Subsalt Imaging in Coatzacoalcos, Mexico, Using Two-pass 3-D Prestack Depth Imaging

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SUMMARY

We describe the application of two-pass 3-D prestack depth imaging to a small 3-D seismic data volume from offshore Coatzacoalcos, Ver., Mexico. The main purpose of the study was to investigate the possibilities of our approach as a useful interpretation and velocity model building tool for accurate depth imaging of the area, which is dominated by salt tectonics. Two-pass 3-D prestack depth imaging was very efficient regarding turnaround time and, most importantly, it provided a significant imaging improvement over previous poststack time and depth migrations. We find that a thick salt body interpretation is more consistent with velocity analyses results than a previous interpretation based on the idea of a thin sill.

INTRODUCTION

Subsalt depth imaging can be one of the most challenging seismic imaging problems, especially when the salt mass has a particularly complicated shape and the velocity contrast between the salt and its surrounding sediments is large (a ratio of 1.5:1 or larger). In these cases, it is reasonable to assume that any approximate imaging method may produce significant mispositioning below salt, or may fail at imaging altogether.

However, one-pass 3-D prestack depth migration can be an unsatisfactory tool for iterative imaging and velocity model building. This is primarily due to the excessive computational and data manipulation demands of 3-D prestack depth migration, and the strain that those demands place on present-day technologies for computer processing and seismic interpretation. Multiple iterations of 3-D prestack depth migration can be excessively costly and time-consuming. Compromises may be introduced into the project to reduce its cost and duration, but these shortcuts may compromise the quality and accuracy of the final result.

A common attempt to reduce the cost of 3-D prestack depth migration has been to use a velocity model derived by iterative 3-D poststack depth migration. Because of the limitation of the poststack method, this approach can fail. CMP stacking and DMO stacking are the most severe approximations commonly applied in seismic processing. Their applications risk destroying any subsalt information in the seismic data, making interpretations based on poststack imaging highly ambiguous. Furthermore, stacking eliminates the opportunity to perform offset-independent migration velocity analysis, an important tool in complex structural imaging.

In the following case history, we used two-pass 3-D prestack depth imaging as an interpretation and velocity model building tool for subsalt imaging offshore Coatzacoalcos, Mexico. We used the "two-step" method: direct splitting of the Kirchhoff operator as described in Devaux, et al. (1996). This is a different two-pass implementation than that described by Canning and Gardner (1996), but the underlying principles of the two methods are the same: cross-line prestack time migration followed by in-line prestack depth migration.

Although two-pass methods are an approximation to one-pass 3-D depth migration, two-step imaging proved to be well suited for this project. By using this method for depth imaging and migration velocity analysis, we were able to resolve the structure of the salt body and produce a 3-D velocity model of the survey area. The 3-D velocity model is suitable for a variety of uses, including one-pass 3-D prestack depth migration. We used the derived velocity model to complete two-pass prestack imaging of 60 additional in-lines through the survey region.

PROJECT BACKGROUND

The area is located north-northeast offshore Coatzacoalcos, Mexico. It belongs to an extension towards the oceans of "Cuenca Salina del Istmo" (Saline basin of the Isthmus). In general, it is characterized by a sand-shale sequence from the Middle–Upper Tertiary period, with a maximum thickness of 14 km. The salt body of interest is considered allochthonous, introduced in between sediments of the Lower to Middle Miocene by buoyant salt diapirism. It is probable that the allochthonous salt is of Triassic/Jurassic age. Tertiary sediments above the salt are constituted by clays (recent), fine grain sandstones, shale and sandstones, and shales (Upper-Middle Miocene). The sediments of interest are below the salt body, and include an alternating sequence of shales and fine to medium grain sandstones, including some thin layers of green bentonite and volcanic ashes. This Lower Miocene formation is potentially an economic target.

This project was undertaken as a test of the two-pass method for imaging beneath complicated salt bodies in the Coatzacoalcos region. A subset of the full survey was selected covering an area of 10 km (In-line) by 5 km (Cross-line), with the purpose of obtaining a better understanding of the morphology of a salt body and to clarify the reflection events below it. This subset represented approximately 60 GB of prestack, CMP ordered traces with all the necessary preprocessing applied to it .

