Velocity resolution and salt boundary placement in subsalt imaging.

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ABSTRACT

The interpretation of salt geometry is a critical aspect of velocity model building for 3D salt and subsalt imaging. Here we investigate the effect of salt boundary placement error in the velocity model building process. Using an example from deep water Gulf of Mexico, we first illustrate how velocity resolution drops beneath salt . We then show how an error in salt boundary placement can produce significant residual moveout in prestack migrated gathers. If this residual moveout is interpreted as arising from a velocity anomaly in the sediment, a velocity update of the sediment will introduce error into the sediment velocity model that in turn introduces false structure into the depth image. We show for this example that the correct placement of salt both flattens gathers and eliminates the false depth structure. Techniques for distinguishing between sediment errors and salt boundary placement errors are discussed.

INTRODUCTION

Because of the large velocity contrast between salt and sediment, any error in the placement of the salt boundary in the velocity model used for depth imaging can result in degradation of the final image. This is particularly true if the migration algorithm is a Kirchhoff algorithm that uses traveltimes obtained with raytracing. Raytracing to compute traveltimes is a high frequency approximation to actual wave propagation, and is very sensitive to velocity discontinuity positioning errors. Typically such an algorithm will use Snell's law to raytrace across velocity discontinuities, or will integrate the ray path equations across the discontinuity after smoothing the discontinuity. In either case, an error in the position of the boundary will cause an error in the traveltime along the ray. An error in the dip of the boundary will be even more problematic, causing the ray emergence angle to the normal of the boundary to be in error. This causes the ray to be displaced after it has traveled a significant distance from the boundary.

The strong ray refraction at salt boundaries has several ramifications for velocity analyisis. The first is that the angle between incident and reflected rays at the reflection point for a subsalt reflector, referred to as opening angle, is often significantly reduced over that for events outside salt. The result is that residual moveout for a given sediment velocity error drops significantly as one moves from areas outside salt to areas subsalt, limiting the effective resolution for recovering velocity errors subsalt.

Sediment velocity error is not the only factor contributing to residual moveout in the subsalt problem; errors in salt positioning contibute as well. This residual moveout can come from several sources. First, if the salt boundary placement error is small, and energy for the target reflectors passes through salt, the target reflectors will be incorrectly imaged across offset, which creates residual moveout. If the placement error is more severe, however, and the energy for the target reflectors does not pass through salt, there is also a chance that the image of other events whose energy does pass through salt will be positioned incorrectly on top of the target events, effectively masking them. In general, such energy will also show anomalous moveout. In either case, a typical scheme to improve the image would be to modify the velocity field so that subsequent migrated gathers have less residual moveout. Suppose, for example, that the residual moveout is due to a salt boundary placement error in salt that is laterally displaced from the velocity analysis location. If the velocity update is done using vertical depth-to-time conversions followed by conventional velocity analysis, then the update will be made to the sediment velocity field above the velocity analysis location rather than to the salt boundary location. The result is a sediment velocity update rather than a salt position update. Subsequent migration will place false depth structure into the section, and will often produce worse residual moveout than that seen in the initial migration.

EXAMPLES FROM THE GULF OF MEXICO

An example of the reduction of sediment velocity resolution is seen in Figures 1a and b. A location beneath a tabular salt body was selected, and horizon based migration was done to a horizon that extended from sediments outside of salt to a location beneath the tabular salt body. Following this, a sediment velocity lens that increased velocity over a thickness of 700 feet with a 20% increase in velocity was inserted just above the horizon, to observe the change in residual moveout. Figure 1a shows the result for a location outside of salt. In this case there is a dramatic difference in the amount of residual moveout seen with the lens as opposed to without. The analogous gathers at the subsalt position are seen in Figure 1b. Here there is very little change in observable moveout between the gathers obtained with the lens, and those obtained without. This indicates that the ability to recover sediment velocity from residual moveout drops significantly as one goes to subsalt areas.

