Optimization of subsalt imaging

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SUMMARY

Successful subsalt imaging in the Gulf of Mexico depends critically on three aspects of the imaging process; the building of an accurate sediment velocity model, defining the geometry of the salt body or bodies, and successful application of 3D poststack and prestack depth migration algorithms. Even if the target subsalt dips are moderate, steep dip imaging is often necessary for defining the geometry of the salt bodies, parts of which may have significant dip. In addition, even though energy that propagates through salt may be dip-limited because of the sharp velocity contrast between sediment and salt, energy that propagates laterally from outside salt may also contribute to the flanks of subsalt reflectors with steep dip. In such areas careful processing to preserve dips is necessary, with the ultimate goal being a subsalt image that is as interpretable subsalt as it is outboard of salt. Here we discuss several techniques for optimizing steep-dip salt and subsalt imaging, including iterative prestack depth migration and velocity updating for sediment velocities, iterative prestack and poststack depth migrations for salt boundary definition, proper interpretation of the salt boundary, and optimal application of a Kirchhoff algorithm for final imaging. These techniques are illustrated with examples from an area of significant complexity in the Gulf of Mexico.

INTRODUCTION

Recent successes in oil exploration subsalt in the Gulf of Mexico have prompted a significant effort throughout the seismic industry towards detailed subsalt imaging. Because the presence of salt causes significant refraction, conversion, and dispersion of seismic energy, 3-D prestack and poststack depth migration have become tools of choice for accomplishing such imaging. Using these methods economically on a large scale, however, requires knowledge of their requirements and limitations when applied to imaging the geology of the Gulf.

Critical to any subsalt depth imaging is the creation of an accurate velocity model. For the Gulf, this consists of determining a sediment velocity field that in essence varies continuously, and determining the position of salt boundaries, often of steep dip, across which the velocity jumps by a factor of two or more. Hence, although much of the Gulf is thought of as having a relatively simple geology, significant complexity arises in the shape of the salt boundary, and in areas where the salt is broken, which may be highly dispersive with velocities intermediate between salt and sediment. Because of this salt complexity, velocity determination, mode conversion, multiples, and shadow zones all pose significant challenges for subsalt depth imaging.

Here we explore some of the factors that are important in obtaining a quality steep-dip subsalt image in the Gulf. Our primary goal is exploring those factors where expense and effort provide the most benefit to a subsalt image, and those where increased effort provides little benefit.

PRE-MIGRATION PROCESSING AND SEDIMENT VELOCITY BUILDING

Numerous methods for creating velocity models are known, including standard velocity analysis using the Dix equation, which essentially assumes a flat earth, and methods that take ray bending into account, such as ray-dependent generalized forms of the Dix equation and reflection tomography. Fortunately, a flat earth approximation holds for much of the sediment velocity field above and outside salt areas in the Gulf. Hence a careful time processing sequence yielding stacking velocities or DMO velocities gives a good starting model. Because of the continuous nature of the sediment interval velocity, a constant-gradient Dix formulation, as opposed to a block-constant formulation, works quite well.

For the example area, we performed conventional preprocessing, and applied a parabolic Radon transform to eliminate multiple energy. Initial stacking velocities were corrected for dip effects to give a starting model, and the velocity was updated following a standard Dix analysis of residual moveout on prestack migrated common-offset-bin gathers. Further details of the velocity model building process will be described elsewhere(Purnell et al, 1997). For the example area, velocity updating provided flat gathers over approximately 70% of the migration output area in one iteration of velocity analysis. Extension of the sediment velocity subsalt provided quite good subsalt imaging in many cases, despite the salt complexity.

