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Short Note

Migration and modeling of seismic data affected by focusing-effect AVO/AVA

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INTRODUCTION

Focusing-effect AVO or AVA is the phenomenon of velocity and/or absorption lenses creating substantial amplitude variations, but only small traveltime anomalies (Kjartansson, 1979). The patterns thus created can interfere significantly with AVO/AVA caused by lithological contrasts at the reflector. To render amplitude analysis feasible, these patterns need to be removed from the image. I will use the acronym "FEAVO" to refer to focusing-effect AVO or AVA in general, reserving "FEAVA" only for specific references to the angle domain. These terms refers only to amplitudes focusing through heterogeneities smaller than the Fresnel zone, as formalized by Spetzler et al. (2004), and which do not cause energy to be lost by sending it outside the finite spatial extent of the seismic survey (i.e., "illumination problems"). Focusing can be positive (usual meaning of term) or negative (i.e., in the case of absorption).

Vlad and Biondi (2002), Vlad (2002), Vlad et al. (2003) and Vlad (2004) have conjectured that the key to removing FEAVO is creating an accurate velocity model that contains the lenses which cause the focusing, then performing one-way wavefield extrapolation migration with this velocity model. I will present a qualitative proof of this statement. I will also analyze the peculiarities of modeling FEAVO effects with one-way or two-way wavefield extrapolation algorithms.

MIGRATING FEAVO-AFFECTED DATA

I will use in my heuristic a constant background velocity model with a FEAVO-causing heterogeneity and a single horizontal reflector of reflectivity one. Since the small size of the heterogeneity localizes the effects it produces, it makes possible to indicate only the presence of focusing in a binary fashion (yes/no). The heterogeneity can be thought of either causing absorption or lens-like focusing by a small amount.

The presence of focusing will be reported to the appropriate *midpoint*, not to the receiver location. This is done because the midpoint coordinate is orthogonal to the offset coordinate

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in the prestack data space.

The figures below feature straight rays which may seem to indicate constant velocity. However, this takes place only for ease of drawing; the reasoning that follows does not require constant velocity. I will also consider a single signed offset *h*. The mental experiments to be performed below will be identical both for any other offset and for the prestack dataset taken together.

Figures 1 and 2 show a seismic experiment decomposed into two separate steps. In the

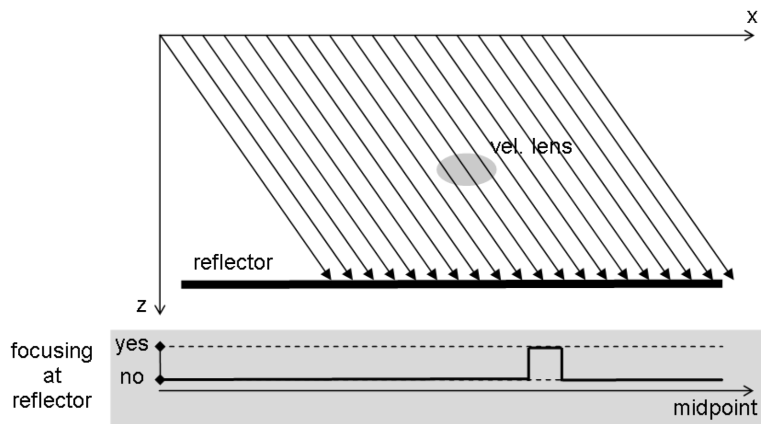

Figure 1: Single offset seismic experiment – part 1: propagation from sources to reflector, and graph with focusing at the reflector nick1-f1 [NR]

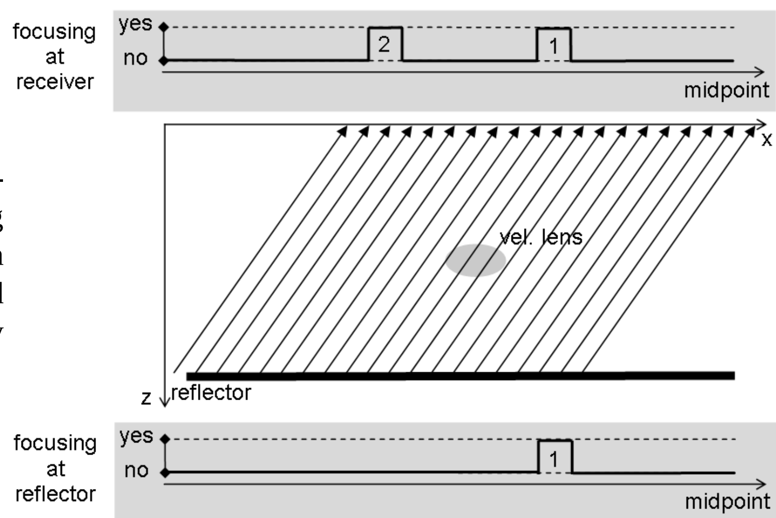

Figure 2: Single offset seismic experiment – part 1: graph with focusing at the reflector (bottom), propagation from the reflector to the receivers, and graph with focusing as recorded by receivers (top) nick1-f2 [NR]

first step (Figure 1), the wavefield propagates from the sources to the reflector. Only a single midpoint local area is affected by focusing. In the second step (Figure 2), the wavefield propagates to the surface. Already existing focusing is preserved, and a new pass through the heterogeneity causes a second focusing area to appear. The focusing areas detected by the receivers at the surface are reported at the appropriate midpoints (not receiver locations) in the upper graph. The two midpoint local areas in which focusing is present are located at the intersection of the two arms of a midpoint-offset "Kjartansson V" (Kjartansson, 1979) with a line of constant offset *h*.

