A Case Study: An example of depth migration off the coast of Tabasco, Mexico

Mark Morford, Centro Nacional de Procesado Sismologico- Pemex*

Summary:

The coast of Tabasco, Mexico is an area with extensive salt domes and salt sheets combined with various complex compressional features. The 3d time migration performed on the dataset was insufficient to resolve the imaging problems in this complex area. In the time migrated dataset, the positioning of the compressional features was not satisfactory and interpretation was difficult due to high levels of noise. Another imaging challenge was defining the base of salt for the various salt bodies and the sub-salt faults and sub-salt sediments which were also not well imaged. This was due in large part to the smooth velocity model required for time migration which introduced errors into ray path and travel- time calculations. A geologically constrained velocity model was constructed and used as input to 3d pre-stack depth migration. This procedure, combined with applying better data preparation achieved improvements in the seismic image.

Introduction:

3d pre-stack depth imaging can be very useful in improving the seismic image in complex areas. In this particular study, the objective was to obtain a better understanding of the regional geologic environment, to verify position of faults, to improve the image at sediment- salt truncations and to generally improve the sub- salt image.

The interpreters for the project had constructed a model which included numerous salt bodies and compressional features which are potential reservoirs. The time migration had trouble resolving the image due to sharp .lateral contrasts in velocity.between the salt at 4300- 4600m/s and the surrounding sediments at 3400m/s. Below the salt bodies, the time migrated dataset lacked clarity and continuity events. Also there are carbonates associated with the compressional features which have widely variable velocities ranging from approximately 3400m/s to 5200m/s which complicate imaging in the area. Pre- stack depth migration was proposed in order to resolve these imaging problems.

Method:

The input data for this study included CMP gathers, a 3d DMO stack volume, a 3d time migrated volume, well velocities and an initial interpretation of key velocity horizons and stacking velocities.

Stacking velocities were used to create an initial velocity model down to the top of the salt. A simple Dix transform was applied to convert stacking velocities into an interval velocity model which was used as input, along with CMP gathers, to the initial Kirchoff pre- stack depth migration

The results of the initial migration with this simple velocity model showed that the noise contained in the time migrated volume was even a larger problem when applying pre-stack depth migration. It was determined that some processing was necessary to clean the gathers. This is important because pre- stack depth migration is sensitive to both noise and irregular offset spacing. This data set is OBC which tends to be noisy and have irregular acquisition geometry and thus is susceptible to some migration artifacts and aliasing problems. Normally the recommendation in preparing gathers for migration is that the less that is applied, the better. This is because there may be primary energy in the gather such as diffractions or steep dip information which may appear to be noise in an unmigrated gather and could be removed by a filtering process. Because of this, careful analysis was done of various noise reduction techniques and migrations were then performed with various pre- migration processes applied in order to determine if any signal was being removed along with the noise. Figure 1 shows an original cmp gather compared to a much cleaner, more balanced gather. which has had a bandpass filter and spectral balancing applied. The latter was used as input to the migration.

Normal incidence ray tracing was used to estimate required migration aperture. Rays are exploded normal to the subsurface depth reflectors and traced to the surface in order to determine how much horizontal displacement will occur at the surface. Using this method it was determined that an aperture of 4800 meters was sufficient to image the steepest reflections. Along with aperture, the other key migration parameters include anti- alias filter and stretch filter which remove noise but also can remove signal, especially steep dip information if they are not properly chosen. In both cases, weak filters were chosen here due to the steep dips found in the Mesozoic age sediment sand along the salt flanks.

Kirchoff 3d pre-stack depth migration was then applied to every 15th inline to a depth of 3000m. These inlines were the velocity control lines and were used to analyze and QC the velocity model and to progress from the original simple model to a more detailed geologic model. The initial migration was run only to 3000m with the idea of concentrating on and improving velocities in the upper section before moving to the more complex, deeper section.

The output from the pre- stack depth migration was CRP depth gathers (Common Reflection Point) as well as a depth stack of the velocity lines. The CRP gathers are very useful in refining the velocity model as they are very sensitive to velocity errors and thus errors are easy to find and correct. The depth stack is also key as the image can be compared to the time migrated image for improvements or to find areas which require more detailed analysis. Residual velocity analysis to improve the velocity model was performed using the depth CRP gathers as input. The residual moveout or depth delay is a measurement of the error or non- flatness in the reflectors within a CRP gather. The residual velocity analysis was performed at a surface spacing of 250 meters for the majority of the survey area with two of the more complex areas requiring a more detailed analysis at an interval of 125 meters. These errors or delays interpreted in the residual analysis were then used as input into a 3d global tomography program which uses a least squares approach to minimize the errors in the velocity depth model. As expected, some errors were found in the initial velocity model and 3 iterations of residual velocity analisis were required to produce an acceptable velocity model down to approximately 3000 meters of depth.

