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# Mapping of 3-D multiples to image space: An example with a Gulf of Mexico dataset

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**ABSTRACT**

I migrate a real 3D seismic dataset from the Gulf of Mexico with shot profile migration and use it to illustrate the mapping of 3D multiples from data space to image space. The dataset contains specular water-bottom multiples, peg-leg multiples associated with a large, shallow salt body, and diffracted multiples originating at the salt edges. Both the water bottom and the salt body have significant cross-line dip which makes it difficult to model the trajectory of the multiples. The location of the multiples in the image domain is severely affected by the presence of the salt and thus do not follow the geometry of the multiple-generating interface. As a consequence, some multiples could easily be interpreted as primaries. I show, by computing subsurface offsets for one sail-line, that the multiples map away from the zero-subsurface offset as they would in a purely 2D model.


## INTRODUCTION

In complex subsurface areas, the propagation trajectory of primaries and multiples can be very complex. Therefore, in these areas, data-space methods to attenuate multiples based on their residual moveout after NMO correction (Hampson, 1986) are likely to fail because NMO may not flatten the primaries and because the residual moveout of the multiples may depart significantly from being parabolic or hyperbolic.

The data-space alternative is SRME (Verschuur et al., 1992). Since SRME uses the data itself to predict the multiples, the complexity of the multiple trajectory is not an issue. Furthermore, no knowledge whatsoever is required about the subsurface. The problem with SRME, specially with 3D data, is that it requires regular, fine sampling, and large apertures in both the inline and cross-line directions. With standard streamer acquisition, and in the presence of cable feathering, these conditions are unlikely to be met in practice. In the cross-line direction in particular, cost and logistic considerations dictate that sampling be coarse and apertures small. The remedy is to apply large-scale interpolation of near offsets and streamers and extrapolation of cross-line offsets. In addition, data regularization is required to deal with cable feathering. A lot of research is currently being carried out on how to address these issues in a way that allows fast and accurate estimation of the multiple model.

An alternative to data-space methods is to attenuate the multiples after migration, *i.e.* in the image domain (Sava and Guitton, 2003). The main advantage of the image domain is that prestack migration can unravel the complex propagation of both primaries and multiples. In Subsurface Offset Domain Common Image Gathers (SODCIGs), the primaries are focused near the zero subsurface-offset line whereas the multiples are smeared along a curve toward the negative subsurface offsets (Alvarez, 2005). Although identification of the multiples is simple in SODCIGs, they are not the ideal domain to attenuate them. Instead, we can transform the SODCIGs to Angle Domain Common Image Gathers (ADCIGs) that are a function of the reflection and azimuth angle (Biondi and Tisserant, 2004). In this domain, the primaries will be flat as a function of the aperture angle for the azimuth of the reflection plane, but will have curvature for other azimuths. The multiples, on the other hand, will not be flat even for the azimuth of the multiple-generating interface, but will instead exhibit a residual moveout that in 2D can be approximated, to a first order, by a simple trigonometric equation (Alvarez, 2005). This equation in turn can be used as the kernel of a Radon transform to focus the primaries and multiples to separate regions of the Radon domain, thereby allowing for their attenuation.

Here I use a real 3D dataset from the Gulf of Mexico to illustrate the mapping of the multiples to image space. The dataset, provided by VeritasDGC, was acquired over a complex salt body with structure in both the inline and the cross-line directions. The water-bottom itself dips about 11 degrees in the cross-line direction making the mapping of the multiples in the image-space cube difficult to predict. The presence of the salt distorts the multiples so much that in many cases it is difficult to discern with certainty which events are multiples and which events are primaries in the migrated cube. An important tool for that purpose are the SODCIGs where the multiples can be identified by their tendency to map to toward the negative subsurface offsets. I illustrate this situation by computing SODCIGs for one sail-line. The goal is to compute SODCIGs inline and crossline for the entire area, but at the time of writing this report the results are not yet available. I show that even in the SODCIGs for one sail-line, however, the multiples are identifiable and clearly distinguishable from the primaries.

## DESCRIPTION OF THE DATA

### Geometry of acquisition

The 3D dataset consists of 20 sail lines each with four active streamers and dual flip-flop shooting. The separation between streamers is 160 m and between receivers is 25 m. The shot interval is 37.5 m (between the flip and the flop). The minimum offset inline is 240 m and each streamer has 288 receivers for a maximum inline offset of 7175 m. Figure 1 shows the acquisition template. Figure 2 shows a map view of the subset of the shots used in this study. Although most sail lines were straight in the East-West direction, a few had significant curvature.

