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Imaging under the edges of salt bodies: Analysis of an Elf North Sea dataset

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ABSTRACT

Depth imaging techniques still face difficulties under the edges of salt bodies. Elf encountered such a problem in a 3-D survey in the North Sea where they hoped to image a reflector that lays beneath a salt body. Based on the 3-D data, Elf created 2-D synthetic model of the salt body and surrounding subsurface. By analyzing this synthetic model using Kirchoff depth migration and raytracing techniques, it became clear that the problem is largely due to poor illumination. The portion of the reflector under the edge of the salt dome only received illumination from a limited range of offsets. In addition to further analysis of both the synthetic and real datasets, investigations of possible solutions such as weighting appropriate offsets, inversion and/or the use of common reflection angle gathers seem warranted.

INTRODUCTION

Hydrocarbons are often trapped under the edges of salt bodies making accurate imaging essential. The complex velocity structure associated with the surrounding subsurface and the salt itself can mask deeper reflectors making structural and stratigraphic interpretation difficult if not impossible. It is a well established fact that prestack depth migration is the most accurate approach for imaging laterally varying media (Ratcliff et al., 1995). After applying prestack depth migration, the discontinuity of the reflector can be partially explained as an illumination problem (Muerdter et al., 1996). This illumination problem can lead to apparent residual curvature in the common reflector point domain. This apparent residual curvature and migration artifacts cause problems with stacking and velocity estimation (Wyatt et al., 1997), ultimately deteriorating the quality of the final image. A 3-D dataset from the North Sea provided by Elf clearly shows a deep reflector that, after migration, becomes discontinuous under the edge of a salt body. Analysis of a 2-D synthetic model based on this real dataset leads to the conclusion that in this case the complex velocity structure results in poor illumination of the reflector of interest. This lack of energy

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causes the reflector to disappear and gives incorrect amplitude results. In this paper we identify the problem areas on the real and synthetic dataset. We then analyze the anomaly using finite-difference generated data and pre-stack Kirchhoff depth migration. Raytracing techniques allow us to investigate the problem of illumination. Finally, we propose possible solutions for this case.

BACKGROUND

Figure 1 is a 2-D line taken from the 3-D survey in the North Sea. It shows the stacked result after we have applied a 2.5-D pre-stack Kirchhoff depth migration. The salt body can be seen in the middle of the section. The reflector we wish to image obviously fades then disappears as it nears the salt body. Figure 2 shows two common reflector point (CRP) gathers taken from this section. The reflector is visible in the CRP gather that is farther from the salt but is almost totally missing in the second CRP gather. There is some coherent energy in the mid-offsets. By analyzing a synthetic dataset based on this real data we will show that this behavior is due, at least in part, to illumination problems.

