltime Equation in Dipping Strata Relative to Reference



Modified from Mota (1954) and Ocola (1972)

When both A and B are moving, as in the CMP experiment neither equation is valid. If we let:

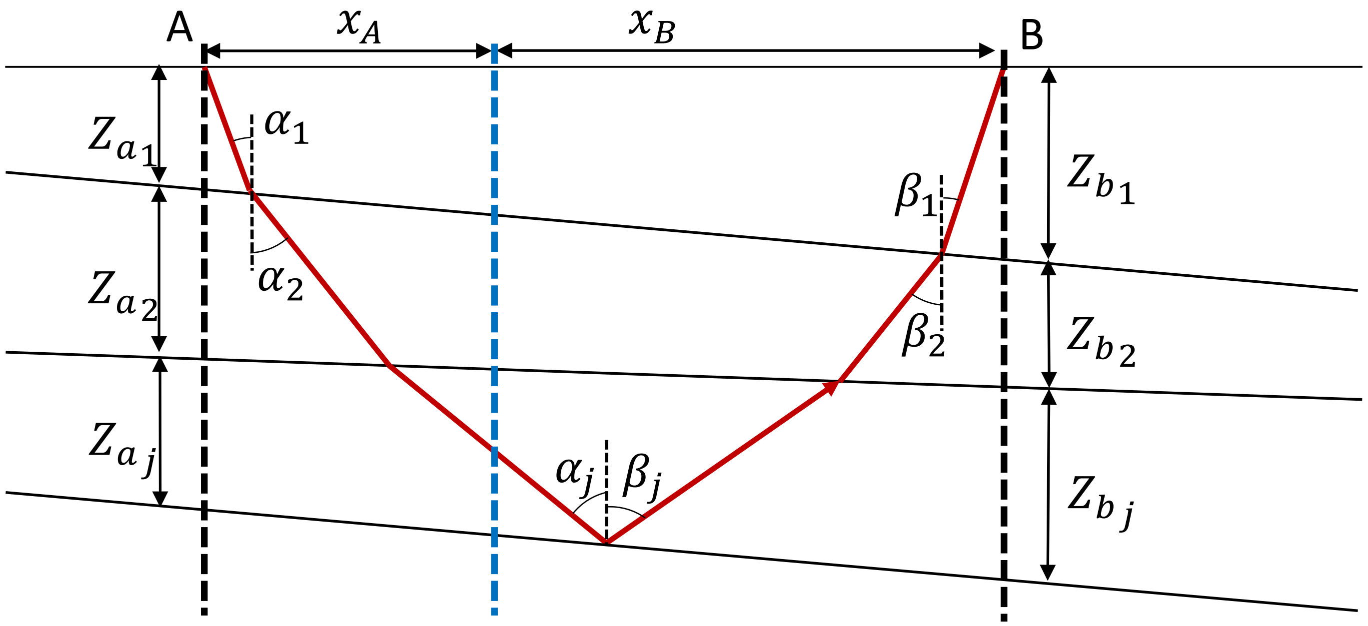
$$\frac{x_A + x_B}{X} = 1$$

$$z_j X = x_A z_B + z_A x_B$$

we may take a weighted average of the traveltime equations

$$T = \frac{x_B}{X}\left[p_B X + \sum_j z_{A_j}(q_{A_j} + q_{B_j})\right] + \frac{x_A}{X}\left[p_A X + \sum_j z_{B_j}(q_{A_j} + q_{B_j})\right]$$

Traveltime Equation for CMP Geometry



Modified from Mota (1954) and Ocola (1972)

$$T = \frac{x_B}{X}\left[p_B X + \sum_j z_{A_j}(q_{A_j} + q_{B_j})\right] + \frac{x_A}{X}\left[p_A X + \sum_j z_{B_j}(q_{A_j} + q_{B_j})\right]$$

$$T = x_A p_A + x_B p_B + \sum_j z_j\,(q_{A_j} + q_{B_j})$$

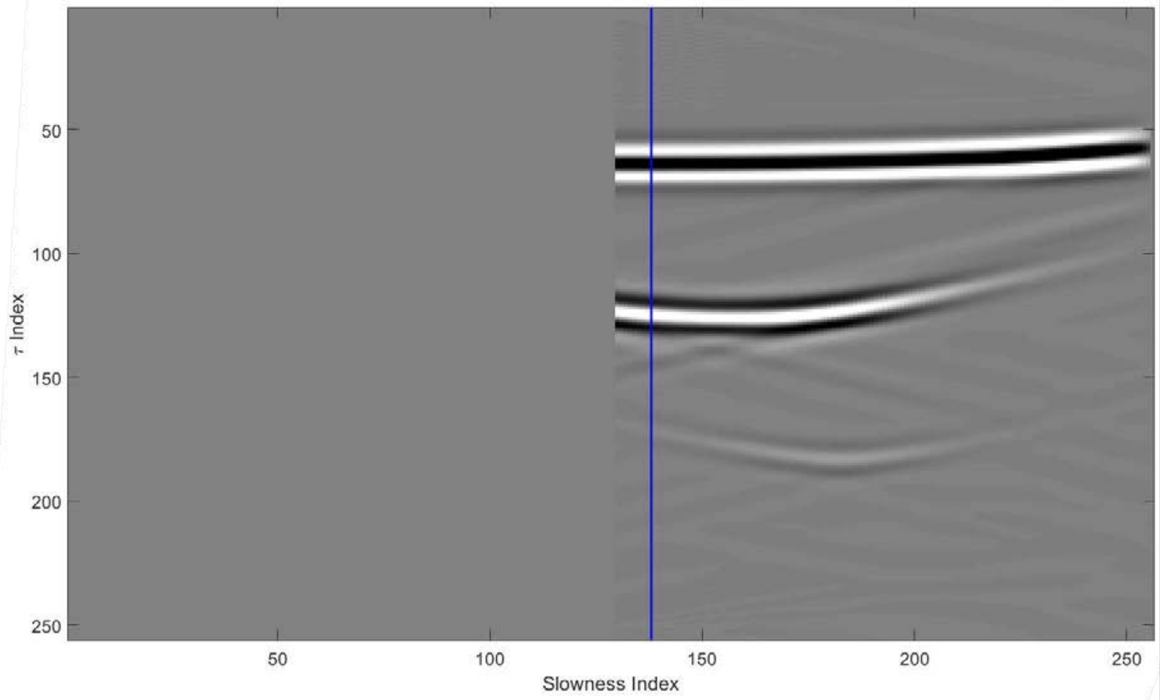
In the CMP experiment $x_A = x_B = \frac{X}{2}$

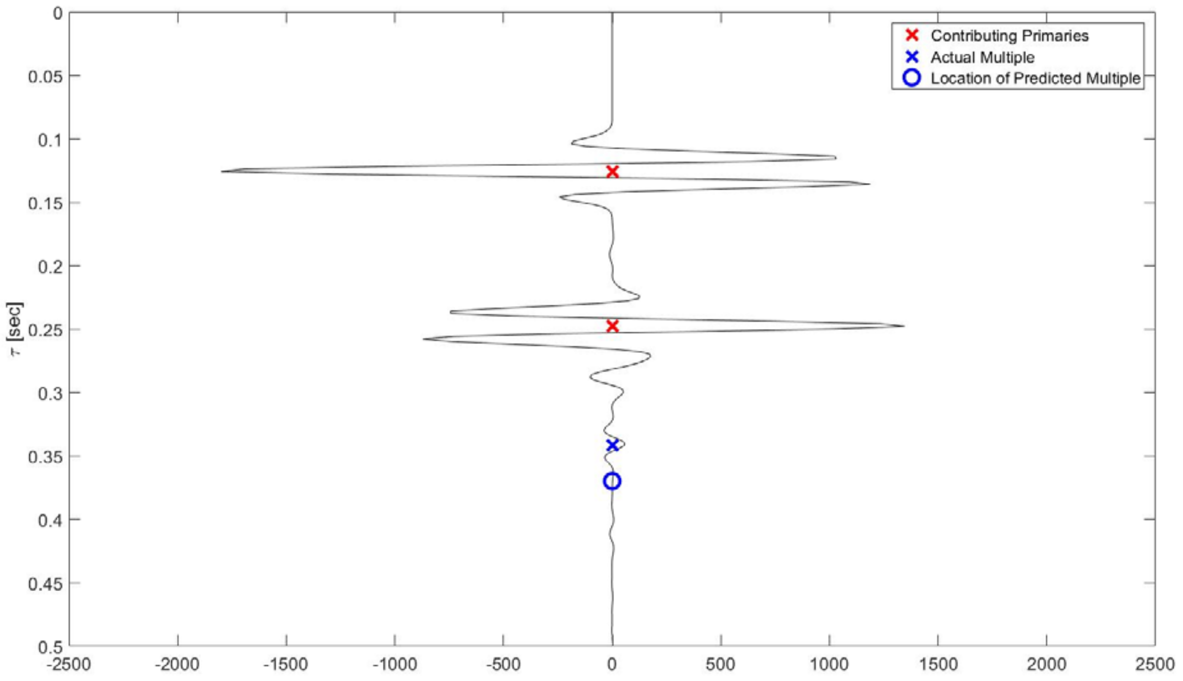
$$T = \frac{X}{2}(p_A + p_B) + \sum_j z_j\,(q_{A_j} + q_{B_j})$$

$$T = X\,\bar{p} + \sum_j z_j\,(q_{A_j} + q_{B_j})$$

Applying 1.5D Algorithms to 2D Data Revisited

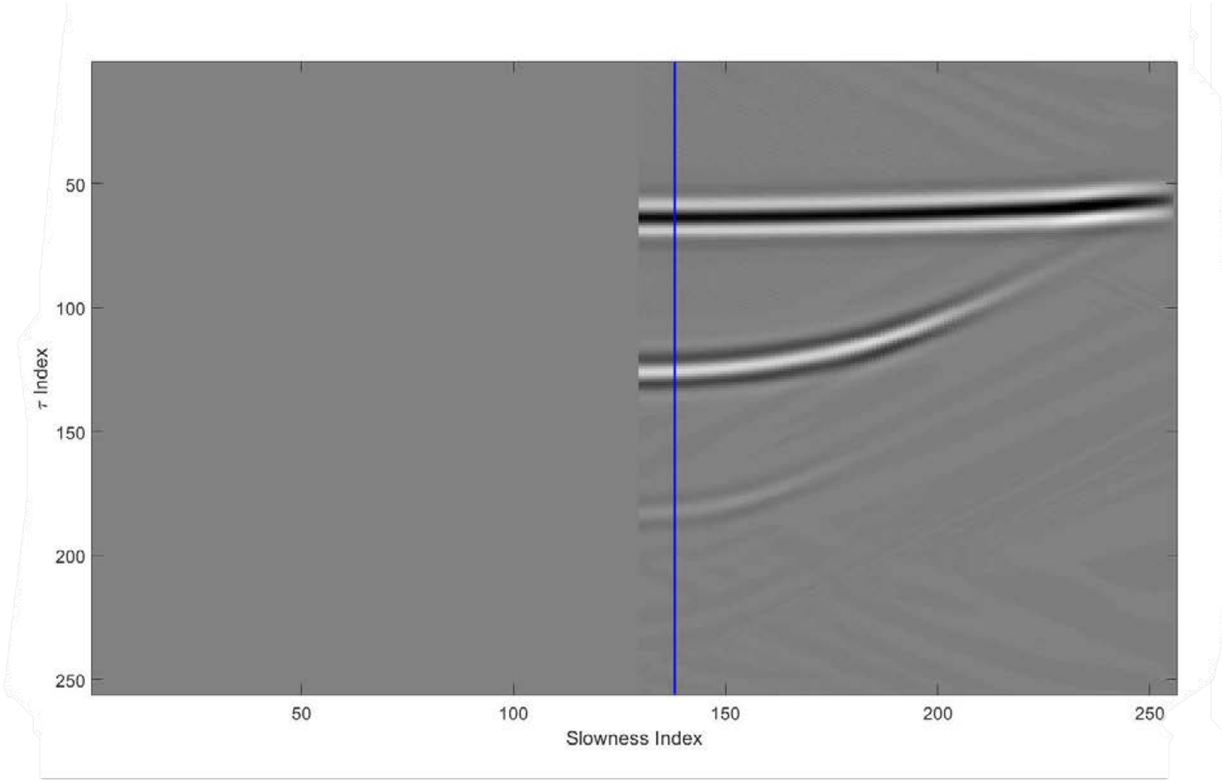
Example for a Shot gather, over a model with an interface dipping at 16^o