The strong currents present in the area caused significant feathering. Figure 3 shows an example for the sail-line at cross-line distance 11440 m. For most shots, the feathering was

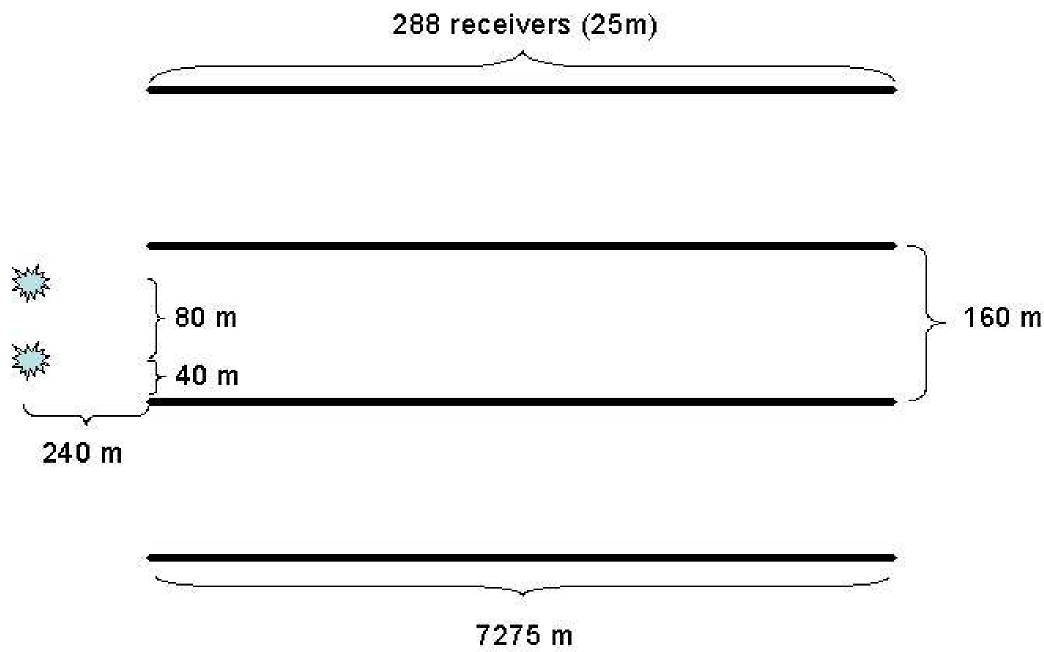


Figure 1: Sketch of the basic acquisition geometry gabriel1-acq_sktch1 [NR]

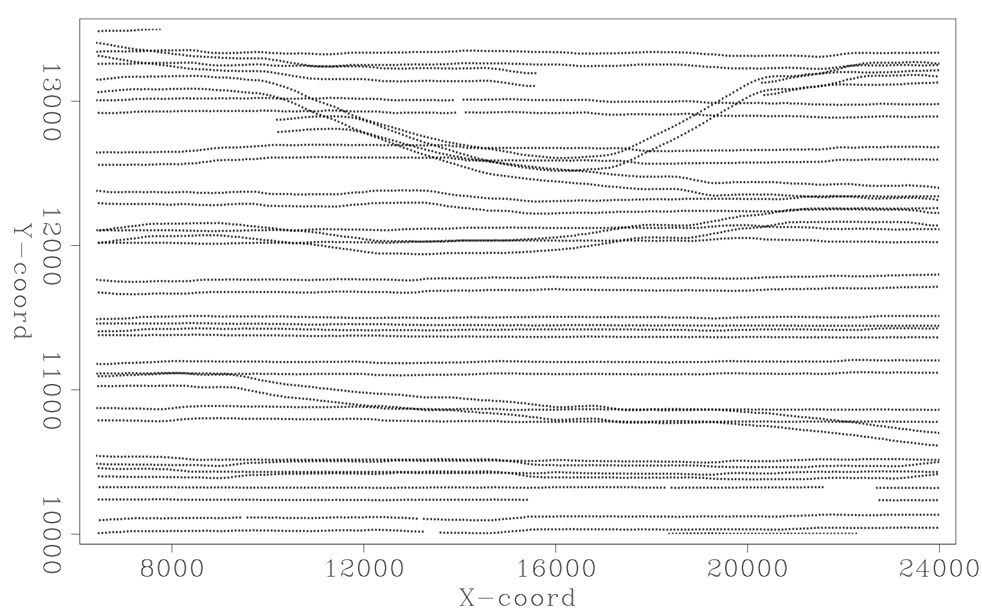


Figure 2: Map view of the source locations. gabriel1-shots_map [CR]

in the same South-North direction. Figure 4 shows the fold of coverage that in some places depart significantly from its design value of 48. Some of the short source lines in Figure 2 we acquired as infill to avoid large coverage holes.