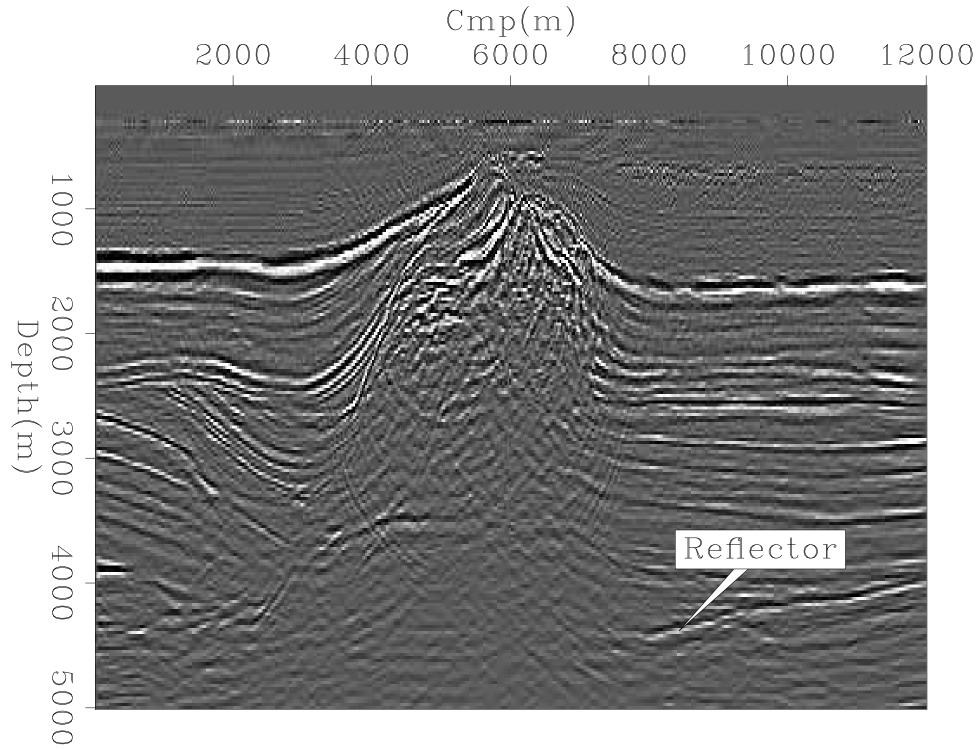

Figure 1: PSDM section from the real dataset marie1-stack.v1448 [CR]

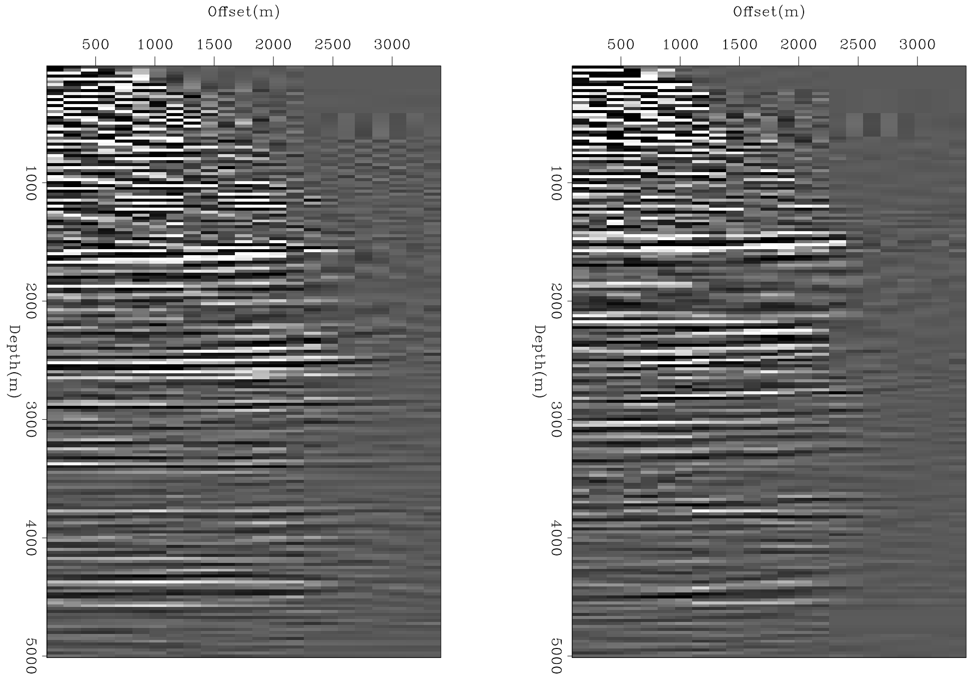

Figure 2: Left: CRP gather from field data at surface location 8500 m showing the flattened reflector. Right: CRP gather from field data at surface location 7500 m showing coherent energy at mid-offsets. $\boxed{\text{marie1-crpreal}}$ [CR]

