Challenges in Time & Depth: Imaging the Eastern Delta OBC Survey, a Case History

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Summary

Immediately offshore of the Mississippi Delta the geological setting conspires with numerous production installations to produce a unique set of problems that a seismic survey must overcome if it is to provide an accurate representation of the subsurface.

Here we present the case history of a survey, the Eastern Delta survey, acquired in this difficult region. State-of-the-art dual sensor ocean-bottom cables (OBC) were employed to overcome the difficulties associated with towed streamer acquisition. Long and short period static solutions, OBC-specific migrations and supra- and sub-salt tomography were used to address the imaging problems created by the geological complexity of the area.

Introduction

The Eastern Delta survey is situated in the Main Pass/Viosca Knoll area of the Gulf of Mexico, just off the coast of Louisiana. Acquisition took place during 2006-2007 and time and depth processing were complete by early 2008. Water depths vary from as a little as 10m to over 500m in the far south-east corner of the survey.

The outflow of the Mississippi delta is well known for the numerous problems it presents to the acquisition and processing of seismic data. Three main obstacles, both man-made and geological, may be identified as standing in the path of a successful imaging result.

Shallow water, platforms and other installations severely limit the feasibility of towed-streamer acquisition making OBC acquisition an inevitable choice. This, in turn, has implications for the imaging of the data in time and depth and for the illumination of shallow reflectors.

The recent geological history of the Mississippi delta creates a heterogeneous and complex near-surface geology characterized by low-velocity channels and gas- or water-charged mud layers. Long and short period static solutions were generated to correct for travel-time distortions created by these structures. Later in the processing travel-time tomography was used to build an accurate velocity model of the region.

Sediment loading from the Mississippi also plays a role in the creation of the numerous salt-bodies present in the survey. Supra- and sub- salt tomography and multiple passes of salt modeling were used to generate an accurate velocity model.

Pre-Processing

The greater complexity of OBC data over surface-seismic is mirrored in the increased attention to detail required during processing. This is especially true during pre-processing, where correct geometry & receiver position QC, PZ summation and de-noise are essential to a successful result. The approach used for this survey has been well described by Specht (2007) and we will not go into it further here.

Statics

As noted by Carvill et al (1996) the Mississippi river dumps an estimated 680 million tons of sediment into the Gulf of Mexico each year. Variations in sediment build-up at the mouth of the river occasionally cause parts of these deposits to fail, generating mudflows, or mud-fingers, that carry quantities of low-velocity mud downslope. The width of the mud-fingers varies spatially. They are about 200m wide on average, but can reach widths of up to 500m. Travel-times through the mud-fingers are substantially slower than for the surrounding sediments.

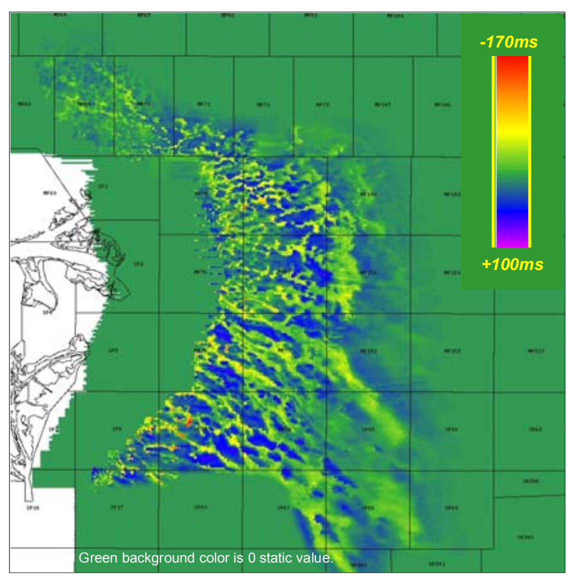

Figure 1: Result of the hybrid statics

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To compensate for these travel-time distortions a tomographic static solution was computed and applied. This was followed by a pass of reflection statics to capture any remaining short period variations.

The tomographic static values were computed using a hybrid technique. This technique combined the tomography output – filtered to remove the very low frequency component – with the surface consistent high-frequency remainder of the pick times minus the delay-times implied by the tomography model. Figure 1 shows the results obtained from this process. The distribution of mud-fingers and their relation to the Mississippi delta can be seen clearly. Corrections range from -170 ms up to +100ms. Figure 2 shows the effect of the application of the hybrid statics and the reflection statics on the data.

