Preservation of AVO after migration

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Summary

This study investigates the effects on Amplitude Variation with Offset (AVO) by migrations of a number of 3D common shot gathers of varying degrees of decimation. It is meant to qualitatively determine proper acquisition parameters. That is, what is the optimal source-receiver configuration in terms of original cost and final images? To carry this out, a simple horizontal model with 3 distinct layers of AVO anomalies has been created. Seismic data from this model were created with varying degrees of decimation, which were then migrated using a Kirchhoff migration technique derived from the theory of Born Inversion. The expected amplitudes of each experiment were then compared, and some simple inversion tests undertaken. Eventually, a more complicated model will be studied. It is the intent of this paper to ensure that ample data is collected at all times in order to introduce unnecessary artifacts, or even worse, erroneous features into the final seismic images, and thus reduce the possibilities of making a poor decision on what to do with the original data.

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Introduction

With the advent of 5D Interpolation(Trad, 2009), shooting correct seismic data has potentially become a less costly proposition for 3D surveys. However, 5D interpolation is not guaranteed, and according to Gespert(2002), there is no substitute for proper acquisition. For this reason, we and a host of others believe that more analysis should be done to put a numerical value on dealing with acquisition. This paper is based on the work of Cooper (2010), and utilizes a simple horizontal structure to examine the effects of decimation on final amplitudes.

The data includes 3 layers of 100 m thickness carrying an AVO 3, 1 and 2 anomalies respectively, interspersed with 100 m padding layers having the same properties as the background medium. This background has values of 2000 m/s, 879.33 m/s and 2400 kg/m3 for the p-wave, s-wave and density, respectively. *Table 1* shows the velocities and densities of the three AVO anomalies, as well as the values of the background medium.

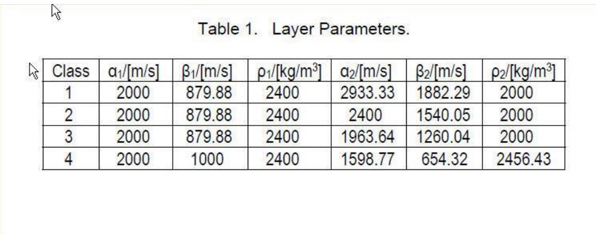

Table 1. Layer Parameters.

Class	α_1/[m/s]	β_1/[m/s]	ρ_1/[kg/m^3]	α_2/[m/s]	β_2/[m/s]	ρ_2/[kg/m^3]
1	2000	879.88	2400	2933.33	1882.29	2000
2	2000	879.88	2400	2400	1540.05	2000
3	2000	879.88	2400	1963.64	1260.04	2000
4	2000	1000	2400	1598.77	654.32	2456.43

Table 1 Parameters of data being examined

The associated well logs for this experiment are shown in Figure 1 and were used to create a 2D data seismic set via Elastic Modelling as described by Kennet (1979) and Mueller (1985). Notice that this model is based on the data proposed by Simmons & Backus (1984). Also, the maximum depth of this data set is 2500 m.

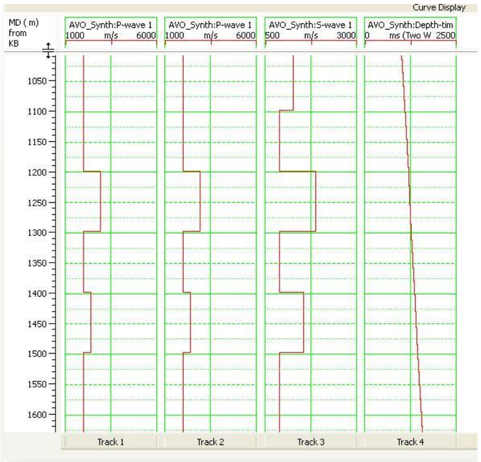

Figure 1 Well logs of data model being examined

3D shot records were then created from this 2D data set according to the varying degrees of decimation, followed by a subsequent migration in the hope of reproducing the Zoeppritz plot shown in *Figure 2*.