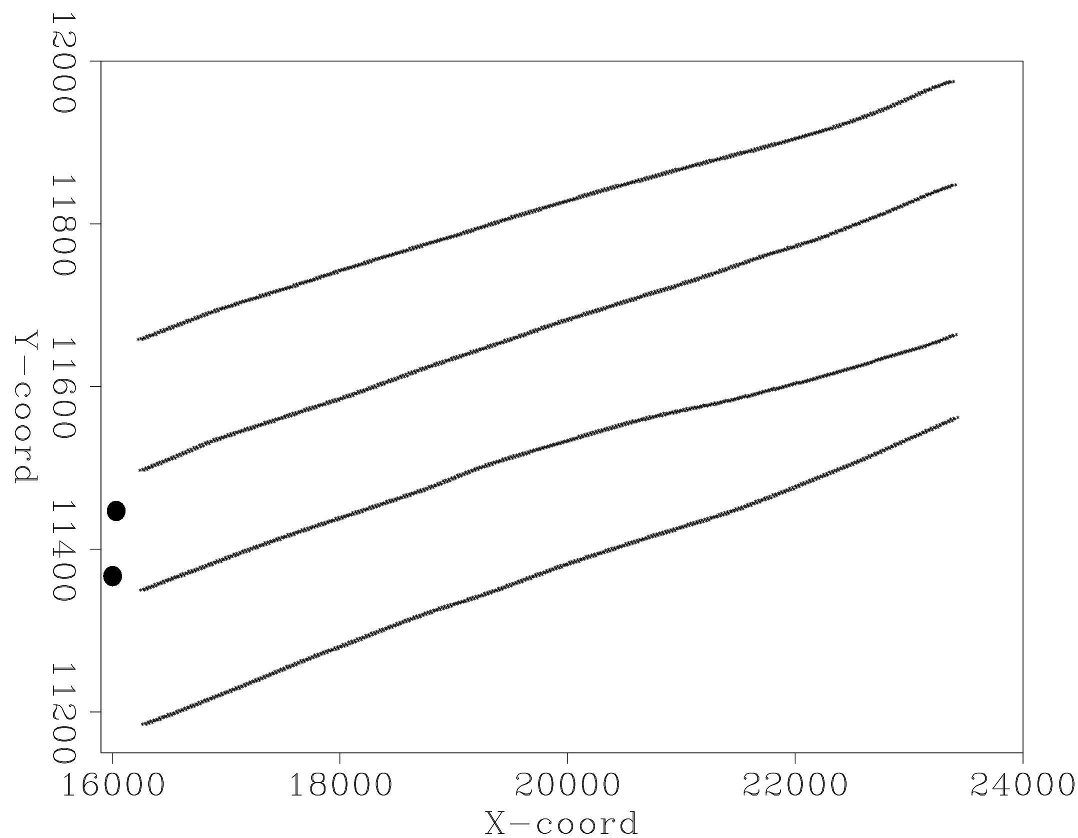


Figure 3: Map view of the receiver cables for one shot illustrating typical feathering. gabriel1-feathering [CR]

**Velocity model**

The velocity model (provided by Norsk Hydro), shows a large, complex salt body with steeply dipping flanks in both inline and cross-line directions (Figure 5). The water-bottom itself dips in some places as much as 11 degrees in the cross-line direction, although it is relatively flat in the inline direction.

**Raw data**

Figure 6 shows a typical shot record with the traces ordered one streamer after the next. The traveltimes are relative to an arbitrary reference. The water-bottom multiple is seen in the close-up look from one the streamers in Figure 7 at about 4 s on the near offset trace. Notice

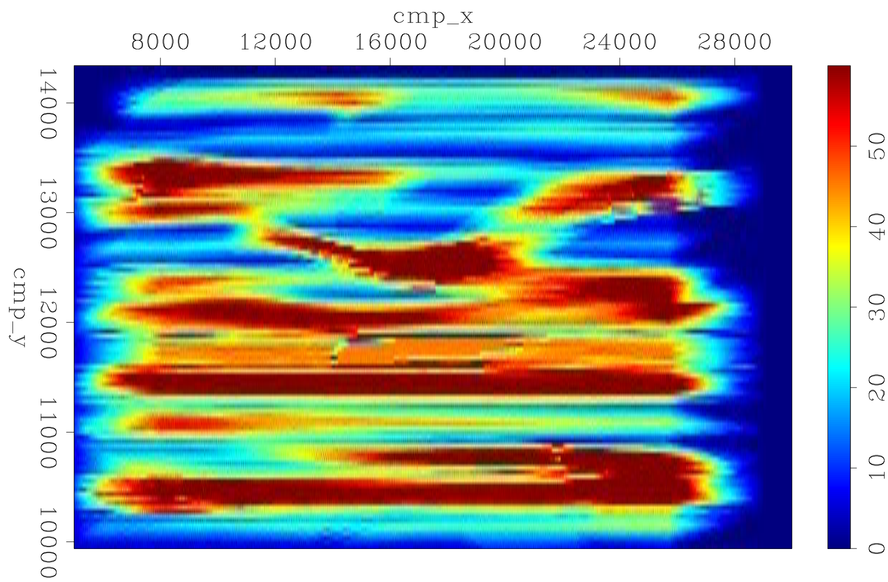


Figure 4: Fold map illustrating relatively uniform coverage. gabriel1-fold [CR]

