Multiples attenuation using WAZ data in VTI anisotropic media.

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Summary

The work presented here illustrates the advantages of multiple attenuation when migrating wide-azimuth (WAZ) data rather than narrow-azimuth (NAZ) data. The multiple attenuation is demonstrated through a 3D anisotropic wave simulation and anisotropic Reverse time migration (RTM) of a salt related model case typical of the Gulf of Mexico (GOM) geology. The process includes construction of an anisotropic model followed by VTI wave equation simulation done with free-surface boundary condition for recording of surface related multiples. One of the advantages of using a WAZ dataset for multiple attenuation is the fact that in this case the multiples are better spatially sampled than in the case of NAZ dataset. Of particular interest is not only in the influence of the input data (i.e. the specific type of WAZ dataset) but also the influence of the techniques used for the depth imaging. We investigate how the process of the multiple attenuation works when the geological model is anisotropic (Vertically Transversely Isotropy) rather than isotropic, and how prestack RTM handles the free-surface generated multiples.

Our conclusion is that depth migration of a WAZ dataset strongly attenuates multiples, and at the same time the use of prestack RTM can help in attenuation of multiples even when a NAZ dataset is used.

Introduction

The poor illumination of the GOM subsalt structures and the noise generated by the migration of multiples in the lower illumination areas is one of the major difficulties in obtaining correct depth migrated images underneath salt bodies. In the past few years numerous publications documented the advantages of WAZ dataset as input to prestack depth migration for imaging subsalt structures (Lewis & al. 2007; Corcoran & al. 2007; Kappor & al. 2008).

A key reason why WAZ datasets attenuate multiples better than NAZ datasets is because of the increased sampling of the multiples in the CMP-time-offset domain. The sampling results in cancellation of multiple energy during prestack depth migration. Most of the publications showing this phenomena use isotropic wave propagation and isotropic prestack depth migration. The focus of this work is to investigate if the increased sampling of multiple energy in the offset domain is valid when the acquired WAZ data is done in the VTI anisotropic media.

Lewis & al. 2007 shows how the multiples are aliased in the case of the NAZ data and goes through a 2½D model to illustrate the fact that WAZ data results with better depth imaging than NAZ data. In our case we kept the same idea of using a 2½D model but have included the anisotropy on the 3D forward modeling and have used reverse time migration for the depth imaging.

It is well known that anisotropy modifies the NMO velocity as shown by Eq. 1 (Thomsen 1986).

$$\boldsymbol{V_{NMO}} = \boldsymbol{V}\sqrt{1+2\boldsymbol{\delta}} \text{ where V is vertical velocity} \quad \text{Eq. 1}$$

For positives values of δ the NMO velocity is higher. The motivation to introduce VTI on our forward modeling is to see if the WAZ data show an aliasing of multiples in the CMP time-offset domain. If this is the case, then what is the impact on the depth migration?

According to Zhou & al. 2006, the forward modeling for the VTI media (Eq. 2) is viewed as the propagation of two quantities p and q, where p being the “acoustic” wavefield and q is an auxiliary variable depending on p and used to simplify the solution of the partial differential equations used of wave propagation.

$$\left[2(\boldsymbol{\varepsilon}-\boldsymbol{\delta})\left(\frac{\partial^2}{\partial \boldsymbol{x}^2}+\frac{\partial^2}{\partial \boldsymbol{y}^2}\right)(\boldsymbol{p}+\boldsymbol{q})\right]=\frac{\boldsymbol{1}}{\boldsymbol{v}^2}\frac{\partial^2}{\partial \boldsymbol{t}^2}\boldsymbol{q}$$

$$\left[(1+2\boldsymbol{\delta})\left(\frac{\partial^2}{\partial \boldsymbol{x}^2}+\frac{\partial^2}{\partial \boldsymbol{y}^2}\right)(\boldsymbol{p}+\boldsymbol{q})+\frac{\partial^2}{\partial \boldsymbol{z}^2}\boldsymbol{p}\right]=\frac{\boldsymbol{1}}{\boldsymbol{v}^2}\frac{\partial^2}{\partial \boldsymbol{t}^2}\boldsymbol{p} \quad \text{Eq. 2}$$

For δ values being equal or greater than ε, the VTI wave propagations can result with instabilities since it generates waves increasing exponentially with time (Grechka & al. 2004).