At this point one could make the argument that migration by definition recovers amplitudes at the reflector, and it cannot solve illumination problems, so effect 1 in Figure 2 will not be removed by migration, and one should instead try a regularized inversion that will smooth out small irregularities. Let us however examine more closely what happens with the energy from that offset when we do shot-profile migration using all shots.

Downward continuation of the shots wavefields is properly described by Figure 1 and will produce at the reflector, as expected, the same focusing as the real experiment. Downward continuing the receivers (Figure 3) with the correct velocity (which includes both the background

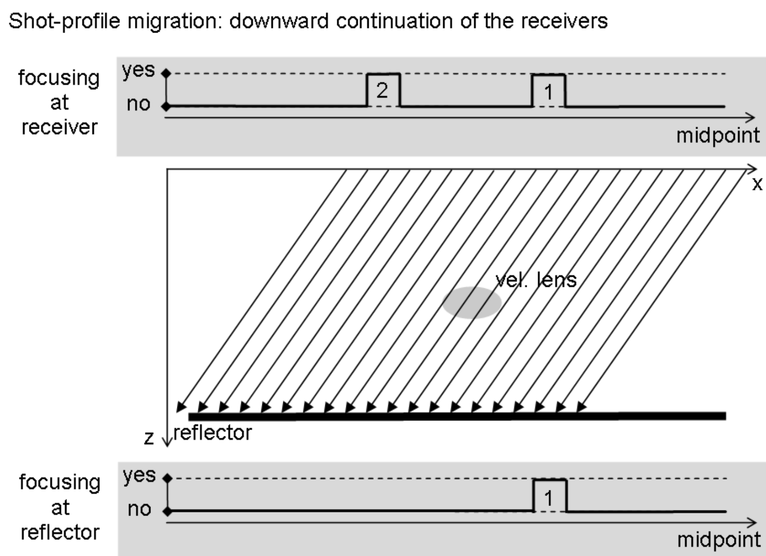

Figure 3: Downward continuing the receivers in shot-profile migration: graph with focusing as recorded in the data (top), downward continuation with the correct velocity through the heterogeneity, and graph with residual focusing at the reflector (bottom) nick1-f3 [NR]

and the heterogeneity) eliminates focusing area 2, but leaves focusing area 1 intact. What the objection stated in the previous paragraph failed to take into account, though, is the imaging condition (Figure 4). The imaging condition, taken as a black box, is not sensitive to the par-

Figure 4: The wavefields need only be *similar*, not *uniform*, in order for the imaging condition to produce a uniform-amplitude (no focusing) reflector. nick1-f4 [NR]

ticular values of either the shot wavefield or the receiver wavefield, but to how close they are to each other. If at one location they are identical (for this idealized experiment we can use the word “identical”), it reports a reflection there with a probability (a.k.a. reflection coefficient) of 1. In our case (Figure 4) the shot wavefield and the receiver wavefield are identical in every point, and therefore the uniform value of 1 for reflectivity is recovered. Shot-profile migration with all sources therefore completely eliminates FEAVO from the image if the correct velocity is provided. Survey-sinking migration, being mathematically equivalent to it (Biondi, 2003), also eliminates FEAVO if the velocity is provided.

MODELING FEAVO-AFFECTED DATA

It is not very straightforward why one-way wavefield extrapolation schemes would cause problems with modeling FEAVO, while they are fine for the adjoint of modeling, migration. There are however differences. Some operations can be irreversible (in the information theory meaning of the word) even if they have an adjoint. For example, summation of several values ("state 1") into a single one ("state 2") has the spreading of the sum as an adjoint. But a large quantity of information (all the frequencies except the zero one) was lost when summing, and spreading cannot recover that. State 2 simply has less information (and more entropy) than state 1, and anything we do to state 2 cannot reverse that (i.e. spreading only recovers the zero frequency). A related phenomenon happens during the imaging condition. Shot-profile migration, in the example previously described, has information on the source wavefield and receiver wavefield before they are combined during the imaging condition. The new state (after the imaging condition) has less information than the old one, and when trying to go back, we cannot recover lost information *without paying more* in computational expenses. What errors were introduced by the loss?