SALT DEFINITION AND INTERPRETATION

Extension of a reasonable sediment velocity subsalt will fail, however, in final prestack imaging, if the salt body is not properly delineated and placed in the sediment field. The standard procedure is to perform poststack depth migration, pick top of salt, perform a salt flood under salt, another poststack migration to pick base of salt, and then to restore the sediment velocity subsalt for initial prestack imaging runs. This procedure is relatively fast because of the use of poststack migration. Where the salt surface is rugose, however, or has significant dip, approximations made in the stacking procedure, salt boundary placement errors in the velocity model, and dip limitations of poststack depth migration all conspire to produce areas where the salt is poorly imaged and difficult to pick. Figure 1 shows an example of this. Figure 1a shows a time migration of one of the salt bodies in the example area. The top, bottom, and right side of salt can be clearly seen, but the side of the salt, although quite clear, is imaged substantially to the left of its proper position. Figure 1b shows a poststack depth migration of the same feature, and although the positioning of the side of the salt is improved, it is still to the left of its proper position, and has a wavelet that is substantially widened with low wavenumber content, suggesting that it is imaging some distance inside the salt boundary in the velocity model. In such areas we have found it necessary to perform prestack migration to pick the salt. An initial prestack migration to image the salt was done with insufficient aperture, resulting in Figure 2a, where the right side of the salt is missing. Increasing the aperture, as described in the next section, yielded the result shown in Figure 2b, with the side and bottom of salt now clear, from which a significantly better salt interpretation could be made. In order to reduce cost, prestack migrations to determine salt geometry can be done in a window following the horizon surface, and only in areas where poststack imaging is of poor quality. Since the salt body represents the major portion of complexity in the model, and in areas may not be adequately imaged even with prestack migration, expertise in interpretation is required to properly pick it in many cases. For the example area, experts from a joint BP/BHP/Western team performed the interpretation (Purnell et al, 1997).

MIGRATION OPTIMIZATION AND FINAL IMAGING

The technique we used here to perform prestack migration was the Kirchhoff algorithm. Because of the computational expense of the algorithm, and its high frequency character, the choice of aperture and method of traveltime generation are factors of critical importance to economics of the process and quality of the image. Since much of the Gulf sediments are low dip, it is tempting to initially use insufficient apertures to reduce computational cost. Unfortunately, the result of insufficient aperture in imaging steep events is reduced amplitudes in the image at best, as seen in the image of the salt body in Figures 2a and 2b, and misleading dip information at worst. Figures 2a and 3a are both sections from the example area imaged initially with an aperture that cut off the dip at roughly 50 degrees. While in Figure 2a the right side of the salt body is essentially missing, in Figure 3a a substantial portion of the dipping events can be seen. The same section migrated with a 40,000 ft. maximum aperture that provided imaging to near 90 degrees is shown in Figure 3b. The increase in amplitudes is clearly evident, but the change in effective dip of the events is even more remarkable. Hence, imaged events with dip near the cutoff dip of the migration may have sufficient coherence to be visible, but should be regarded as possibly having incorrect dip. For the final volume output image of the example survey, it was necessary to maintain the large aperture for proper imaging.

In addition to aperture, the choice of traveltime generation algorithm can affect subsalt imaging. While numerous first-arrival techniques can be used to generate traveltimes (Audebert et al, 1994), we have found that subsalt imaging is enhanced in complex areas using maximum-energy raytrace techniques (Albertin et al, 1996). For final imaging, we have found the benefit of a maximum-energy wavefront construction technique (Vinje et al, 1992) to outweigh the additional cost over first arrival methods.

Substantial improvement in the final image may also be accomplished by post-migration processing on migrated gathers. Unfortunately this requires output gathers for a substantial portion of the output volume, which may increase the run time of the Kirchhoff algorithm. In this case, we felt the benefit outweighed the cost, and output gathers were obtained for the entire 6 GOM block volume output image. Once these gathers were obtained, muting of the gathers and residual velocity analysis subsalt could be performed to enhance the final stacked image.

Careful application of the techniques described above can be quite effective for subsalt imaging. Examples of the benefits of these techniques are not reproduced here, but will be shown at the oral presentation of this paper.

CONCLUSION

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We have described a number of techniques to optimize subsalt imaging. Determination of much of the sediment velocity field can be done with careful determination of stacking or DMO velocities as a starting model, followed by one or two iterations of prestack migration on sparse gathers or lines. Salt boundary determination can largely be done with poststack migration, but windowed prestack migration and interpretation knowledge can improve the result in areas where poststack migration has difficulty. Finally, use of wide apertures, and maximum-energy traveltimes for Kirchhoff migration, as well as residual velocity analysis can significantly enhance the results of steep-dip salt and subsalt imaging.

