Interpretation of Sub-Salt Converted Waves

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Summary

Despite improvements in 3-D imaging capabilities through the use of Pre-stack Depth Migration (PreSDM), interpretation of the resultant images in the areas of complex salt bodies is confused by additional events that are not primary PP reflections. This paper analyzes the results of seismic imaging underneath steeply dipping salt flanks using real and synthetic datasets. Based on real data problems, imaging of acoustic and elastic synthetic data sets show that some of the sub-salt sedimentary section may include converted waves. A practical way to correctly image these sub-salt converted waves is introduced.

Introduction

Sub-salt imaging is one of the most important tasks of oil and gas exploration in the Gulf Of Mexico (GOM) today. Accurate sub-salt seismic images are crucial for a successful exploration program. Although imaging technology is regularly improving, there is still room for enhancement of sub-salt imaging and interpretation, especially beneath steep dip salt flanks.

In most cases 3-D PreSDM images are used to interpret sub-salt sedimentary structures. This technique assumes that the seismic data consist of primary pressure reflections. This is not always the case. In areas of low illumination, the seismic images may include migration artifacts. Some of the sub-salt reflections may also include some sort of converted waves (Purnell, 1992, Wu et al., 2001). In this paper one type of converted wave is modelled and shown how these waves are imaged in the sub-salt section. The waves are converted at the top of salt interface (TOS) from pressure (P-waves) to shear waves (S-waves). The converted waves travel through the salt as shear waves and are converted back to P-wave at the TOS interface on the way to the surface.

The Problem

PreSDM is normally applied to provide improved interpretability of the subsalt sedimentary section. Base of salt (BOS) and the sub-salt dips are not positioned correctly on time migrated seismic data (figure 1) due to the large velocity contrast between the fast salt velocity and the surrounding sediments, and due to the irregularity of the salt bodies. In order to correctly image the sub-salt section we need to create a velocity model that describes the salt body and the sedimentary velocity field and then apply depth migration (figure 2). In most cases the salt image as well as the sub-salt image is improved. However, in some cases, we observe that the sub-salt sedimentary dips close to the salt body are not correct, although the base of salt image is correct. What can be the reason for the wrong sub-salt image close to the salt body ?

The Geological Model

In order to closely examine the sedimentary sub-salt image a geological model that resembles a typical GOM sub-salt cross section (figure 3) was created.

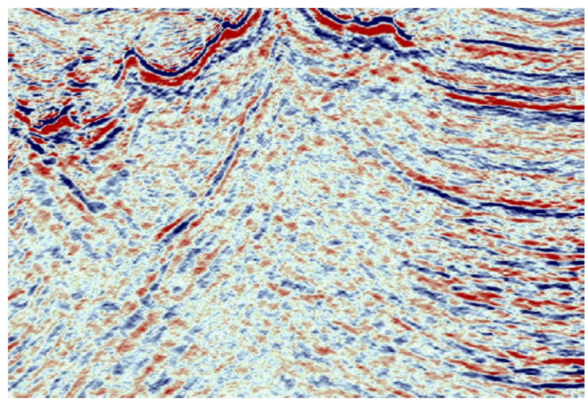

Figure 1: Time migrated section. The base of salt is under migrated, and the sub-salt sediments are dipping upwards. Data courtesy of PGS/Diamond Geophysical.

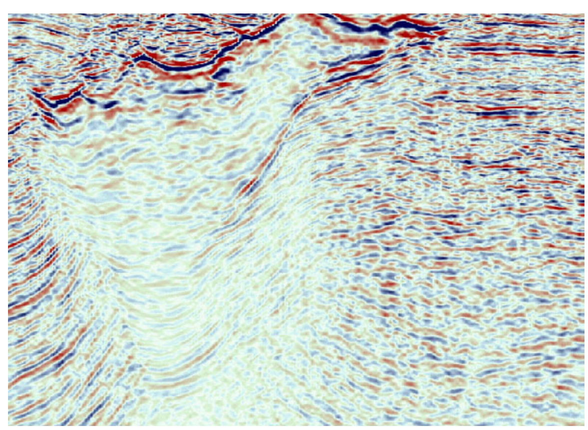

Figure 2: Pre-stack depth migrated section. The base of salt is migrated correctly, but the sub-salt sediment image is questionable. Original data courtesy of PGS/Diamond Geophysical.

