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Complex-salt model building using a combination of interactive beam migration and layer-stripping RTM

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Summary

A new salt velocity model building methodology is proposed which allows effective testing of different salt interpretation scenarios. In this methodology, we combine the strength of efficiency from interactive beam migration with the accuracy of layer-stripping RTM to derive a more accurate salt geometry. Using interactive salt geometry editing and efficient beam migration, a large number of salt interpretation scenarios are quickly tested and narrowed down to a small number of likely salt interpretation cases. This is followed by a reduced number of layer-stripping RTM runs to single out the final salt velocity model. Redatuming the wavefield from the surface to a user defined subsurface datum plays a pivotal role in this methodology; it enables improving the quality of beam migration and the efficiency of RTM.

Introduction

Prestack depth migration has been used routinely for subsalt imaging. To produce a good subsalt image, an accurate velocity model is required. The generation and refinement of the velocity model in a routine production project is often a complex process (Singer, 2005). The model typically has multiple embedded salt bodies with complex geometries.

The need for accurate interpretation of salt in salt model building has been emphasized by many authors (Sayers and Herron, 2007; and Mosher et. al., 2007). The identification and definition of the shape of the salt geometry is a critical and time-consuming step for a successful subsalt imaging project. Salt interpretation can account for about 70% of a typical depth imaging project timeline as pointed out by Reasnor (2007).

The existing salt velocity model building methodology may not be effective in the complex areas where the salt geometry is not clearly identifiable in the seismic migration image. The industry's standard salt model building method follows an iterative flow of sediment floods and salt floods. At each step of this standard flow, only one top of salt (TOS) or one base of salt (BOS) interpretation is allowed. The fundamental assumption for this methodology is that the salt boundary is well imaged by seismic migration, and therefore the salt boundary is interpreted and picked with certainty. This may not be true for areas with complex salt geometry, where the salt boundary is poorly defined in seismic migration images. In the case of complex salt geometry, or for whatever reasons the salt geometry is not well imaged, the standard salt model building methodology breaks down, and it demands a new more effective salt model building methodology.

Generally, salt model building and prestack depth migration are part of an iterative process that requires integration of salt interpretation and depth processing. Salt interpretation is often not clear-cut for a complex salt geometry, and often requires testing different interpretation scenarios, especially for base of salt (BOS) where imaging is sometimes 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 velocity model building (Hill, 1990; Wang et al., 2008).

Reverse time migration (RTM) has shown great potential, not only as a final imaging tool but also as a velocity model building tool. RTM has high accuracy in modeling complex wave propagation including turning waves and multiple bouncing waves such as prism waves (Jones, 2007). RTM not only defines steeply dipping events better, it also shows great potential to image shadow zones by improving event termination at salt boundaries and to better image rugose TOS and BOS. Therefore, RTM shows great potential to define a more accurate salt model, especially for complex salt geometries (Yoon et. al. 2008; Ortigosa et. al., 2008)

New methodology for salt model building

The basic assumption of the current standard methodology of salt model building is that TOS is clearly defined in sediment flood migration images, and BOS is well defined in salt flood migration images. In many complex areas, the salt boundary is not clearly identifiable by seismic imaging, especially when there are multiple salt bodies in close proximity. In the case of a deeper second salt body, it is seldom that we can interpret the second deeper salt geometry with any certainty. Many interpretation scenarios need to be tested before finalizing the salt interpretation. Clearly, the existing standard salt model building methodology is not effective for building such complex salt models.

The proposed methodology takes advantage of the sensitivity of seismic depth migration to salt geometry. In some areas, due to the high velocity contrast between low velocity sediment and high velocity salt, the accuracy of the salt geometry has first order impact on depth migration image quality in the areas around or beneath salt bodies.

There are two key components in the proposed salt model building methodology: 1) Interactive beam migration; 2) Layer-stripping RTM. The efficient interactive beam migration tools (Wang et. al., 2008) are used to quickly test a very broad range of salt interpretation scenarios. Typically, about 20 to 30 salt models are tested by using interactive beam migration and are narrowed down a smaller number of more likely salt interpretation scenarios (for example three to five models). Then more accurate and high quality layer-stripping RTM (Yoon et. al., 2008) are used to nail down one final model from the remaining three to five models.