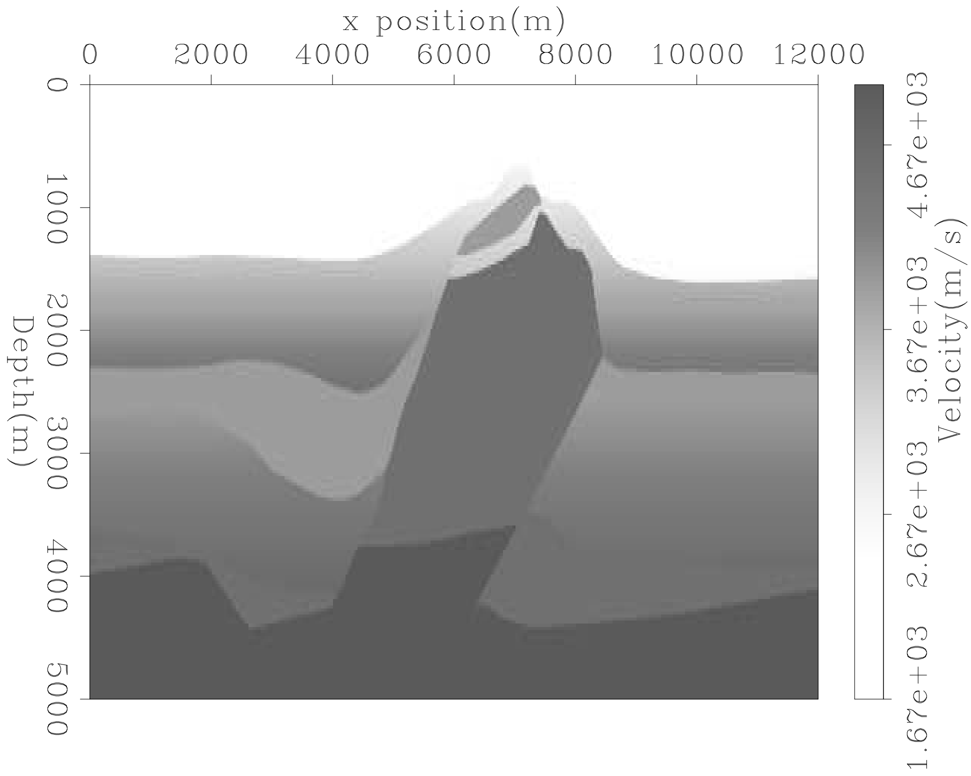

Figure 3: Synthetic velocity model $\boxed{\text{marie1-vel}}$ [CR]

SYNTHETIC EXPERIMENTS

Elf created a 2-D synthetic model based on their 3-D survey. This velocity model can be seen in Figure 3. The model has source spacing of 50 meters, receiver spacing of 25 meters, and a full offset range of 190 m to 3340 m. Figure 4 shows raypaths consistent with the synthetic model's geometry overlaying the velocity model. There is a definite shadow zone on the reflector under the edge of the salt body.

Migration

Our work up to this point has concentrated on analysis of the 2-D synthetic model. To analyze the finite-difference generated data we began by constructing travel time maps using a fast-marching eikonal solver (Fomel, 1997). The pre-stack Kirchhoff depth migrated common-offset sections obtained by this method can be seen in Figure 5. The depth migration code used was developed by us using Genkir3D, a package designed to aid in the development of Kirchhoff imaging applications. (Biondi, 1998). Figure 5 displays many interesting features. The only processing that has been done is pre-stack Kirchhoff depth migration followed by stacking the common offset sections. Comparing the stacked section to the velocity model shows that we have done a good job of imaging even the steeply dipping reflectors. However, there are fairly strong migration artifacts and noise in the area beneath the edge of the salt. The most interesting feature is on the reflector we wish to image almost directly beneath the edge of the salt body. The strong reflector suddenly disappears then reappears as a faint event. This corresponds with Figure 6 which shows common reflector point (CRP) gathers illustrating that away from the edge of the salt we did flatten the events and the reflector is quite strong but near the salt our reflector becomes practically non-existent. It is this intriguing behavior that we examine next.

Raytracing

Having realized that there is a problem, we must now clearly define it before we can try to solve it. Based on the work done by Muerdter et al. (1996), we hypothesize that we are seeing an illumination problem. Raytracing is an obvious way to investigate where the energy is going. Creating raypaths is a straightforward process. We first used a paraxial raytracer to shoot rays from each source location to the section on the reflector being investigated. We then matched the rays at the reflector that obeyed Snell's Law, looping over the offset range in increments of 25 meters. The resulting raypaths for the entire offset range have already been displayed in Figure 4. We have already shown the existence of a shadow zone in Figure 4. This figure shows the coverage obtained with the full offset range used in the synthetic model. Comparison with Figure 5 shows a definite lack of density of rays in the area where the reflector disappears from the stacked section. It is clear that the primary problem in this area is poor illumination. However, there is some energy reaching this portion of the