Interpretation of Sub-Salt Converted Waves

This model was used to create a synthetic dataset which was then processed and imaged in order to investigate the sub-salt sedimentary image. Normally seismic data is processed and imaged assuming that the wave-field contains P-waves only. In order to simulate a more realistic case, acoustic and elastic simulation were used for modeling (figures 4, 5) with both acoustic and elastic datasets being computed. Both data sets were processed assuming P-waves only.

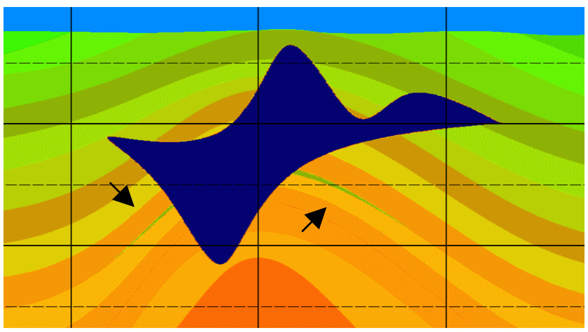

Figure 3: Gulf Of Mexico geological model. Two sand bodies are located underneath the steeply dipping salt flanks.

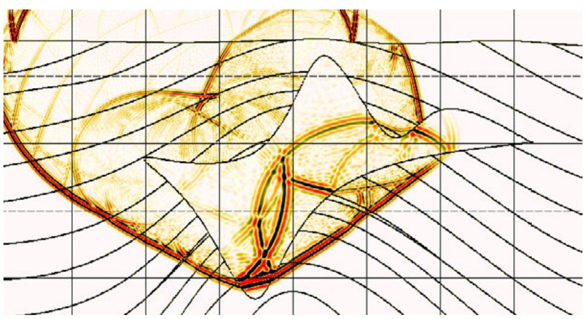

Figure 4: Acoustic wave simulation. High order approximation of the acoustic wave equation is used for modeling. Only pressure waves are propagated.

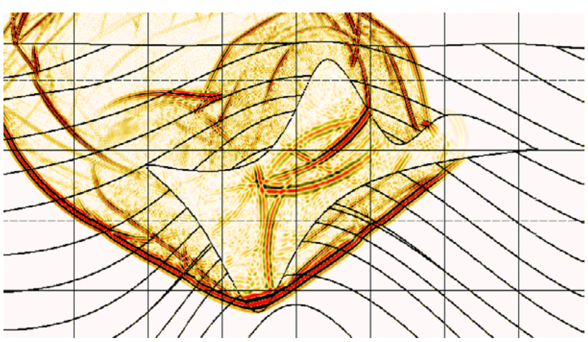

Figure 5: Elastic wave simulation. High order approximation of the elastic wave equation is used for modeling. Both pressure and shear waves are propagated.

Analyzing both datasets gave the opportunity to learn if some of the sub-salt section that is normally interpreted as a primary or pressure wave-field contains converted waves.

Processing and Imaging

Two datasets (one acoustic and one elastic) were generated using the geological model shown in figure 3. A basic time processing sequence was applied in order to prepare the data for depth migration. Using the exact model, PreSDM was applied producing a depth migrated section (figures 6, 7). The differences between the acoustic and elastic images were closely examined.