Pre- stack depth migration was then performed on selected inlines and crosslines again with the salt flood where there was salt using a salt velocity of 4500m/s. Tests of other velocities ranging from 4300-4700m/s for the salt were performed and 4500m/s gave the best image of the base of salt. Even so the base of salt was not imaged everywhere. the reason for this is currently being investigated, including applying newer, more sophisticated wave equation migration algorithms.

Following definition of the salt, a sediment velocity flood was incorporated into the model below the salt. The sediment velocity initally used was 3800m/s and this functioned quite well as a staring point.. In order to get a better sub- salt image, it was necessary to smooth the velocity volume using a filter of 8 samples in each dimension. This helped to reduce the migration artifacts present below the truncation poiints of the salt.

In the areas disrupted by thrust faulting a reduction in velocities was seen where the compressed sediments truncated against the main disconformity. This reduced velocity agreed with the interpreter's idea that this was a highly fractured zone and that would tend to reduce the velocity. Close to the faults there was a problem with noise including multiples and some loss of clarity. The amount of noise was inconsistent, sometimes less, sometimes more than in the time migration.

In the deeper part of the section the residual analysis was much more difficult and tomography did not function very well. When possible, well velocities were used as a guide, but there was very little well information at depths greater than 3000 meters. In this case the more time consuming, less- efficient method of trial and error was necessary. This was a problem where the model in the near surface or the salt body itself was complex and the ray tracing to calculate travel times was not successful. Also, tomography had trouble in the low signal to noise areas near major faults and fractures. The tests of various models verified that using a simple model at depths from 7000- 13,000 meters gave the best, results. A simple model at depth reduced over- migration, crossing reflectors and migration artifacts.

Figure 2 shows a comparison of the smooth rms velocity used in time migration in contrast with the more detailed geologically constrained interval velocity constructed using the above mentioned process. The detail contained in the interval velocity model along with consideration of known limitations in Kirchoff depth migration is key in producing a quality depth migration. Kirchoff depth migration algorithms can manage velocity models that are more complex than models appropriate for time migration algorithms, however very high frequency changes in the lateral velocity model do cause problems for the Kirchoff migration. This is due to the fact that Kirchoff migration is based on ray tracing which becomes unstable in such cases.

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Examples:

Figure 3 shows typical results from the study. In general, the salt is better defined in the depth migrated section as shown in Figures 3b and 3c. Also sediment truncations against the salt are improved in depth. Figures 3d and 3e show that there is more continuity and trends are clearer in the Mesozoic age section in the depth migrated result. The depth migrated results also help define the fault locations, whereas in the time migrated sections these were typically over or under migrated.

Conclusion:

Based on results similar to Figure 3, the project was considered a success. By building and using a geologically constrained velocity model coupled with pre- stack depth migration the seismic image was improved. As is well understood, depth migration algorithms are more stable in areas of lateral velocity variation and are better able to image in areas with lateral contrasts. The results were useful in achieving a better understanding of the geologic environment and confirming the geologic model of the interpreter. It was determined that the data preparation was also a key to the noise reduction and improved interpretability of the depth migration.

3d pre- stack depth migration- Tabasco

Figures:

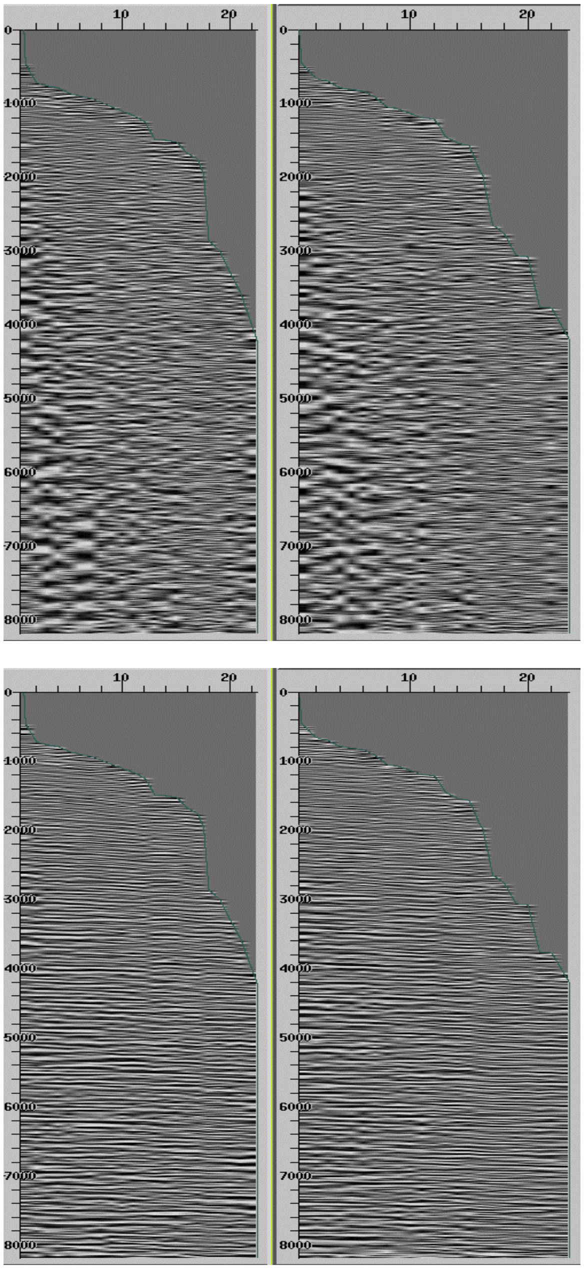


Figure 1. The upper gathers are original CMP gathers. The lower gathers are after application of a bandpass filter and spectral balancing. There is a dramatic improvement in the processed gathers and testing showed migration with these gathers improved continuity and reduced noise in the migrated product.

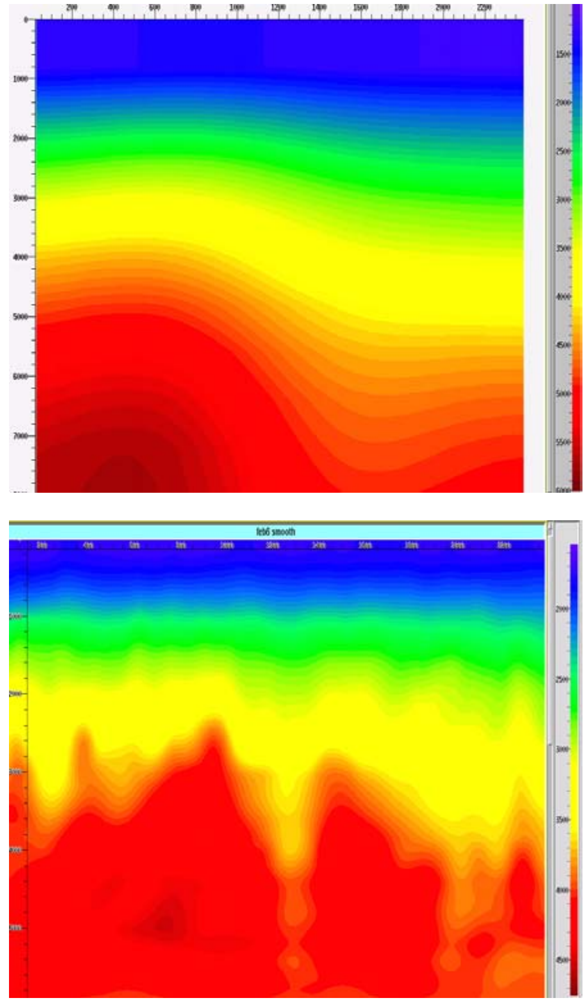
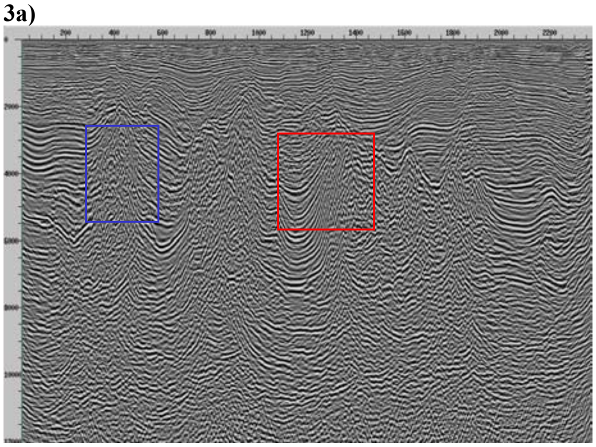