This survey had previously been subjected to poststack time and depth migration, but the results were ambiguous for the base of the salt body in the subset. Figures 1 and 2 show results of two-pass 3-D prestack depth imaging of survey line 1351 using two alternative interpretations of the salt: a thin sill that was the result of a previous conception derived from 3-D time and depth poststack migrations, and a thick mass alternative, proposed after obtaining some preliminary results of this study.

DEPTH IMAGING

The operation sequence for this project was as follows: cross-line Kirchhoff time migration followed by iterative 2-D prestack depth migration and the velocity model building for 10 in-line sections in the survey; interpolation of a laterally consistent 3-D model from the 10 2-D in-line models, and cross-line time migration followed by in-line 2-D prestack depth migration for 60 in-field in-lines within the survey area. During cross-line migrations the offset content of the data was binned to 400 m increments.

Cross-line migration aperture

Before embarking on the above processing sequence we felt it was necessary to test various apertures for the cross-line migration. Initially, we tested cross-line aperture as small as 250 m, but we later concentrated on apertures of 1000, 1500 and 2000 m. Generally, the top of salt seemed well-imaged in all cases above 1000 m, but the base of salt showed improvements for the apertures of 1500 and 2000 m. The same held true for the subsalt reflections. In addition to these tests, we also tried an aperture of 4000 m. We could not distinguish any significant differences between the 4000 and 2000 m apertures. Because of this, we used a cross-line migration aperture of 2000 m.

Our initial worry in conducting these cross-line aperture tests was that the mispositioning, due to the time migration operator used during cross-line migration, would cause excessive loss of reflector energy in the subsalt region for large cross-line apertures. But our conclusions afterwards were that (1) moderately large cross-line apertures were necessary for proper imaging of the top of salt, and (2) small cross-line aperture were sometimes insufficient for cancelling out sideswipe energy in our in-lines.

Iterative in-line depth migration and model building

Using cross-line migration, ten in-lines were constructed across the survey area at a spacing of 500 m. These in-line data were then used for 2-D imaging, velocity analyses and model building.

We initially tried to build a velocity model by prestack picking and tomographic inversion using the Sirius Tomopack software. However, we were unable to construct robust, laterally consistent models above the salt using tomography alone. Therefore, we abandoned this approach.

Using migration focusing panels and differential moveout analyses, we were able to achieve excellent results for the top of salt using vertical velocity gradients with an initial velocity that varied modestly throughout the survey area.

After imaging the top of salt in all ten lines, we performed salt velocity flood migrations to image the base of salt. As noted earlier, picking the base of salt on the resulting images was not always an unambiguous activity. Fortunately, migration velocity analyses provided substantial evidence as to the nature of the base of salt geometry.

Figure 3 depicts line 1351 showing the location of the focusing analyses used to fine tune the interval velocity field. The black line at CDP 2440 indicates the location undergoing velocity analyses. Figure 4 shows three focusing panels and migration moveout windows for this location. The white lines on the focusing panels indicate various depth error picks associated with this particular migration.

The depth error picks shown in Figure 4 approximately follow the middle of the panel. The vertical line down the middle of the panel represents a depth error of zero, which is associated with the velocity used for the migration. Notice that for the panels on the left and right, we have picked negative and positive depth focusing errors, respectively. These picks would indicate velocities below the top of the salt that were lower or higher than 4500 m/s, the actual velocity used.

As Figure 4b shows, a large focusing bull's eye lies near the zero depth error axis at a depth of 4600 m, indicating that 4500 m/s is, in fact, the correct migration velocity from the top of the salt down to this depth. The associated migration moveout gathers strongly substantiate this interpretation. The gather on the left (Figure 4a) shows an overcorrection, which indicates a velocity lower than the correct velocity, and the gather on the right (Figure 4c) shows an undercorrection, denoting a velocity that is too high.

