AAPG Datapages/Search and Discovery Article #90174 CSPG©2014 CSPG/CSEG/CWLS GeoConvention 2012, (Vision) May 14-18, 2012, Calgary, AB, Canada

Effects of lateral heterogeniety scales on AVO trends

Ramin Saleh*, Department of Physics, University of Toronto, Toronto, Ontario
rsaleh@physics.utoronto.ca
and
Emmanuel Bongajum, Department of Physics, University of Alberta, Edmonton, Alberta
bongajum@ualberta.ca
and
Bernd Milkereit, Department of Physics, University of Toronto, Toronto, Ontario
bm@physics.utoronto.ca

Summary

Amplitude Versus Offset (AVO)-trends and variations are often used in hydrocarbon exploration as fluid/gas indicators. The importance of possible effects of lateral heterogeneity scales on AVO analysis has been mentioned in previous studies but never studied in detail using the conventional common mid point (CMP) analysis. In this work we use elastic forward modeling to investigate the relationship between the AVO responses and heterogeneity scale. A comparison of the AVO modeling results from synthetic stochastic models of gas hydrate reservoirs with the classical one, confirms that heterogeneity will modulate or destroy simple AVO trends in land-based multichannel seismic data.

Introduction

AVO analysis can be an important application for exploration projects when dealing with reservoirs (e.g. gas-hydrate) characterized by large horizontal boundaries and layering. The sensitivity of AVO to the layered structure may also provide information about the lateral extension of gas-hydrate zone. The framework for AVO analysis is grounded in the propagation plane waves. It is generally understood that systematic amplitude variations with offset/angle (AVO/AVA) depend on changes in the P-wave velocity(Vp), S-wave velocity (Vs), density and Poisson's ratio at a plane interface (Young and Braile, 1976). AVO-trends and variations are used in hydrocarbon exploration as fluid/gas indicators (Castagna et al., 1998; Shuey, 1985). However, the simple 2-layer plane wave approximation may lead to potential pitfalls in the interpretation and inversion of AVO trends (Allen and Peddy, 1993). This can be attributed to the fact that amplitudes of the reflections depends on the source-receiver offset, the depth and geometry of the reflecting boundary as well as the constituents of the boundary. Therefore it is also referred to as Amplitude Variation with Angle (AVA), as the angle is a factor in determining the reflection amplitudes (Kolos, 2009). Various gas-hydrate models for AVO analysis have been studied before. These models include a simple two layer model, a layered model with sharp contrasts and stochastic models where the heterogeneity of the gas hydrate zone is defined by varying levels of horizontal correlation length (Kolos, 2009 & Milkereit et al., 2011). However, AVO analysis in the CMP domain for these heterogeneity models has not been done yet. The fact that AVO analysis is based on CMP gathers emphasizes the importance of investigating the problem in the CMP domain.

Zoepptritz equations make an assumption that the incident wave is planar. This is only a good approximation if the scale of the experiment is very large, however in reality plane waves are difficult to find and point sources have curved wave fronts (Kolos, 2009). In the heterogeneous situation, however, the lateral variation in the distribution of the gas hydrates will invalidate the above approximation. Consequently, this study probes the critical situation, where the Zoeppritz AVO model breaks down.