Exploding-reflector modeling with the one-way wave equation is a popular way of generating seismic data. At each depth level, the reflectivity values are spread to all offsets, added to the wavefield being upward propagated from below, then the wavefield is marched upwards to the next level. The fact that the wavefields travel along only a single propagation leg is accounted for by halving the velocity, effectively multiplying the traveltimes by two. This produces correct traveltimes, correct geometry of FEAVO patterns (Kjartansson V's), and the FEAVO in the resulting data is eliminated by migration. The problem is that focusing, while localized when compared to the size of the survey, is not a binary condition. Figure 5 shows the details. If only pure absorption is involved, it would not matter whether the heterogeneity lied closer to the beginning than to the end of the travel path: multiplication of amplitudes by an absorbtion factor is commutative. But if velocity is at play, as it is often the case, then the microscale of the effects (assumed to be divergent in the figure) will look different if: (A) the wavefront goes along legs 1 and most of 2 and then encounters the velocity anomaly, as in the real experiment, or (B) it travels only along leg 2 in the numerical experiment and the traveltimes are multiplied by two. The microcharacter of the FEAVO effects will look different than for real data. This is a second-order effect only, but it is real. It can be ignored if the scope of the analysis is of a larger scale, but it can be important in particularly amplitude-sensitive processes, such as Wavefield-Extrapolation Migration Velocity Analysis, which inverts amplitude anomalies into velocity updates. There are only two cases when the approximations of one-way modeling are not a problem. The first is when the anomalies are purely due to absorption. The second case is when migrating the modeled data with the correct velocity and with an imaging algorithm close in accuracy (adjoint if possible) to the one used in modeling. In other cases, especially when studying the behavior of FEAVO itself, this effect should be taken into account. Two-pass one way or two-way wave equation algorithms should be used

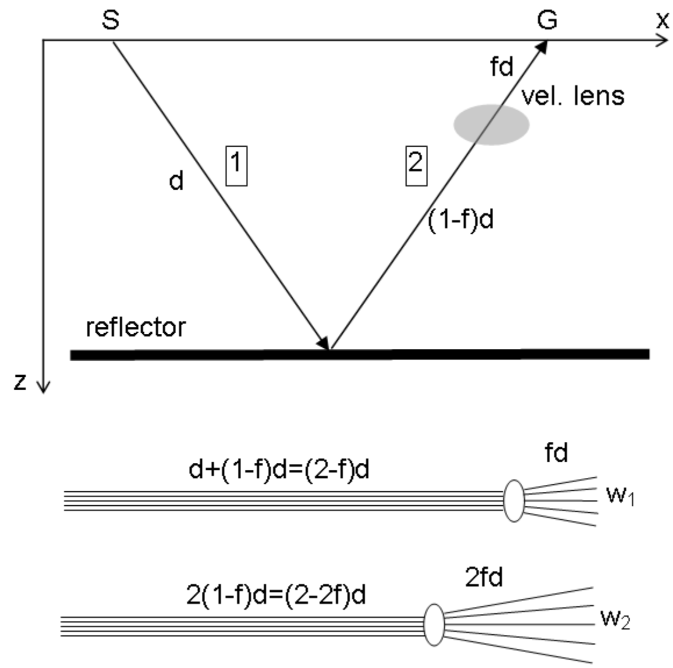

Figure 5: Performing a real experiment or two-way modeling, in which the energy travels along leg (1) then along leg (2) produces a focused beam of width w_1. This can be different from the beam of width w_2 produced by doubling traveltimes obtained by one-way modeling, even if at a scale at which the width of the beams is negligible, the travel paths are identical. nick1-f5 [NR]

for FEAVO modeling in such cases.

CONCLUSIONS

This paper presented a qualitative proof that focusing-effect AVO/AVA (FEAVO/FEAVA) can be removed from the seismic image just by a single pass of one-way wavefield extrapolation migration. Modeling such data is more complicated. If just correct-velocity images of the modeled data were needed, then the data could be modeled with one-way exploding-reflector schemes. If data needed to be analyzed before migration, or if incorrect velocities were used for migration, then modeling should be done with a two-way scheme, or a two-pass, one-way one.

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REFERENCES

Biondi, B., 2003, Equivalence of source-receiver migration and shot-profile migration: Equivalence of source-receiver migration and shot-profile migration:, Soc. of Expl. Geophys., Geophysics, 1340–1347.

Kjartansson, E., 1979, Analysis of variations in amplitudes and traveltimes with offset and midpoint: SEP–**20**, 1–24.

Spetzler, J., Jocker, J., Smeulders, D., and Trampert, J., 2004, Validation of first-order wave diffraction theory by an ultrasonic experiment:, *in* 74th Ann. Internat. Mtg. Soc. of Expl. Geophys., 2180–2183.

Vlad, I., and Biondi, B., 2002, Velocity estimation for seismic data exhibiting focusing-effect avo: SEP–**111**, 107–123.

Vlad, I., Biondi, B., and Sava, P., 2003, Velocity estimation for seismic data exhibiting focusing-effect AVO (part 3): SEP–**114**, 101–110.

Vlad, I., 2002, Velocity estimation for seismic data exhibiting focusing-effect avo (part 2): SEP–**112**, 47–64.

Vlad, I., 2004, Velocity estimation for seismic data exhibiting focusing-effect avo (part 4): SEP–**115**, 265–272.