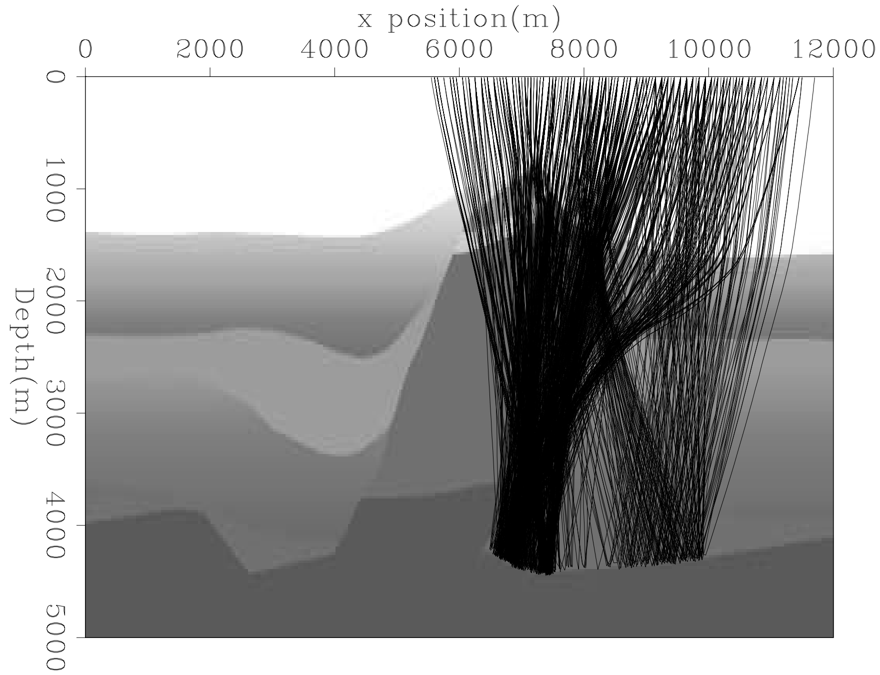

Figure 4: Raypaths through the synthetic model impinging on the problem section of the reflector marie1-overlay2.full [CR]

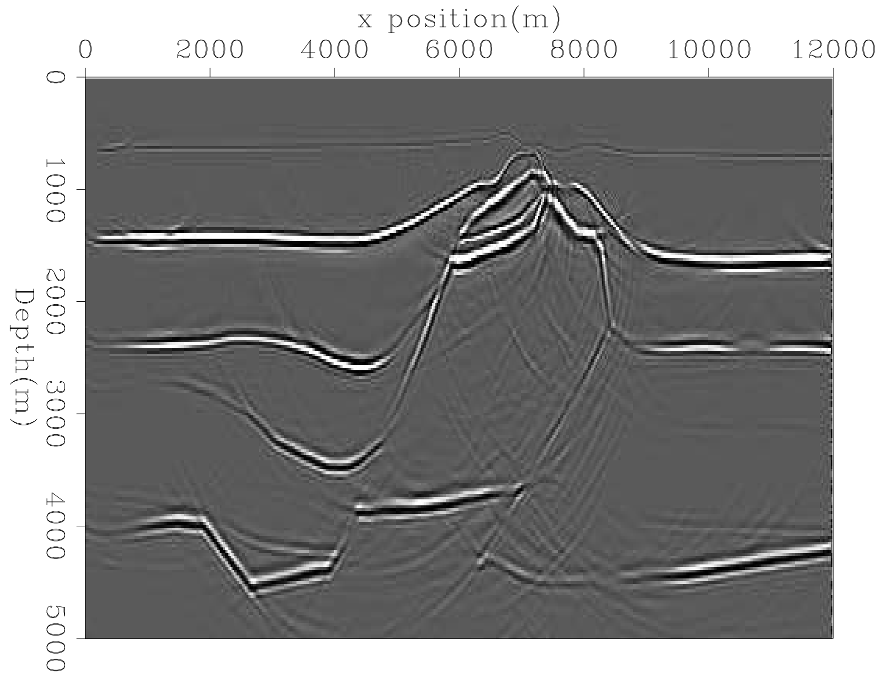

Figure 5: PSDM synthetic result using the eikonal solver to find traveltimes marie1-stack.v [CR]

reflector. The next task was to determine what range of offsets contributed to the energy received from this area. From Figure 6 it appears that there is some coherent energy in a mid-offset range. Figure 7 shows that the near offsets (160 m - 1560 m) do not contribute, nor do the offsets beyond 2360 m (Figure 8). Figure 9 shows the mid-offset range that does contain the energy from the area we are interested in. The offset range that does contribute is between 1560 m and 2360 m. This compares favorably to the coherent energy visible in Figure 6. Since we know that some energy