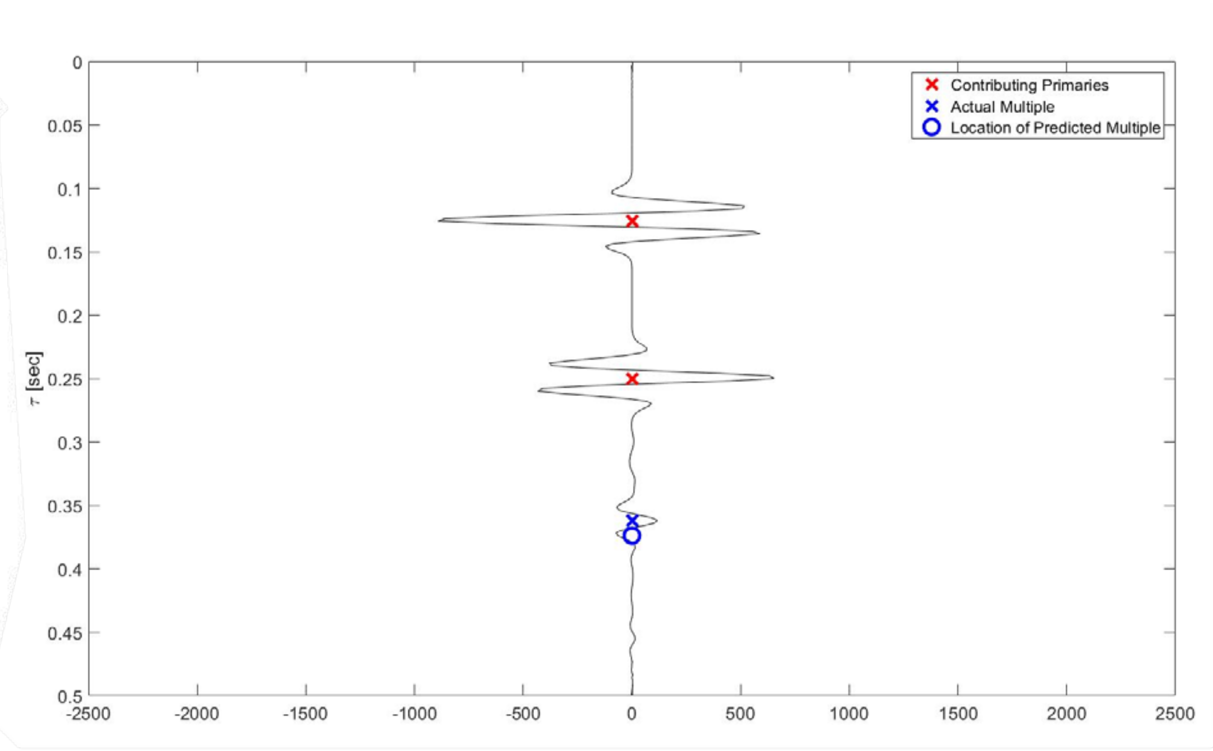




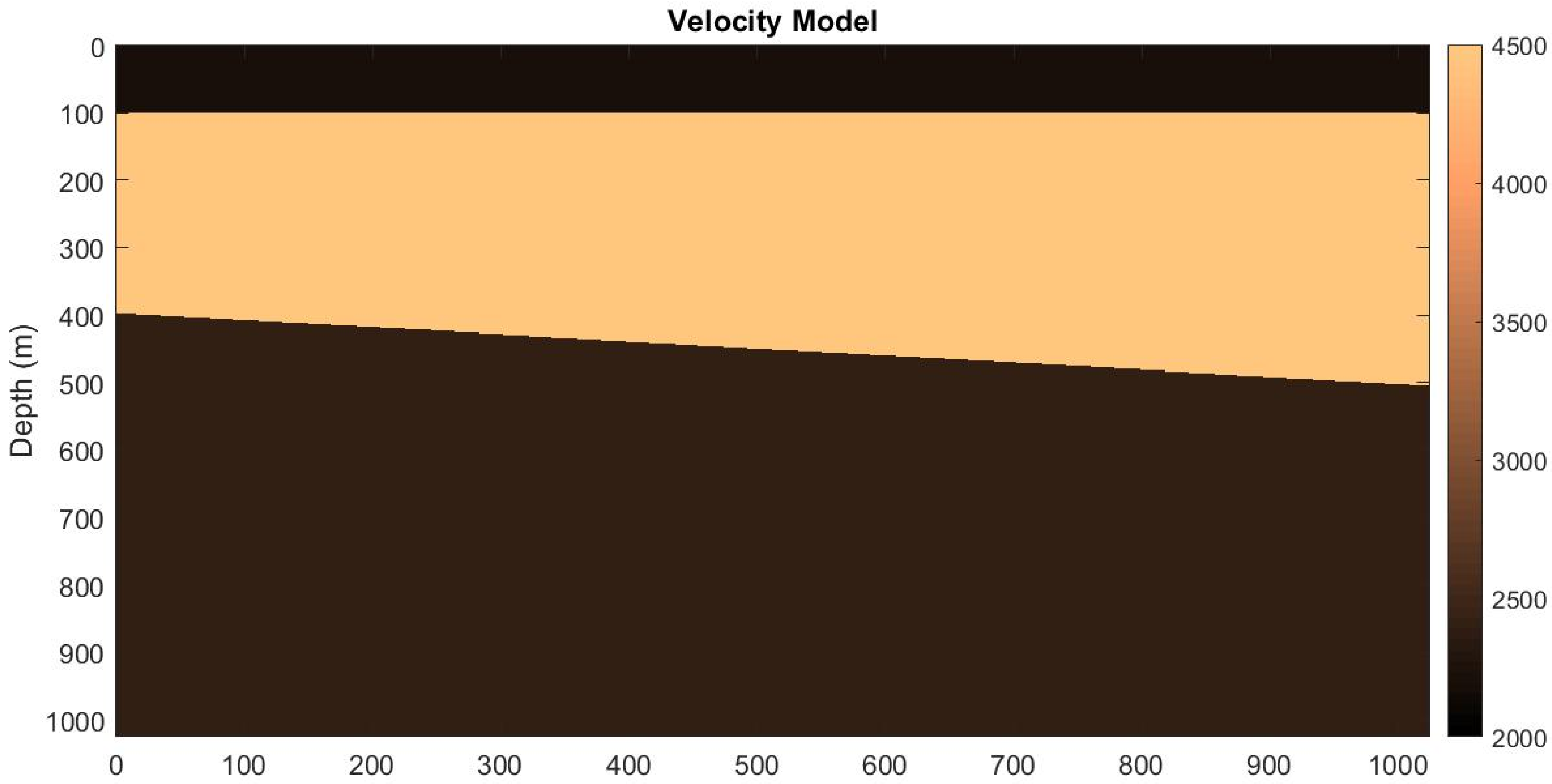
Applying 1.5D Algorithms to 2D Data Revisited