As a technique that handles naturally the full (i.e. two-way) wave propagation, RTM offers a great advantage. It migrates the primaries and as well it migrates the multiples. If we want to correctly demonstrate the influence of the input data only, we have to use a migration operator that is the closest possible to the full wave propagation.

Method

This work is based on a typical GOM salt related geological model (Fig. 1) consisting of vertical velocity and two anisotropic parameters, δ and ε fields. The model is 2½D and contains a water layer (4900 ft/sec) two salt bodies (14800 ft/sec) and sedimentary layers with velocities varying from 5200 ft/sec to 13200 ft/sec. For δ and ε, we have considered a simpler model (Fig. 2). Starting at the water bottom, ε equals 7% (δ = 5%) and around 17000 ft depth its value increases up to 20% and (15% for δ).

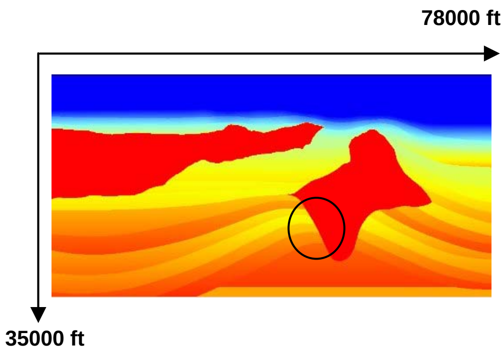

Fig.1: Velocity model used to simulate WAZ data. The velocity values range from 4900 ft/sec for the water (blue) to 14800 ft/sec for the salt (red). The encircled area represents a particular interest for depth imaging. The correct image over this area depends on the accuracy of the migration operator when crossing two salt bodies.

The depth imaging of the circled area is interesting because the forward propagation and backward propagation have to cross the two salt bodies before migrating to the correct location. Furthermore, low illumination and top and base salt multiples make the imaging of this area very difficult.

The modeling and RTM use a high order finite differences scheme that has an accuracy close to spectral methods. In order to avoid the computation artifacts in the areas where the medium change from isotropic to anisotropic (water-sediment or salt-sediment) we have smoothed both ε and δ volumes using a 4 point operator.

Using marine acquisition geometry, we have modeled 460 shots with a shot interval of 160 ft. Each shot has 83 streamers spaced by 160 ft and each streamer contains 328 receivers with a receiver interval of 80 ft. The minimum offset in the X (Xline) direction is 40 m and its maximum value is 29380 ft. Along Y (Inline) direction, the minimal offset is 0 and its maximum value is 13120 ft. Fig.3 shows a map of the fold in the CMP domain and a layout of the 83 streamers for shot no. 100. In order to construct a simulated dataset that resembles real data, the source signal used is a second order, 30 Hz Ricker wavelet. The total recording time is 12 sec using sample rate 8 ms.

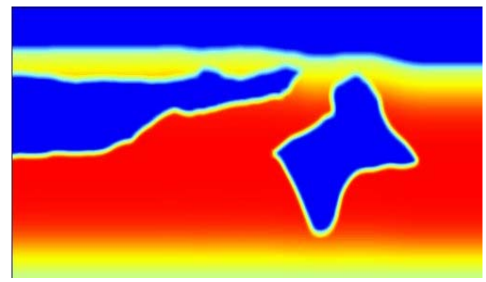

Fig. 2: A smooth variation of δ (5% - 15%) and ε (7% - 20%), following the water bottom geometry, has been included on the modeling in order to simulate a VTI media. The blue area (salt and water) are isotropic media.

