Seismic Elastic Modelling

Satinder Chopra, Arcis Corporation, Calgary, Canada

2005 CSEG National Convention

Summary

Seismic modeling experiments were performed to understand the seismic responses associated with a variety of subsurface conditions. These include effect of vertical velocity gradient, horizontal velocity gradient, horizontal density gradient, variation in shot depth for reflection response, velocity model dependency on log segmentation, effect of using different wavelets for seismic response and seismic imaging of the top of a reservoir below a gas cloud using a walkaway VSP configuration. Substantial effort was devoted to the different modeling exercises to generate the synthetic data which was later processed for the given objective. Seismic modeling forms an important part of routine and special processing and in quality assurance ands such exercises enhance that understanding.

Introduction

Seismic modeling is essentially the construction of geologic computer models and simulating their seismic wave propagation response. The term *forward modeling* is used to refer to this process. The synthetic seismic traces so generated are then compared with the real seismic data. If there is agreement between the two with an acceptable level of accuracy, the geological model used can be considered as a reasonably accurate model of the subsurface. On the other hand, if the geological models are known with sufficient accuracy, such synthetic responses are used to validate the choice of acquisition and processing parameters and to verify interpretation decisions. Thus seismic forward modeling today forms an important part of routine and special processing and in quality assurance. Besides this, forward modeling of seismic data for complicated structures provides new insights and incentives to develop newer methods of imaging.

The propagation of seismic waves through the real earth is usually studied with the help of the wave equation, which is based on two fundamental laws of physics, *viz.* Newton's second low of motion (f = ma) and Hooke's law of elasticity (relating stress to deformation) (Bording and Lines, 2000, Margrave and Manning, 2004, Krebes, 2004). For a homogeneous elastic medium, combining these two laws gives the following wave equation.

$$\nabla^2 u = \frac{1}{v^2}\frac{\partial^2 u}{\partial t^2}$$

where ∇^2 is the Laplacian and represents the sum of the second order derivatives of the wavefield spatially.

u is the wavefield (for hydrophone recording it would be pressure wavefield)

v is the wave velocity in the medium; also given as the square root of the bulk modulus to density.

$\frac{\partial^2 u}{\partial t^2}$ is the second order derivative with respect to time.

This formulation assumes that particle displacements are small compared with the propagating wavelengths. Sometimes the density is assumed to be a constant, as observations are unable to determine density and so the variation with direction may not be a valid assumption.

The wavefield in elastic media is described by a vector and so solving the wave equation by using say finite-difference techniques would require the computation of all three components of the wavefield at once. This renders the process computationally expensive. To make the process affordable, geophysicists have often considered the acoustic media approximations to the wave equation. The wavefield in acoustic media is represented as a scalar quantity rather than a vector, i.e. the physical quantity propagating in the form of waves can be represented as a scalar (single number) at each location in space and time. The reflection and transmission behaviour of waves in the two media are different. In elastic media at an interface, some of the P-wave energy transforms to an S-wave energy and vice versa, whereas in acoustic media all P-wave energy is conserved. The acoustic wave equation does not yield shear waves and so can be used for modeling zero – offset P-waves.

Seismic wave propagation in the real world media is in many respects different from propagation in an ideal elastic media. Perhaps, the only drawback of the elastic assumption is that it ignores the inelastic nature of the subsurface. Wave attenuation and dispersion significantly affect the amplitude and travel time of the wavefield. Attenuation losses can be considered by including the quality factors Qp and Qs for P and S-waves respectively in the analysis.

So, we can distinguish between the following solutions:

1. scalar wave equation: density is constant, wavefield is a scalar
2. acoustic wave equation: wavefield is a scalar but density varies with direction.
3. elastic wave equation: wavefield is a vector and so both P-velocity, S-velocity and density are taken to be varying.
4. elastic wave equation: wavefield is a vector and so both P-velocity, S-velocity and density are taken to be varying, includes the quality factors Qp and Qs (also referred to as the viscoelastic solution). Anisotropy of the media can also be taken into account in this option.

We used Tesseral modelling software to carry out different modelling options for different applications.

Elastic modeling application to study the effect of velocity variation on seismic response

For a simple layer-cake subsurface velocity model, it is possible to study the P-wave and converted waves on the synthetic response. The snapshots that the software allows one to generate is a great help in this identification, by following the position of the emanating wavefronts as each shot is fired.