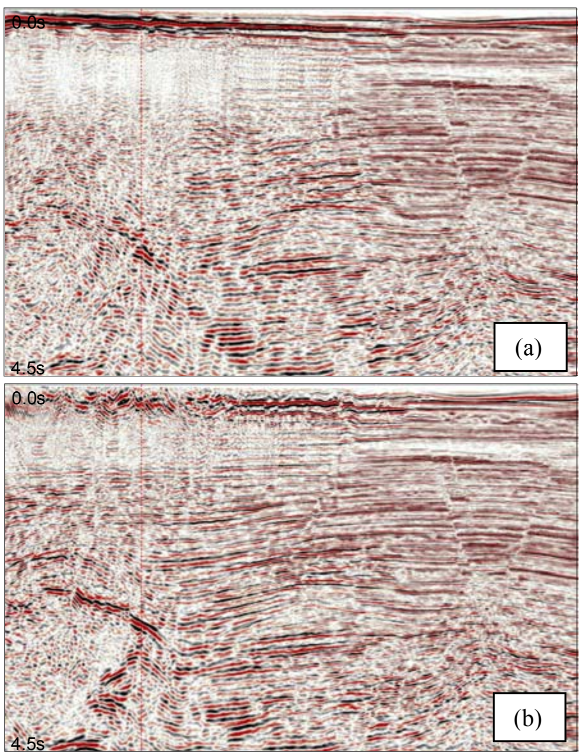

Figure 2. (a) 3D Post-stack time migration without static corrections. (b) 3D Post-stack time migration after application of long and short period corrections.

Depth Imaging

Specht (2007) demonstrates the importance of performing the imaging in time with data located at the acquisition surface. This is equally important for depth imaging. Given the geometry of the salt bodies and the shallow, high-resolution features that we wished to image, Kirchhoff depth migration was selected for the imaging of this survey.

In towed streamer acquisition the small difference in towing depth between the gun-array and the cables allow the use of one set of travel-times for sources and receivers. In this survey the sources and receivers can be separated vertically by up to 500m. This large separation requires the use of two separate sets of travel-times, one for sources and one for receivers, both computed from their respective acquisition surfaces.

Sediment loading from the Mississippi River has caused the salt to move up from the 150 million years old mother Louann salt layer, producing numerous shallow allochthonous salt bodies. Deeper autochthonous salt features associated with Louann are also prevalent. In places the salt has remained rooted producing vertically elongate salt stocks and tongues with steep flanks (see Figure 3.) These numerous salt features must be incorporated into the velocity model.

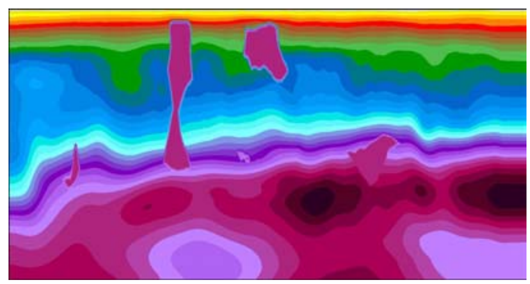

Figure 3. Inline section through the final salt model, illustrating the diverse range of salt geometries.

The first step in the model building was to derive a velocity model of the sediment using 3D grid-based tomography. The inputs to the tomographic inversion are residual curvatures picked from image gathers and dips measured from PSDM stacks. The smoothed and de-salted time migration velocity field was used as the starting model.

OBC data naturally contains a wider range of source-receiver azimuths than narrow-azimuth towed streamer data. In addition, data from an existing streamer survey – adjacent to this one and acquired in an orientation orthogonal to it – was used to provide aperture. These two factors resulted in a large distribution of source-receiver azimuths within a CMP bin. To fully utilize this information the tomographic inversion employed a full-azimuth tomography, in which rays are traced along a 360^0 range of azimuths (see Figure 4.)