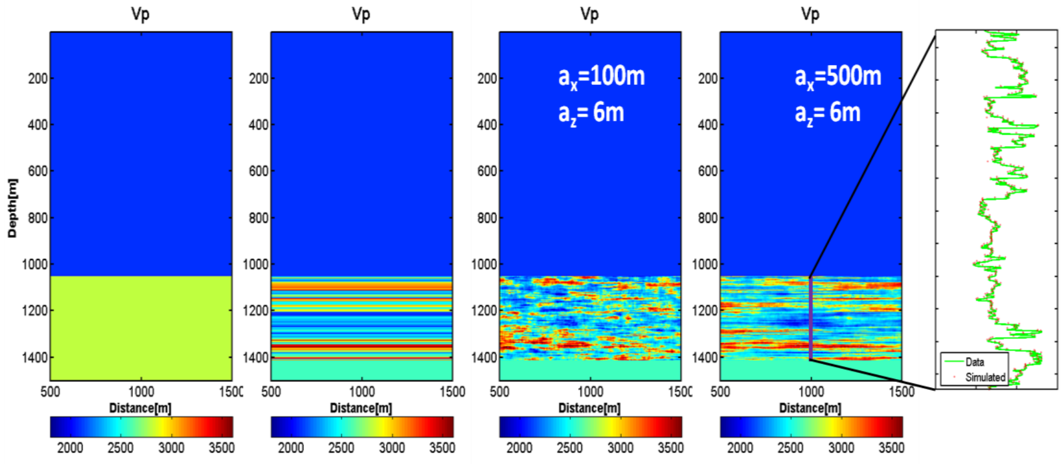

Fig1: P-wave velocity models for studies of AVO trends from a gas hydrate reservoir model From left to right: a) 2-layer reference model; b) layered gas hydrate model; c) small-scale velocity model; d) large-scale velocity model; e) velocity log from reservoir matches models. [From Milkereit et al., 2011].

Method

Seismic models were created with variables P-wave velocity, S-wave velocity, and density models. These rock properties were chosen to simulate naturally occurring gas hydrate deposits in the Arctic.

Various explicit staggered-grid finite difference (FD) methods have been developed to model seismic wave propagation in 2D/3D viscoelastic media (Robertsson et al., 1994; Bohlen, 2002). The viscoelastic FD modeling approach can handle complex subsurface structures with high intrinsic attenuation or significant scattering attenuation.

In this study, finite difference modeling was used to obtain AVO data because it allows for complicated sets of reflections and the propagation of non-planar waves. In addition, the finite difference modeling approach can handle P-waves and S-waves, surface-waves, attenuation, scattering, wave conversion, plane and spherical waves, and arbitrary source and receiver locations. For all the models used in this study, the top layer represents fluid-saturated sediments with Vp, Vs and density values of 2100m/s, 900m/s and 2100kg/m3 respectively. The middle layer represent sediments that are completely saturated by gas hydrates, where maximum values approach 4000m/s for Vp, 2000m/s for Vs, while the density remains relatively unchanged (Huang et al., 2009). The average values for these respective parameters are 2630m/s, 1130m/s and 2140 kg/m3 respectively.

The 2D models consist of 6000 by 4000 grid points in x and y direction respectively, with a grid spacing of 0.5 meter. The acquisition geometry consist of 14 shots which are spaced 200m apart, starting from x=200m to 2800m; a surface receiver arrays with 621 receivers at 5 meter intervals. The source signal is a Ricker wavelet, with a central frequency of 50 Hz. The 2D models are simulated using geo-statistical methods (Deutsch and Journel, 1998). Note that heterogeneities are modeled such that they are conditional to the information (well log), which is indicated with thin white line at x=1000m in Figure (2). The spatial scale lengths are obtained by fitting parametric functions to experimental variograms or covariance's derived from existing geophysical data (e.g. logs). The modeling of these spatial fluctuations is based on the assumption that the variation observed at the log scale is stationary (Milkereit et al., 2011).

Note that for source frequencies ranging from $f_{min} = 25Hz$ to $f_{max} = 75Hz$ and for a gas-hydrate reservoir at a depth of 1200m, Fresnel zone radius would be ranging form 440m to 260m.

Consequently, the effect of heterogeneity scale lengths on incident waves form different sources with variable frequencies would be different.