Example for a CMP gather, over a model with an interface dipping at 16^o

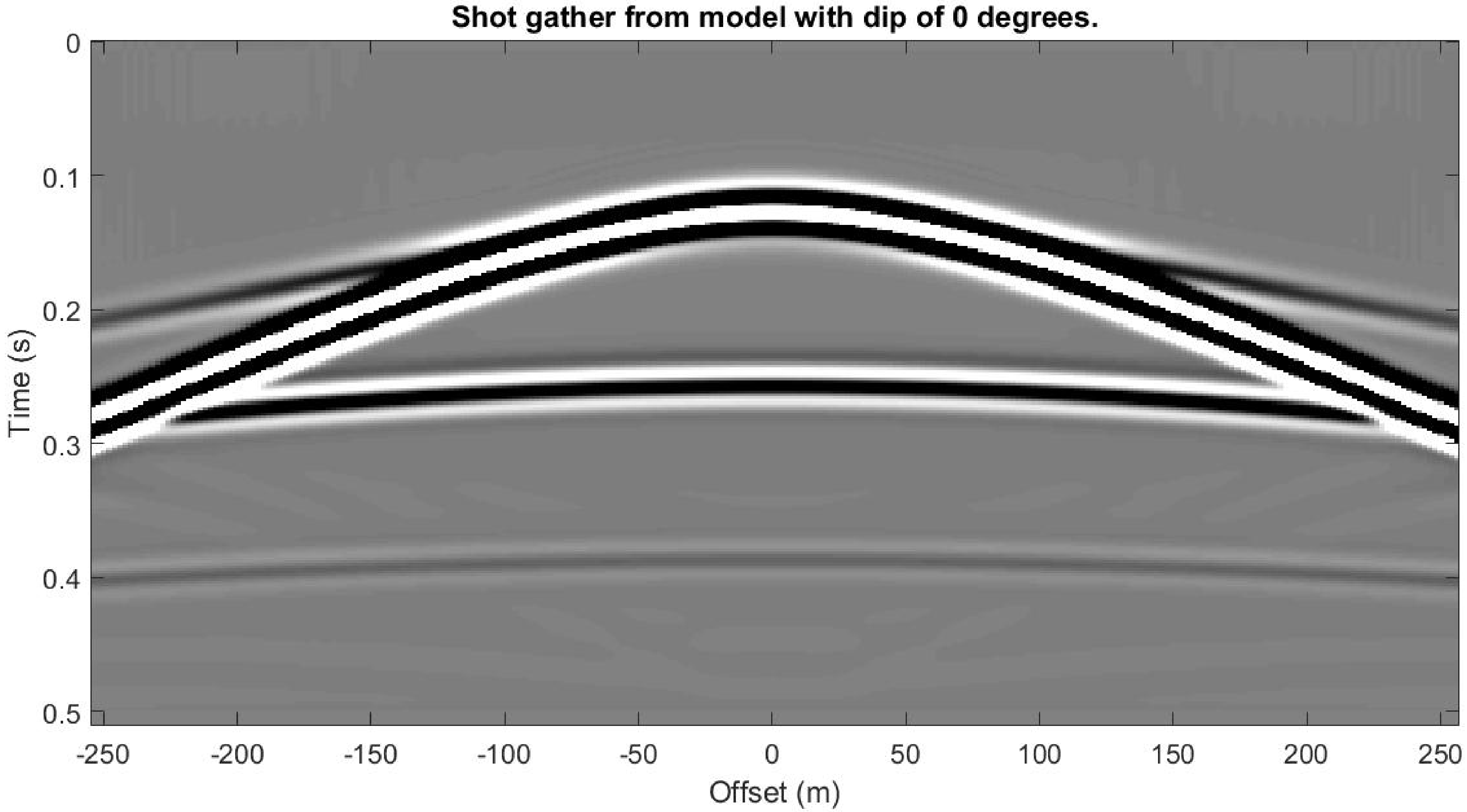




Velocity Model



Interface Dipping at 0 degrees – Shot Gather



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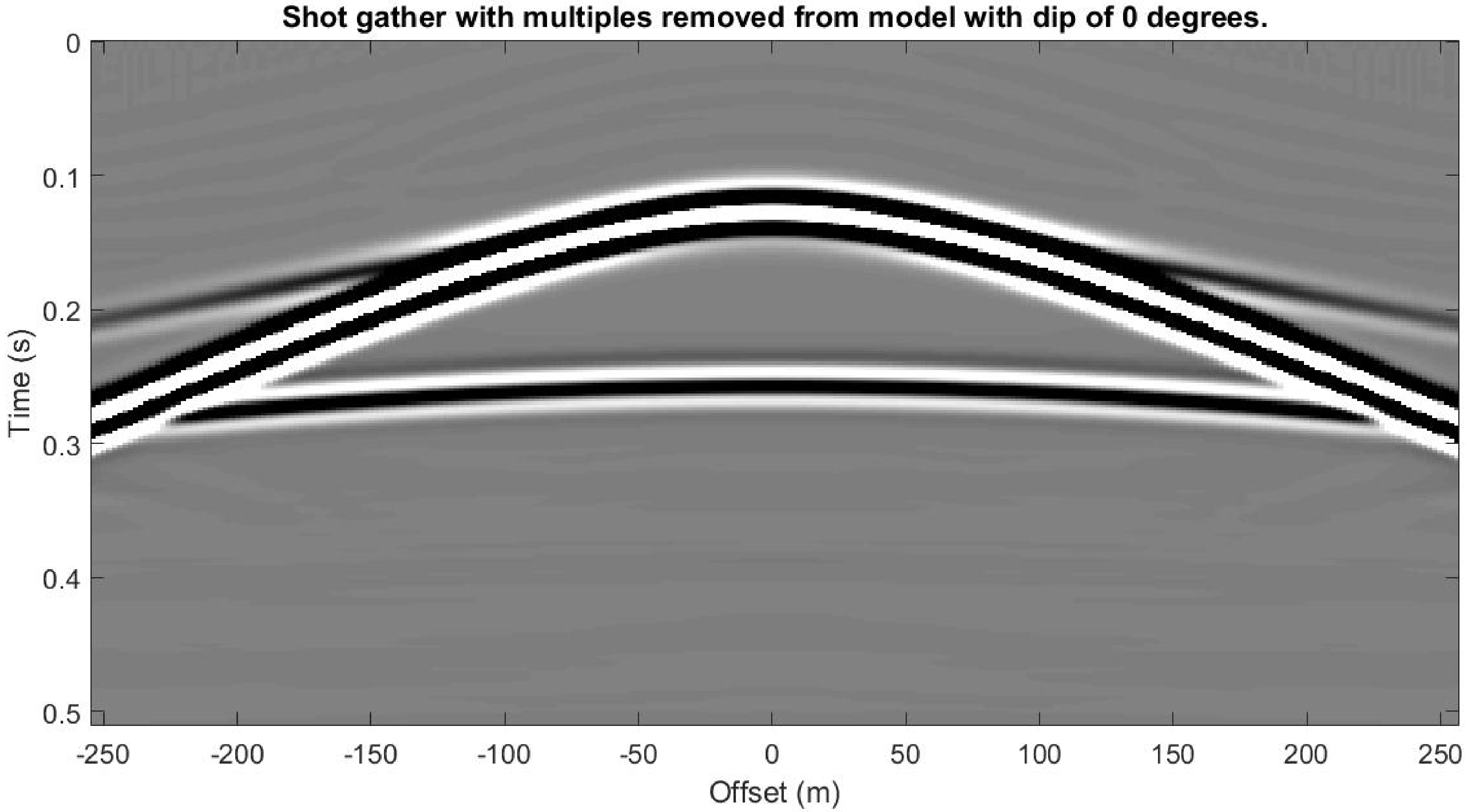
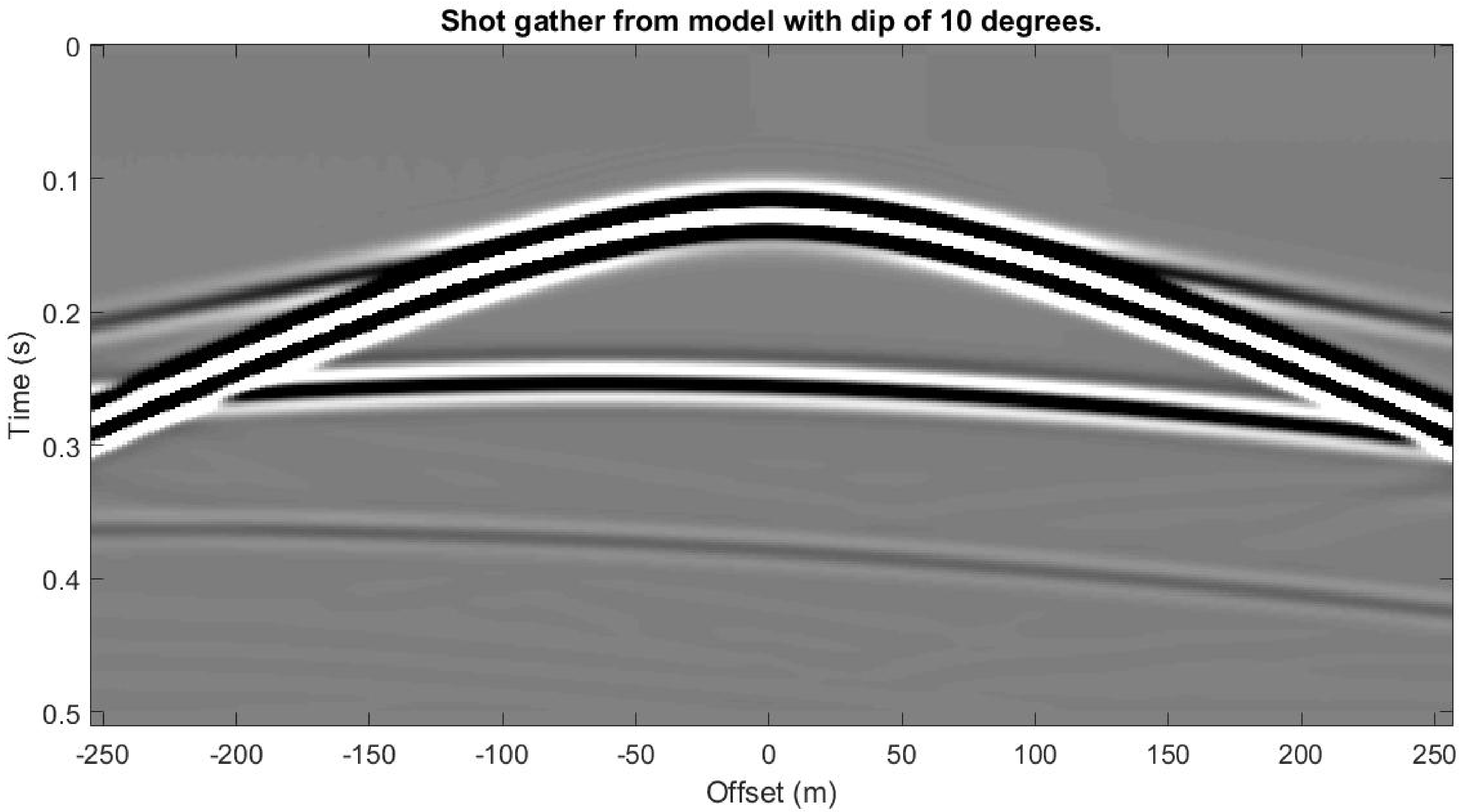


