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Executive Summary

This report presents major advances in progress made through the report period from April 1 to June 30 of 2010 for the CO_2 sequestration training project in the Dickman field, Ness County, Kansas (Figure 1).

A key element to the research is three-component (3C) numerical modeling of the Dickman area seismic response. Here we present an overview of reflectivity modeling including historical developments, non-mathematical technical overview, and bibliography.

The original plan was to use Geokinetics reflectivity software (SOLID), but we have been collaborating with Prof. Subhashis Mallick (U. of Wyoming) who has developed a comparable code (ANIVEC). Unlike SOLID that is tied in to Geokinetics processing system, ANIVEC is a stand-alone code. Further, SOLID is an isotropic code while ANIVEC supports arbitrary anisotropy due to shale, thin layering, vertical fractures, etc. We have installed ANIVEC on Macintosh laptop and desktop machines, as well as our departmental linux cluster. Initial tests (reported here) indicate ANIVEC is ideal for our application and gives us flexibility to run many more simulations without the need for assistance from Geokinetics personnel.

The initial ANIVEC tests reported here include a simple 3-layer model and simulation from the Humphrey 4-18 well using the sonic log for P-wave speed, constant Vs/Vp ratio, and constant density.

A second key element to our work is the ability to rotate horizontal data components from the simulation output. This will allow us to populate the 3D 3C seismic survey design with simulated response traces that are correctly oriented along the source-receiver azimuth. Here, we report successful tests of data rotation using the SeismicUnix program for SU Horizontal data ROTation (suhrot).

Finally, we report progress in compiling a summary of SEG literature related to CO2, with the intention to make a 'CO2 Reader' for internal use by the team. We are also studying the possibility of offering this to the SEG Publications Committee for publication as a reprint series book.

Reflectivity modeling and ANIVEC

Introduction to reflectivity modeling

Numerical seismic modeling is applied to simulate wave propagation in complicated earth models. Of many methods available, reflectivity modeling is best suited to our work due to its unique properties. This method can model all waves propagating in elastic or anelastic media with high numerical stability and accuracy but relatively little computation cost.

Reflectivity modeling was first proposed by Thomson (1950), and Haskell (1953) modified the method to simulate surface wave propagation. The name was, however, introduced by Fuchs and Muller (1971) to describe a technique in which all multiple reflections and conversions between wave types were retained in part of the structure. This modeling method represents wave propagation in the frequency-wavenumber domain, and it mainly deals with coefficient (or propagator) matrix computation (Kennett, 1975; Kind, 1976; Kennett, 1983; Müller, 1985). Finally, by use of Fourier transforms, the seismic response is transformed back into the time-space domain. Excellent work was done in this area by Fuchs and Müller (1971).

Reflectivity modeling is always carried out in a cylindrical coordinate system, through which one can conveniently reduce wave equations to 1D. The modeling theory describes wave behavior in stratified earth models in a convenient way, where all wave types can be decomposed into upgoing and downgoing waves; and waves can be decoupled into P-SV and SH wave types (Kennett, 1983). Reflection, transmission, conversions of all wave modes, and the corresponding multiples inside thin layers inserted between two half spaces or a free surface and a half space can be fully modeled. Moreover, modeling in the frequency-wavenumber domain makes it easy to handle absorption in anelastic media (Temme and Müller, 1982). The result is a synthetic elastic multicomponent common midpoint gather (CMP) gather. In the absence of dip or lateral velocity variation, this is equivalent to a common shot gather (CSG) for the layered model.

The description of ANIVEC given below is a slightly modified version of sections of the User Manual by Subhashis Mallick (unpublished).

Introduction to ANIVEC reflectivity modeling program

ANIVEC (Mallick and Frazer, 1987) is a computer program that generates complete three-component synthetic seismograms for a subsurface composed of fluid and elastic (isotropic or anisotropic) beds separated by horizontal parallel interfaces. Any degree or symmetry of anisotropy can be modeled, even triclinic (21 elastic constants). The beds may micro-layered.

The input model to ANIVEC can be a plain text file, well-log file in LAS format, or a set of SEG-Y files describing the subsurface elastic properties in depth at different locations. The ANIVEC algorithm correctly handles finite-frequency phenomena, such as diffraction, tunneling, and caustics, so ANIVEC seismograms are more accurate than those obtained from ray theory. At user option, ANIVEC however allows computing partial seismograms such as primary reflections only, P-wave reflections only and so on. ANIVEC is meant for use by those who must interpret three-component seismic data or investigate the effects of anisotropy in bedded earth sections.

The seismic source in ANIVEC is a point or source, excited by a unit force or by a symmetric point moment tensor. (A diagonal moment tensor gives an explosion). A point source can be located off the line and can be buried at any depth. ANIVEC outputs either conventional surface or OBC seismograms, i.e. shot gathers, or vertical seismic profiles (VsP's). Each output ``trace'' consists of one vertical and two horizontal components of motion, i.e. the same components found in exploration with geophones on land.

ANIVEC uses the Kennett invariant imbedding procedure (Kennett, 1983) with extensions necessary for general anisotropy and for efficiency in the computation of VsP's. This algorithm was chosen because it is stable, and flexible, i.e. easily customized, and because it leads to a code that is easy to interpret physically, and is easy to maintain.