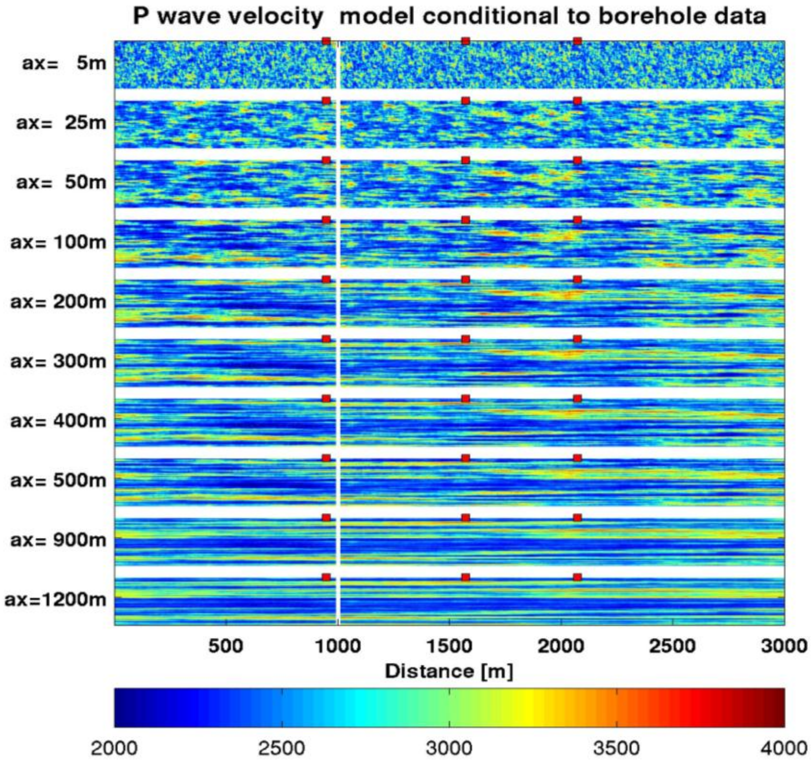

Figure 2: Stochastic models with different lateral heterogeneity scales *ax*, increasing from top to bottom. Note that vertical heterogeneity scale is 6m and is constant for all the models. This scale length is obtained using the borehole data statistics.

For all the models, the highly saturated gas-hydrate layer lies between two fluid-fulfilled sediment layers. The top sedimentary layer starts from the surface and extends to 1200m below. The middle gas-hydrate layer lies between 1200m to 1440m. The bottom sedimentary layer is located between depths of 1440m and 2000m.

The red squares represent the CMP bins chosen for this particular study. The white line in the plot shows the location of the log data. The data condition our statistical model. The log's location is arbitrary and chosen to be x = 1000 m for this particular calculation.

