Beam-based Interactive Imaging for Salt Interpretation and Salt Model Building

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Summary

It is well understood that accurate salt interpretation is critical to subsalt imaging. When reflections from the salt-sediment boundaries are not discernible, it takes many iterations to test various scenarios based on the geologic consistency of reflectors underneath the salt. Multiple iterations with wave equation migration are extremely time consuming and its computational cost is unacceptably high. We have developed a new methodology by incorporating demigration, fast beam migration, and polygon-based salt model update. We first demigrate a prestack depth-migrated image to a subsurface datum, which provides well-focused reflections at their unmigrated locations on a regular grid. Next, we pick inline and crossline ray parameters by dip scan. We then carry out fast beam migration to test different salt boundaries to evaluate the geologic consistency of reflections under the salt. This methodology enables us to interactively test many scenarios to generate the final model much faster than iterations using other migration techniques. Application to a 3-D field data set from the Gulf of Mexico demonstrates the effectiveness our methodology.

Introduction

In the recent *The Leading Edge* special issue on subsalt exploration (November, 2007), the need for accurate interpretation of salt and salt model building was emphasized (Sayers and Herron, 2007; and Mosher et. al., 2007). The identification and definition of the shape of the salt geometry form a critical and time-consuming step for a successful subsalt imaging project. Salt interpretation and salt model building are a major part of a typical depth-imaging project (Reasoner, TLE, November, 2007).

The use of prestack depth migration for salt model building is an iterative process that requires integration of salt interpretation and depth migration. Salt interpretation is often not clear-cut for complex salt geometry, and often requires testing different interpretation scenarios, especially for the base of salt (BOS) where imaging is often poor. Since depth imaging is an iterative process of velocity model building and depth migration, it is often desirable to develop fast depth migration algorithms for testing different velocity models (Wang and Pann, 1996; Hua and McMechan, 2001, 2003; Fei and McMechan, 2006).

Beam-based migration (Hill, 1990; Gray, 2005) has been proposed for use in complex salt model building, due to its salient features of steep-dip and multi-pathing capability as well as its relative efficiency as compared with wave-equation migration. Recently, Gao et. al. (2006) attempted to integrate salt interpretation and velocity model building using fast beam migration, and demonstrated that the fast beam migration could serve as an interactive imaging tool for subsalt velocity model building. Since the subsalt imaging result of the current salt model defines the next salt interpretation test scenario, interactive response for this process is critical. In this paper, we describe a new methodology to interactively update the salt geometry using fast beam migration. Our method consists of four steps: demigration of a prestack depth-migrated image, picking ray parameters, revision of salt boundaries, and fast beam migration.

Polygon-based Salt Model Building and Editing

One key component of our methodology is editing of the salt model using polygons which allow us to easily revise the salt boundaries. A typical GOM velocity model could contain multiple embedded salt bodies of complex shapes. The multiple pairs of the top and base of salt could be utilized in the standard practice of using single-valued surfaces to represent a body of salt. When modifying/editing a complex salt geometry, it is time-consuming to modify each of those surfaces. To complicate this, multiple salt bodies sometimes join and become a single salt body, or the other way around. Therefore, a single-valued surface-based salt model building methodology becomes inefficient for revising a complex salt model. Instead of using the standard surface-based TOS and BOS approach, we have developed a new easily edited polygon-based approach which does not require surfaces to define the top and base of the salt. Figures 1A and 1B show an example of using a polygon to define how much salt we want to add into the model, and Figures 2A and 2B show an example of using a polygon to carve out a piece of salt to define an overhang structure. The geometries defined by polygons in each inline or crossline section are interpolated to create a 3D salt body.

Salt Model Refinement by Interactive Migration

Typical production timelines put tremendous pressure upon the interpreter to make a prompt choice among various interpretation scenarios – which may result in sub-optimal salt model. This is especially true in areas where the salt boundary is not clearly imaged as shown in figure 3A. If there are clearly discernible subsalt reflections, one can change the salt geometry and migrate to determine the best salt geometry based on the geologic consistency of subsalt reflections. In order to interactively test many different salt boundaries, we need a very fast migration algorithm such as beam migration.

The quality of fast beam migration is highly dependent upon the quality of ray parameters picked by dip scan. (Gao et. al., 2006; Fei and McMechan, 2006). It is a particularly challenging task to pick prestack ray parameters in the crossline direction because of a large spatial sampling and a poor signal-to-noise ratio. The use of demigrated data makes ray parameter picking much easier because of a smaller and more regular crossline sampling distance, in both inline and cross-line direction, and an improved signal-to-noise ratio. The use of demigration for velocity model update has been reported before (Kim et. al., 1996; Wang et. al., 2005; Mosher et. al., 2007).