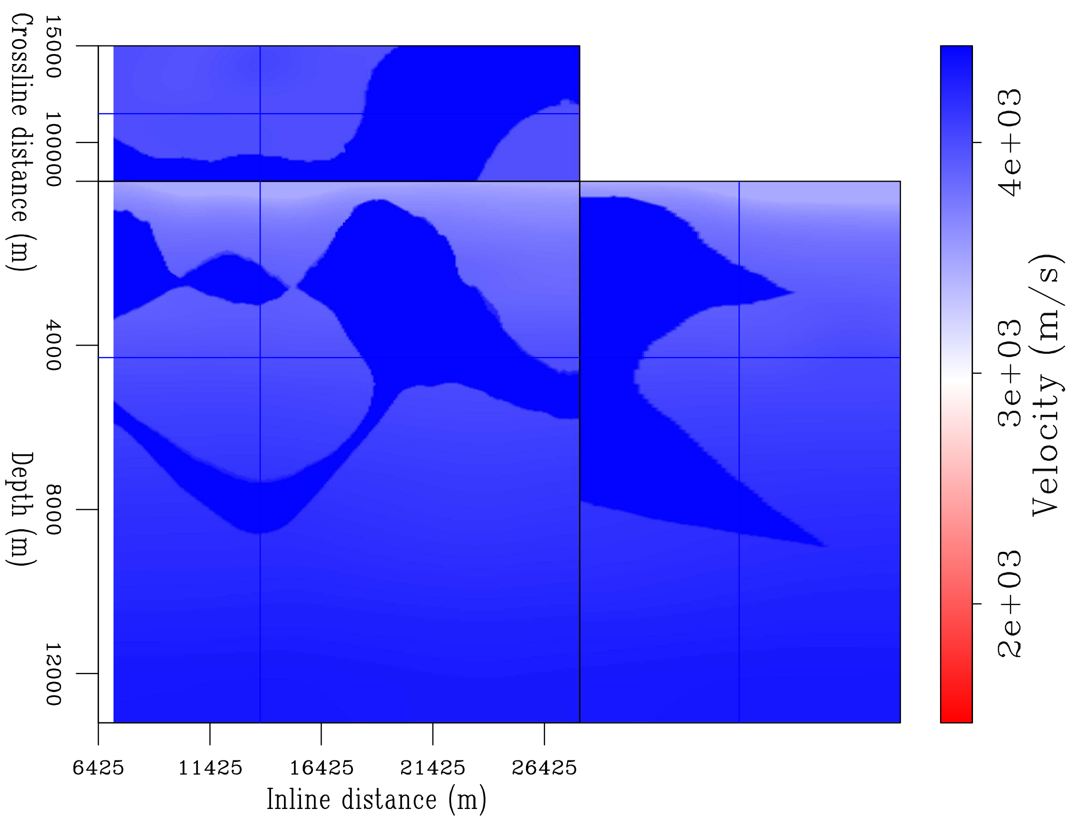


Figure 5: Subsurface velocity model. Note the strong dips in both the inline and cross-line directions. gabriel1-vmodel [CR]

also the diffractions and complex moveout of some of the reflectors due to the 3D nature of the subsurface and the complex wave propagation it produces.

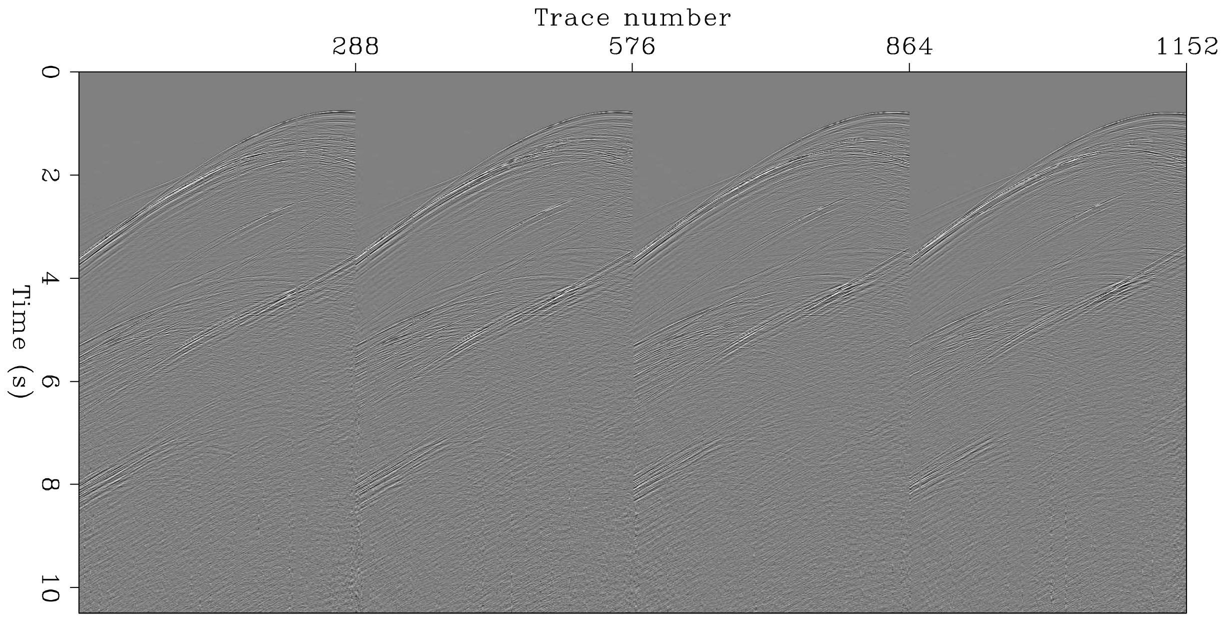


Figure 6: A typical shot record showing the data from the four streamers. gabriel1-shot1 [CR]