Numerical results and CMP analysis

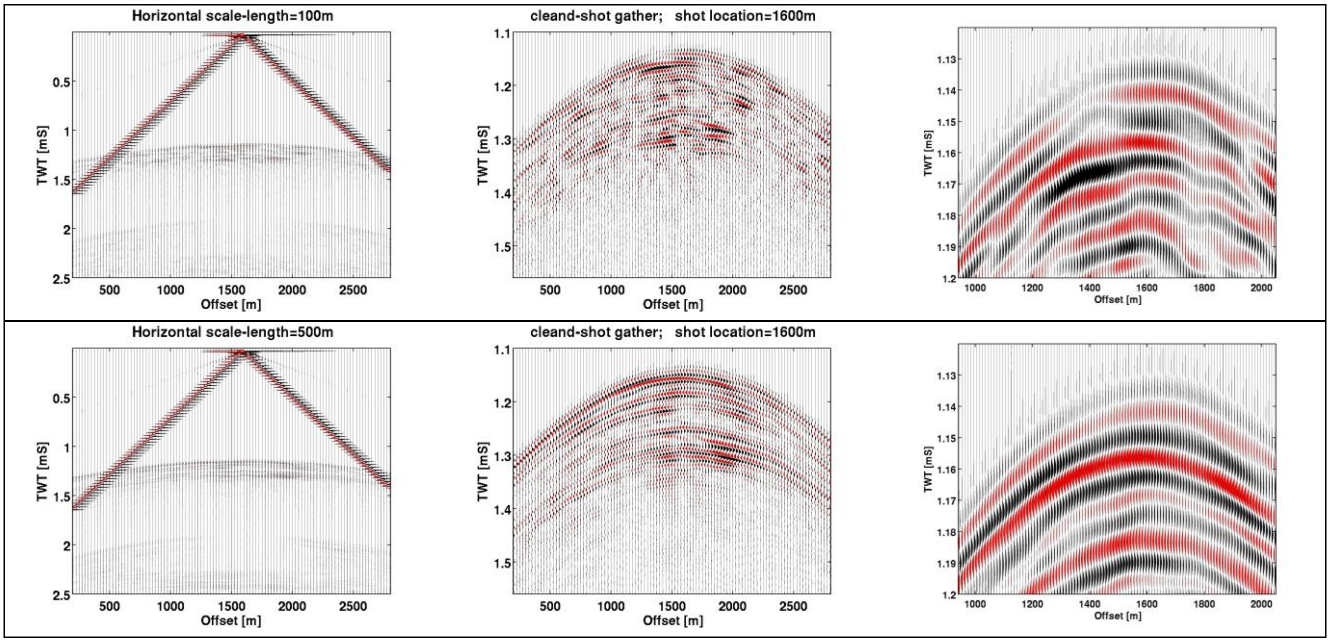

Figure 4: Vertical component of the elastic wavefield models with lateral heterogeneity of 100m(on the top) and 500m(at the bottom). The left column illustrates raw shot data. The middle plot illustrates the data with surface-waves subtracted. Note that PP- reflection amplitudes are not constant. On the right, you can see the zoomed in plot to follow the trends more easily.

Two of the ten statistical models illustrated in Figure (2), have been used as input to the 2D finite difference code. For each model, the surface waves were removed from the data, sorted into CMP bins, and NMO corrected. Figure (4) shows plots of three CMP gathers used for AVO trend assessment. The locations of these CMP gathers are annotated in Figure (2) with red squares. Note that the middle layer initial model is a statistical one, so we have to make an approximation for its properties to derive the classical AVO trends. Two extreme AVO trends are calculated for: 1) pure gas hydrate middle layer and 2) The average model, which represents the mean value of a statistical layer. AVO trends based on Zoepptriz equation predict constant to decreasing trends for azimuths smaller than 30^o. Similar trends are observed in the numerical results. Based on the location of the CMP gather, the trend is changing from decreasing to constant (see Figure (4)). The results suggest that the AVO trends for each CMP gather is sensitive to the complexity of the models