Figure 1 shows such a velocity model and the synthetic elastic response. The individual response for the different wavetrains (P-wave:purple, C-wave:blue) is marked. In real situations, velocity and density gradients in both horizontal and vertical directions are encountered. So, introduction of a vertical velocity gradient in layer 3 of the model (Fig. 1(b)) has the effect of reducing the intensity of reflection from the interface corresponding to the base of the third layer. Many other similar exercises were performed.

Application of elastic modelling to a walkaway VSP acquisition

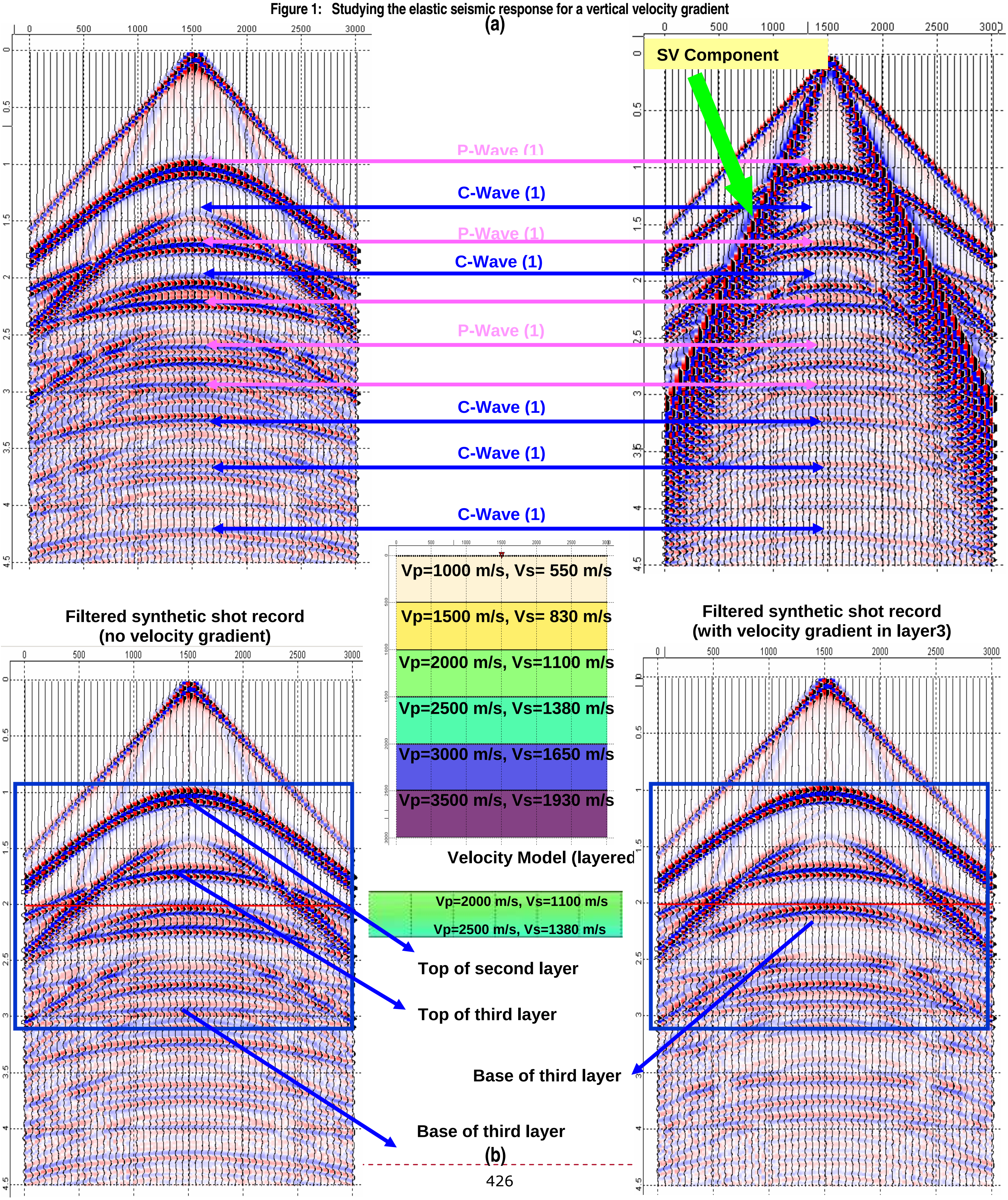
It is well known that the migration of a gas cloud above a reservoir causes serious attenuation and velocity variation problems. The surface seismic data does not image the top of the reservoir under the gas cloud, inspite of all the problems that the processor may face during its processing. So such a real situation was taken as an example to demonstrate how a walkaway VSP could be used as a means for lateral reservoir delineation away from the well.

