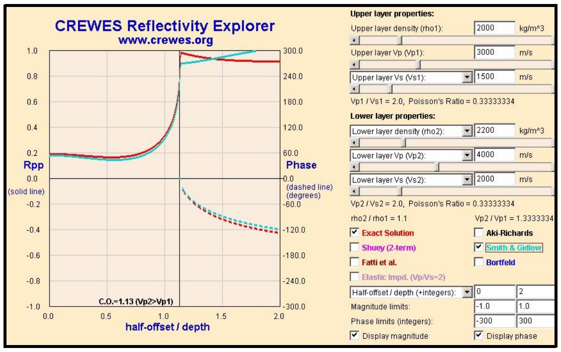
Volume 12, No. 5 June-July 2001

# CREWES NEWS

The Consortium for Research in Elastic Wave Exploration Seismology

## CREWES Introduces Reflectivity Explorer




CREWES is pleased to announce a new member of its Explorer family of web-based applets.

Reflectivity Explorer allows the user to view large number of AVO-related approximations to the P-P reflection co-efficient for any combination of earth properties. The results can be displayed as functions of either angle or offset.

Zoeppritz Explorer, announced in May's CREWES NEWS, has also been improved. An option for specifying ratios of velocities or densities rather than absolute values has been added, together with other display options. The source code for both of these applets is available to sponsors from the 2001 CREWES Software page.

Access either Explorer via the "Interactive Demos" link on the CREWES homepage. Suggestions and queries regarding these utililties should be directed to Chuck Ursenbach at ursenbach@crewes.org. ***CN***

## Using NMO for amplitude-preserving migration

*This is a summary of June's presentation by CREWES Visiting Scholar, Dirk Gajewski. Dirk can be contacted at gajewski@dkrz.de.*

The concept of normal move-out (NMO) is fundamental to Applied Seismics. The NMO of traveltimes of neighbouring receivers depends upon the curvature of the wavefront. The curvature of the wavefront determines the geometrical spreading. This indicates that the geometrical spreading of a seismic wave can be determined from traveltimes. Moreover, the difference in traveltimes of neighbouring receivers determines the slowness of the seismic wave. Slowness and curvature are basic properties of seismic wavefronts which are entirely independent of the model and wave type.

For any kind of AVO analysis, the removal of the geometrical spreading of the seismic wave under consideration is required. Closed-form solutions are available for only very simple types of models. However, as described above, geometrical spreading is determined by the NMO. A generalized NMO expression allows the geometrical spreading to be determined from traveltime information of multi-fold reflection data. Moreover, the generalized NMO expression, which corresponds to an extension of the well-known T**2-X**2 method to 3-D heterogeneous (an)isotropic media, allows the establishment of a very efficient amplitude-preserving pre-stack depth migration (APPSDM) of the Kirchhoff type, where all required quantities are determined from traveltimes. APPSDM is a pre-requisite for any AVO analyses in heterogeneous (an)isotropic media. ***CN***

## In This Issue...



### CREWES Staff and Students Garner CSEG Awards

The CSEG held in May this year saw several CREWES students and staff receiving awards for their work.

**Jon Downton** and **Larry Lines** co-authored a brace of award-winning papers: "Constrained three parameter AVO inversion and uncertainty analysis" and "AVO analysis at Pikes Peak".

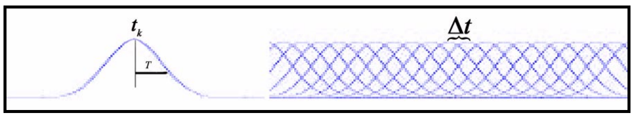
**Rob Stewart**, **Han-xing Lu**, **Henry Bland**, and **Lawrence Mewhort** won an award for their paper, "A lake-bottom cable seismic survey: acquisition and processing".

Congratulations to all concerned. We look forward to presenting more of our work at the SEG at San Antonio in September. ***CN***

## In Focus: Signal slicing

*Gary F. Margrave*

It is often desirable to decompose a signal into a set of more elementary signals that are more-or-less independent. A common example is the decomposition into a set of signals with different frequency pass-bands such that, when superimposed, the original signal is recovered. A classic way to achieve this is to design a set of peaked functions that completely "span" the frequency spectrum. The Gaussian can be used for this purpose and is a zero-phase filter with excellent rejection properties. Alternatively, in the time-domain, a trace can be temporally localized by multiplication by a Gaussian window.



