P234 VIRTUAL SOURCES, A NEW WAY TO REMOVE OVERBURDEN PROBLEMS.

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Summary

By shooting on the surface with geophones placed in the subsurface under troublesome overburden we can simulate a survey that has very advantageous "Virtual Sources" at the buried geophone locations and is easy to image. This is a way to achieve reproducible data over targets spoiled by heterogeneous, scattering and possibly changing overburden. The method allows us to use the full spatial bandwidth of the overburden scattered source energy and achieve near perfect deconvolution for overburden transmission effects.

The method has applications for enhanced reservoir characterization and production monitoring. The method has been tested for P waves but also has promise for improved shear applications. While this paper will introduce the benefits, there is a cost that lies in providing suitably positioned subsurface geophones. We hope that recognition of the benefits will serve to help down-hole seismic application and bring down this cost.

Theory

The theory is simple. Consider the trace Tij obtained by seismic source Si shooting into a receiver Rj situated below a complex overburden, as shown in Figure 1. The vast bulk of the early energy received by Rj will be down-going but this may consist of various multi-path arrivals with different directions and reverberations giving a complex signature.

If we were to correlate Tij with the recorded down-going part of Tij then this complex signature would be filtered to an auto-correlation function at zero time, a perfect phase deconvolution. We can repeat this for all shots Si recorded by Rj. By summing records over all shots we can simulate a downward radiating zero-phase Virtual Source at the location of Rj. By also adjusting the amplitude responses to some desired spectrum we can simulate a downward radiating source with a short pulse. This is suggested in Figure 2. The simulated records from Virtual Source Rj into receivers Rk are given by

$$Tjk = \Sigma_i \; Tij^{-1} * Tik$$

where Tij^{-1} is the inverse of the down-going signal in Tij. (Remember, i is the surface shot index, j is the subsurface Virtual Source index and k is the subsurface receiver index.) The phase spectrum of Tij^{-1} may be obtained by time reversal of an early gate of Tij and the amplitude spectrum may be adjusted as desired between using that of Tij (match filtering) and the inverse of Tij (pulse shortening). In many cases a good working approximation to Tij^{-1} is indeed the time reverse of Tij which gives perfect phase deconvolution.

In conventional downward projection as used in imaging we would downward project the shot signals using a simplified Greens function derived from a simplified velocity model yielding operators which are travel time shifts and some scaling. By using receivers under some problem overburden we can exactly correct for the earth and acquisition response through the overburden without any need for deriving an overburden model or projection operators, we measure them. In fact, as we shall see, the more complex the overburden and the more the scattering, the better this method will work.

We can arrange subsurface receivers to give 2D and 3D coverage of a target.

Examples

First we show a 2D synthetic example. Figure 3 shows a 2D subsurface model with a complex overburden and simple but normally unresolved subsurface. Figure 4 shows a receiver gather computed from the model and the portion above the blue line taken as down-going energy. Figure 5 shows the Virtual Source computed receiver gather (black) overlain by a synthetically modeled record using the exact model (red). Figure 6 shows two migrated PSDM stacked images one using the Virtual Source approach and no knowledge of the overburden and the other imaged from surface using the exact model used to create the data. We can see that the Virtual Source result is less disturbed and zero phase. In practice we would never be able to accurately derive a model this complex. We also did not take advantage of the option to amplitude deconvolve the Virtual Source result which would have made it sharper, we just used the time reverse of Tij to approximate Tij^{-1}.

In Figure 7 we show an image from a real dataset recorded in a 45 degree slanting well instrumented with 3 C geophones 8 m apart. The well is under a channeled overburden subject to varying near surface conditions and above a reservoir where we wanted to observe production related changes. The result is shown for the vertical component.

Discussion

The method has some rather attractive properties.

The method allows us to image under severely scattering overburden such as karst topography, basalt, rugged salt or other seismically challenged situations. We can do this simply without having to perform statics, velocity modeling, dereverberation or any modeling of the troublesome overburden. We start processing at the receiver level. Shots should be distributed on the surface so as to give a full down going radiation pattern at the receiver Virtual Source locations. This is more onerous for a simple overburden, as this will require full shot sampling. The method is also ideal for time-lapse work using fixed receivers. The fixed geometry requirements are strictly satisfied even if the surface shot locations cannot be exactly repeated. The method also allows good repeats with different source waveforms e.g. dynamite and Vibroseis and differing near surface coupling and static conditions. As we measure a far field calibration signature for every shot into every geophone we can arrange for a desired wavelet at our Virtual Source location. All phase errors and feasible spectral differences are removed in Tij^{-1}.

It turns out for P-waves that the requirement to separate out the down going part of Tij for determining $^{-}$ is not critical. A choice of a suitably long gate around the first arrivals to catch enough of the scattering caused coda and key reverberations is all that is required. In the examples we have tried the method is robust in regard to gate length. This is because the down going energy dominates the up going. This is an advantage of our Virtual Source approach over physical down-hole sources which will radiate up into the problem overburden which will back scatter adding noise to the desired downward radiating energy. With the Virtual Source we have a source with a controllable radiation pattern and known zero phase signature.

With multi-component receivers we can generate virtual P sources with no associated shear and shear sources of desired azimuthal polarization with no associated P. The latter requires extracting the desired shear polarization components from the Tij measurements.

The method is generic and may be used with a variety of down hole geometries depending upon the target application and probably budget. Two of these are shown in Figure 8. With fixed down hole or seabed receivers the method is synergistic with passive listening and micro-seismic measurements and is thus an attractive method for the Smart instrumented oil field. Since the Virtual Source waveform is synthesized and does not depend upon the phase of the physical sources the method is also an attractive way to implement the so called "day light imaging" techniques based upon natural noise sources, particularly if the noise originates from surface scattering.