An example of residual moveout arising from energy masking is seen in Figures 2-4. The acquisition geometry was dual-source six-cable marine with a maximum offset of 6000m inline. The time migration shows a flat structure with a slight dip to the left that increases with depth, as seen in Figure 2a. This particular line was located a significant distance from the two nearest salt structures in the crossline direction. A subsequent 3D prestack depth migration using the sediment velocity field without the salt, followed by depth to time conversion, revealed strong residual moveout as seen in Figure 2b. Dip in the crossline direction at the location of the residual moveout was significantly less than in the inline direction, and was such that a normal pointing upward from the horizons pointed slightly way from the two salt bodies. Judging from the small dip, we initially concluded that the residual moveout was due to a sediment velocity anomaly, and that the energy contributing to events with anomalous moveout missed the salt bodies. Conventional velocity analysis followed by time-depth conversion was then done to update the sediment. A subsequent prestack depth migration showed significant false structure, while residual moveout was not significantly reduced. Following this, an interpretation of the top salt was made, and a salt-flood velocity model was produced using the initial sediment velocity field with the two salt bodies inserted. Prestack migration using this model produced the depth section in Figure 3a, with essentially linear structure. The migrated gathers are shown in Figure 3b, and show very little residual moveout. Our conclusion is that most of the energy contributing to the events with strong residual moveout in Figure 1a is in fact passing through the salt, and is masking the actual events in the image when migrating with a velocity field without the salt. Figure 4 shows a 3D view of the area, with the salt structures shown, the target line migrated with the anomalous sediment velocity shown to the left, and a crossline shown to the right.

Having seen how residual moveout due to salt mispositioning can be misinterpreted as a sediment velocity anomaly, methods for distinguishing the cause of residual moveout can clearly benefit the velocity model building procedure. In this case, the migrated time section provides the strongest clue that the depth structure found in Figure 2a is false. In order for a time migrated section to have a simple horizon structure, and the actual horizons in depth to have complex structure, it is necessary for image rays to travel to the complex horizons with a specific traveltime that produces the simpler time image. In this sense the complexity of the velocity field and the complexity of the horizon structure must balance one another to give the simple time structure. It is unlikely that this occurs for actual geology, indicating that the complex depth structure is false. In cases where the time section shows significant complexity, such an analysis is not possible. 3D raytracing studies may then provide additional information to distinguish the source of the residual moveout. Similarly, migrations done with spatially localized subsets of the input data can also be useful in identifying the source of energy contributing to the image. Finally, it is interesting to note that 2D traveltime tomography would be ineffective in updating the velocity model on this line, since it cannot place the velocity update off of the line to where the salt bodies are located.

CONCLUSION

Residual moveout on migrated gathers is the primary source of information for velocity model updating in production imaging. Often, the residual moveout is attributed to sediment velocity error, but as one moves to areas near salt or subsalt, the residual moveout can come from other sources as well.

Residual moveout due to sediment velocity error drops significantly as one moves subsalt, which limits its usefulness in determining subsalt velocities. In the first example presented here, a significant velocity error that produced substantial residual moveout in gathers outside salt was found to produce essentially no residual moveout subsalt.

Residual moveout can come from errors in salt boundary placement as well, and often the residual moveout is substantially greater than that due to errors in sediment velocity. If the boundaries are incorrectly interpreted and placed in the model, subsequent 3D prestack migration may show significant moveout on primary subsalt events whose energy passes through salt.

A final source of the residual moveout may be masking energy that obscures primary events. In the second example presented here, masking energy was initially misinterpreted as sediment velocity error. Correct placement of the salt into the original sediment velocity field gave a correct depth migrated image with simple structure and very little residual moveout.