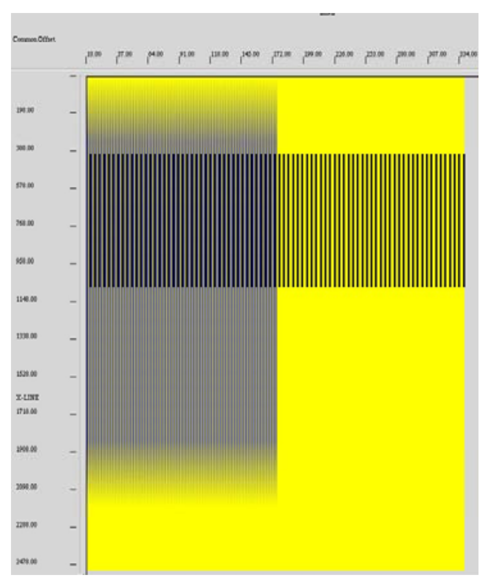

Fig. 3: The fold map CMP-offset of the acquisition used for the modeling. Each shot contains 83 streamers (black lines) and 328 receivers per streamer covering a surface of 29380 ft by 13120 ft.

The objective of this work is to demonstrate the ability of using WAZ recorded data to attenuate artifacts generated by the multiple. Therefore, multiple removal processing (such as SRME) was not applied to the data prior to migration. The NAZ dataset has been limited to three cables meaning a maximal offset in Y direction of 320 ft. In the study four sets of prestack RTM were run: two using both WAZ and NAZ datasets with an **absorbing** water surface and two using both WAZ and NAZ datasets and with a **reflecting** free surface.

Since the model used for studying 3D modeling and migration phenomena of WAZ and NAZ datasets is 2½D, instead of migrating a large swath of shots (460 x 350 total) to a single output line, we have migrated a line of shots (460 shots) to a 3D volume (2500 Xlines x 350 Inlines) then stacked all the migrated inlines to a single line. In the 2½D case it can easily be demonstrated that migrating multiple 2D swaths of shots and receivers and outputting a single line is equivalent to migrating a single line of shots over a 3D volume and stacking the results to a single inline. It is much more cost effective to migrate a single line of shots than multiple 2D swaths.

Fig. 4 shows the RTM depth section of the NAZ (i.e. 3 streamers) dataset. One can observe a good imaging of the top and base of the upper salt body but the lower part of the second one is missing. The base of the salt on the right side (A) and the sediments in this area are missing. The problem relates more to illumination rather than noise caused by multiples. The WAZ results (Fig. 5) shows almost the same imaging issues in this area.

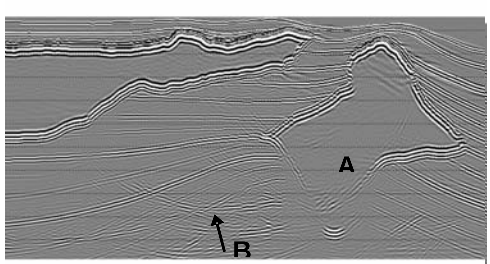

Fig. 4: Reverse time migration of the NAZ dataset. The right side if the lower salt body (A) is not imaged due to low illumination in this area. The termination of the reflectors against the flank of salt (B) is completely lost due to the multiple artifacts migrated in this area.

The left side of the base salt (B) shows clearly the strength of the multiples and their effects on the migration. This noise completely overpowers the imaging around the base salt.

Figure 5 shows a very different image of the base salt. The multiple noise is still there but much more effectively attenuated. The sediments terminate at the correct location and they show clearly the position of the base salt. The base salt itself is better imaged than in the previous case. This is related to the fact that in the case of the WAZ migration 27 times (83 cables vs. 3 cables) more data was used than in the case of the NAZ migration.