Interface Dipping at 10 degrees – Shot Gather



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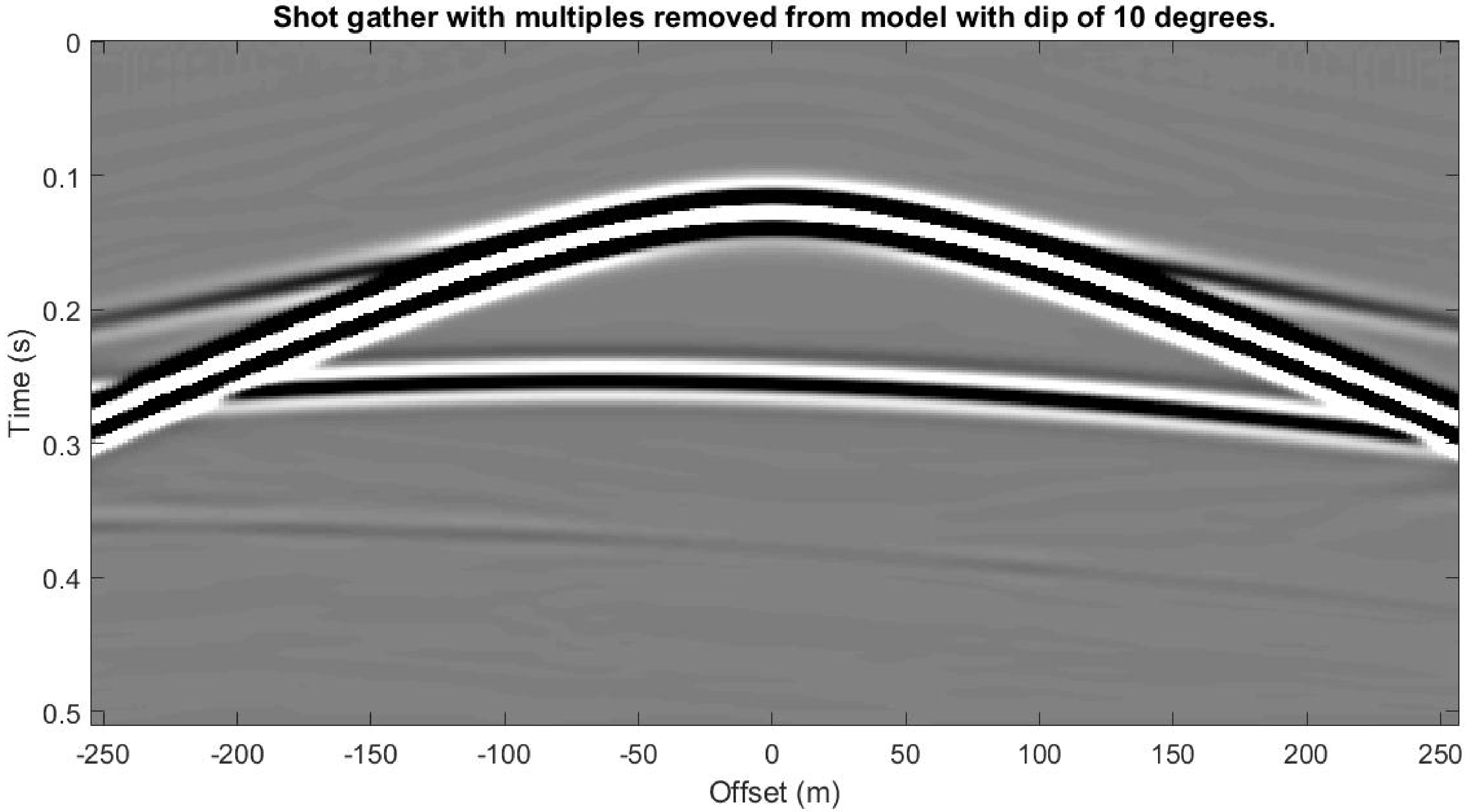
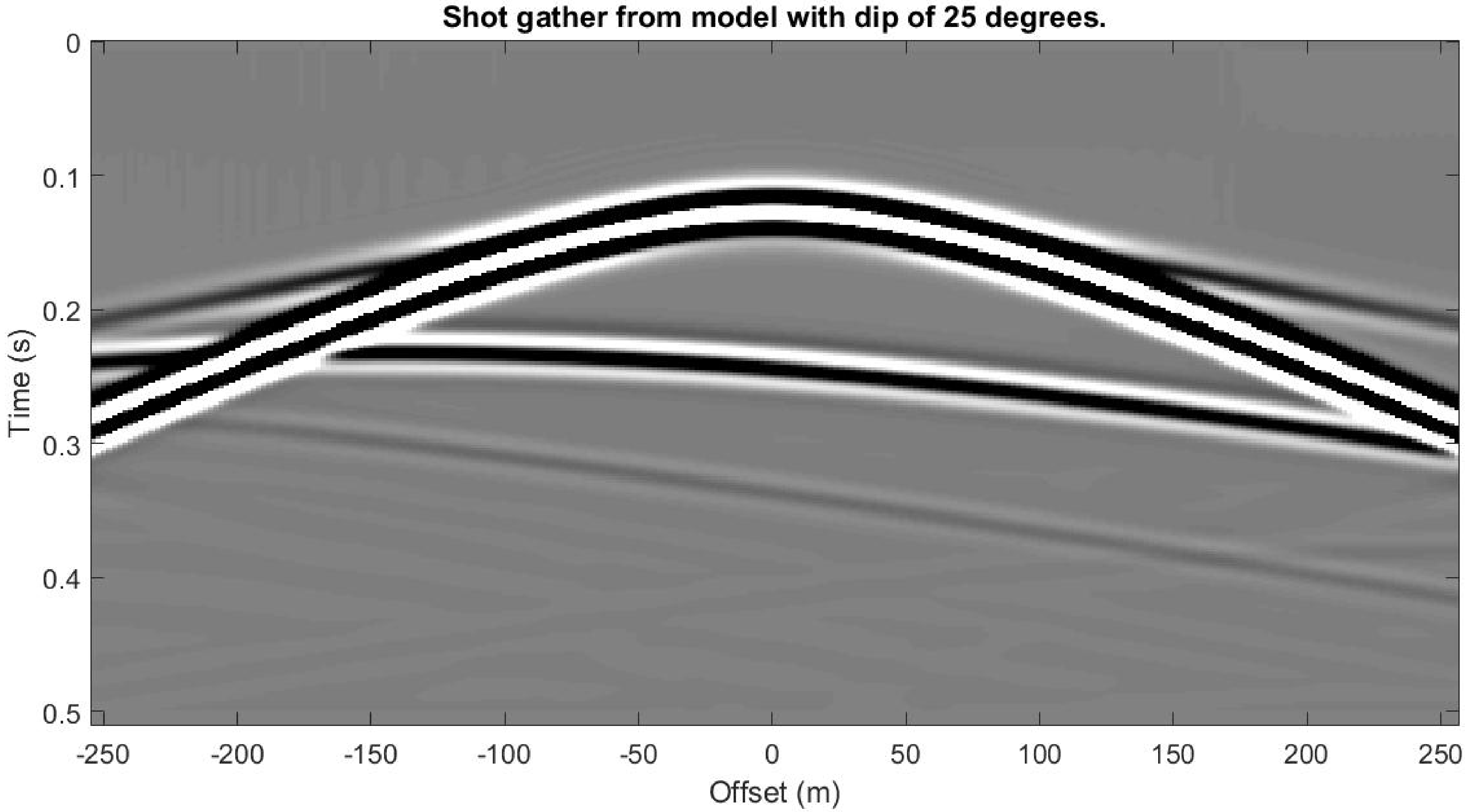


Interface Dipping at 25 degrees – Shot Gather



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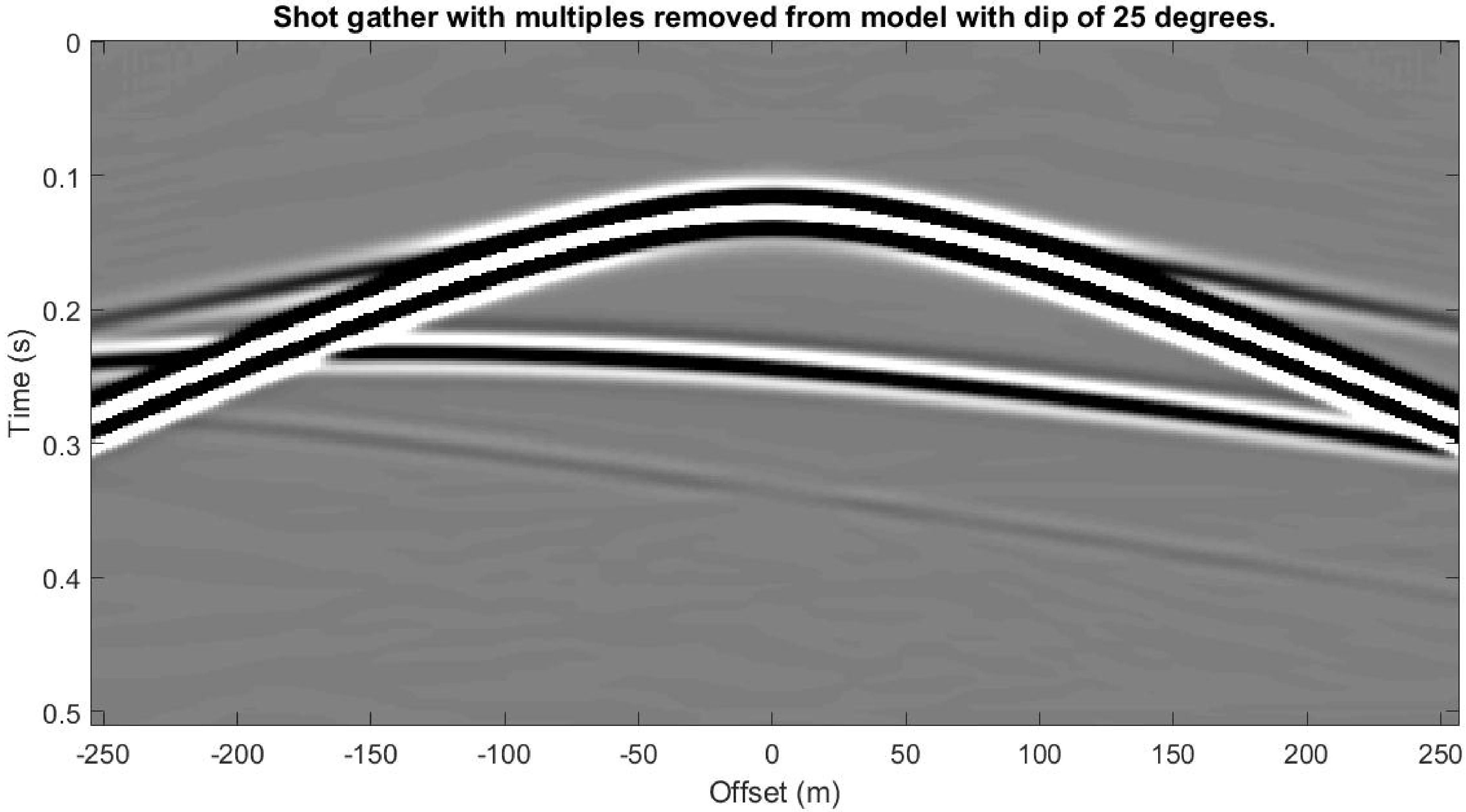
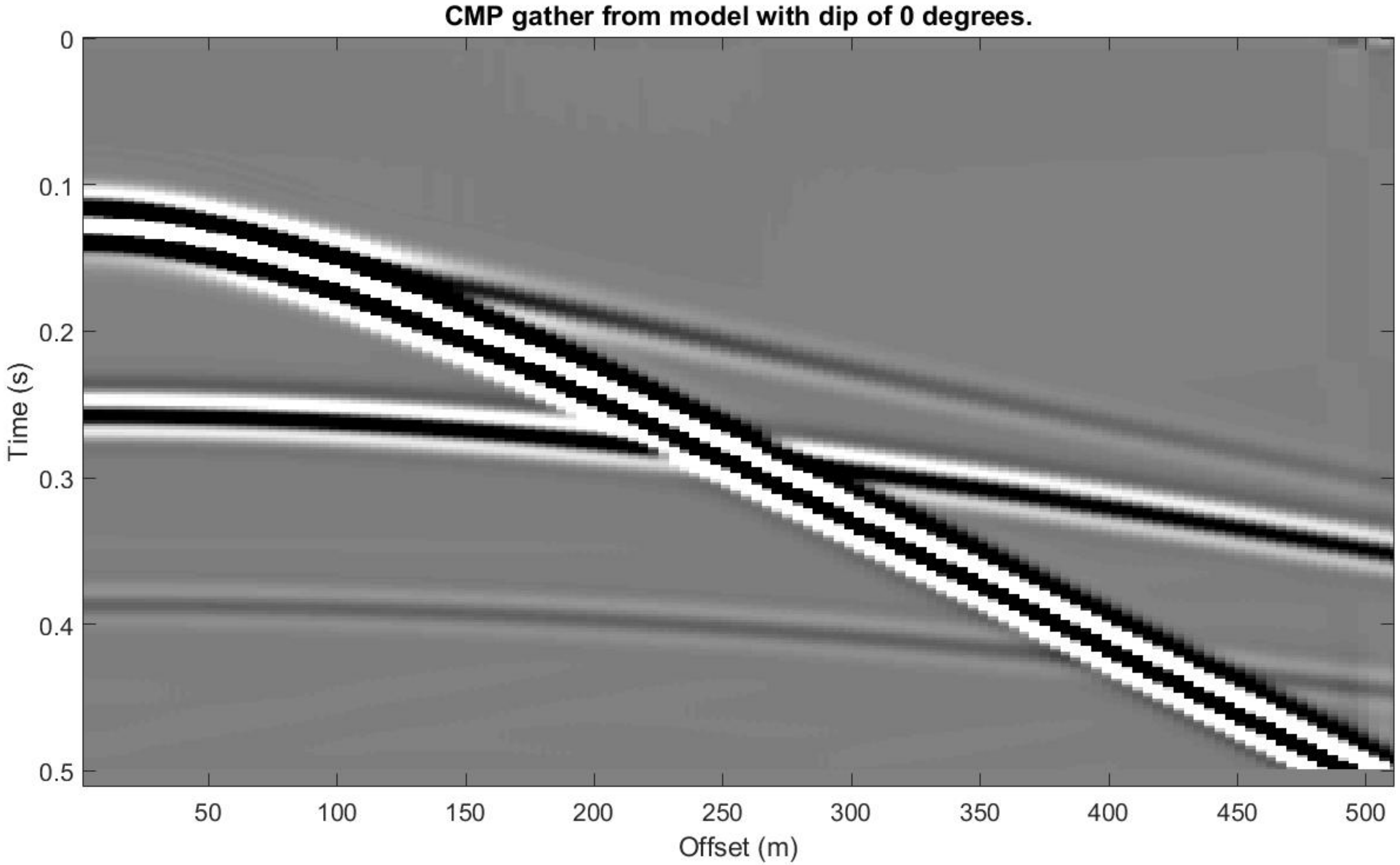