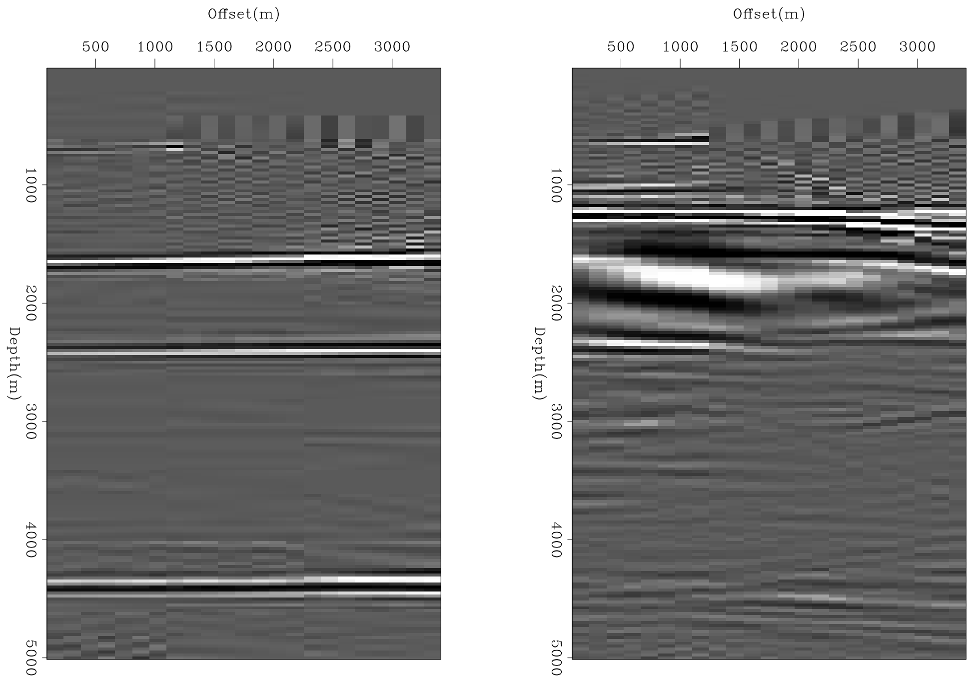

Figure 6: Left: common reflector point gather taken from surface location 10000 m showing flattened events. Right: CRP gather taken from surface location 8350 m with reflector of interest missing at near and far offsets, also residual curvature of events. Note that the synthetic data is shifted approximately 1000 m in the positive x direction in comparison with the real data (Figure 1). marie1-crpgather [CR]

gets through to this portion of the reflector, the next question is where does it go? To answer this, we placed a point source on the reflector at the point of the mysterious gap and traced rays from the reflector to the surface. Figure 10 shows the resulting irregular energy spread at the surface. This figure seems to indicate that illumination coverage may be improved by using wider offsets. However, this is an acquisition decision, not a processing one.

FUTURE WORK

The problem with illumination in this case is clear. It may be possible to examine it further by finding traveltimes from the synthetic model with a more sophisticated