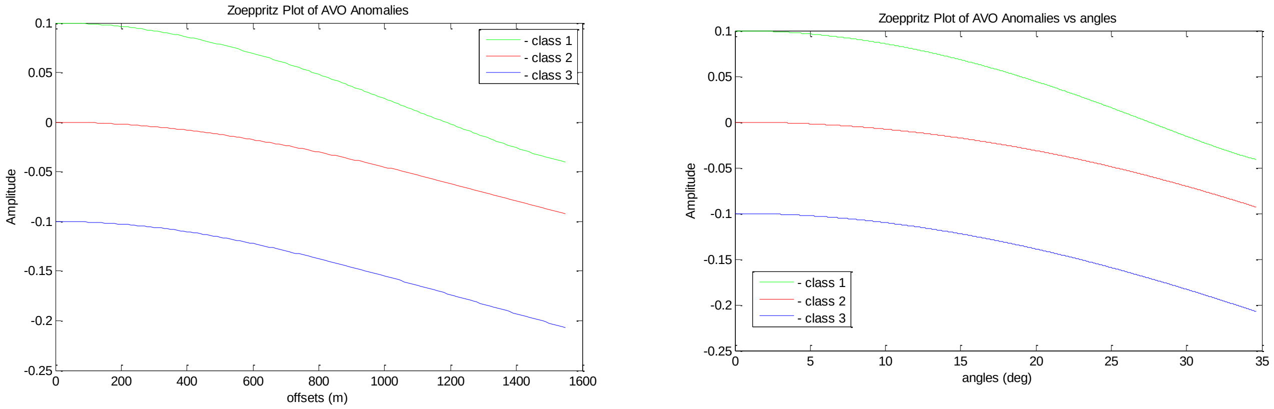

Figure 2: *Expected Zoeppritz plots after migration*

Theory and/or Method

The shot records were created by resorting the traces in the 2D Elastic Modelling data into an orthogonal grid of 1000 by 1000 m, with shot and receiver line spacing being varied to account for the correct decimation. These shot records were then inverted with Kirchhoff migration algorithms based on the theory of Born inversinon as detailed by Bleistein et. al.(2001). The algorithm being used is an implementation of the following reflectivity function(Bleistein et. al., 2001, p. 227) for determing an image point of a subsurface:

$$\beta(\mathbf{y}) = \frac{1}{8\pi^3}\int d^2\xi \frac{|h(\mathbf{y},\boldsymbol{\xi})|}{a(\mathbf{y},\boldsymbol{\xi})\left|\nabla_y \emptyset(\mathbf{y},\boldsymbol{\xi})\right|} \cdot \int i\omega d\omega e^{-i\omega\emptyset(\mathbf{y},\boldsymbol{\xi})} u_{S(\mathbf{x}_g,\mathbf{x}_s,\omega)} \quad (1),$$

Where

$\beta(\mathbf{y})$ = the reflectivity at an image point **y**, i.e. some (x,y,z) point in Cartesian Coordinates

$|h(\mathbf{y},\boldsymbol{\xi})|$= the Beylkin determinant

$a(\mathbf{y},\boldsymbol{\xi})$ = the amplitudes for both source and receivers, as per Transport equation

$\emptyset(\mathbf{y},\boldsymbol{\xi})$ = the total traveltime, as per Eikonal equation (Shearer, 1999, Appendix 3)
$u_{S(\mathbf{x}_g,\mathbf{x}_s,\omega)}$ = the scattered wavefield being inverted for, with $\mathbf{x}_g$ and $\mathbf{x}_s$ denoting the source and receiver positions, If one takes the Beylkin determinant, the amplitudes and the total travel time together, i.e.
W= $\frac{|h(\mathbf{y},\boldsymbol{\xi})|}{a(\mathbf{y},\boldsymbol{\xi})|\nabla_y \emptyset(\mathbf{y},\boldsymbol{\xi})|}$,(2)
These weights can be determined based on common shot, receiver or offset. In the case of this document, we will be looking at only common shot migration.