## SHOT PROFILE MIGRATION

In order to efficiently migrate the data with shot profile migration, I removed the time samples before the water-bottom arrival and compensated by applying a linear frequency shift to the source wavelet. The propagation through the water layer was done in two depth steps and from there down the depth sampling was 10 m. For the sake of computer time, only two reference velocities were used to propagate the data at each depth step. These reference velocities were computed with Lloyd's algorithm (Clapp, 2004). The aperture in the inline direction was 9 km (1.2 km in front of the streamer and 0.6 km at the end of the streamer) and the cross-line aperture was 4.8 km (2.4 km in the up-dip direction and 1.4 km in the down-dip direction). Four hundred frequencies were used from 6 to 40 Hz. Figure 8 shows an inline and a cross-line sections taken from the migrated cube. The depth axis is with respect to an arbitrary reference. The inline section is at crossline 10240 m and the crossline section is taken at inline 12000 m. The migrated data was filtered in depth and a gain proportional to the depth squared was applied for display purposes. Since it is not easy to identify the multiples in Figure 8, I windowed the image below the salt body between 8000 and 16000 m in the inline direction as shown in Figure 9. The crossing events are an indication of the presence of the migrated multiples and their interference with the legitimate, possibly weak subsalt primaries. Again, it is not immediately obvious which of these reflections are primaries and which are multiples without the help of prestack migrated images as a function of subsurface offset or aperture

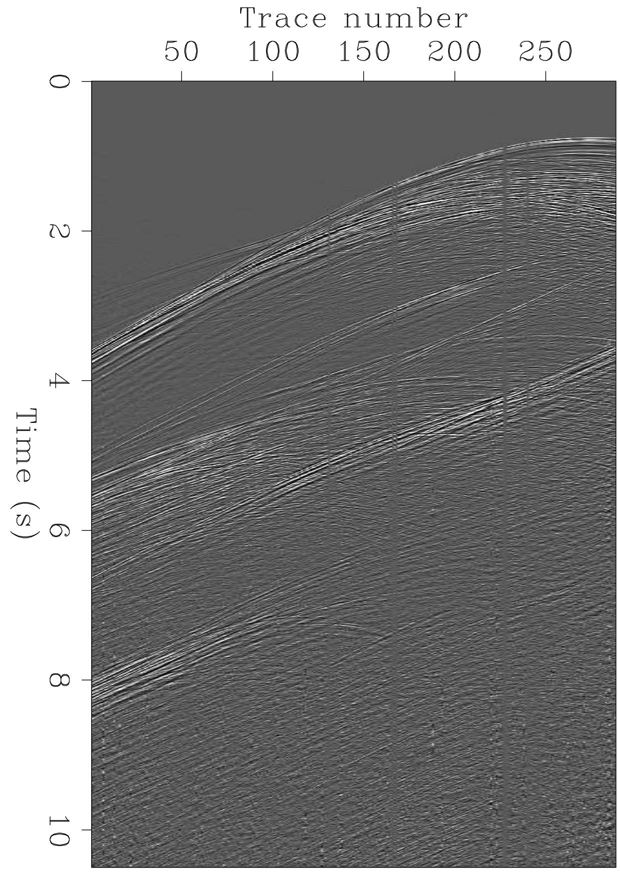


Figure 7: A close-up view of the shot for one of the streamers. gabriel1-shot_str1 [CR]

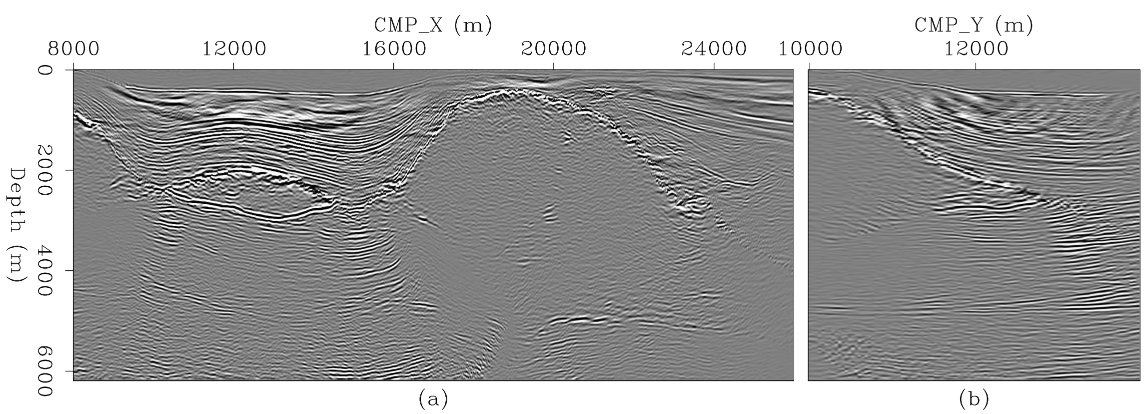


Figure 8: Shot profile migration. Panel (a) is the inline section at crossline 11440 m. Panel (b) is the crossline section at inline 12000 m. gabriel1-mignooffs1 [CR]

and azimuth angles. Computing subsurface offsets, however, is very expensive and at the time of this report I have computed only inline subsurface offsets and only for one sail line. The results are presented in the next section.