Interactive beam migration for salt model building

The input for our interactive beam migration flow are a prestack depth migration volume and its associated velocity model. Figure 1 shows a flow chart of how we perform salt interpretation scenario testing using the interactive beam migration tools.

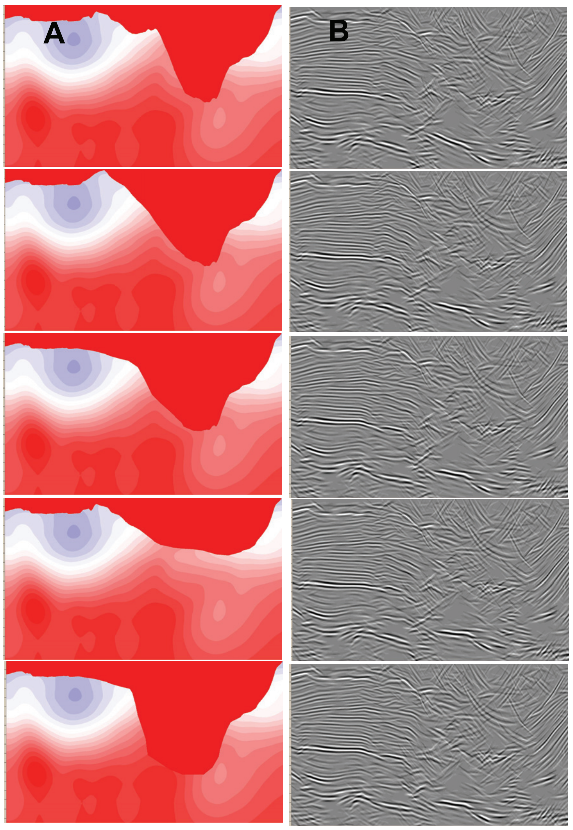

***Figure 2**: A) Corresponding salt interpretation and velocity models; B) beam migration images;*

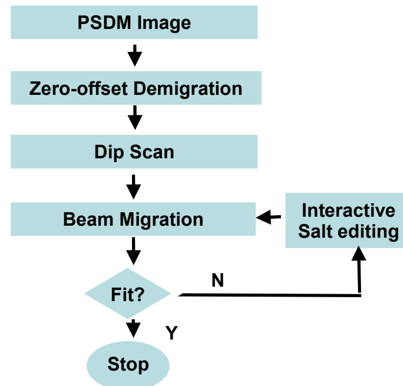

***Figure 1**: Flow chart of interactive beam migration for testing different salt interpretation scenarios.*

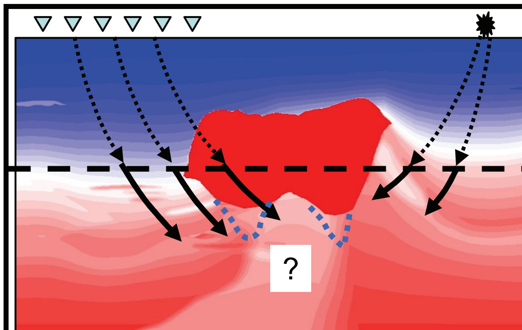

***Figure 3**: Schematic diagram showing redatuming of both receiver side and source side wavefields from surface to a subsurface datum.*

We first perform a wave-equation based post-stack demigration to a subsurface datum, above which the velocity model is already finalized. Typically the subsurface datum is directly below the TOS. By running the down going migration (using the PSDM volume), and up going demigration, we effectively achieve a wavefield redatuming from the surface to this subsurface datum.

The demigrated wavefield is used as the input for post-stack beam migration to test different salt interpretation scenarios. One of the components contributing to efficiency in the interactive beam migration flow is the polygon-based interactive salt editing tool, which enables us to quickly and interactively add or remove a segment of salt (Wang et. al., 2008).

Figure 2 shows a few examples of salt velocity models and the corresponding beam migration images for a 3D data set from the Gulf of Mexico(GOM). The image is not clear as to whether or not there is a salt keel or how deep it may reach. For this example, more than 20 salt models are tested using the interactive beam migration tools and are narrowed down to three models which are then further tested by using more accurate local RTM.