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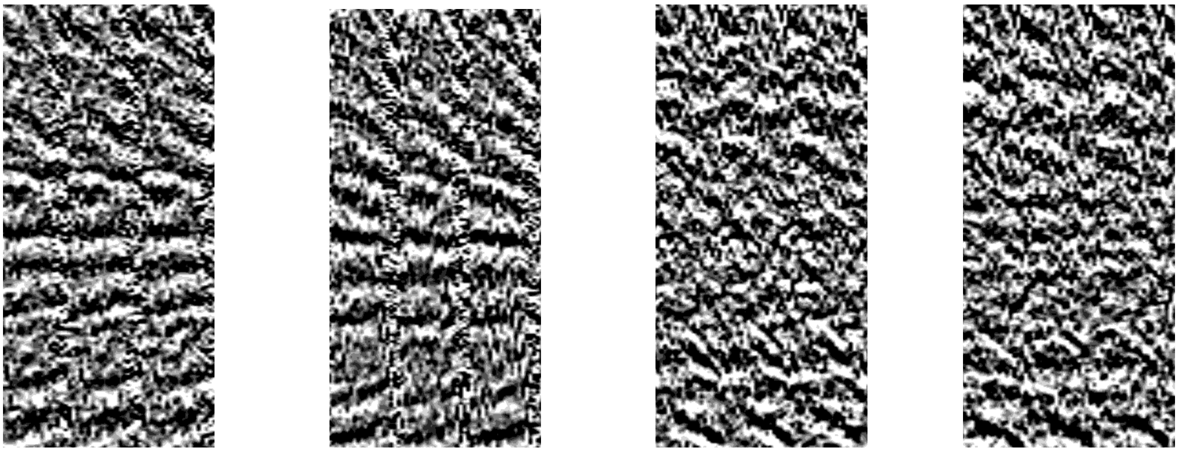
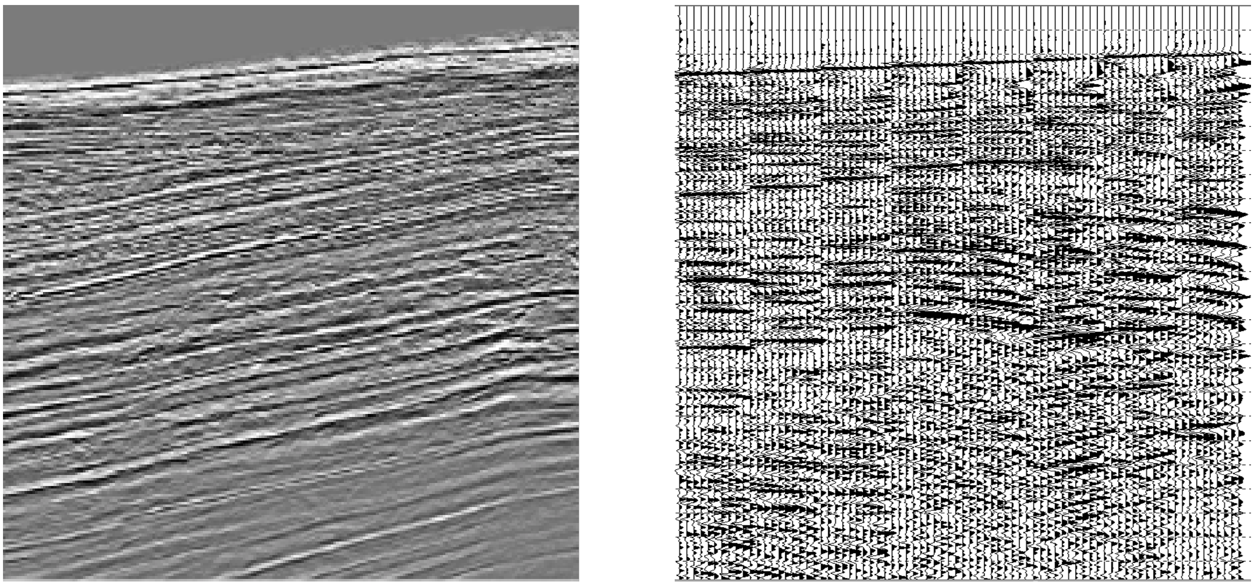
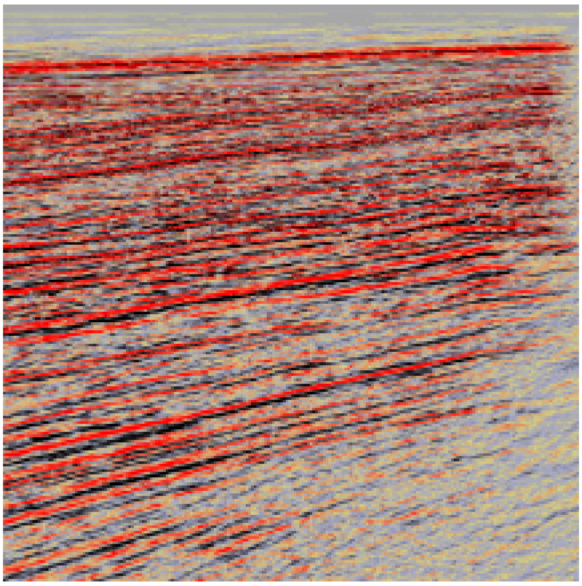
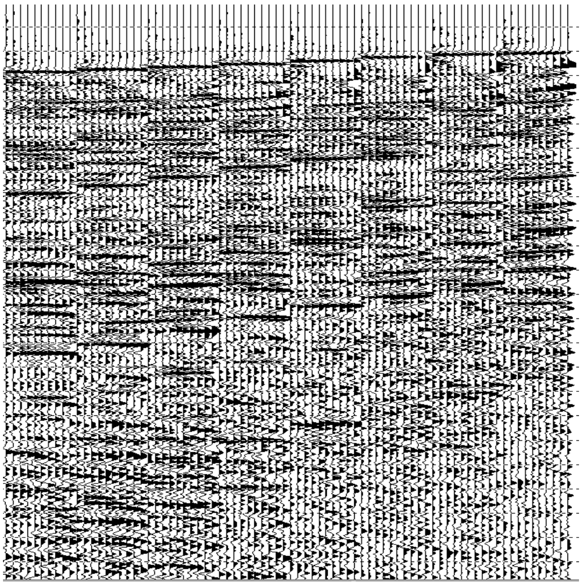