Walkaway shooting combines the advantages of continuous surface seismic shooting with those of borehole seismics. A subsurface model is required to begin with for designing a survey and making sure that the target area is adequately illuminated. Looking for unambiguous events on the survey data helps refine the model. Finally a satisfactory model can be used in migrating the data.

Figure 2 shows a velocity model depicting a migrated gas cloud above a reservoir that causes severe attenuation and velocity variation problems. The top of the reservoir under the gas cloud will not be seen on the surface seismic data.

The objective of shooting this walkaway was to be able to pick the top of the reservoir away from the well. The shot gather data is sorted into receiver gathers and the weak reflection events are separated from the more energetic direct arrivals.

Figure 1: Studying the elastic seismic response for a vertical velocity gradient



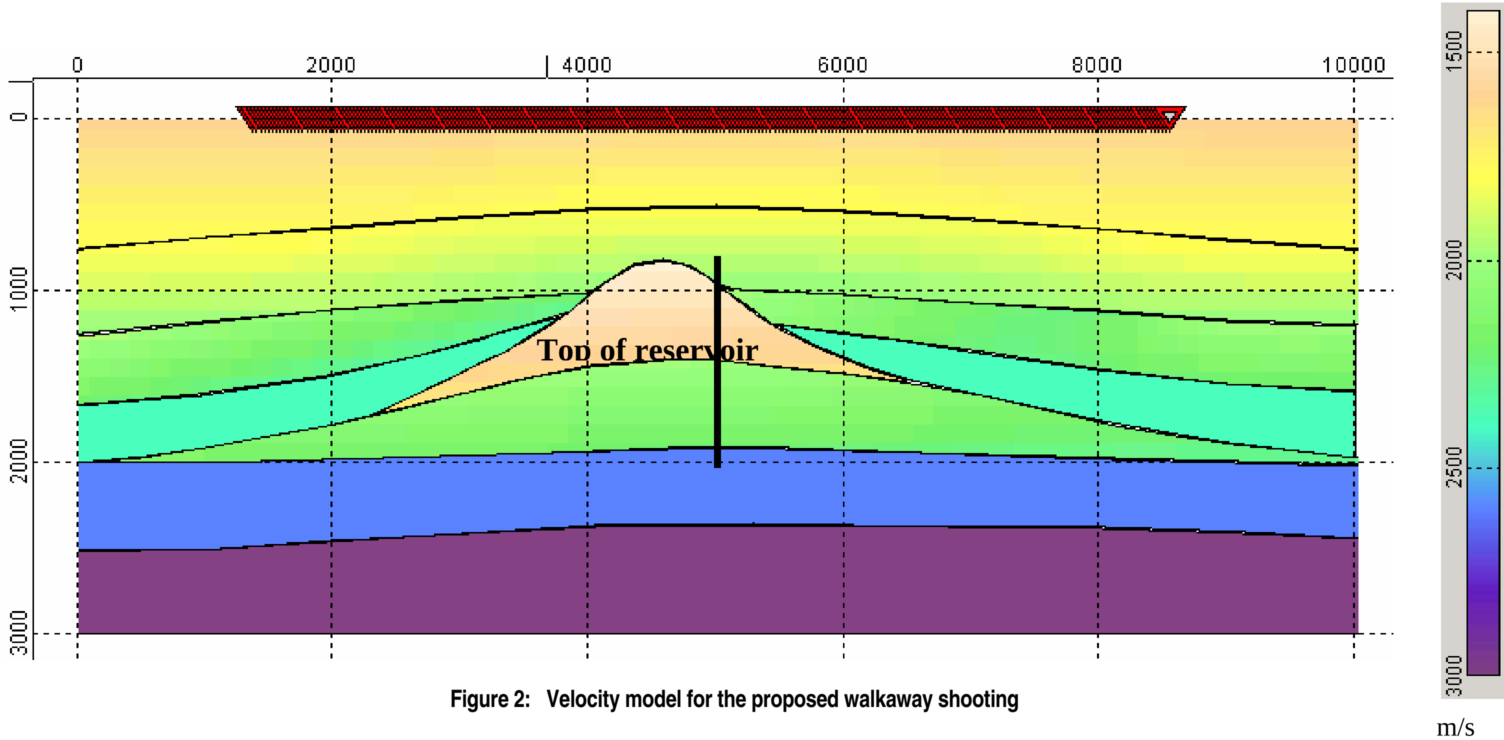


Figure 2: Velocity model for the proposed walkaway shooting

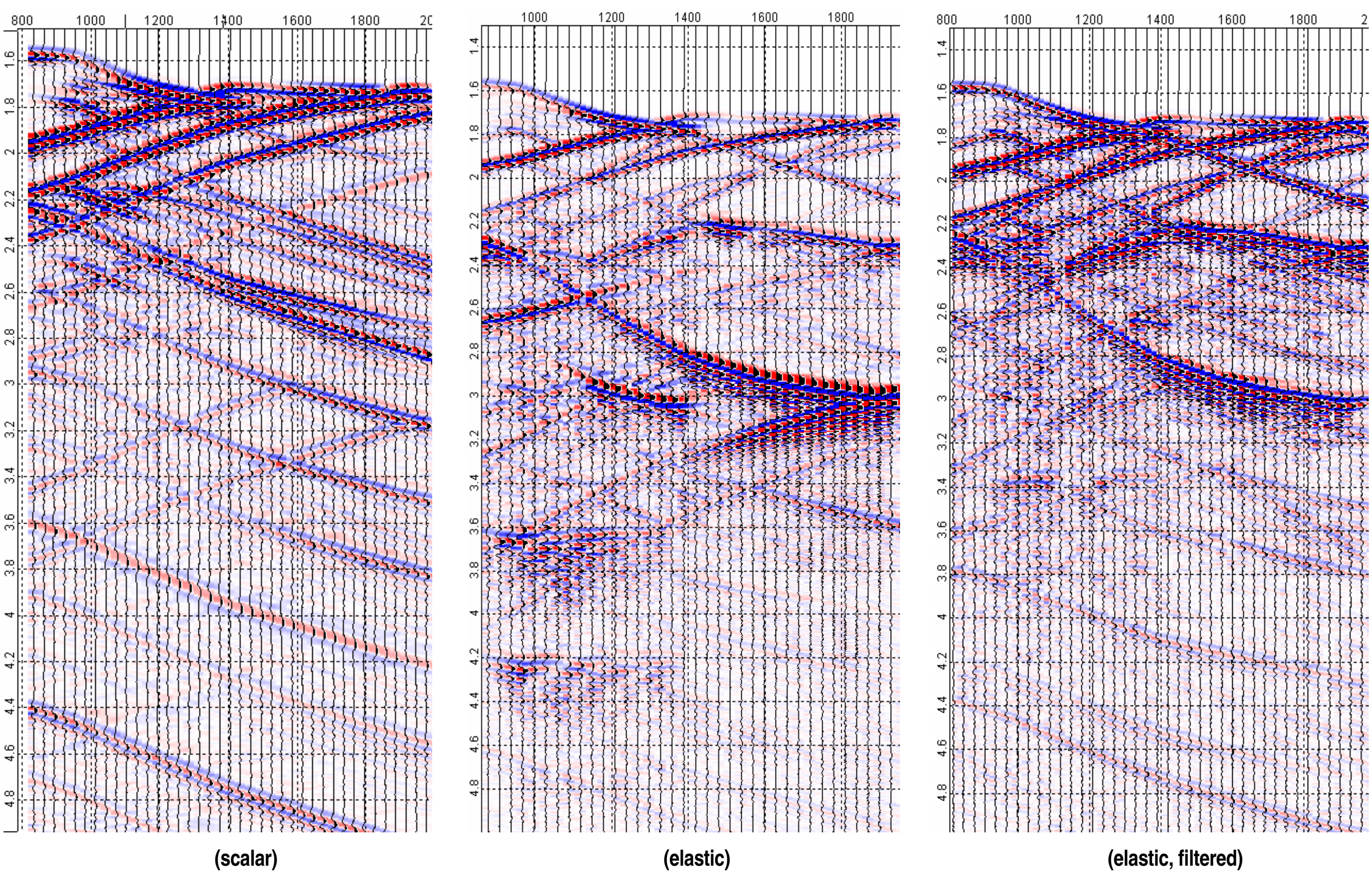
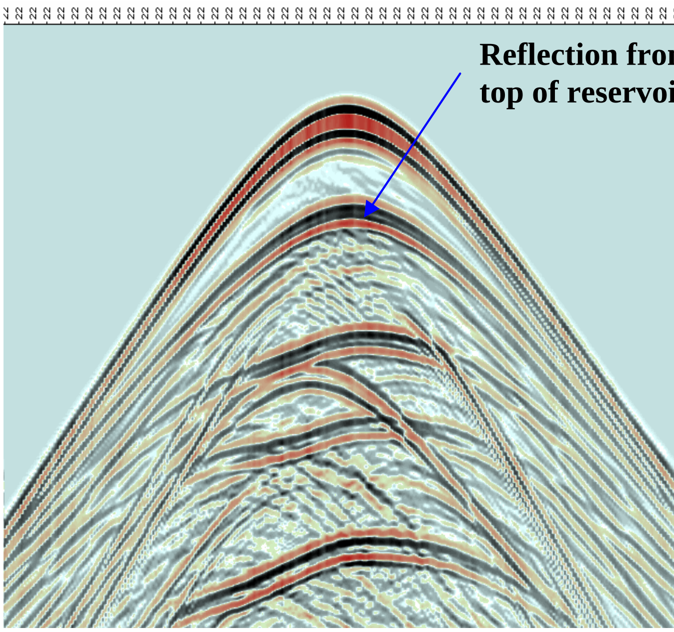