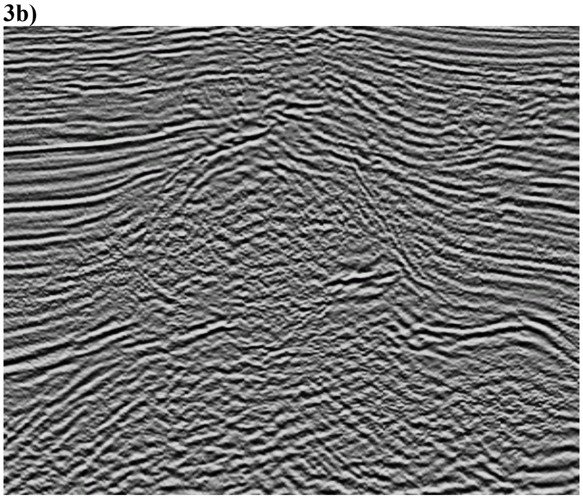
Figure 2. Typical inline showing RMS velocity on top and interval velocity below. The interval velocity model has more detail and more correlation with geology. Producing a quality depth migration was very dependent on constructing and inputting the correct velocity model.

3d pre- stack depth migration- Tabasco

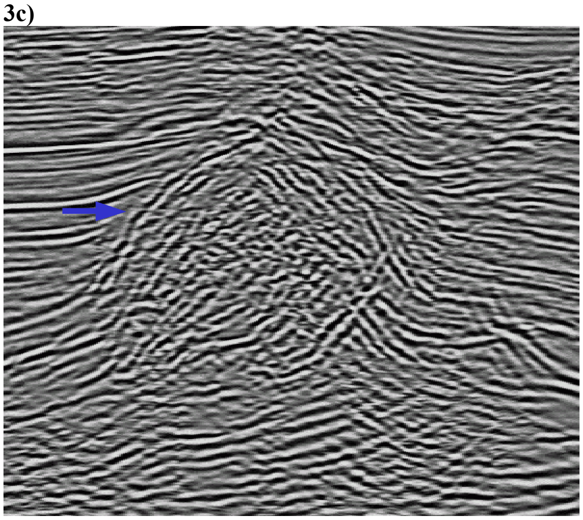
3a)



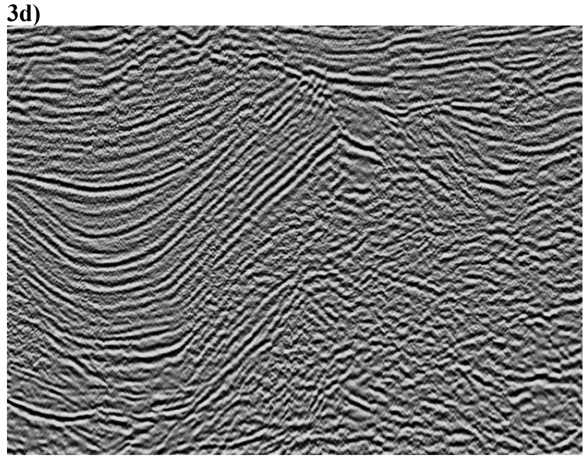
3b)



3c)



3d)



3e)

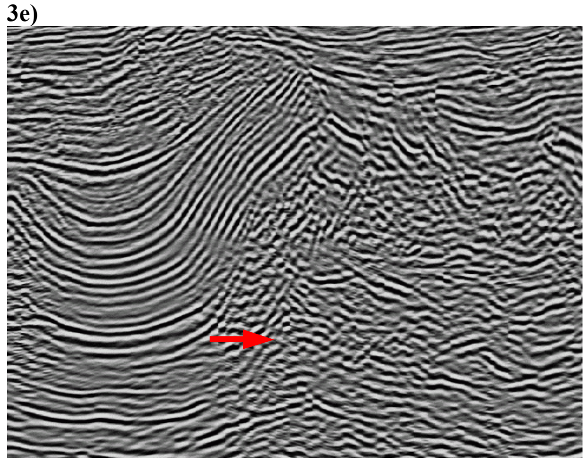


Figure 3. 3a is a complete depth migrated inline. 3b and 3c are the time and depth migrated sections respectively for the zone indicated by the blue window. The depth result has better salt definition. 3d and 3e are the time and depth migrated sections respectively for the zone indicated by the red window. This is a compressional zone with complex faulting and high noise content in the seismic section. Picking a trend and determining fault position was easier using the depth migrated section.