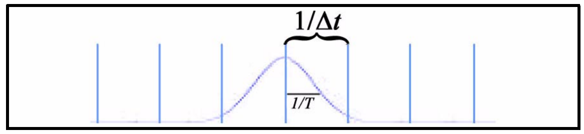

*A single Gaussian*  *A set of Gaussians.*

Let's consider how this is done in the time domain. Let $g_k(t) = a\exp\left(-\frac{[t-t_k]^2}{T^2}\right)$ be a prototypical Gaussian window (above left) where $T$ is called the *width*, $t_k$ is the window centre time, and $a$ is a normalization constant to be determined. Then, the assertion that a signal can be decomposed with a set of these windows is equivalent to the mathematical requirement that $\sum_k g_k(t) = 1$.

Graphically, this asserts that the set of Gaussians (above right) sum to unity. It turns out that this requirement can only be satisfied approximately but with any desired degree of precision. To see why, note that the equation describing the sum of Gaussians can be rewritten as a convolution of a single Gaussian with a Dirac comb:

$$\sum_k g_k(t) = g_0(t) \bullet c(t)$$

The Dirac comb, $c(t)$, is a sequence of impulses at an interval $\Delta t$, one at each Gaussian location in the above, right picture. Interestingly, the Fourier transform of the Gaussian is a frequency-domain Gaussian whose width is $1/T$ and the Fourier transform of the comb is a frequency domain comb whose impulses are spaced at $1/\Delta t$. Since summing to unity is equivalent to asking for a time-series that contains only dc (0 Hz), the desired condition in the Fourier domain is $\hat{g}_0(f)\hat{c}(f) = a\ spike\ at\ dc$. That is, the product of the frequency-domain Gaussian and comb is to result in a single spike at dc (below).




The product of these two functions is an infinite sequence of impulses again but whose magnitudes come from the Gaussian. Thus the desired dc spike is at the centre of the Gaussian and is by far the largest. The next largest spikes, at $f = \pm\frac{1}{\Delta t}$, represent the largest term of the error. Clearly, this error approaches zero as the Gaussian spacing, $\Delta t$, also approaches zero. This entire argument can be made precise and it results that the normalization factor for the Gaussians must be $a = \frac{\Delta t}{(T\sqrt{\pi})}$ and the error term is estimated by

$error(t) \approx 2\cos\left(\frac{2\pi t}{\Delta t}\right)\exp\left(-\left[\frac{\pi T}{\Delta t}\right]^2\right)$. From this it follows that, for example, if $\frac{T}{\Delta t} = \frac{1}{2}$ then the maximum error is -21 decibels while if $\frac{T}{\Delta t} = 2$ the maximum error is -340 db. An example is shown below for a case where $T$=.4sec and $\Delta t$=.2sec. The fact that the summation curve tails off at each end is due to the computer simulation only conducting the summation over a finite time interval (0-4 sec) and is an edge effect outside the scope of the theory here.

So, by using each Gaussian in the picture above to window a time series, we can produce a set of localized signals that very nearly sums to the original. Similarly, by repeating these arguments in the frequency domain, a set of Gaussian filters can be designed that, upon summation, faithfully reproduce the full spectrum.

This property of Gaussians can be exploited in a number of ways. TVSW algorithms commonly use Gaussian slicing in the Frequency domain. Gaussian beam migration uses Gaussian slicing in the $(x, \omega)$ domain. And, as we will show at this year's Sponsor's meeting, we can use Gaussian slicing in the time domain to implement a robust time-variant deconvolution. ***CN***

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# Using the wavelet transform (WT) for time-variant spectral whitening

*Victor Iliescu*

Frequency attenuation (Q-loss) causes seismic signals to be strongly nonstationary, by which we mean that the spectrum of a propagating waveform progressively attenuates. This is a problem for standard deconvolution theory that assumes a stationary seismic wavelet. A measure of frequency attenuation is the quality factor Q. If the Q factor is estimated, then an inverse Q-filter can be applied that, in theory, will transform the embedded nonstationary wavelet into a stationary one. A far simpler approach has been the common practice of time-variant spectral whitening (TVSW). TVSW uses a complete set of band-pass filters to decompose a signal into a set of narrowband signals. Automatic gain control (AGC) is then applied to each narrowband signal and they are summed back together.