Figure 3: Synthetic VSP response

Synthetic VSP data for 240 shots at 30 m interval (covering a horizontal span of 7200 m) were computed using the configuration of shots and receivers (in well) as shown in Figure 2. 80 receivers at 15 m interval were used in the well. As seen in Figure 2, vertical velocity gradient was introduced in the top three layers, the gas cloud and the reservoir layer. The synthetic VSP response was computed using the scalar and elastic options. The elastic response was recomputed to filter out the source generated SV waves that tend to mask some of the useful reflections. The wavetrains associated with the SV component can be detected by means of a comparison of the different computed VSP response as shown in Figure 3. It is possible to study the different reflection wavetrains and their amplitude variations on these records.



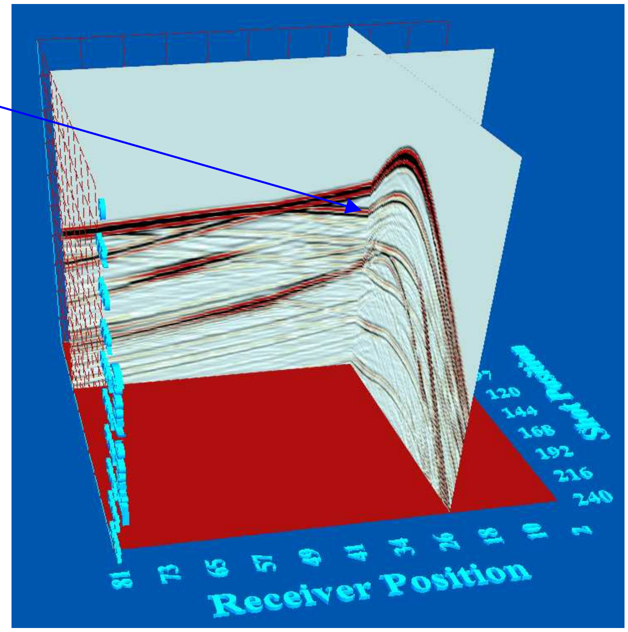


Figure 4: Synthetic walkaway VSP response (receiver position 22)

Figure 5: Synthetic VSP response seen in 3D

The data for the 240 shots was subsequently sorted with respect to receiver positions. Figures 4 and 5 show receiver gather 22. The reflection corresponding to the top of the reservoir is seen clearly. The 3-D view displays the VSP data conveniently, the receiver positions being on one axis and the shot positions on the other. The vertical axis is time.

This exercise demonstrates the effectiveness of a walkaway VSP in an area where the complex nature of the subsurface (gas cloud) would result in poor surface seismic response. In such a case, suitable receiver profiles will indicate the structure of interest and can be used to verify the corresponding reflections on real data.

Conclusions

Elastic modeling is a very useful tool for understanding the seismic response for different subsurface configurations and the inherent complications they present. Two applications presented here have demonstrated this and more will be discussed in the poster.

Acknowledgements:

The author is grateful to Tesseral Technologies Inc. for graciously providing the modeling software, and to Ivan Iantsevitch and Alex Kostuykevych for their help in understanding the working of different options in the software and discussions.

Thanks are also due to Arcis Corporation, Calgary, for permission to publish this paper.

References

Margrave, G. F., and Manning,P.M., 2004, Seismic Modelling: An essential interpreter's tool, Presented at the 2004 CSEG National Convention.

Bording,P., and Lines,L., 2000, Seismic Modeling makes waves, AAPG Explorer, December issue.

Krebes,E.S., 2004, Seismic Forward Modeling, CSEG RECORDER, April issue, p 28-39.