RTM technology for improved salt imaging in the Santos Basin, Brazil
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Summary

Reverse time migration (RTM) is now recognized as a powerful imaging tool. With its ability to account for rapid spatial variations in the velocity model and to utilize all wavefront information, RTM can produce superior images of the most complex structures. This is why RTM is frequently used to interpret salt structures in regions known to have complex salt geometries like the Gulf of Mexico. With the application of recent advancements such as Vector Offset Output and 3D angle gathers, the imaging capability of RTM is enhanced even further. In this paper we demonstrate that significant improvements result when advanced RTM tools are used for salt imaging even in the Santos Basin in offshore Brazil where the salt geology is relatively simple compared to the Gulf of Mexico.

Introduction

RTM is a pre-stack two-way wave equation depth migration which is recognized as being able to produce superior sub-salt images compared to other migration algorithms such as Kirchhoff, control beam migration (CBM) or one-way wave equation migration (Zhang et al., 2009; Etgen et al., 2009). Given the high accuracy of RTM, the sub-salt image quality is now limited by the accuracy of the velocity model which, in turn, is very sensitive to the definition of the salt body. For this reason, RTM is often employed not only for final migration but also for salt interpretation in regions where the salt geometry is complex and difficult to image (Reasnor, 2007; Buur and Kuhnel, 2008). An RTM image allows a more conclusive determination of the salt structure, and thereby improves the reliability of the velocity model and the final image.

In the case of the Santos Basin in offshore Brazil, RTM is typically used for final migration but is rarely used for salt interpretation. CBM is used instead (Huang et al., 2010b) because the salt geometry in Santos Basin is known to be mostly tabular and less complex than in areas like the Gulf of Mexico. This paper will show that even in the Santos Basin, there are areas where a CBM image does not allow conclusive determination of the salt structure. RTM technology can greatly improve the image in such areas leading to more reliable salt interpretation which is crucial to the quality of the final pre-salt image.

A recent advancement can separate the RTM image into Vector Offset Output (VOO) components illuminated from different directions (Xu, Q. et al., 2011). We show that the resulting improvement in the signal-to-noise ratio of poorly illuminated areas can be very useful for salt interpretation.

A comparison of CBM- and RTM-derived salt geometry

In the test area, a salt model interpreted purely from CBM images had already been built and showed the presence of steep salt flanks and overhangs. Figure 2a shows the CBM image of a line migrated using a second sediment flood model with a constant salt velocity inserted in the upper section of the salt overhang structures. At this stage of model building, the shallow parts of all salt overhangs have been defined and a migration with this model should image the salt structures underneath. However, the CBM image in Figure 2a contains a large number of migration swings that can mislead an interpreter. Figure 2b is a 35 Hz RTM image migrated using the same velocity model. This image reveals the salt structure with much greater clarity and was much easier to interpret.
The two independent salt interpretations derived from the CBM and RTM images were used to build two different salt flood models. Figure 3 compares these two velocity models overlaid on the RTM images migrated using each model. The RTM-based model in Figure 3b produces a clearer base of salt and subsalt image, confirming that the RTM-derived salt model is more accurate.

**RTM with Vector Offset Output (VOO) stacking**

Xu, Q. *et al.* (2011) proposed a technique to divide the RTM output of each shot into a number of tiles (typically 9) with each tile corresponding to a different vector offset range as measured from the shot location (Figure 4). Given the local geological structure, it is then possible to selectively combine migration outputs from only the vector offsets that contribute to the signal at a given location. This reduces signal contamination by noise from shots not contributing to the illumination of a particular area. Figure 5a shows an RTM image migrated using a salt-flood velocity model. In the highlighted region, the base is unclear and difficult to interpret. Local geology indicates that the base of salt at this location must be illuminated mainly by shots to its east. A partial stack that combines only the RTM outputs illuminated from the east (VOO tiles 1, 4 and 7) is shown in Figure 5b. The contribution by shots from other directions, which is almost all noise, is separated from the signal energy near the base of salt at this location. This VOO image of the base of salt is far easier to interpret.