Note that the actual inversion is greatly simplified if one assumes a constant velocity medium. However, when accounting for a v(z), and using the weights for W above proposed by Zhang et. al. (2000), results can be seen to be significantly better (Lahr, Margrave & Liu, 2016). The drawback is greater computing time. However, this can be reduced by using parallel computing technologies, and setting up the weights in a lookup table based on offsets.

The actual experiments were carried out on data sets with shot and receiver line spacing of 10, 50, 100 and 200 m respectively. The shot and receiver spacing remained at 10 m.

Examples

To illustrate the simple effect of decimation on amplitudes, a shot record at x = y = 0 m and their respective migrated images are shown in *Figure 3*, where each image represents a slice occuring at the AVO 3 layer beginning at 300 m depth corresponding to the levels of decimation noted above.

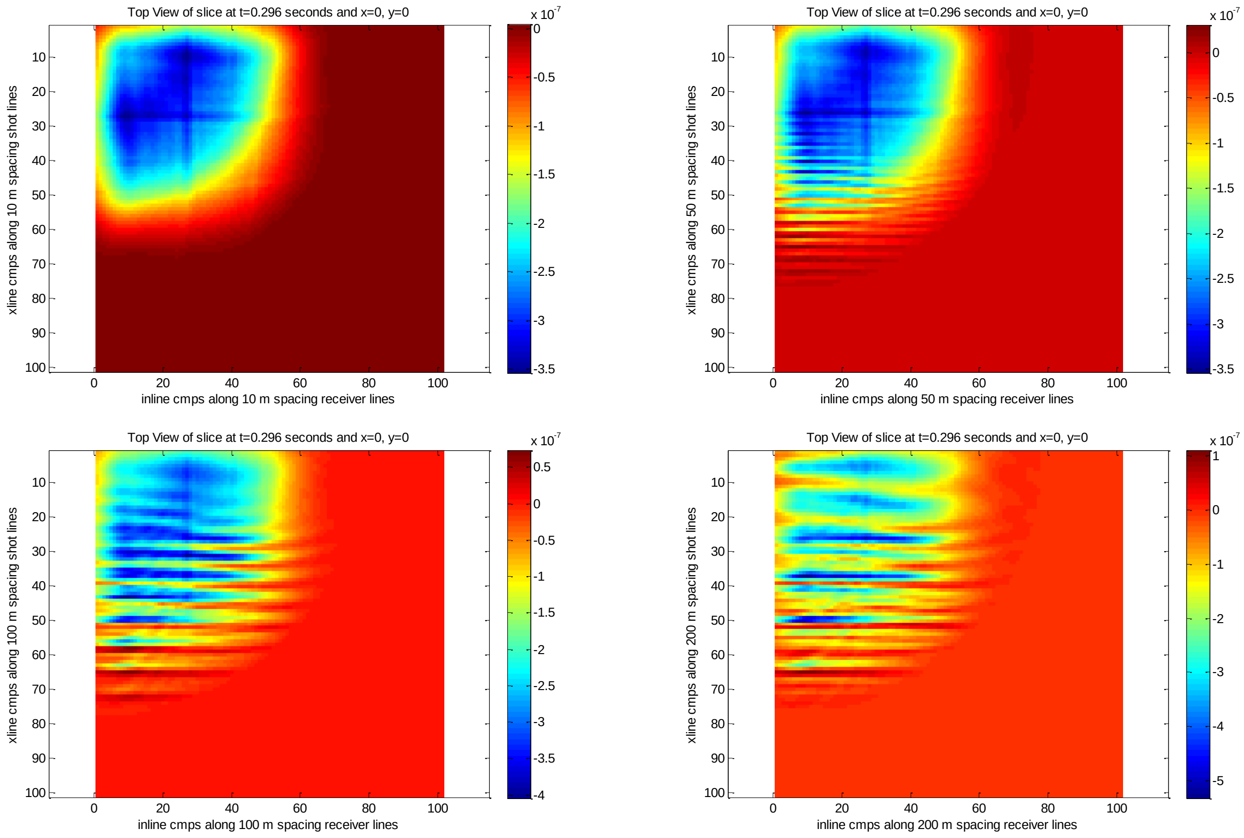

Figure 3: Slice for shot at x=y=0 at 298 ms after migration, from left to right, top to bottom, line spacing of 10, 50, 100 and 200 m respectively.