Interface Dipping at 0 degrees – CMP Gather



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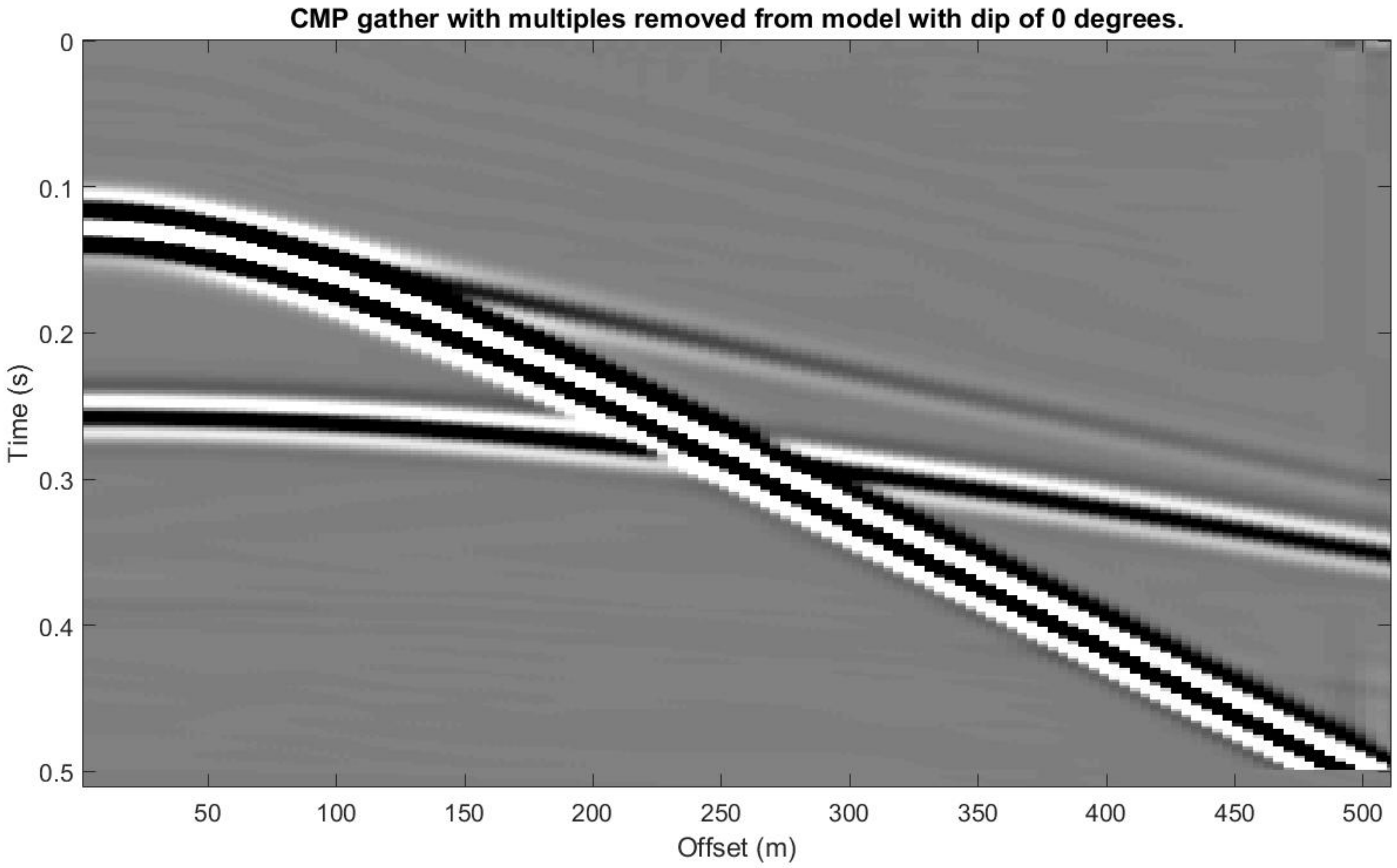

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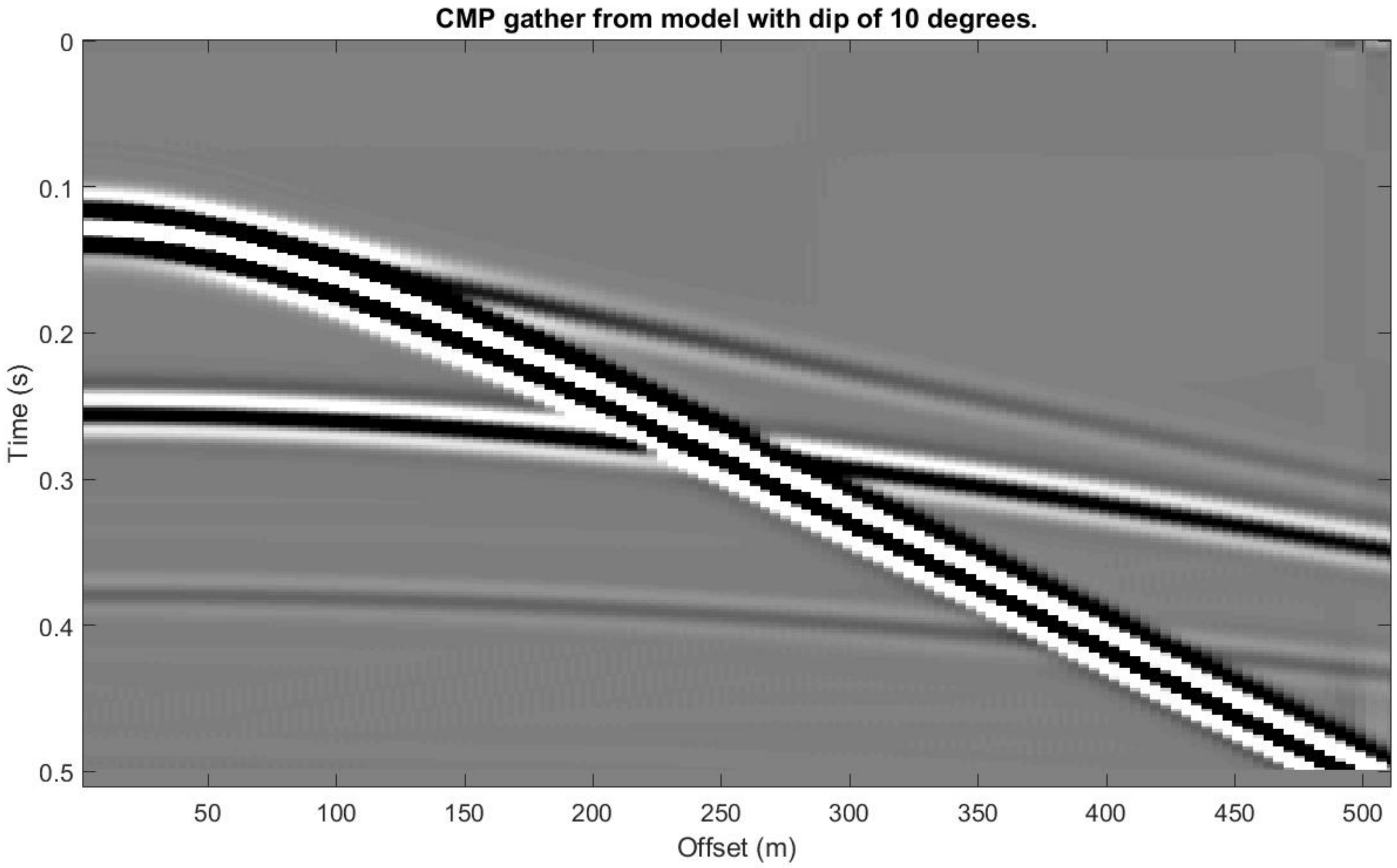