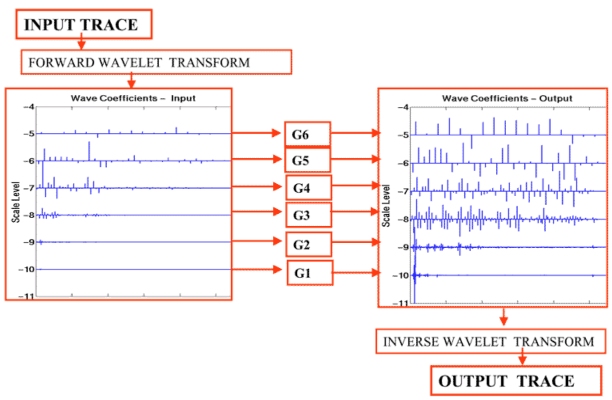


*Figure 1. The effect of gain function (G1-G6) applied to various levels of decomposition in the wavelet domain.*

We have used the WT to achieve a kind of TVSW. The WT decomposes a signal into a time-scale frame. Though conceptually similar to a time-frequency decomposition such as is achieved by band-pass filters, the wavelet domain is distinct in that scale is inversely related to frequency. For each scale, the wavelet domain provides a time series containing the detail found in the signal at that scale. For each scale level, we divide the signal by a smoothed version of its Hilbert envelope (Figure 1, above), then the enhanced signal is inverse transformed from the wavelet domain to the time domain. This is quite similar to the TVSW algorithm except that we work in the wavelet domain.

Figure 2 (above, right) shows a reflectivity series (2a), which is used to generate both a stationary (no attenuation) synthetic trace (2b) and an attenuated (Q=25) trace (2c) in the time domain. The attenuated trace is used as input for the TVSW technique (2d), the WT whitening technique (2e), and simple AGC (2f). Comparing the traces (2e) and (2d) with the stationary case (2b), one can see that the result of the WT method (2e) is less noisy than that of the TVSW technique (2d) and this is encouraging. Figure 3a (bottom) represents the amplitude spectrum of the attenuated (input) trace (2c) and in Figure 3b it can be observed that the amplitude spectrum of the WT method result (2e) has been whitened reasonably well in the frequency range from 0 to 100 Hz. We find that the WT method whitens well to about half the Nyquist frequency. We are continuing to explore the possibilities of the WT. ***CN***

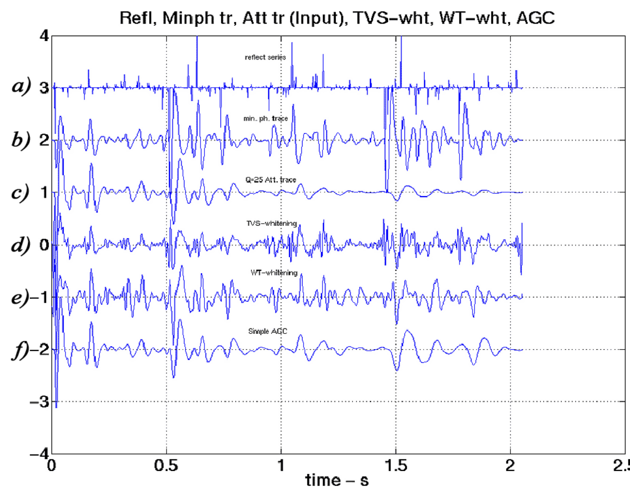


*Figure 2. Representations in time domain:*
*a) Reflectivity series, b) Minimum phase trace,*
*c) Attenuated (input) trace Q=25,*
*d) TVSW applied to c, e) WT-whitening applied to c,*
*f) Simple AGC*