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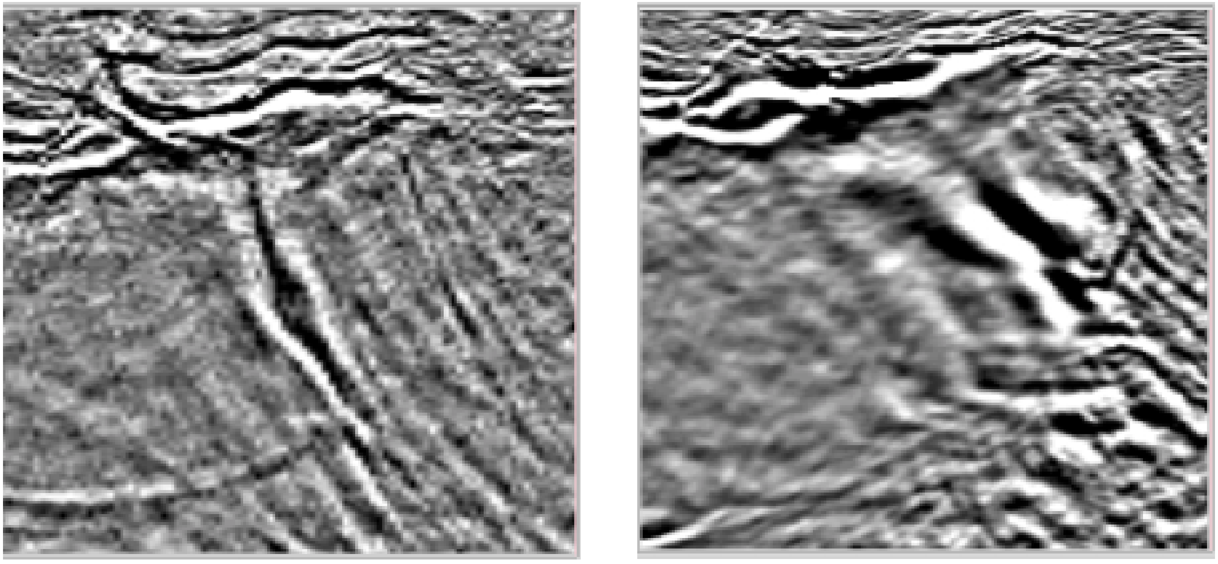
REFERENCES

Albertin, U. K., Cabrera, J., Chang, W., Fowler, P., Stankovic, G. and Ward, L., 1996, A comparison of Kirchhoff migration results for the SEG/EAGE salt model using several traveltime generators: 66th Ann. Mtg. Internat. Soc. Expl. Geophys., Expanded Abstracts, 662-666.

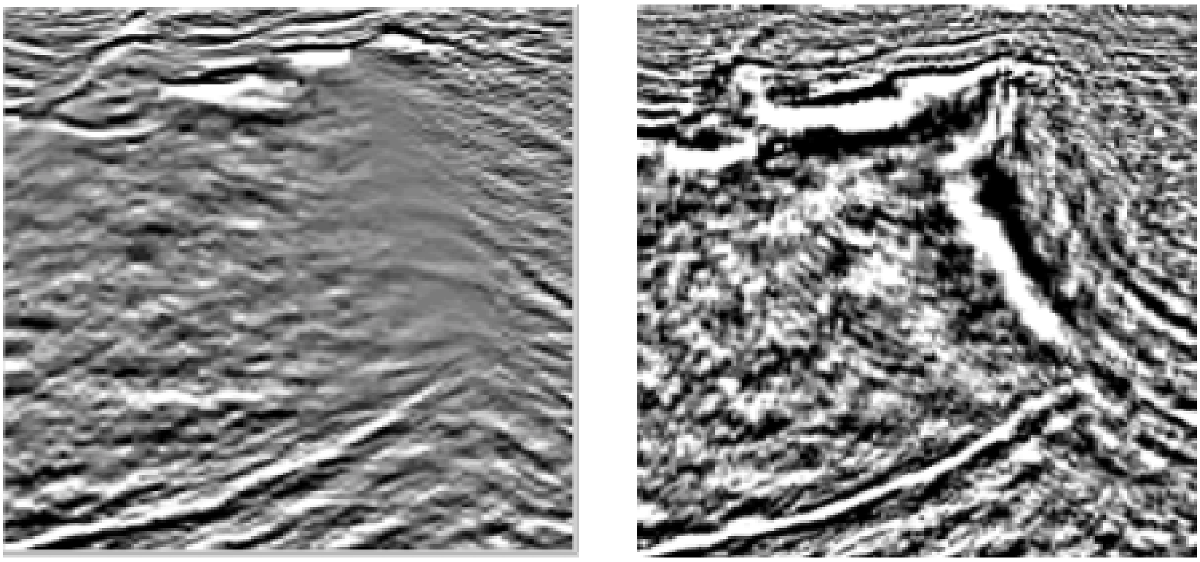
*Audebert, F., Biondo, B., Lumley, D., Nichols, D., Rekdal, T., and Urdaneta, H., 1994, Marmousi traveltime computation and imaging comparisons: Annual Report of the Stanford Exploration Project, **80**, 47-66.*