Layer-stripping RTM for salt model building

To make RTM more affordable for testing several possible salt interpretations, such as how deep the salt keels go (Figure 3), we first perform RTM-based wavefield redatuming, which redatums the shot-based wavefield from the surface to a subsurface datum above which the salt geometry is fixed.

There are a few important benefits of performing RTM-based wavefield redatuming. The computation cost can be dramatically reduced by only performing RTM using a redatumed wavefield below the subsurface datum, due to two main factors. First, computation grid size can be greatly increased with depth while still avoiding dispersion noise, because the minimum velocity is much higher at greater depth. For example, assuming the minimum velocity is increased from 1.5 km/s at the surface to 2.5 km/s at the redatuming surface of 6 km depth (assuming velocity increases with depth), the computation grid size can be increased by a factor of 1.67, considering three dimensions in space and one dimension in time which would translates to speed-up by a factor of seven. Second, the migration aperture can be much reduced. The required migration aperture is linearly proportional to the target depth. The computation savings due to the smaller required aperture is true for both the RTM-redatuming step as well as the subsequent multiple RTM runs using the redatumed wavefield. Additional cost saving can be achieved by identifying and pre-selecting only those input shots which contribute to the illumination if the target areas. Other benefits of using redatuming for RTM, such as saving on computer memory and other resources, are discussed in Guan et. al., (2008).

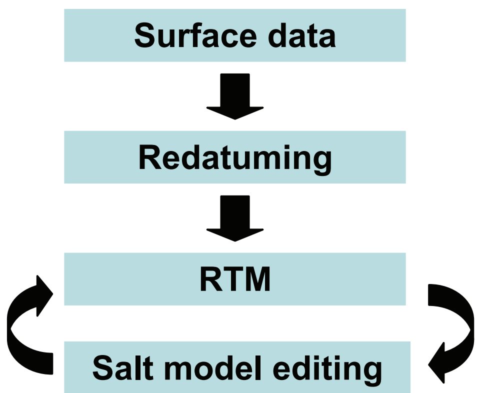

***Figure 4**: Flow chart for layer-stripping RTM.*

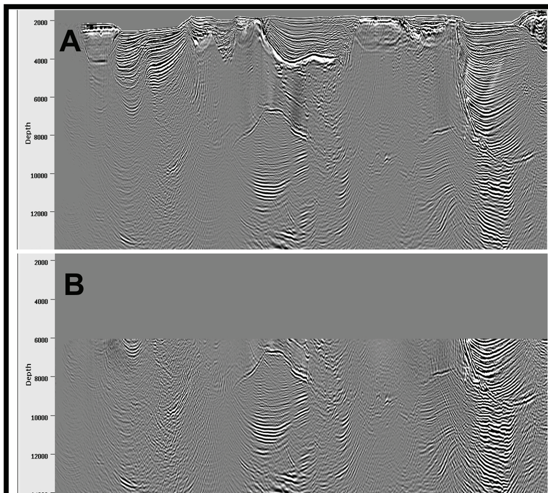

***Figure 5**: A) RTM image using surface input data; B) RTM image using redatumed wavefield.*

Figure 4 shows the flow chart for our layer-stripping RTM. First, input shot gathers (or selected shot gathers) are redatumed from the surface to a user-defined subsurface datum. On the source side, the forward-modeled wavefields are saved to local disk on the redatuming surface at a given time interval. One alternative view of source-side redatuming is that it converts a point source at the surface into an area of sources in the subsurface datum. On the receiver side, the receiver wavefields (input shot records) are reverse-time propagated and the wavefields on the redatuming surface are saved to local disk. The saved redatumed wavefield is used to test different salt velocity models by performing multiple RTM runs.

We have developed a 3D RTM-based redatuming tool to redatum the wavefield from the surface to a subsurface datum. Figure 5 shows an example of the effectiveness of the 3D RTM-based redatuming. Figure 5A is a 3D RTM image created by performing an one-step RTM run using the surface input data; Figure 5B is the corresponding RTM image by using the redatumed wavefield at 6 km depth. Except for some visible amplitude differences, the two image qualities are very comparable.