Figures 1a,b,c and d. Figure 1a shows horizon migrated gathers from a location outside salt. In Figure 1b a significant velocity lens was introduced into the velocity model, and the resulting residual moveout can be seen at the center of the gather. Figures 1c and 1d show analogous gathers under salt, and little change in moveout is seen. This suggests that residual moveout is ineffective in distinguishing subsalt velocity in this area.



Figures 2a-b. Figure 2a shows a time migration along an inline through the area of interest, revealing relatively simple linear horizon structure. Figure 2b shows 3D prestack depth migrated image gathers along the line using a sediment velocity model without salt. Significant residual moveout is seen in the middle right of this section, which is actually due to masking energy that is obscuring primary events.





Figures 3a-b. Figure 3a shows a 3D prestack depth migration done with the original sediment velocity model, with the addition of salt structures located off of the inline. The top of salt and a salt flood have been added to the velocity model at this point. The depth migration reveals simple linear horizon structure similar to the time migration. Figure 3b shows the corresponding image gathers, and shows that the masking energy has been eliminated with the addition of salt to the velocity model. The conclusion is that the energy contributing to the anomalous image in Figure 1b actually passes through salt

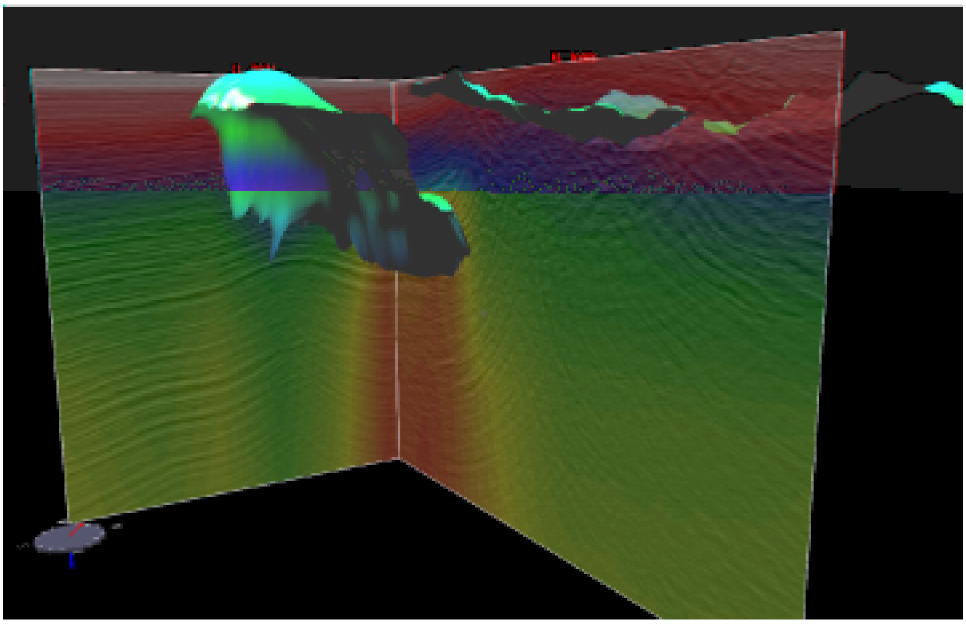


Figure 4. A 3D view of the area of interest, showing the two salt bodies located off the line, the inline depth migrated section corresponding to Figure 2a to the left, and a crossline section to the right.