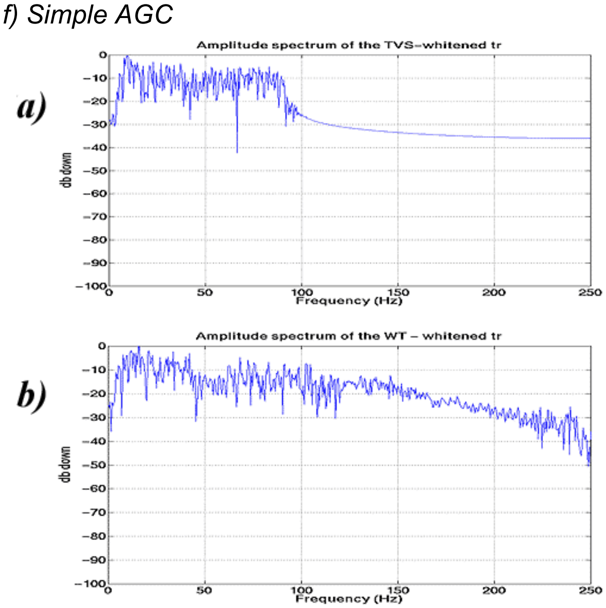


*Figure 3. a) Amplitude spectrum of the input trace,*
*b) Amplitude spectrum of the WT whitened trace.*

## Single-well imaging

*Louis Chabot*

There are many unresolved questions when looking at the logs acquired with current well-logging acoustic and resistivity imaging tools. For example, is the fracture crossing the borehole induced by drilling or is it caused by a fault? This question and others are especially important to resolve when chasing a fractured compartmented reservoir with a horizontal borehole. Answers to these questions might lie in single-well imaging.

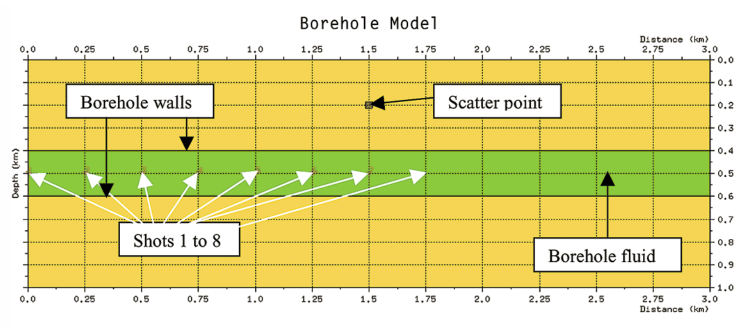


*Figure 1. The borehole model with one scatter point. The distance axis is defined as the x-axis while the depth axis is the z-axis. The scatter point is located at (1500m, 200m). There are eight shot points spaced 250m apart and 3000 receivers spaced 10m apart in the fluid-filled borehole, along the borehole axis. The fluid-filled borehole layer has a P-velocity of 1500m/s, while the borehole wall material has a P-velocity of 2600m/s.*

Single-well imaging refers to the placement of a transmitter and receivers in the same borehole and looking at the propagation of the acoustic and elastic wavefield in and around the borehole. The single-well imaging investigated in this work uses the full-waveform as acquired by an acoustic well-logging tool. Work in single-well imaging was initiated by Hornby (1989) and pursued by Coates et al. (2000). The work done at CREWES builds upon those published works and attempts to create a processing flow to image acoustic impedance contrast away from the borehole wall. As a first attempt, a full-waveform acoustic sonic dataset, acquired in the field, was processed with known seismic processing methods to image scattered energy around the borehole. The results obtained, presented by Chabot, et al. (CREWES Research Report, 2000) were encouraging.

More recently, the finite-difference code provided by G.T. Schuster, J. Xu and Y. Luo (University of Utah) and based on an algorithm described by Levander (1988) was used to simulate the acoustic wave propagation in and around the borehole. The borehole model chosen is a fluid-layer model, as shown in Figure 1, and is a qualitative approximation to the more complex borehole environment (Paillet and Cheng, 1991). The model is two-dimensional, characterized by a horizontal fluid layer confined above and below by identical elastic layers, with the top layer having a scatter point embedded into it. The horizontal fluid simulates the fluid-filled borehole. Using a 30-Hz Ricker wavelet as the source in the model, the dimensions of the borehole model were scaled at a ratio of 1:333 (real:modelled). Only P-wave propagation was allowed in the model. Several shots were set off along the borehole axis where synthetic full-waveforms were recorded at all the receivers along the borehole axis. Next the synthetic raw dataset generated was processed with the following steps: geometry, filtering, followed by equivalent-offset migration (Bancroft, et al., 1998). The results of this processing flow applied to the synthetic dataset are presented in Figure 2. The energy from the scatter point has been successfully focused.