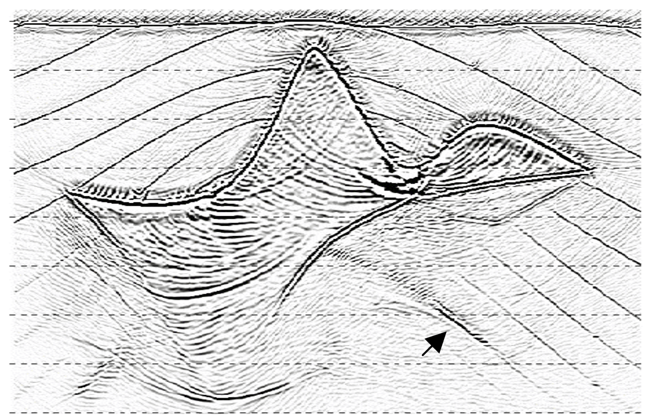

Figure 6: Pre-stack depth migration result of the acoustic dataset. A Kirchhoff summation algorithm using maximum energy was used for travel-time calculation.

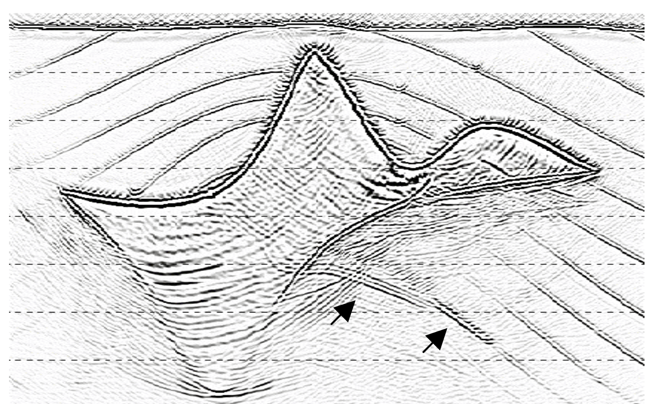

Figure 7: Pre-stack depth migration result of the elastic dataset. The same model that was used to migrate the acoustic dataset was used to migrate the elastic dataset. A strong sub-salt reflection is evident on this image.

As expected from analyzing real datasets, two typical problems can be seen on the PreSDM results of both the acoustic and elastic modeled data. One is the degradation of the image of the steep flanks of the salt body, and the other is the low illumination area underneath the salt flanks. However a clear difference is apparent between the two depth sections. A much stronger and more continuous reflection from the low velocity sub-salt sand layer can be seen on the elastic dataset depth section. On both sections we can identify the sub-salt high amplitude sand layer reflections. On the PreSDM results of the elastic model however (figure 7), this reflection is broken into two segments. Since this reflection does not exist on the acoustic result (figure 6) it is probably a wave that was converted from pressure to shear when propagating through the salt body.

Imaging of the Sub-Salt Section

Careful analysis of wave propagation underneath the salt body revealed the following observations:

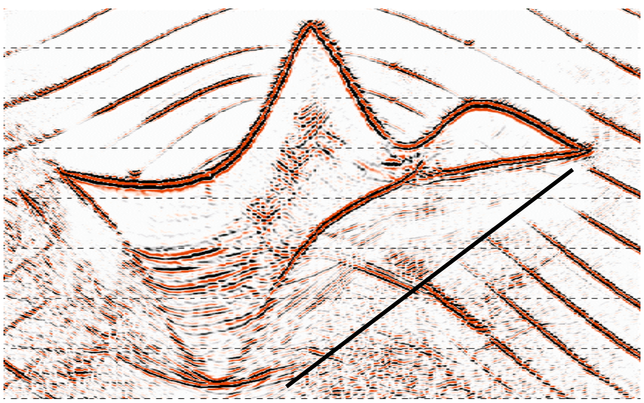

Figure 8: Pre-stack depth migration result of the elastic dataset. The salt velocity used in migration was the P-wave velocity.