Purnell, N., Inman, K., Leary, T., Grubitz, G., Albertin, U., Kapoor, S. J., and Chang, W., 1997, Fast track 3D pre-stack depth migration of the Neptune structure, offshore Gulf of Mexico: Submitted to the 67th Ann. Mtg. Internat. Soc. Expl. Geophys.

Vinje, V., Iverson, E. and Goystdal, H., 1992, Traveltime and amplitude estimation using wavefront construction: 54th Ann. Internat. Mtg., EAEG, Expanded Abstracts, 504-505.



Figures 1a-b. Figure 1a is a time migration of the salt structure. Top, bottom, and side of the salt are all clear, but the side is severely mispositioned. Figure 1b is a poststack migration of the same feature. The side is now closer to its correct position, but is poorly imaged.



Figures 2a-b. Figure 2a is a prestack depth migration with insufficient aperture. The top and base are well imaged, but the side is absent. Figure 2b is a prestack migration with aperture sufficient to image vertical events. Top, base and side of salt are now clear.

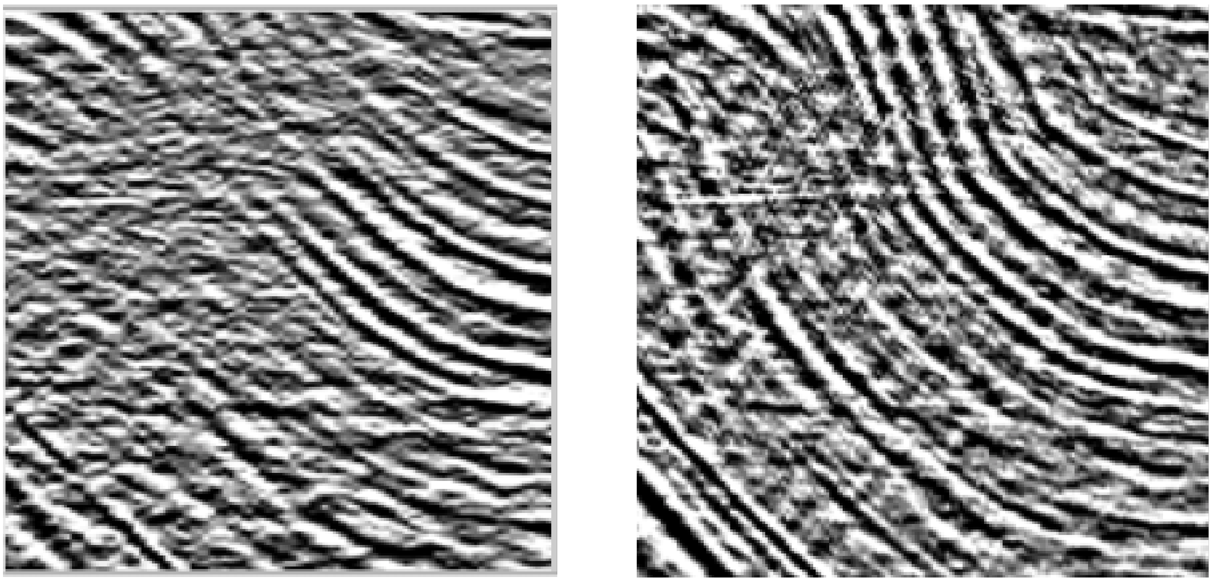


Figure 3a-b. Figure 3a shows a prestack migration run with an aperture that limited the dip to 50 degrees. Figure 3b shows the same area migrated with an aperture providing dip to 90 degrees. The false dip seen in Figure 3a is striking.