Future directions in this research include the search for an axial-geometry finite-difference model, the inclusion of S-wave propagation in the numerical simulation, and physical modelling. ***CN***

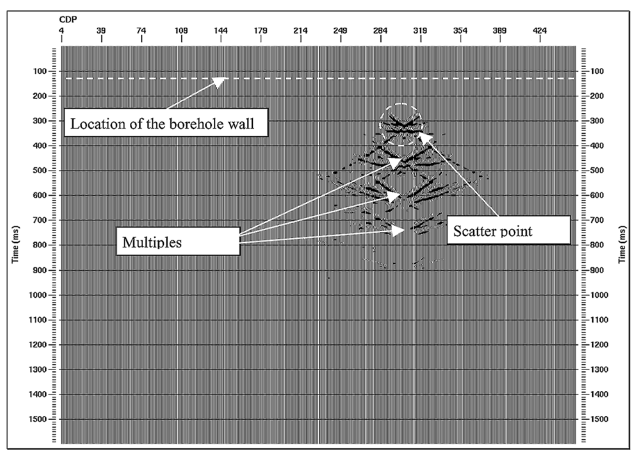


*Figure 2. With the help of the proposed processing flow, the energy from the scatter point is focused at approximately CSP 304 and 310ms (white dashed circle). This location closely corresponds to the expected position of the scatter point at CSP 304 and 287ms. Note that there are several ghosts of the scatter point at 440ms, 595ms and 750ms due to the multiple energy created by the reverberations, predominantly between the borehole wall and the scatter point.*

## Vibroseis Deconvolution: Frequency-Domain Methods

*CREWES is pleased to present Katherine Brittle's thesis abstract. The thesis is available to Sponsors.*

A vibroseis sweep is often used as a source signal for seismic exploration. During the process of vibroseis acquisition, reflections of the sweep signal are recorded with geophones. Processing techniques are required to remove the embedded vibroseis sweep from the recorded trace. Traditional vibroseis processing involves cross-correlating the trace with the sweep used in the acquisition, producing an embedded zero-phase Klauder wavelet. However, it is also possible to remove the vibroseis sweep using the method of frequency-domain sweep de-convolution (FDSD). This method utilizes the frequency-domain to remove the sweep from the trace. The two sweep-deconvolution methods are compared by using synthetic traces, which include variations in sweep type, random noise and minimum-phase earth-attenuation. A comparison of the vibroseis deconvolution methods with the inclusion of Q values is provided through the use of model data and a vertical seismic profile. Further analysis is also completed with the VSP corridor stacks and with three seismic lines, determining the effects of the sweep deconvolution methods on field data. Results from the study indicate that frequency-domain sweep deconvolution is an excellent method for vibroseis deconvolution, allowing amplitude and phase information to be processed more accurately than with the method of crosscorrelation. The amplitude and phase accuracy for the final result, due to the lack of sweep dependency in FDSD, is important for further amplitude analyses and seismic interpretation techniques. ***CN***

### Contact Details

Readers wishing to contact staff and students should note that all CREWES usernames are attached to the @crewes.org domain. ***CN***

### Student Graduation

Congratulations to **Katherine Brittle** who successfully defended her M.Sc. thesis, 'Vibroseis Deconvolution: Frequency-Domain Methods', in June. The abstract of this thesis is presented left.

Katherine is now working for Imperial Oil in Calgary. We wish her all the best in her future career. ***CN***

### Sponsors Meeting 2001

We would like to remind our sponsors to begin planning for the 2001 CREWES Sponsors Meeting, which is being held 18-20 November.

This year, we are returning to the Delta Lodge at Kananaskis, in the Rocky Mountain foothills. However, as in 2000, we will be holding several complimentary workshops in Calgary.

Watch this space, and visit our website, www.crewes.org, for further details! ***CN***

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