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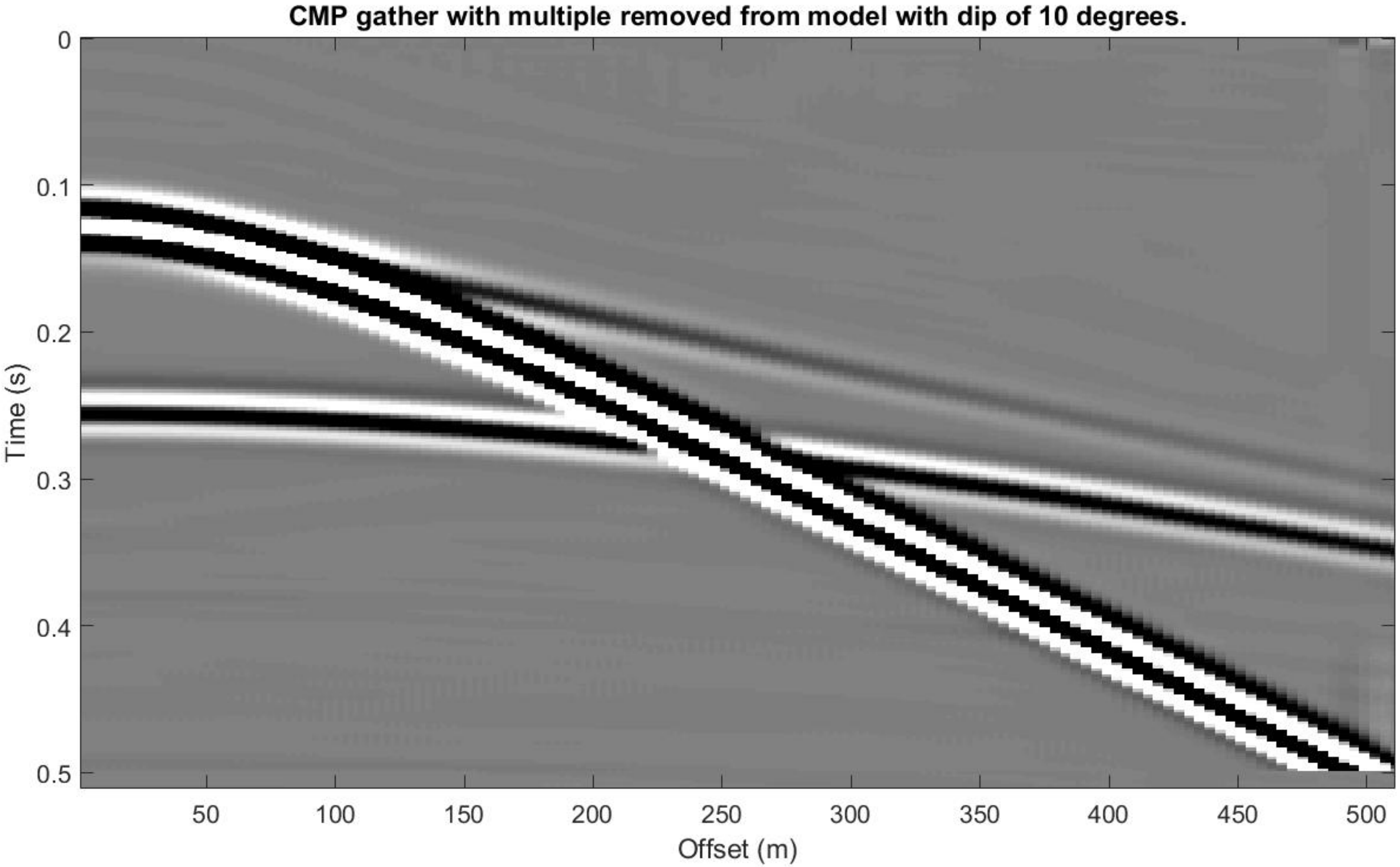
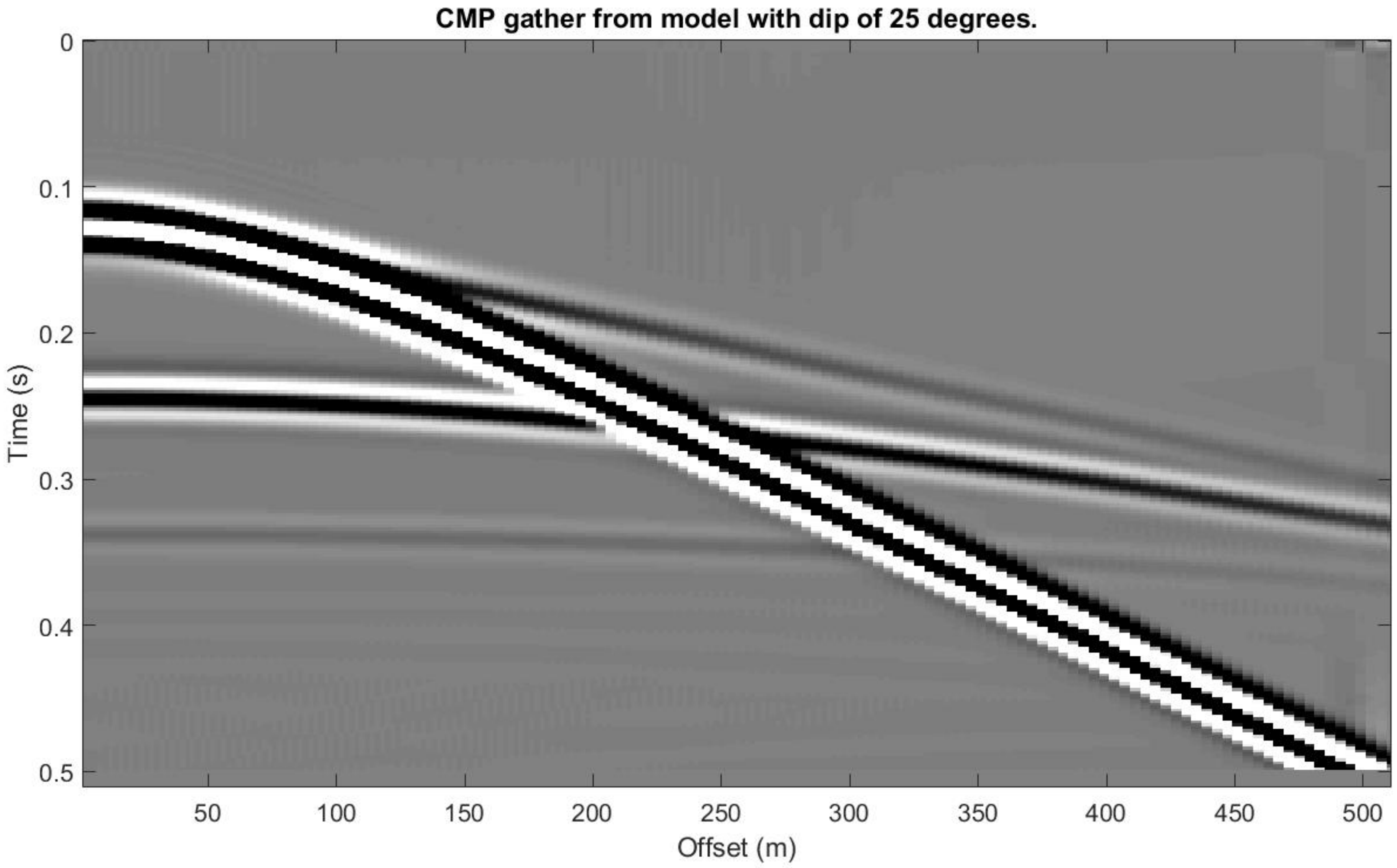