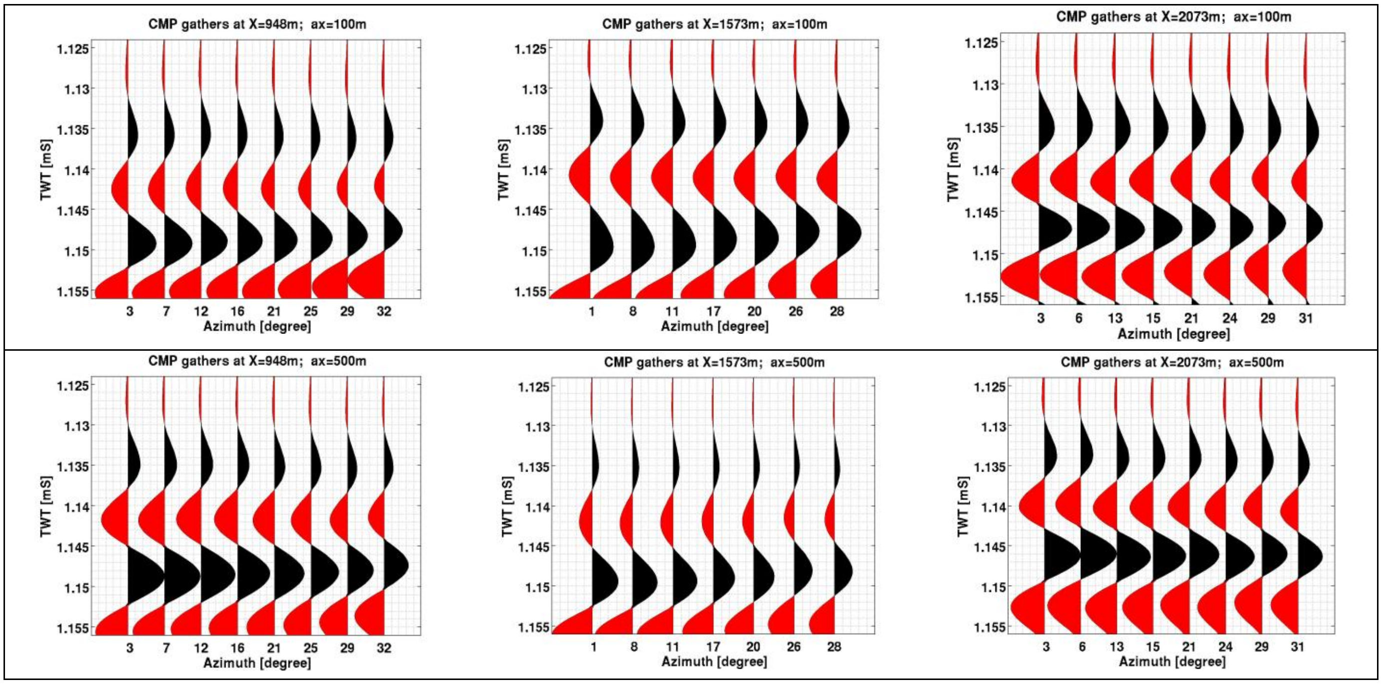

Fig 5: The Vertical component of Common midpoint (CMP) gather data for CMP location at x=948m, 1572.5m and 2072.5m. Plots on the top correspond to a lateral heterogeneity scale length of 100m, and the lower one corresponds to a 500m scale. The AVO-trend on the right and on the left, show a decreasing trend. But the one in the middle shows almost no change in amplitude.

Conclusions

This study shows that once you have introduced heterogeneity at reservoir level, highly variable amplitude trends are expected for reflected waves in both shot and CMP sorted data. Thus AVO trends based on reflections from boundaries with not lateral variability in physical parameters can break down. Detailed studies on the effect of lateral heterogeneity scale length is still ongoing.

Acknowledgements

Funding for this work was supported by NSERC.

References

Aki, K., and Richards, P. G., 2002, Quantitative seismology, theory and methods. University Science Books, 2nd Edition.

Allen, J. L. and Peddy, C. P., 1993, Amplitude variations with offset: Gulf Coast case studies. SEG Geophysical Development Series, 4, 126p.

Bohlen, T., 2002, Parallel 3-D viscoelastic finite-difference seismic modeling. Computers and Geosciences, **28** (8), 887-889.

Dallimore, S. R. and Collett, T. S., 2005, Scientific results from the Mallik 2002 gas hydrate production well program, Mackenzie Delta, NWT Canada. Geological Survey of Canada Bulletin 585.

Huang, J.W., Gilles Bellefleur and Bernd Milkereit, 2009, Seismic Modeling of Multi dimensional Heterogeneity Scales of Mallik Gas Hydrates Reservoirs, Northwest Territories of Canada. Journal of Geophysical Research, doi:10.1029/2008JB006172.

Kolos, D., 2009, Investigations of seismic wave amplitude variations with offset - response of gas hydrate reservoir models. BSc report, Dept. of Physics, University of Toronto.

Shuey, R.T., 1985, A simplification of the Zoeppritz equations. Geophysics, **50**, 609-614.

Young, G. B., and Braile, L. W., 1976, A computer program for the applications of Zoeppritz's amplitude equations and Knott's energy equations. Bull. Seis. Soc. Amer., **66**, 1881-1885.