Conclusions

Virtual Sources have promise for using scattered energy to allow simple and superior imaging under heterogeneous overburden. They also have a role for high fidelity reservoir monitoring applications with fixed buried receivers and changing overburden or non-repeatable source locations.

Acknowledgements

We would like to thank Shell management for permission to present this paper and for our colleagues who contributed by discussion and encouragement.

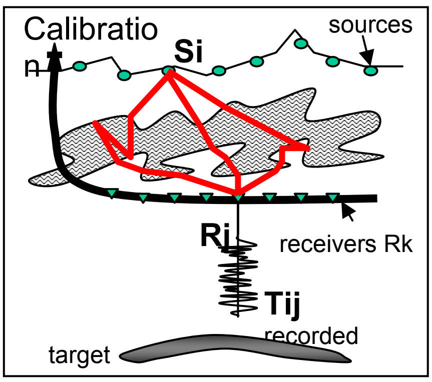


Figure 1

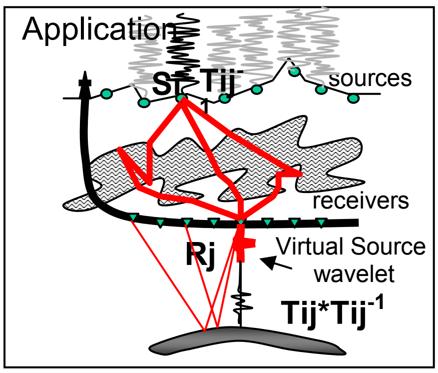


Figure 2

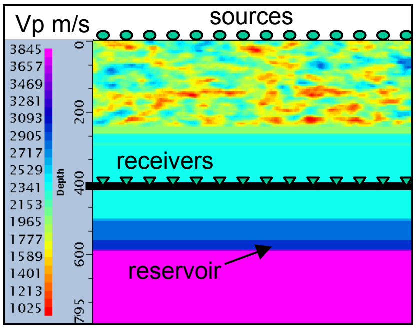


Figure 3

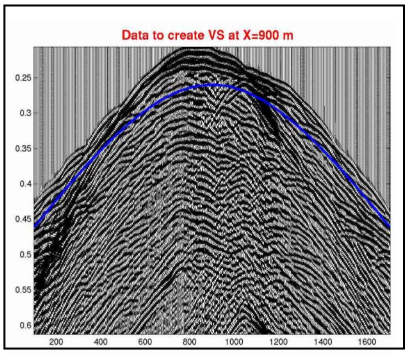
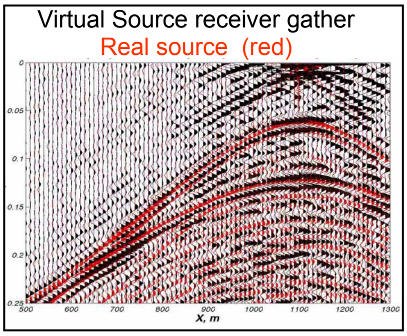


Figure 4



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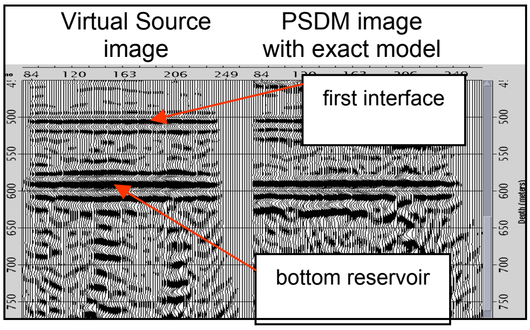

Figure 6

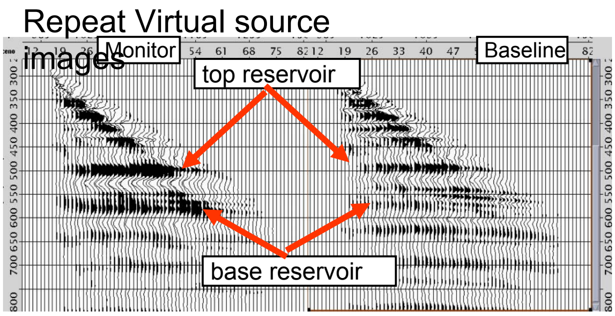

Figure 7

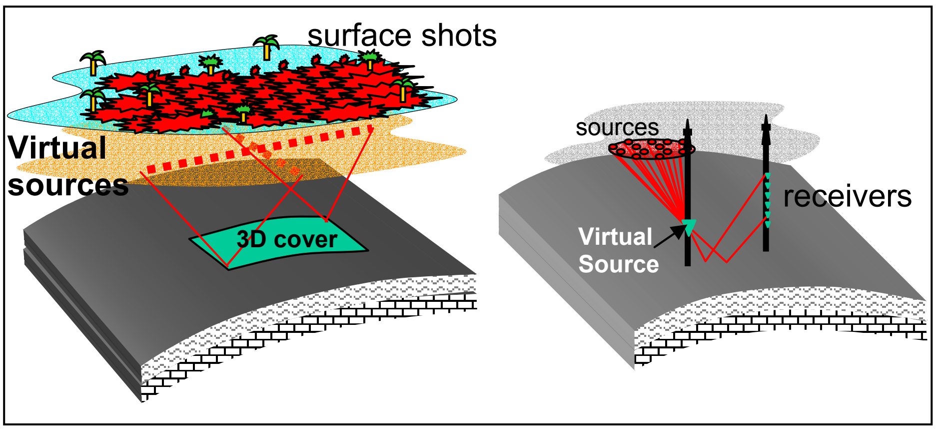

Figure 8