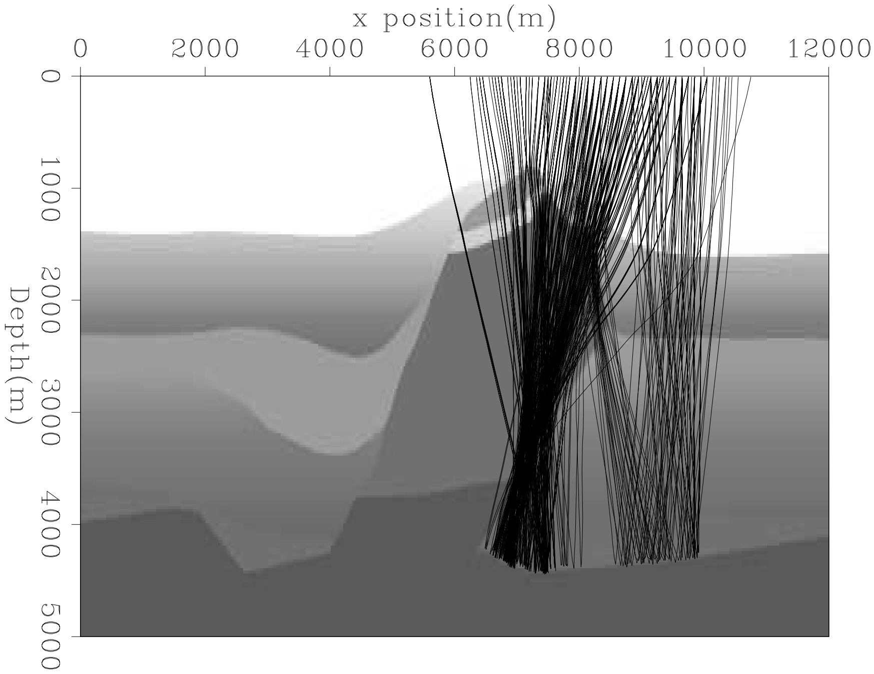

Figure 7: Raypaths through the synthetic model, only near offsets marie1-overlay2.near [CR]

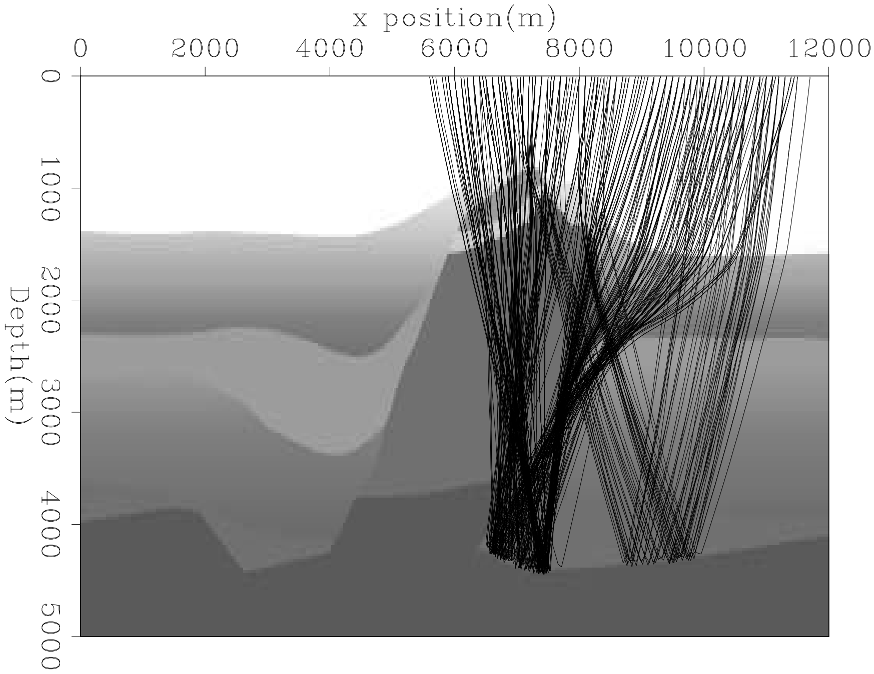

Figure 8: Raypaths through the synthetic model, only far offsets marie1-overlay2.far [CR]