**RTM 3D angle gathers for intra-salt tomography**

For intra-salt tomography, the information provided by CBM gathers is quite accurate where salt structures are simple and where continuous reflections from evaporite layers are available. In areas where the halite and evaporites are mixed or where the salt structure is complex, RTM produces a better image and its gathers should provide better residual move-out information for tomography. To compare intra-salt tomography from CBM and RTM gathers, a test area of about 400 km² containing regions of both layered and mixed salt was selected. The RTM gathers are 3D sub-surface common angle gathers (Xu, S. *et al.*, 2011) that contain both sub-surface azimuth and reflection angle information. Since the survey used in these tests is NAZ, the 0º azimuth gathers, contained the most information. Huang *et al.* (2010a) showed that these 0º azimuth gathers are still more reliable for velocity inversion than the commonly used 2D RTM sub-surface angle gathers (Sava and Fomel, 2003).

Two migration algorithms were applied using the same constant salt velocity model to output CBM surface offset gathers and RTM 3D sub-surface angle gathers. The CBM stack and gathers at a location with a mixture of halite and evaporites in the salt are shown in Figure 6a. Figure 6b shows the corresponding RTM stack and 0º azimuth gathers. The move-out is broken and inconsistent on the CBM gathers while it is clean and consistent on the RTM gathers. The CBM gathers have been muted to discard artifacts that are a result of events being focused at multiple depths near a large velocity contrast (Xu and Huang, 2007). RTM is free from such artifacts and its angle gathers do not require muting. The results of tomographic velocity inversion on the two sets of gathers were equivalent where the salt structure is simple and the salt has continuous evaporite layers. In complex areas, tomography on 3D RTM gathers provided a better velocity update. Figure 7 shows a comparison of intra-salt tomography results in an area where the salt is a mixture of halite and layered evaporites as shown in Figure 7a. Figure 7b, c and d are magnified, 25 Hz RTM images of the base of salt at this location. They were migrated with a constant salt velocity, salt velocity computed from CBM gathers, and salt velocity computed from RTM gathers respectively. On the RTM gather result, in Figure 7d, the base of salt is more continuous and the sub-salt sediments are more coherent.

![Figure 2: CBM image (top) and RTM image (bottom) migrated with a second sediment flood velocity model – a sediment model with constant salt velocity inserted in the colored sections. Arrows in (b) highlight areas of improved imaging with RTM](image-url)
RTM technology for salt imaging in Santos Basin

Figure 3: RTM images migrated and overlaid with independent salt interpretations based on the CBM image in Figure 2a (top) and the RTM image in Figure 2b (bottom). The RTM-based interpretation improves the image near the base of salt. Arrows in (a) and (b) indicate key areas where the interpretation is different. Circles highlight improved imaging in (b). Magnified views of the circled locations are shown above.

Figure 4: In an advanced application of RTM, the migrated output aperture of each shot is divided into nine tiles, each corresponding to a different Vector Offset Output (VOO) (Xu, Q. et al., 2011).

Figure 5: Full RTM stack (top) and partial RTM stack of VOO tiles 1, 4 and 7 (bottom) migrated with a salt-flood velocity model. The partial stack produces a cleaner image of the base of salt at this location.
Conclusions

Our work demonstrates that even though the geology in the Santos Basin is relatively simple, the accuracy of salt geometry definition and salt velocity can be significantly improved when RTM technology is employed in the model building phase. Compared to ray-based migrations, RTM produces superior images of salt structures which enables a reliable definition of salt geometry. In areas where poor illumination inhibits conclusive interpretation, RTM with selective VOO stacking can improve signal-to-noise ratio and aid interpretation. The information provided by 3D RTM angle gathers for intra-salt tomography ensures a more reliable salt velocity update and an improved image of complex salt. The combined result is a better salt model and, consequently, a better image of the pre-salt target.

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EDITED REFERENCES
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