How the amplitudes compare to the expected Zoeppritz plot for an AVO 3 anomaly is shown in *Figure 4*

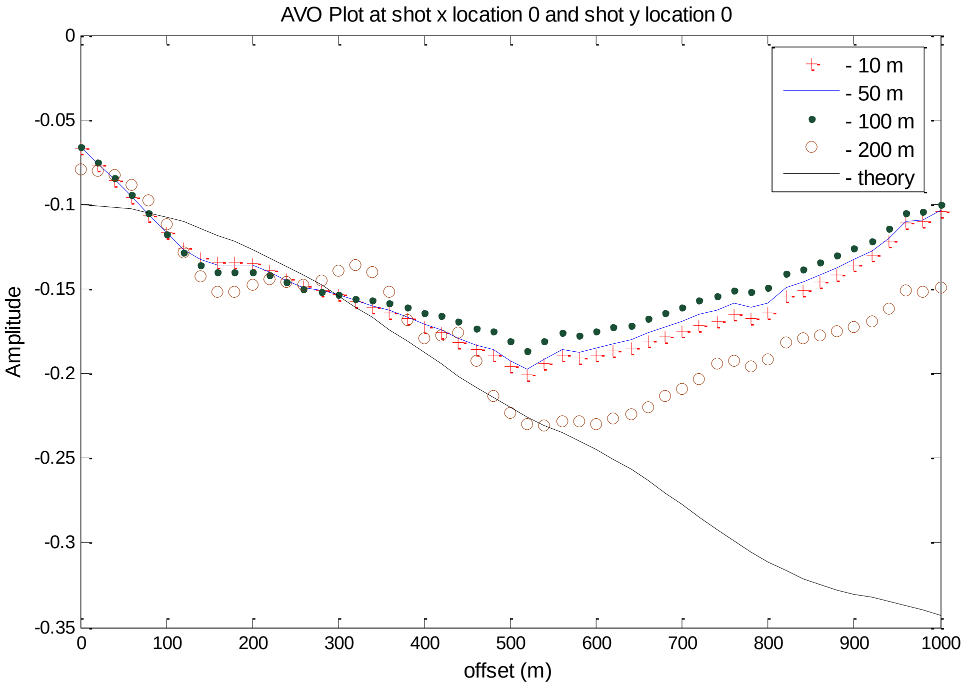

Figure 4: Amplitude curves for line spacings of 10(black), 50(green), 100(blue) and 200(magenta) m.

As can be seen in Figure 4, none of the amplitudes for the respective line spacings have been properly restored. As well, a significant edge effect can be observed for all of the different line spacing. However, one can see a clear degradation of the migrated amplitudes as the line spacing increases, as one would expect the migrated amplitudes to closely follow the expected Zoeppritz trend. So, as expected, the amplitudes migrated at 10 m line spacing, are restored the best, while the line spacing at 200 m are the poorest. It is surprising to note that the data for the 200 m line spacing follows the general trend of the Zoeppritz curve longer than the other curves. It does have a far greater error than the other three lines, all of which seem to hug the Zoeppritz curve reasonably well.

Conclusions

We have shown that proper amplitude restoration using migration will deteriorate with increased line spacing for a simple horizontal model of several AVO layers. Keeping in mind that the model used here is incredibly simple, we feel that further study is warranted with more complex data. Tests to see how simple inversion tests are effected by the decimation noted here are in the process of being carried out. Also, ideas about how 5D interpolation can help improve the above results are being considered.

Acknowledgements

CREWES

Dr. Sam Gray and Dr. Daniel Trad for their input

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