On some of the other in-line sections, the migrated image alone more clearly supports our interpretation of a thick salt body and may also show intriguing structures beneath the salt.

3-D model building and in-field migrations

After making our final interpretations of our ten reference in-lines, we used a 3-D model builder to reconcile our ten 2-D interpretations, generate a 3-D structural model, and define a 3-D velocity grid. Next, we used the 3-D grid to produce 60 in-fill lines across the survey with 75 m line spacing. Each in-line prestack depth migration required about 20 minutes to run on GTRI's NEC SX-4 supercomputer.

CONCLUSIONS

This study represents the first attempt to do 3-D prestack imaging in the Coatzacoalcos area using a two-pass method by direct splitting of the Kirchhoff operator. Results are relevant considering that they made possible an alternative interpretation of the salt body, and are raising considerable interest regarding the application of the same approach to areas with similar geologic settings in Campeche Bay. From our viewpoint, two-pass 3-D prestack depth imaging provided a significant imaging improvement as compared with previous poststack time and depth migrations. Furthermore, the project was rather cost-efficient and did not require an excessive amount of both computational and interpretational time.

REFERENCES

Canning, A., and Gardner, G. H. F., 1996, A two-pass approximation to 3-D prestack depth migration: Geophysics, 61, 409-421.

Devaux, V., Gardner, G. H. F., and Rampersad, T., 1996, 3-D prestack depth migration by Kirchhoff operator splitting: Expanded Abstracts, 66th Annual SEG International Meeting and Exhibition, pp. 455-45

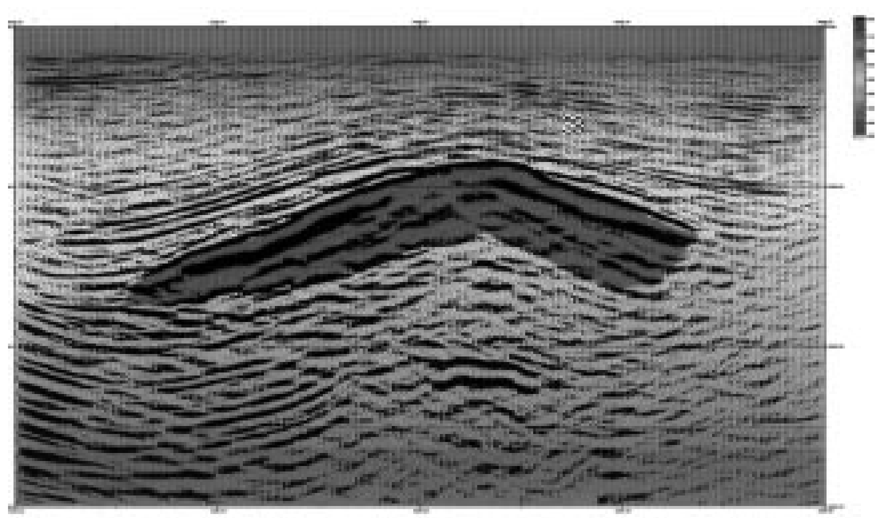


FIG. 1. Two-pass depth imaging usin a thin sill interpretation.