Figure 3 shows an example of post-stack WEM demigration result. Figure 3A is an example of prestack depth-migrated image, using an initial velocity model shown in figure 3B. Because of the lack of discernible reflections from the base of the salt (BOS), the BOS picking was uncertain in the initial model. Although the reflection from the BOS is lacking in the image, there are many mispositioned subsalt reflection events, clearly indicating that the salt geometry is incorrect. The migration image is used as a reflectivity model to perform post-stack WEM demigration using the same migration velocity model to a datum surface at a depth of 3200 m. Demigration places migrated events at their unmigrated locations. Instead of demigrating the events to the surface, we demigrated the events to a subsurface datum. Since the events are closer to their correct migrated locations, there are fewer conflicting events. Figure 3C shows the demigrated seismic data in time, Note that the reflection events are not crossing each other. In addition, demigrated data are given on a regular grid with a small spacing. The lack of crossing events and the data on a regular grid allow us to pick the dip of the events with a high degree of reliability which is critical to beam migration.

Once the dip of the events in the demigrated data is determined, we are able to quickly test many possible salt geometries with a fast beam migration algorithm to derive a correct salt geometry. Figures 4A, 4B, and 4C show three examples of velocity models based on three possible salt interpretations, and figures 5A, 5B, and 5C show the beam-migrated images using these three velocity models shown in Figure 4A, 4B, 4C, respectively. Since figure 5A clearly indicated that there should be more salt, we added more salt as shown in figure 4B. However, the beam migrated image shown in figure 5b suggested that the amount of the salt we added was not enough. Note that the gaps between the subsalt reflectors across the salt still exist. After many iterations, we finalized the salt geometry as shown in figure 4C. The final beam-migrated image shown in figure 5C shows the positioning of the subsalt reflections is geologically reasonable. The gap below the steep salt flank might be due to the lack of illumination.

The importance of making this process interactive must be emphasized. It is critical to maintain the continuity of the interpretive thought process while exploring various geometry scenarios. Batch processing is only sufficient when testing a few discrete predefined models. By adding interactive capabilities, the interpreter can immediately compare the image quality difference between the proposed modification and the current model. Since the subsalt image is highly dependent upon the shape of the salt body, the ability to quickly view the image and modify the shape of the salt is critical to reduce the time to define the correct salt geometry. With the use of demigration and fast beam migration, we can test many different scenarios almost instantaneously.

After we finalized the salt interpretation and built a final velocity model, we performed 3D WE-based prestack depth migration. Figures 6 and 7 show the comparison of the prestack depth-migrated images using the initial and final models. With the final model, we have a subsalt image that is better in quality and makes more geologic sense.

Conclusions

We have developed a new methodology for determining the shape of salt bodies by incorporating demigration, fast beam migration, and a polygon-based representation of salt bodies which is very efficient in testing various salt geometries. Demigration places the reflections at their unmigrated locations on a grid with a spacing suitable for picking ray parameters. In addition, the use of a subsurface datum below the top of salt for demigration considerably simplifies the wave paths and facilitates the use of beam migration to test different salt shapes. This technique helps us finalize the best salt model based upon the geologic consistency of subsalt reflections much faster than using other migration techniques. Application to a 3D data set from the Gulf of Mexico demonstrated the effectiveness of this new interactive imaging methodology.

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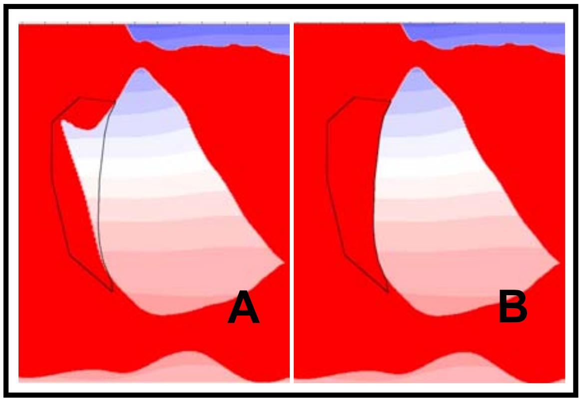

Figure 1. Adding a piece of salt: (a) before adding additional salt; (b) after adding additional salt;