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To prevent ray-paths that have traveled through salt from influencing the sedimentary velocity estimate a salt mask was used. Initial results indicated another high-velocity layer in addition to salt, which was identified as a possible carbonate layer. To incorporate this information into the velocity model tomography was performed in two passes.

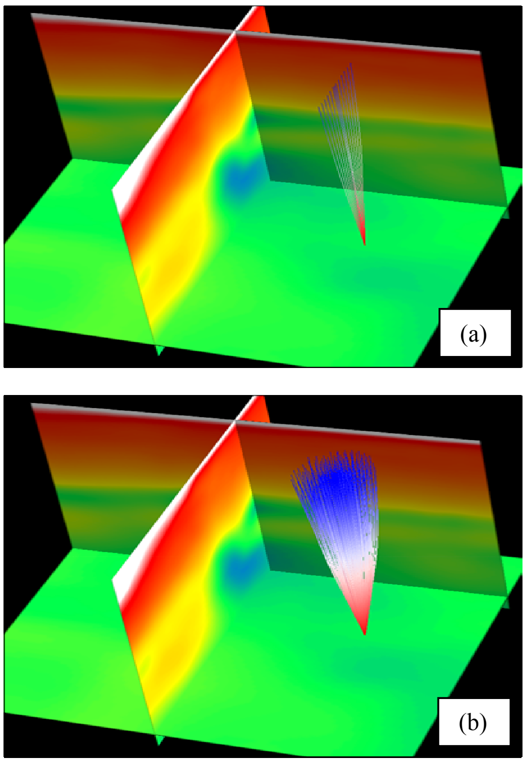

Figure 4. Diagram illustrating (a) narrow- vs. (b) wide-angle tomography.

In the first pass both salt and carbonate were masked out. In the second pass salt only was masked allowing the tomography to introduce the carbonate layer into the velocity model.

During the interpretation phase of the model building multiple passes of salt modeling were used to define salt overhangs.

The sedimentary velocity model was extended beneath salt by interpolating the basin velocities. However, the presence of salt reduces the over-burden stress on strata underlying the salt body causing a slow down in velocity compared to the equivalent sediments in a basin. Failure to incorporate this information into the model can lead to events being positioned too deep and imperfectly imaged. Sub-salt tomography was used to incorporate the effects of salt on the sedimentary velocities into the model.

Finally, the dramatic change of velocity across the sediment-salt interface causes reflections to exceed the critical angles at relatively small offsets. This well-known phenomenon causes a problem for the muting of the data prior to the creation of the final stacked image. A critical-angle mute was automatically created from the final velocity model to provide crisp stacked images without artifacts.

Figure 5 shows the final results of the time and depth imaging.

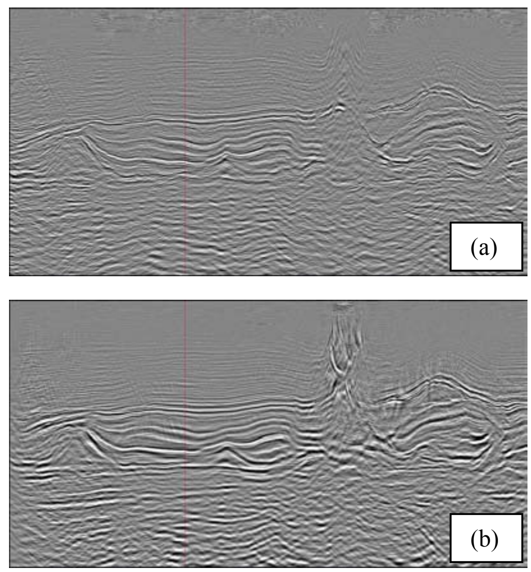

Figure 5. (a) Final 3D pre-stack Kirchhoff time migration converted to depth. (b) Final 3D pre-stack Kirchhoff depth migration.

Imaging the downgoing wave

In OBC acquisition the hydrophone data is combined in the PZ summation process with the vertical component of the geophone data to give the upgoing P-wave (Figure 6a.) The upgoing P-wave, which is free of the receiver ghost and receiver side multiples, is then carried forward into the remainder of the processing sequence.