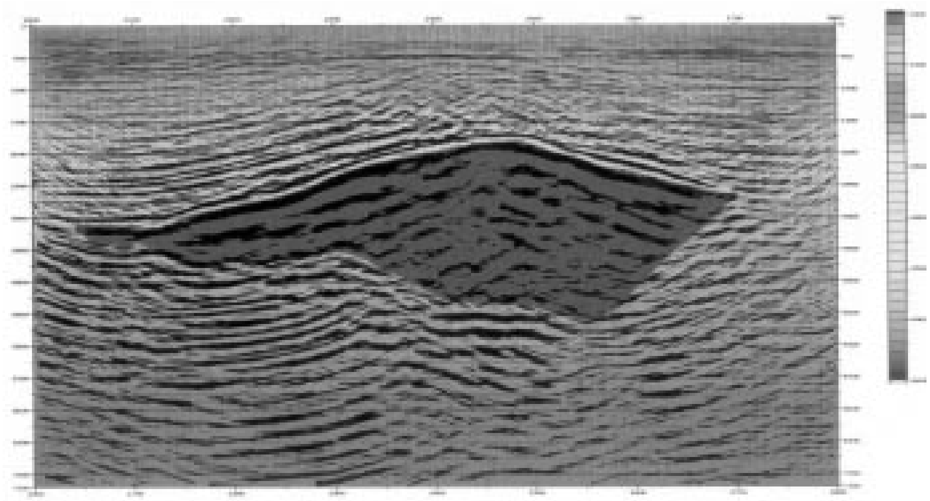


FIG. 2. Two-pass depth imaging using a thick salt body interpretation.

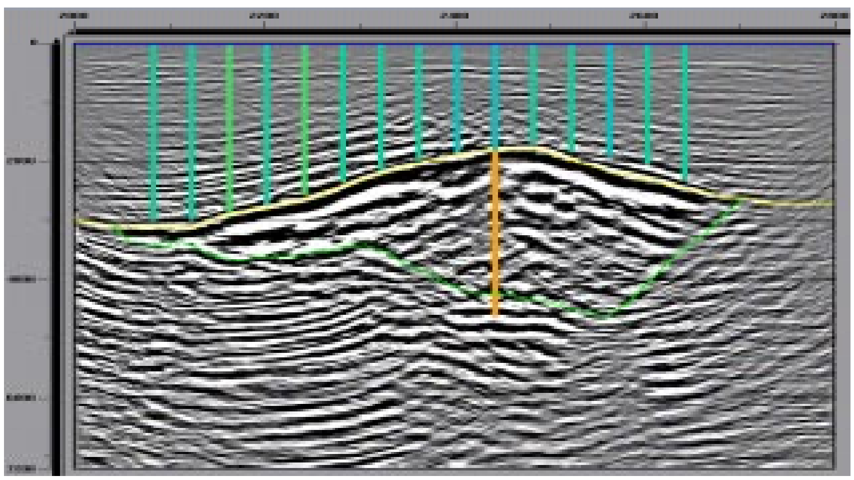
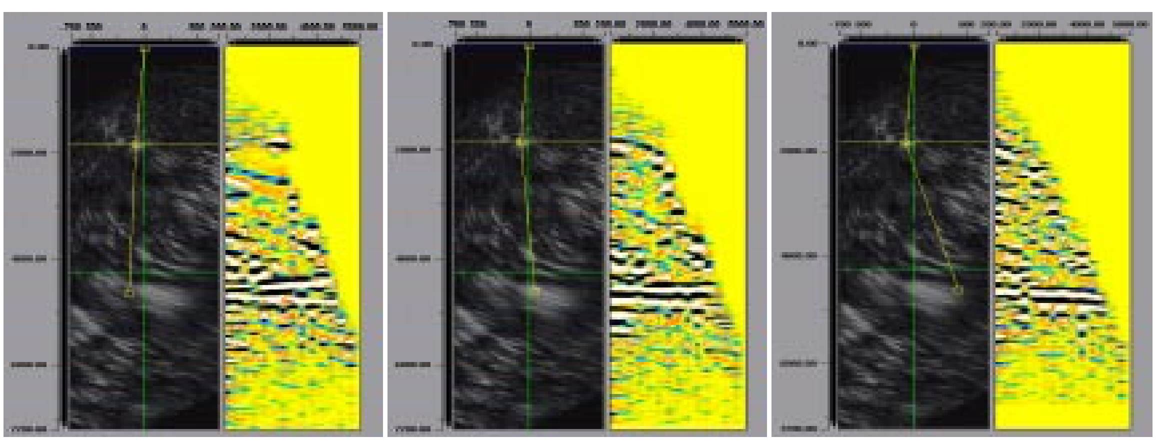


FIG. 3. Location of focusing analyses for the definition of the base of salt.



a) b) c)

FIG. 4. Focusing panels for a) velocity lower than 4500 m/s; b) velocity of 4500 m/s; and c) velocity higher than 4500 m/s.