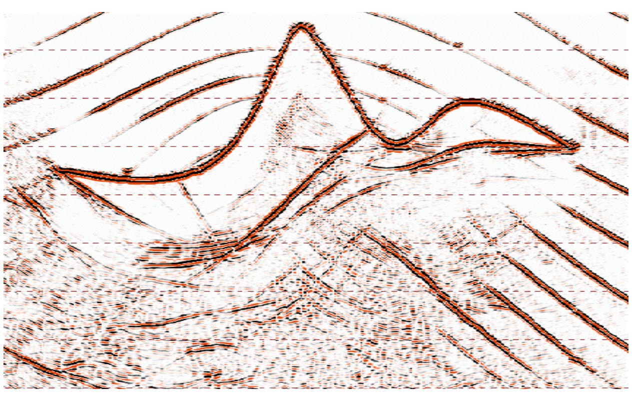

Figure 9: Pre-stack depth migration result of the elastic dataset. The salt velocity used in migration was the S-wave velocity.

The sub-salt sedimentary section was imaged from two different directions (see separation line on figure 8). A segment of the sub-salt sediments was migrated to its true position without propagating through the salt body. The dip of these sediments in the migrated images is correct. Another segment of the sub-salt sediments was migrated through the salt body. These are not P-waves, but converted waves that propagated as S-waves inside the salt body. These waves are over-migrated since they were migrated with the faster pressure salt velocity rather than the slower salt shear velocity. Is there a way to resolve the wrong sub-salt image? Yes, we can replace the fast P-wave salt velocity by the slower S-wave salt velocity and migrate the data again (figure 9). Now the sub-salt converted waves are migrated with pressure velocity outside the salt, and with shear velocity inside the salt. The base of salt is under-migrated, but the sub-salt converted waves are migrated correctly.

Conclusions

The initial purpose of this study was to analyze sub-salt converted waves. As a result we discovered that analysis of sub-salt converted waves can help in explaining 'wrong' sub-salt dips. During interpretation we normally assume that all reflections consist of primary pressure waves. The large impedance contrast between salt and sediment can result in mode conversion of seismic waves.

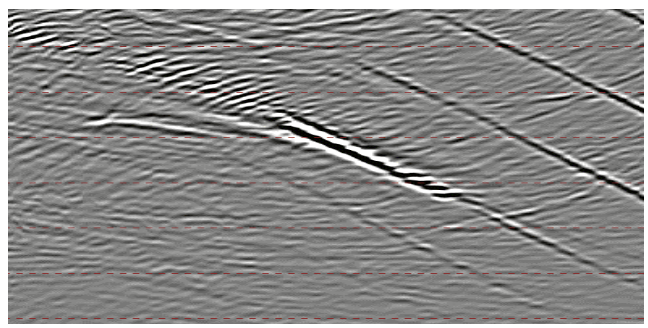

Figure 10: Target sand layer image using pressure waves only.

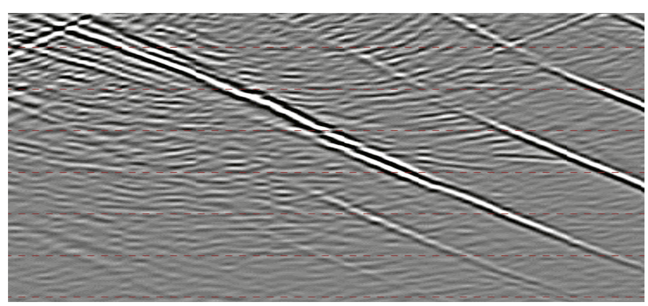

Figure 11: Target sand layer image using pressure and shear waves.

Converted waves travel in the sub-surface along a different path than the primary pressure waves. If the earth is treated as an elastic medium rather than an acoustic one (figures 10, 11), then a better understanding of the differences between seismic images and a geological interpretation can be obtained. Deriving a more correct interpretation from seismic data requires that appropriate attention be paid to the migration of converted mode events. Seismic modeling plays an essential role in this process.

Acknowledgement

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References

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Wu R., Guan H., and Wu X, 2001, Imaging steep sub-salt structures using converted wave paths, *Expanded Abstracts of the Technical Program*, SEG *71th Annual Meeting*, 845-848.