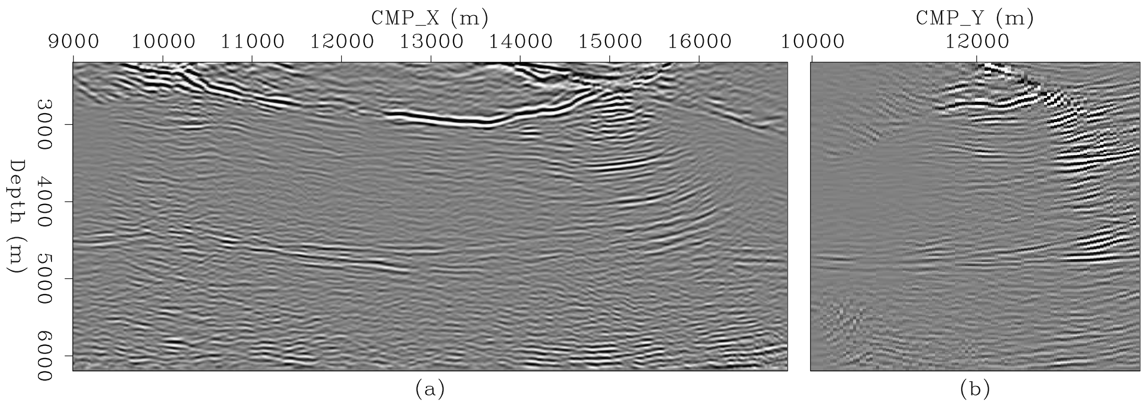


Figure 9: Close up view of the migrated cube to show the interference between the multiples and the weak subsalt primaries. Panel (a) is the inline section at crossline 11440 m. Panel (b) is the crossline section at inline 12000 m. gabriel1-mignooffs1_win [CR]

## DISCRIMINATION OF MULTIPLES

### Inline image gathers

Figure 10 shows the same inline section as in Figure 8 but this time taken from the migration of only one sail line. Notice that the salt boundaries are poorly imaged because of the complexity of the salt geometry in the cross-line direction. Much more data needs to be migrated from the cross-line direction in order to get these reflections as can be seen by comparing with Figure 8. The right hand panel is now a subsurface offset gather taken at the center of the window in Figure 9 (CMP position 13200 m). Although not all the multiples are imaged in this migration because of the lack of cross-line data as indicated for the salt reflections, those imaged can be identified by their moveout away form zero toward the negative subsurface offsets in the offset gather. Notice in particular the multiple at about 4 km depth and -400 m subsurface offset. Figure 11 shows three subsurface offset gathers taken at different lateral positions. The first SODCIG (panel (a)), taken at about the center of the window in Figure 9(a) (CMP position 13200 m), shows evidence of multiples at about 4000 m depth at -400 m half-subsurface offset. This multiple is difficult to identify in Figure 9 because it essentially stacks out. It is, however visible in the constant subsurface offset section of panel (b) in Figure 12 (left oval). The second SODCIG (panel (b)), taken below the big salt body in Figure 8(a) (CMP position 20800 m) shows no clear evidence of multiples below the salt. The strong event below 20000 m and about 5000 m in Figure 8 is actually the base of the salt and the events below it are subsalt primaries (see also the oval in panel (a) of Figure 12). The last SODCIG, (panel c), taken where the sediments meet the salt flank (CMP position 24900 m), show evidence of multiples below

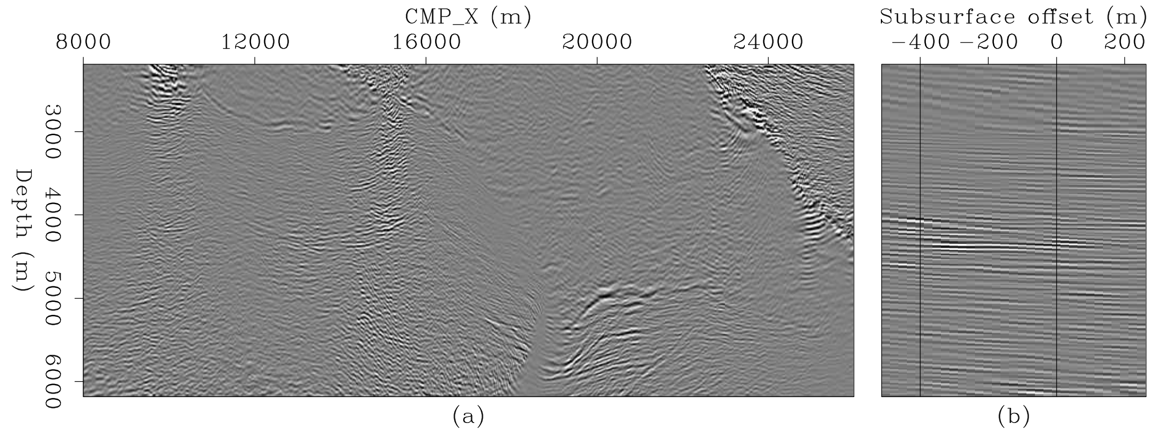


Figure 10: Migration of one sail line. The left panel is an inline subsurface offset common image gather. gabriel1-2dmigoffs1 [CR]