Interface Dipping at 25 degrees – CMP Gather



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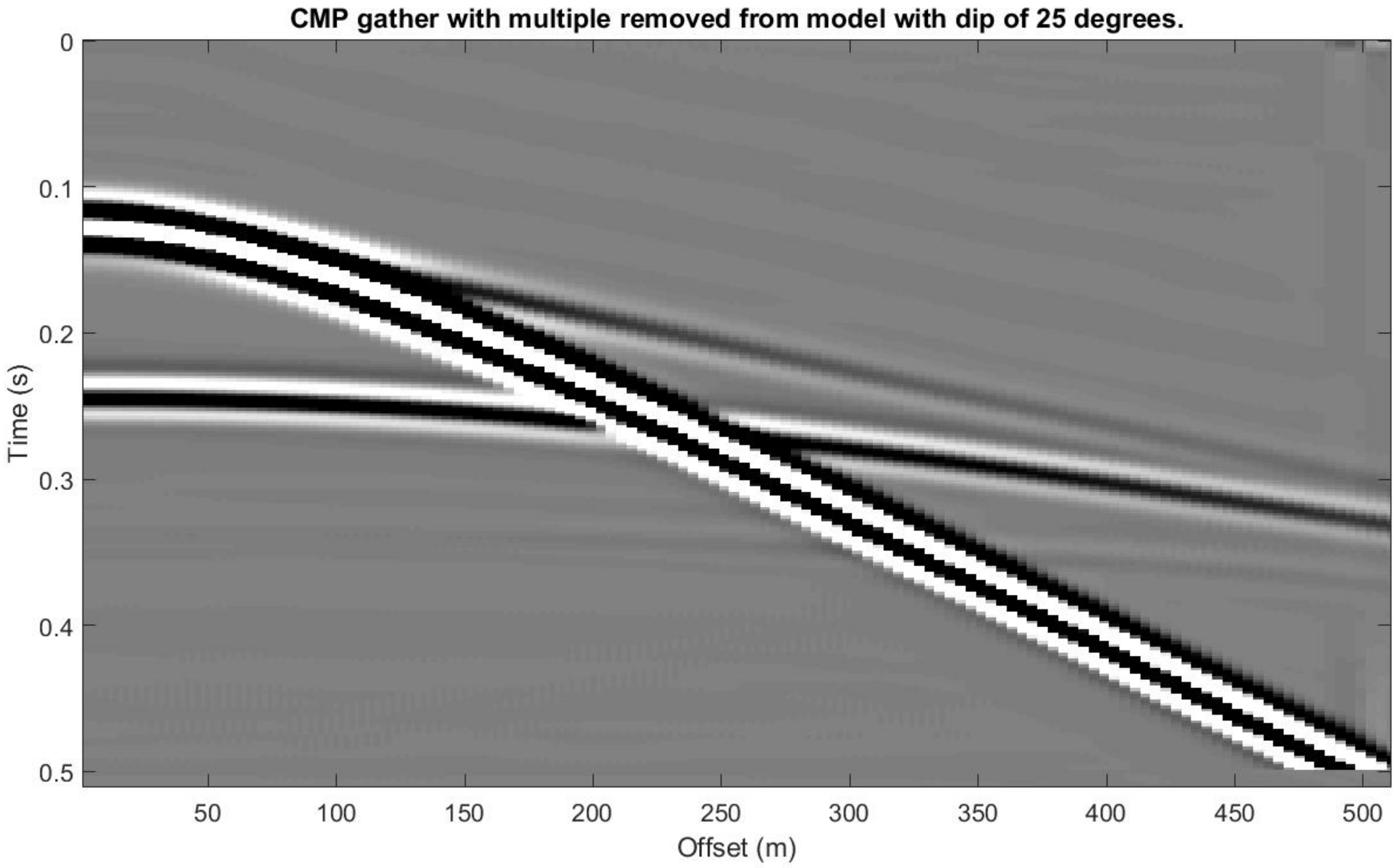
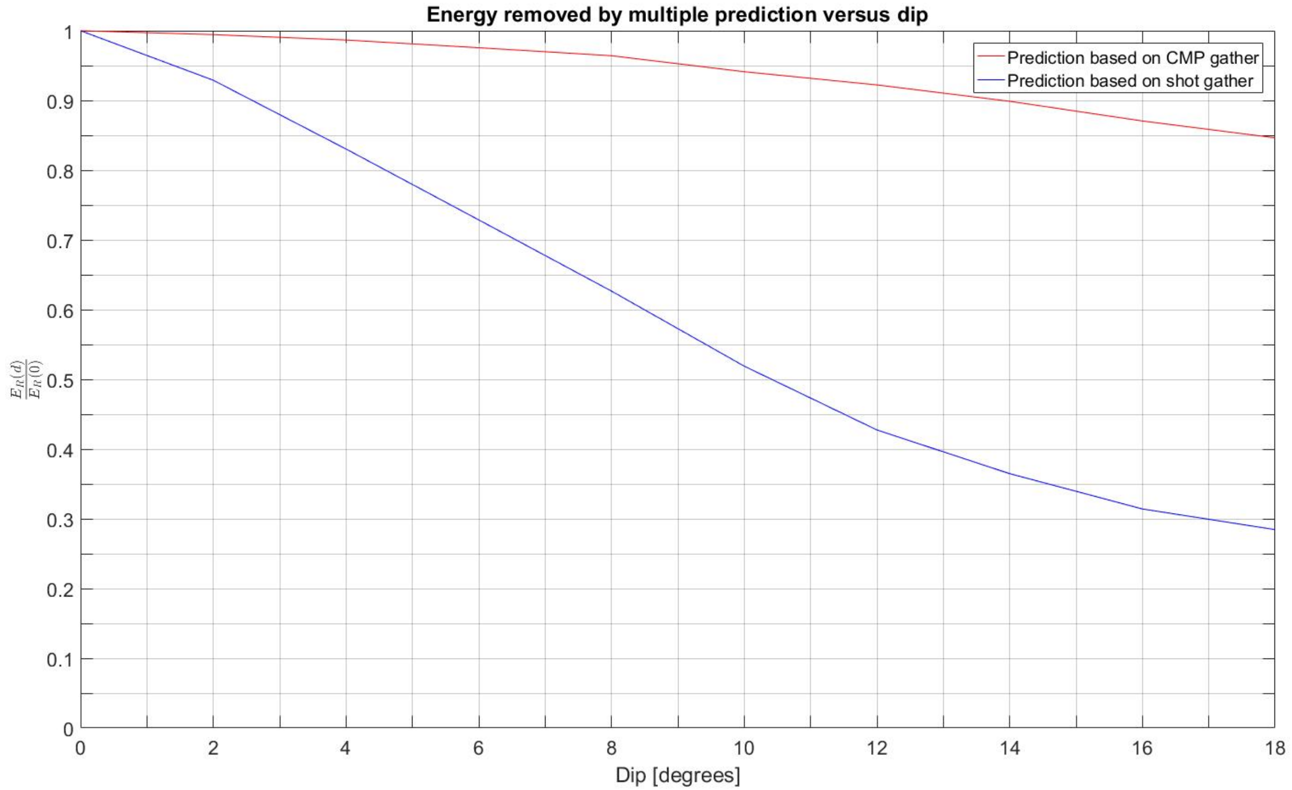
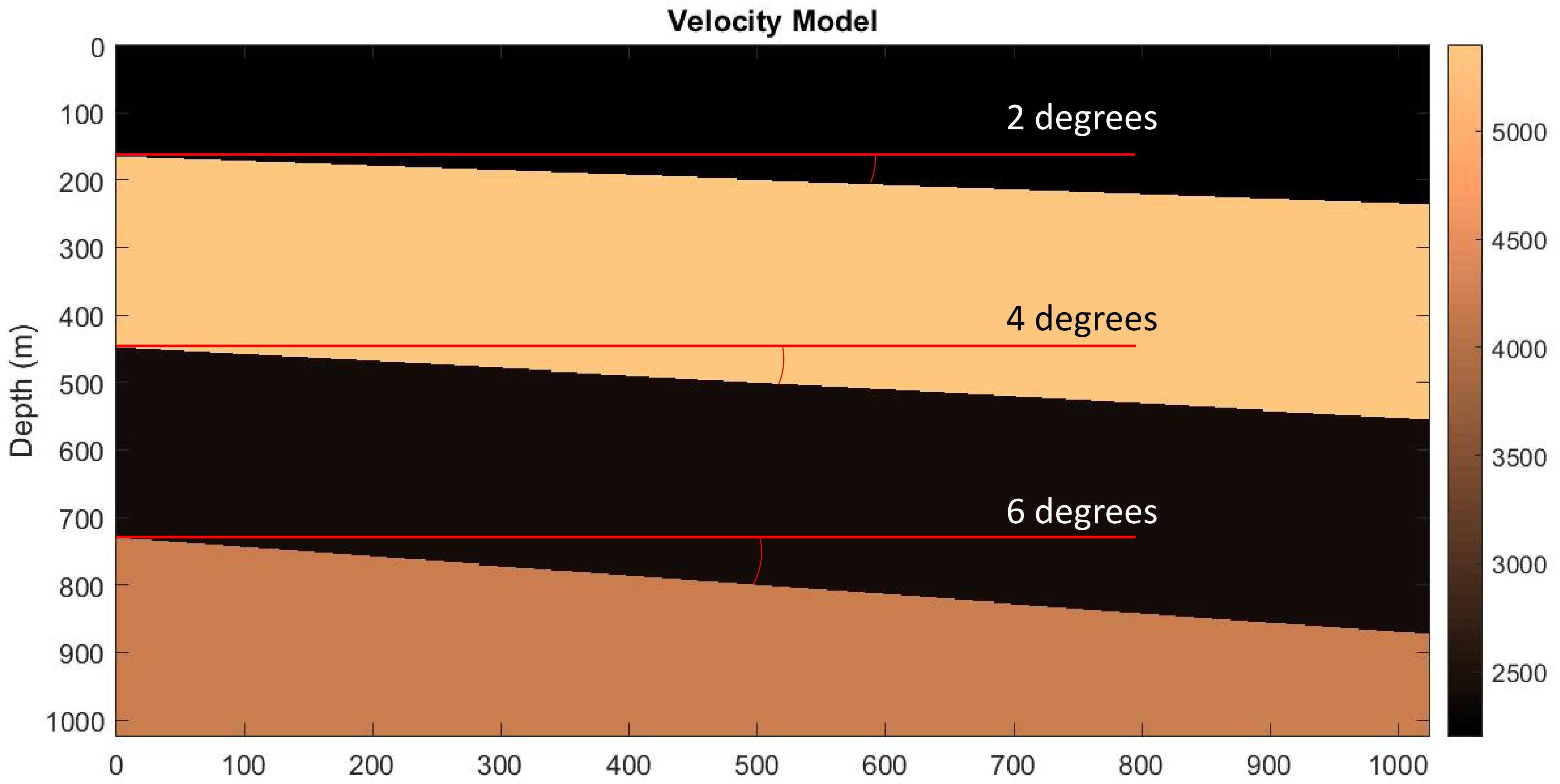


Comparisons of Shot Gather and CMP Gather Predictions

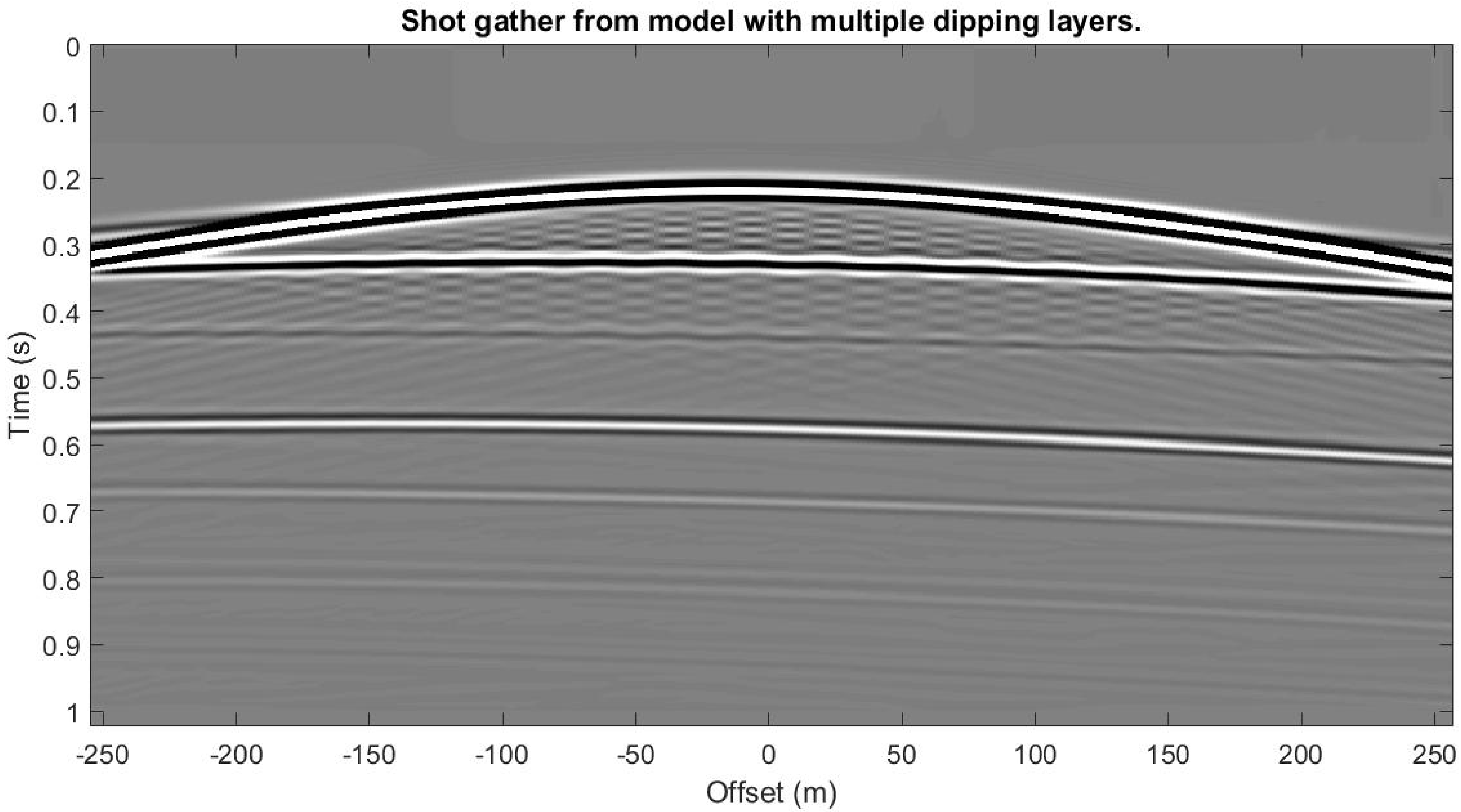


This graph shows the total energy removed by the prediction versus dip, relative to the energy removed in the “perfect” zero dip case for the CMP gathers (red) and the shot gathers (blue). Assuming all of the energy differences are related to the multiple being removed from the data and not dip induced changes in the reflection coefficients (which is approximately true), and keeping in mind that a value of 1 represents a perfect prediction, it can be seen that the CMP prediction performs much better than the prediction on the shot gather, as dip increases.