One technical challenge we have to face and resolve is the “data explosion” problem. A typical 3D NAZ survey only has six to eight cables, and even a development WAZ survey has only up to 80 cables in a super shot gather. However, after redatuming, in the crossline direction we need to save a few hundred lines, so the data volume could be exploded by one to two orders of magnitude. To solve the “data explosion” problem, we have developed wavelet-transform based data compression techniques which are able to achieve compression ratios of 10:1 to 50:1.

Figure 6 shows an example of how layer-stripping RTM is used to test different salt velocity models. This is the same 3D data set shown in Figure 2. Interactive beam migrations are used to test more than 20 different salt geometries. Three more likely salt models (Figure 6, left column) are narrowed down, then layer-stripping RTM is used to produce the RTM images shown in right column of Figure 6. Based on the RTM image, the bottom salt geometry is chosen to be the final model, which makes more geological sense. Figure 7 shows another example of using layer-stripping for salt model building. The bottom left salt model results in a RTM image which is more focused and more consistent with regional geology.

Conclusions

We have developed an effective salt model building methodology which allows effective testing of many different salt interpretation scenarios. The new methodology takes advantage of the sensitivity of migration images to salt geometry changes. The efficient beam migration and practical interactive salt editing tools allow us to quickly test a large number of salt interpretation scenarios. The accuracy of RTM, especially in areas around and beneath salt bodies, makes it an effective tool for building good salt models.

The redatuming of the wavefield plays an important role in this methodology. Redatuming enables us to use a layer-stripping type of salt model building approach. For the interactive beam migration step, the redatuming is achieved by wave-equation based down-going migration and up going demigration; and for the layer-stripping RTM step, the redatuming is directly achieved in the shot domain. Data compression is a practical way to address the "data explosion" problem of 3D redatuming.

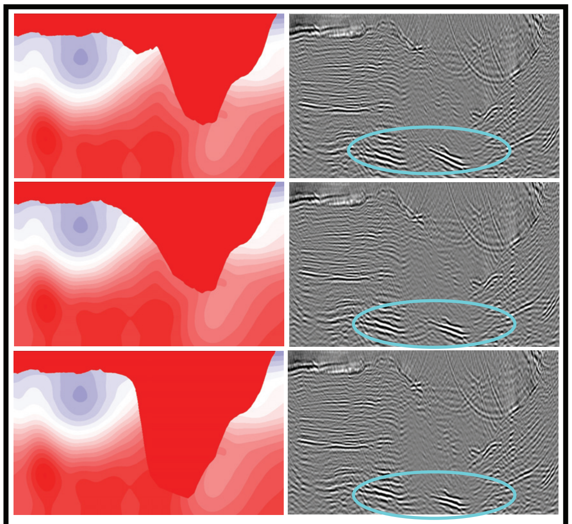

***Figure 6**: Left column shows different salt interpretations and velocity models; Right column shows the corresponding layer-stripping RTM images using the velocity models on the left.*

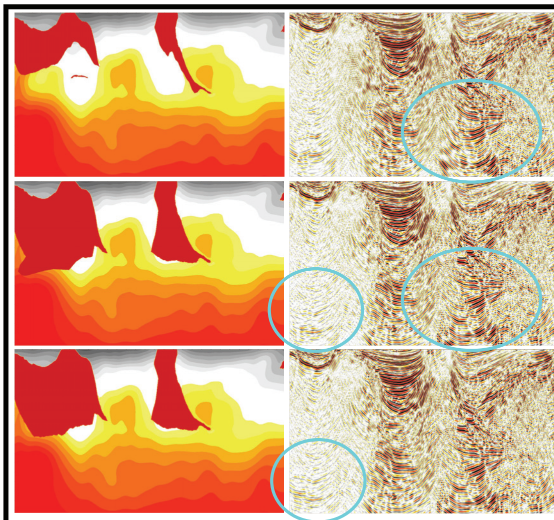

***Figure 7**: Left column shows different salt interpretations and velocity models; Right column shows the corresponding layer-stripping RTM images using the velocity models on the left.*

Acknowledgments

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