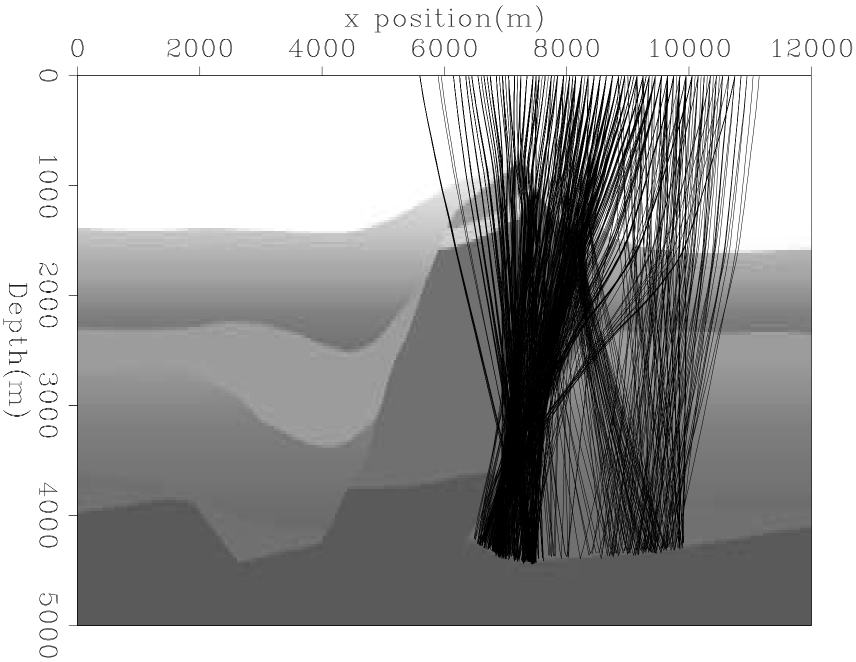

Figure 9: Raypaths through the synthetic model, showing the range of offsets that do receive energy from the section of the reflector under the edge of the salt body marie1-overlay2.mid [CR]

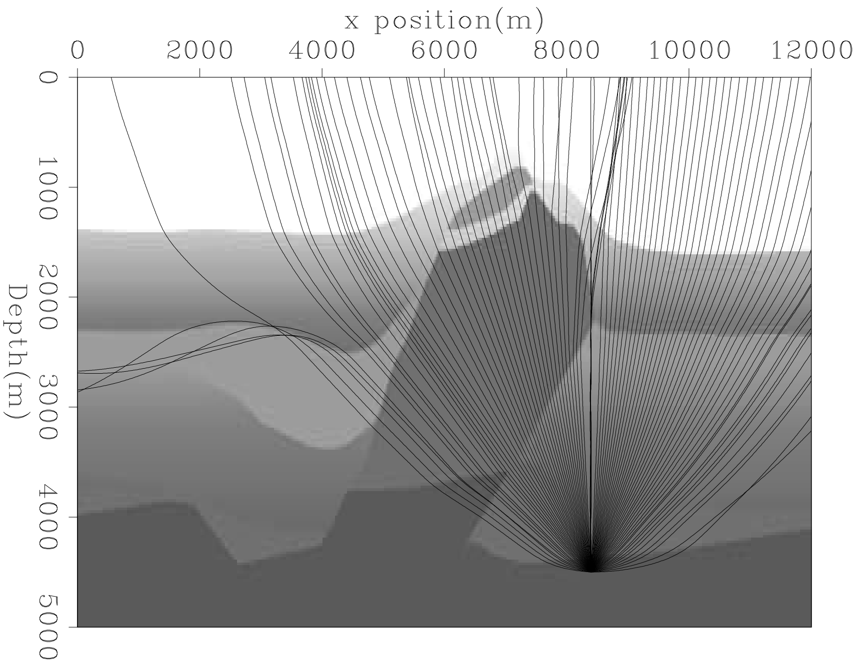

Figure 10: Raypaths from a point source located at the problem spot on the reflector marie1-rayup.8445 [CR]

raytracing algorithm that utilizes maximum amplitudes and/or multiple arrivals. This won't solve the problem but might be useful. One of the most obvious solutions is to simply weight the appropriate offset range before stacking. It would be fairly easy to weight the offsets according to the amount of illumination they provide to the region in question. This would be a fast and easy way to increase the amplitudes along the missing part of the reflector. This is obviously not a perfect solution but it is a possibility. In addition to the offset weighting, inversion is an option. Presently there is a substantial amount of noise and artifacts obscuring parts of the reflector. If this noise can be attenuated by the inversion process, the small amount of energy we receive from the shadow zone may be visible. Also, the inversion process will help correct for inconsistent ray coverage along the reflector. Future investigations may also include the use of common angle gathers rather than common offset gathers. Common angle gathers provide a more equalized amplitude versus angle panel (Xu et al., 1998). This may allow us to see the weak events that must exist in this shadow zone but are obscured by noise and/or migration artifacts. Actual solutions to this problem are sensitive to our knowledge of the velocity field. Obviously with the synthetic model this is not a great concern but when we begin work on the real 3-D dataset it will be a factor. Further analysis and velocity refinement might be needed for any of the solutions implemented.

CONCLUSIONS

The analysis of the synthetic model clearly indicates that the fading/disappearing phenomenon seen in the migrated section of the real data is due at least partially to poor illumination. Fortunately, it is also apparent that some energy does get through to this reflector. Since there is energy arriving from the reflector, we should be able to image it by using weighting, inversion, and/or common angle gathers. Ultimately the methods developed while dealing with the 2-D synthetic dataset must be applicable to the real 3-D dataset.

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