One disadvantage of the upgoing P-wave, which is related to the large receiver spacing in the crossline direction, is that the sub-surface illumination for shallow reflectors is quite poor (Figure 6b.) When water depths are shallow the effects of this problem are small. As water depths increase it results in areas of the shallow section that contain poorly illuminated reflectors or no data at all.

It is a trivial step in PZ summation to also output the downgoing P-wave. The downgoing wave is composed

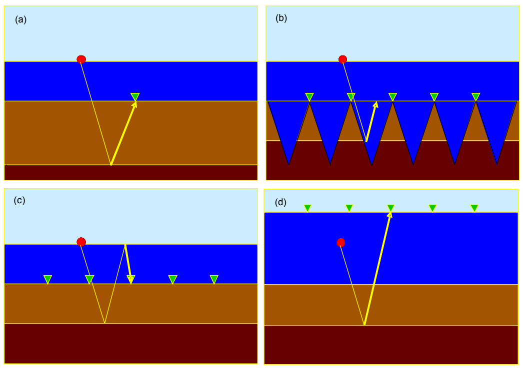

Figure 6. (a) The upgoing P-wave, resulting from PZ summation. (b) For shallow reflectors the upgoing P-wave has poor illumination. (c) The downgoing P-wave has better illumination for shallow reflectors. (d) Imaging of the downgoing P-wave by positioning of receivers above the sea-surface.

entirely of multiples but has the advantage of providing much better illumination of the subsurface (Figure 6c.) Since standard migration algorithms, Kirchhoff or one-way WEM, image the upgoing part of the wavefield this downgoing energy can be incorporated into the final image by considering the receivers to be located at twice the vertical water-depth above the sea-floor (Figure 6d, see also Ronen et al, 2005; Grion et al, 2007.)

The majority of the Eastern Delta survey was acquired in water of shallow enough depth that the illumination problems associated with the upgoing wavefield were inconsequential. In the south-east corner of the survey, however, water-depths exceed 500m and here the shallow imaging exhibits areas of poor illumination (Figure 7a.) In this area the downgoing wavefield was imaged and incorporated into upgoing image resulting in much better illumination of the shallow reflectors (Figure 7b.) At present this processing has only been applied in trial-mode to a portion of deep water data.

Conclusions

The area in the Gulf of Mexico offshore of the Mississippi river was for a long time designated a “no data zone” on account of the large number of obstacles that stand in the

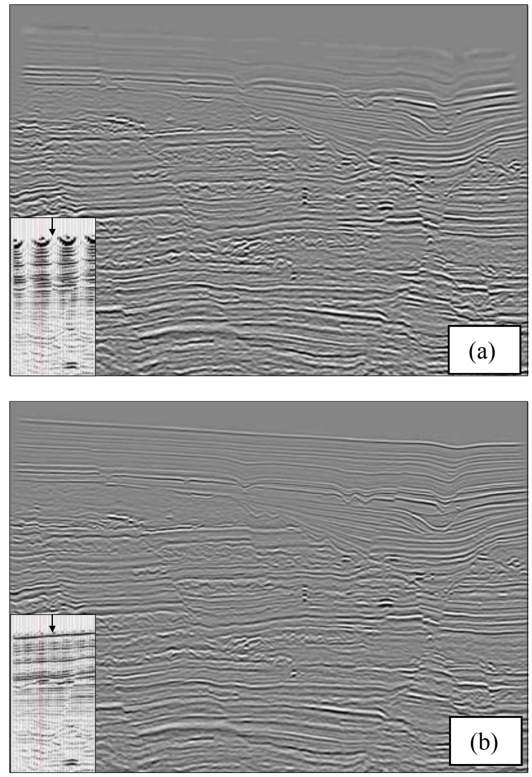

Figure 7. (a) Inline from a Kirchhoff pre-stack time migration using upgoing P-wave only. Inset, crossline section – arrow marks the location of the crossline. (b) Same line after Kirchhoff pre-stack time migration incorporating the upgoing and downgoing wavefield. The imaging of shallow reflectors is considerably improved.

path of the processor. We have shown how careful processing involving a full range of pre-processing and time and depth imaging techniques – long and short period static corrections, OBC-specific migrations, supra- and sub-salt tomography and the imaging of downgoing waves – all contribute to the creation of a well-imaged dataset.

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2008 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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