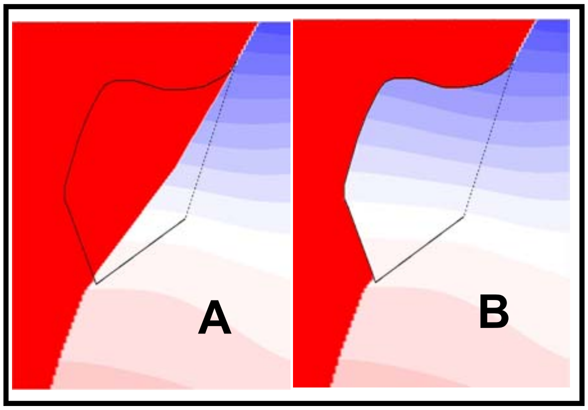

Figure 2. Removing a piece of salt: (a) before removing some salt; (b) after removing some salt.

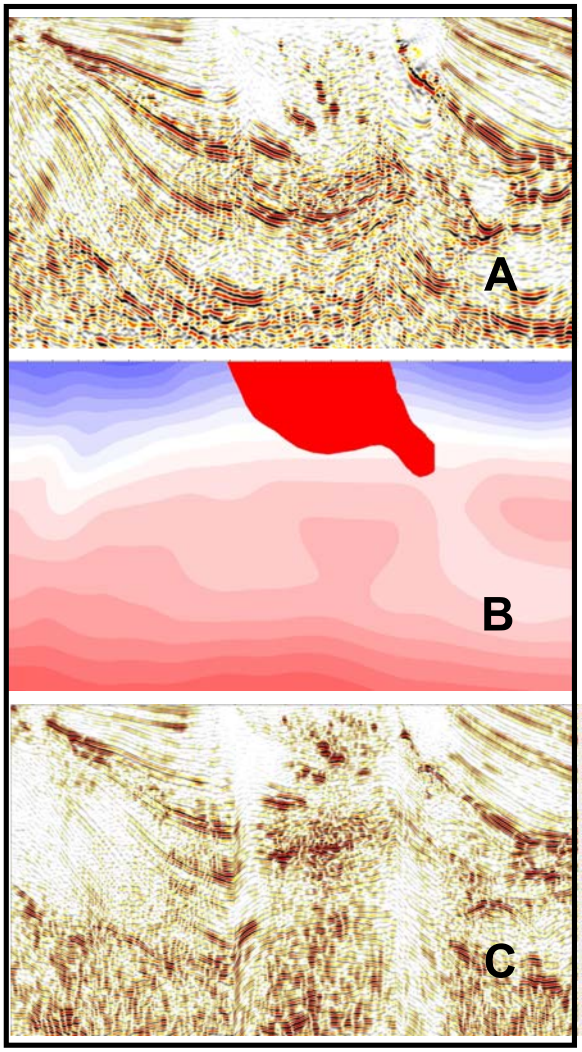

Figure 3. Post-stack WEM demigration of presatck WEM image: (a) Presatck WEM image used as an input for demigration; (b) The same migration velocity model used for demigration; (c) The demigrated seismic data in time after demigration.