4000 m depth. To further illustrate this point, Figure 12 shows a comparison between the image taken at zero subsurface offset, which should be mostly (but not exclusively) primaries, and that obtained at -400 m half-subsurface offset, which should be mostly multiples. Notice in particular the multiple above a depth of 3000 m to the right of the inline distance of 24000 m as indicated by the right oval. Also notice the flattish event at about 4000 m depth and 13000 m inline distance (left oval). This is likely to be a multiple obscuring the weak primaries.

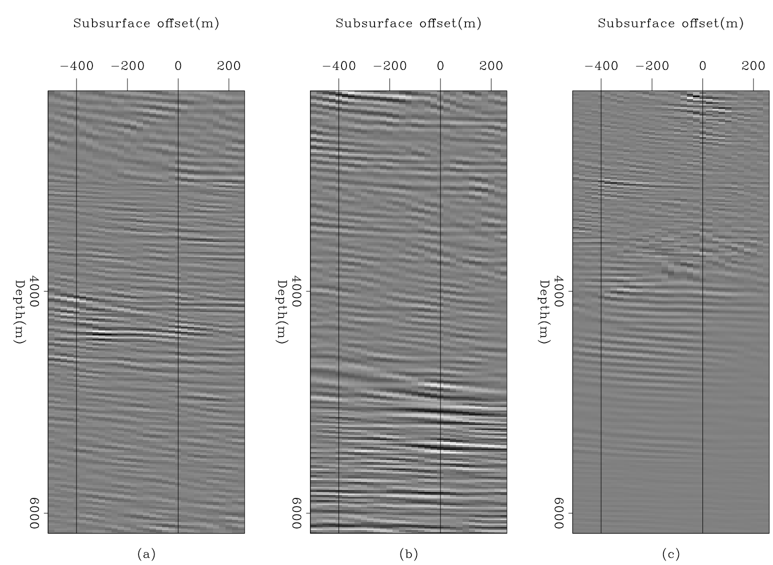


Figure 11: Subsurface offset common image gathers taken at lateral positions (a): 13200 m, (b): 20800 m and (c): 24930 m. gabriel1-2dsodcigs1 [CR]

Since I expect to attenuate the multiples in ADCIGs rather than SODCIGs, it is interesting to see how the multiples in this 2D migration are mapping to ADCIGs. This is illustrated in Figure 13 that shows ADCIGs for the same SODCIGs shown in Figure 11. Again, notice in panel (a) the down curvature of the multiple at about 6000 m at zero aperture angle. There