Both migrations shown in Fig. 4 and 5 do not allow the wavefield to reflect at the water surface, so the operator does not generate free-surface multiples. Using the option to reflect or absorb at the free-surface has an advantage and an inconvenience. When the RTM operator reflects at the free-surface like in modeling, we observe the primaries migrating to a shallower depth since the primary energy correlates at the real reflector due to direct wavepath and above the reflector due to the free-surface reflected wavepath. However the multiples are going to migrate deeper due to direct wavepath and at the reflector due the free-surface reflected wavepath.

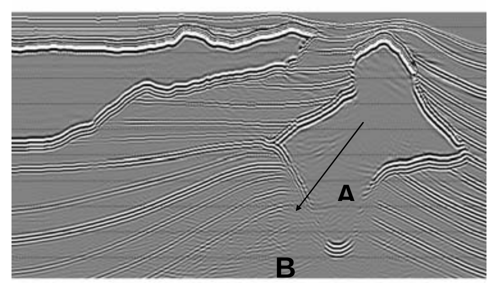

Fig. 5: Reverse time migration of the WAZ data. Comparing to Fig. 4, one can notice that the base of salt on the right side (A) is a migrated a little bit better but the illumination problem remains unsolved for the reflectors. The artifacts generated by the multiples have been strongly attenuated (B) and we can see now a clear termination of the sediments against the salt body.

If the RTM operator does not reflect at the free-surface, the primaries migrate at their location but we loose the advantage of migrating the multiples energy back to the reflectors. The image shown in figure 6 clearly supports this argument. This figure shows the migration of the NAZ dataset with an operator that reflects at the free-surface. One can see that in general the image is noisier than the image shown in figure 4 but at the target area, the operator allows an image that can be very close to the images obtained using the WAZ data.

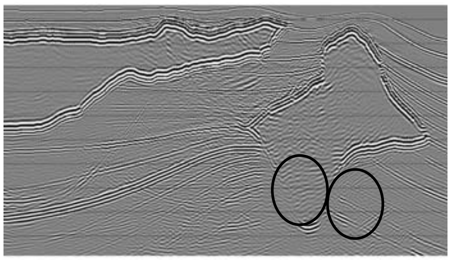

Fig. 6: Reverse time migration of t NAZ data with a migration operator that reflects at the free surface. We can see that the operator bring different noise but allow a better imaging of the reflectors at the target.

The Fig. 7 summarizes three results: RTM of the NAZ dataset, with and without free-surface reflection and RTM of the WAZ dataset. We can clearly observe that the image produced using the WAZ dataset is better focused on each side of the salt, and as well the sediments terminations.

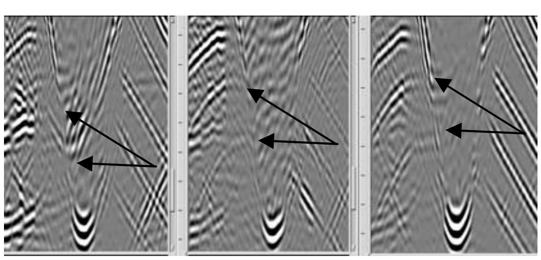

Fig. 7: This figure shows an enlarged view of the depth migration around the base of salt using (A) NAZ dataset and no free surface reflections on the RTM, (B) NAZ dataset and free surface reflections on the RTM and (C) WAZ dataset and no free surface reflections on the RTM.
The terminations of the reflectors (marked by the arrows) is much better migrated with WAZ dataset and we can see that even with NAZ dataset the migration with an operator reflecting at the free surface allows to better imaging of the target.

Conclusions

This work demonstrates that the use of WAZ data as a natural way to remove the multiples' artifacts remains true even in the case of VTI media. The imaging condition used on the RTM does not allow to completely remove the multiples artifacts. Since its operator back propagates correctly multiples and primaries energy, the RTM remains the only technique that can overcome the challenges of correct subsalt imaging. Considering the free-surface as reflecting rather than absorbing allows the multiples to contribute positively to the primary imaging.

Acknowledgments

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EDITED REFERENCES

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