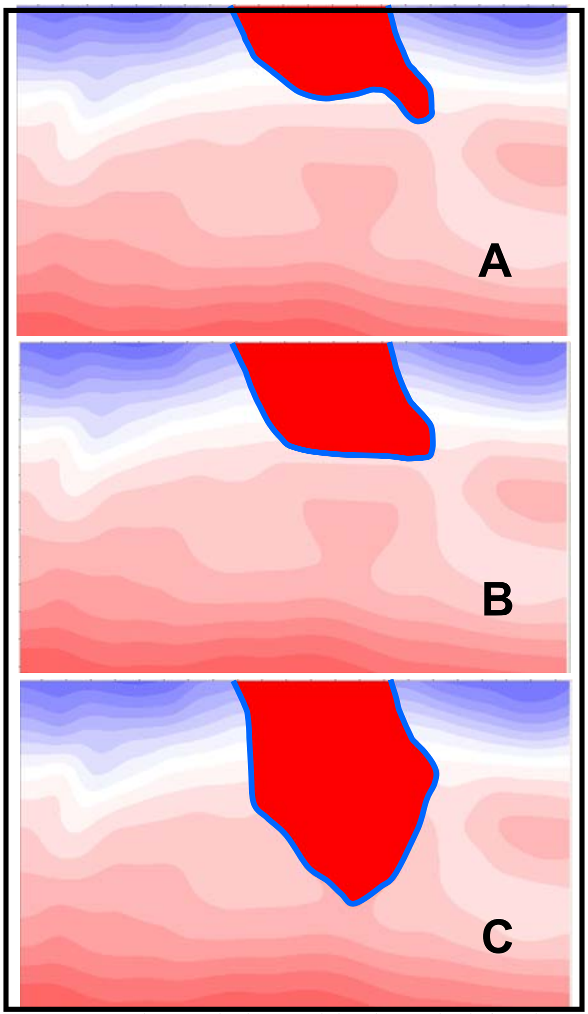

Figure 4. Three velocity models shown in left column (A,B,C).used for interactive beam migrations.

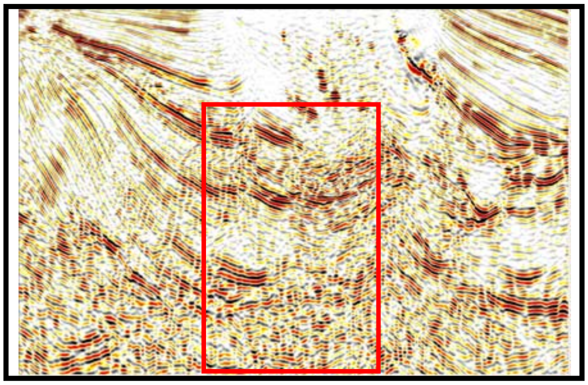

Figure 6. Prestack WEM image using the initial velocity model shown in Figure 4A.

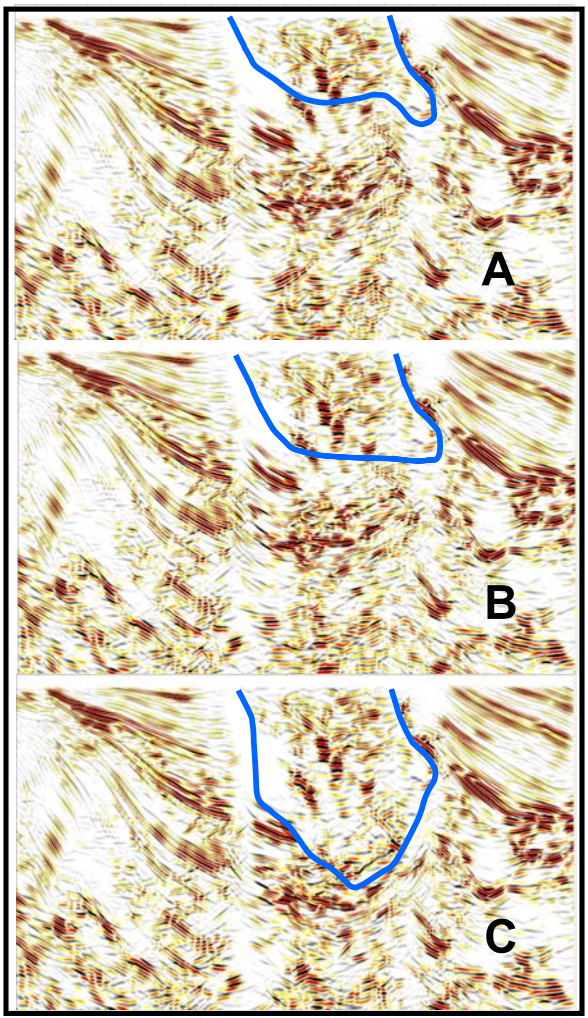

Figure 5. Interactive Beam Migration results, using the three velocity models shown in left column Figure 4.

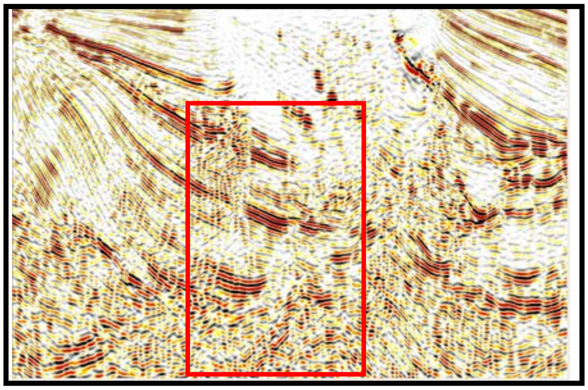

Figure 7. Prestack WEM image using the final velocity model shown in Figure 4C.

EDITED REFERENCES

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