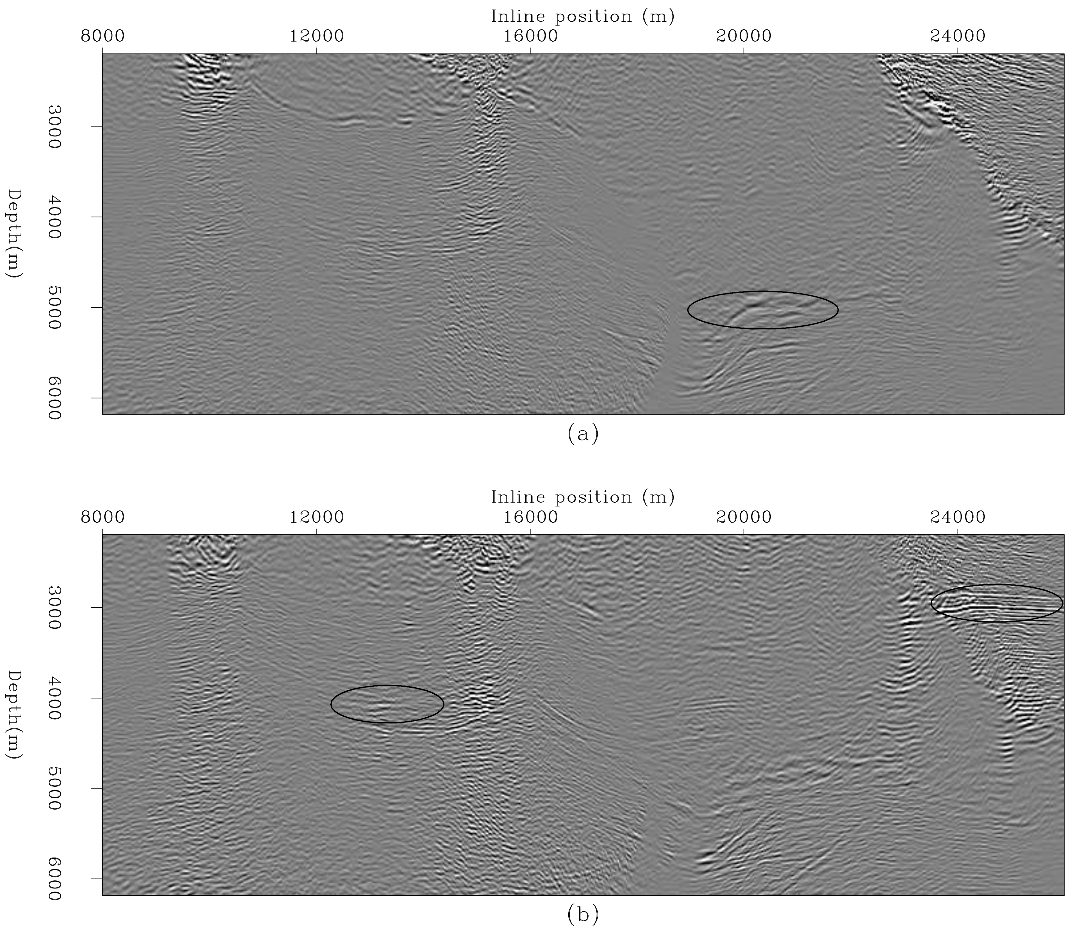


Figure 12: Common subsurface offset sections taken at (a): 0 and (b): -400 m half-subsurface offset. gabriel1-2dcoffs1 [CR]

seems to be another multiple at above 7000 m depth. In contrast, no clear evidence of multiple can be seen in the ADCIG in panel (b). In panel (c) there is some evidence of multiples at a depth of about 6300 m depth but at the same depth there seem to be primaries as well. The situation will probably be more clear once the ADCIG is computed after migrating all the data.

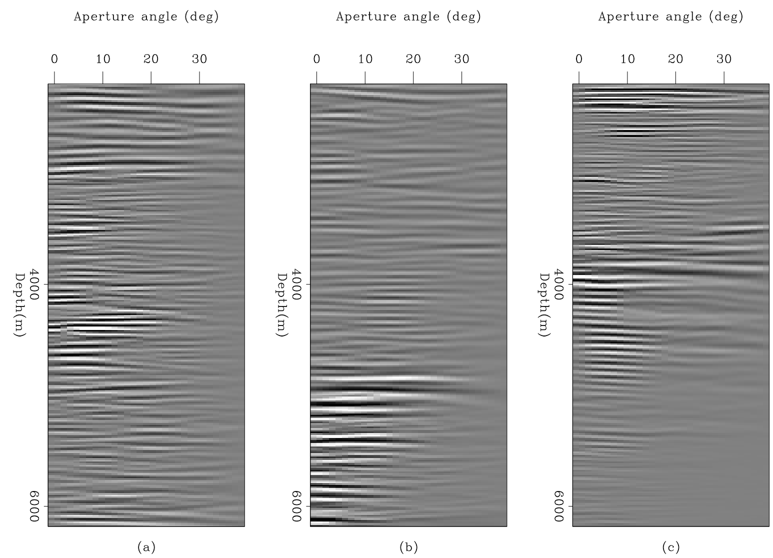


Figure 13: Angle domain common image gathers corresponding to the subsurface offset domain common image gathers in Figure 11 gabriel1-2dadcigs1 [CR]

## DISCUSSION

In complex areas, the image space is an attractive domain to attenuate the multiples, provided that we can design a Radon transform to separate them from the primaries. The presence of large salt bodies and in particular their steeply dipping salt flanks in the cross-line direction severely distort the imaging of the multiples. A full 3D migration is necessary to image the multiples. In order to discriminate between primaries and multiples, and to attenuate the multiples, we need to compute prestack image gathers as a function of subsurface offset or aperture and azimuth angles. Computing prestack images is expensive, but they can be used not only to attenuate the multiples but also to assess the accuracy of the migration velocity model and even to back project residual moveout information into velocity corrections. The expense of computing the full prestack image (inline and cross-line subsurface offsets and from them angle gathers as a function of aperture angle and reflection azimuth) is thus well worth.

At a relatively small additional cost (an additional convolution), it is attractive to use the image space version of SRME to get an initial estimate of the multiple model (Artman et al., 2007). I expect, however, that diffracted multiples, and specular multiples from reflections with a significant cross-line dip components, will not be accurately modeled. For these multiples, exploiting their particular behavior in terms of their residual moveouts as a function of aperture angle and reflection azimuth, is the best way to attenuate them.

## CONCLUSION AND FUTURE WORK

Complex subsurface distorts multiples and make their identification difficult in the image space. We can either compute an approximate multiple model with an image space version of SRME or, better, compute full 3D angle gathers in order to exploit the different characteristics of the residual moveout of the multiples and the primaries as a function of aperture angle and reflection azimuth to attenuate them. This is the focus of my current research.

## ACKNOWLEDGMENTS

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