Velocity Model



Prediction from Shot Gather over Multiple Dipping Interfaces



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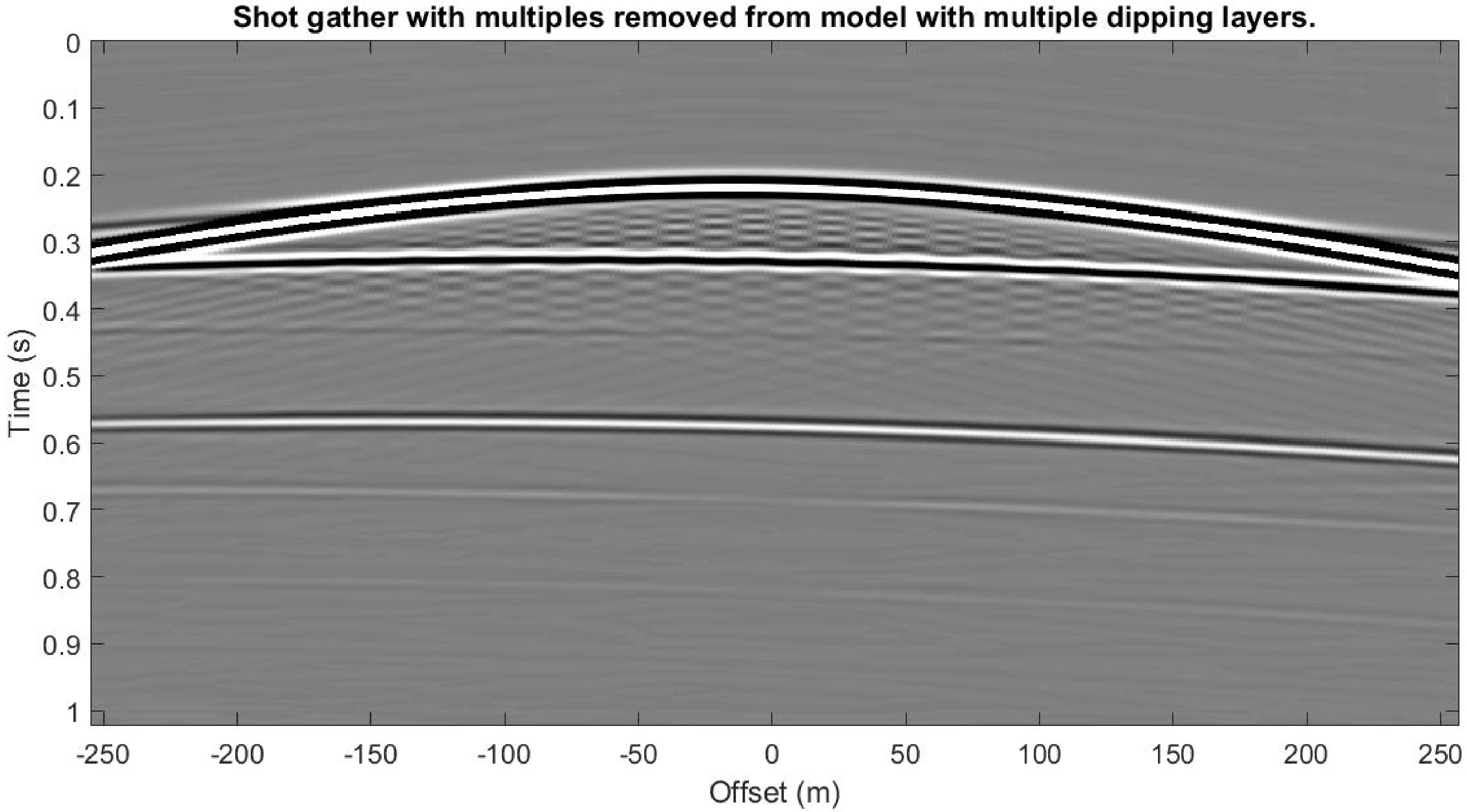

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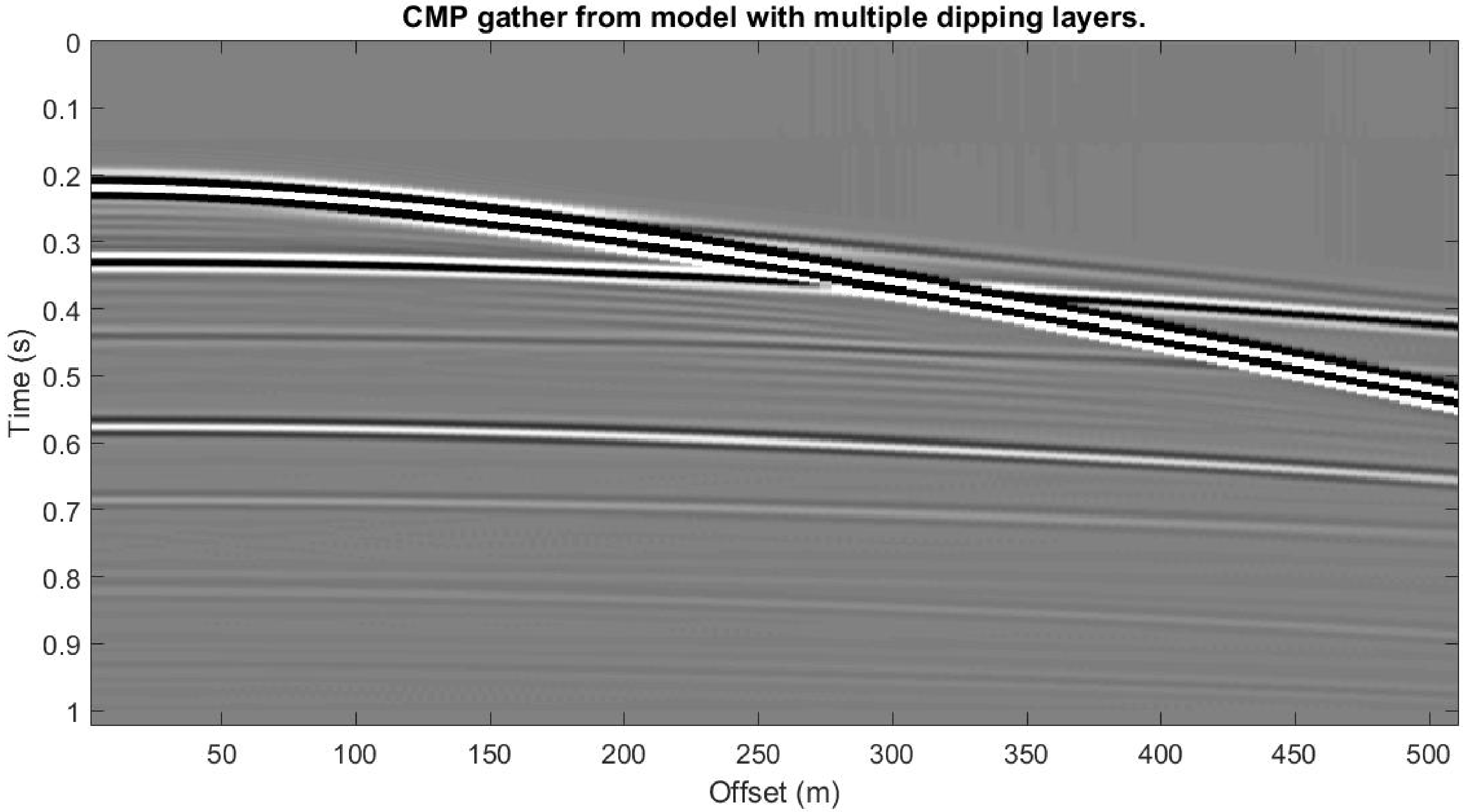

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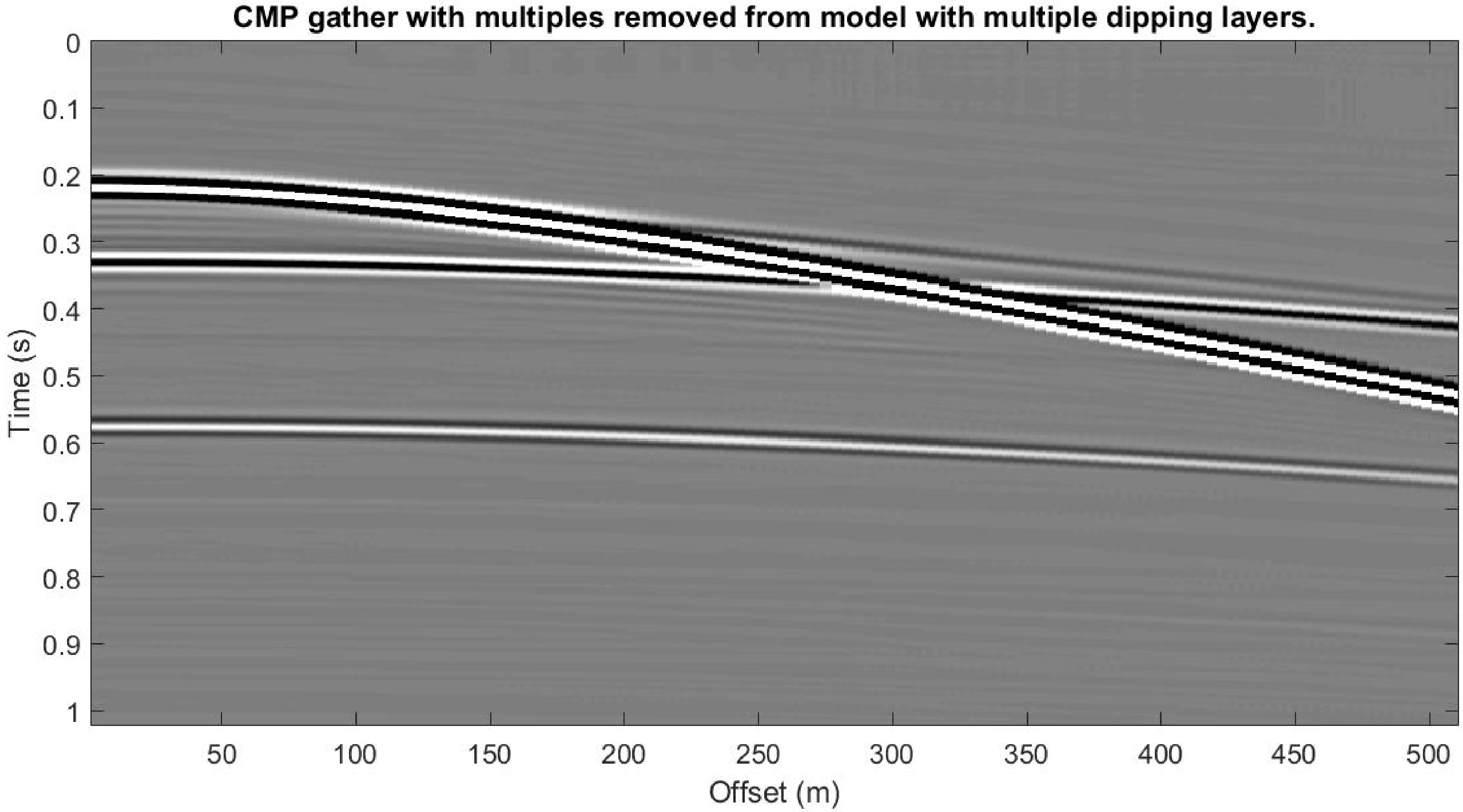

Conclusions

- Methods of internal multiple prediction based on the inverse scattering series in both 2 and 1.5 dimensions were reviewed.
- Appropriate applications of each were discussed along with the tradeoff between cost and accuracy for different mediums.
- The 1.5D algorithm was shown to be unsuccessful in predicting multiples on shot gathers when the data was collected over 2D geology.
- However, when the prediction was performed on CMP gathers, which inherently averages the source side and receiver side slowness, it was shown that the 1.5D algorithm remains fairly robust in the presence of 2D geology.
- If dipping layers are expected, this workflow could improve prediction computation time.

Acknowledgements

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Questions?