All converted events and multiple reflections that occur in field data are found in ANIVEC seismograms, although surface waves and direct waves can be deliberately omitted by the user for interpretation purposes. Additionally, interbed multiples can also be omitted from the ANIVEC algorithm.

ANIVEC was originally written for the CRAY computer, but it has now been ported to parallel computers using message passing interface (MPI) directives.

Before running ANIVEC, we need to have an input earth model either as a text file or LAS file or a set of SEG-Y files. Formats for LAS or SEG-Y files are standard. ANIVEC expects the model input in a text file format to be in a specific format.

For text file input models, ANIVEC requires a description of each layer describing its symmetry (i.e. whether the layer is isotropic, hexagonal, micro-bedded, and/or fractured). Depending upon this symmetry, each layer is then described by a set of additional parameter lines. Let's use a simple example, shown in Figure 2 is a five-layer model in text-file format. As shown, each layer is described in first line by an ASCII text character variable called "Symmetry". Based on the type of symmetry, the layers are further defined by one to multiple sets of lines:

Layer 1
Symmetry=I (isotropic): For isotropic layer, an additional line is required to describe the layer and this line contains P-wave velocity (Vp), P-wave attenuation (QP), S-wave velocity (Vs), S-wave attenuation (QS), density (ρ) and layer thickness. The velocities are either in meters per second or feet/second, depending upon the unit of measurement you choose in the GUI code as will be described in the later part of the document. The layer thickness is also either in meters or feet depending upon the choice of unit in the GUI code. Finally, the density is always assumed to be in g/cm3.

Layers 2 and 3
Symmetry=H (Hexagonal) A hexagonally symmetric layer can be described for text-file input in three different ways. (1) using Thomsen parameters (Thomsen, 1986) and density, (2) using five elastic constants C11, C13, C33, C44, C66, and density, and (3) by defining the layer to be composed of a set of isotropic micro-bedded layers (Schoenberg, 1983).

Layer 4
Symmetry=F (Fractured): Using this option, the user can generate a macro-bed composed of horizontal anisotropic micro-beds. The macro-bed can then be fractured by a fracture system which strikes north-south, i.e. parallel to the y-axis, and dips east at angle α to the horizontal. Finally the fractured macro-bed can be rotated.

Layer 5
Symmetry=O (Other): This is the last type of symmetry that could be provided to ANIVEC in text input mode. This is shown for Layer-5 in Figure 2. In this case, the layer is described by three additional lines:

- Elastic constants C11, C12, C13, C14, C15, C16, C22, C23, C24, C25
- Elastic constants C26, C33, C34, C35, C36, C44, C45, C46, C55, C56
- Elastic Constant C66, Density, Layer thickness, ϕ, θ, ψ, QP, QS1, QS2.

Layer thickness is either in meters or feet. Density is in g/cm3. Finally, the units for the elastic constants are exactly the same as described above for hexagonal symmetry.

Method and results for a 3-layer text earth model

Here we will first use a 3-layer earth model to display how ANIVEC works and test the efficiency of ANIVEC.

The first step is to generate the model, as a text file as described using any text editor. Our 3-layer model is given by:

```
I
3000.0 100.0 1600.0 100.0 2.2 20.
I
4000.0 100.0 2500.0 100.0 2.1 400.
I
3000.0 100.0 1600.0 100.0 2.2 1000.
```

We see this model consists of isotropic layers (denoted by I), the parameters in each layer are Vp, Qp, Vs, Qs, Density, Thickness where all units are MKS.

We create a directory and copy the model file into that directory. From the directory, invoke the GUI code by typing in the following command:

% anivec_aa <CR>

where <CR> means return.

Then we will have a window, shown in Figure 3, appearing on screen.

- Choose “Create a new model” option.
- Choose the working directory by clicking the “Select” button beside the text box under “Directory Path Name”
- Click “OK” button.

The input parameter selection dialog will then appear (Figure 4). Choose the “Input Model File Name” by clicking the “SELECT” button beside the text box and choosing our model file name. The choices are (1) unblocked well-log, (2) blocked well-log, (3) text-file, and (4) SEG-Y file. For text-file, the file format is described above in detail. *For this test we choose text-file.*

- Choose the Unit of distance (meters or feet). Depending upon your choice, the source-receiver geometry will be in meters or feet.
    - *We choose meters as unit of distance in the test.*

- Choose the source wavelet. The choices are (1) Hanning Window, (2) Ricker, (3) Boxcar, and (4) User-supplied.
  - *Here we choose Hanning 5-65 Hz as source wavelet for the test.*

- Choose the time-length in milliseconds for the computed synthetic responses and the sampling interval (also in milliseconds).
  - *Our time length is 8000 ms and sample interval is 4 ms.*

- Choose whether or not you would like to include direct arrivals and free-surface multiples in your output synthetic response.
  - *We choose to include direct arrivals and free surface (as we must to simulate Rayleigh waves).*

- Choose "Geometry". The choices are (1) Surface seismic grid, (2) OBC grid, (3) VsP grid, (4) Surface seismic azimuthal, (5) OBC azimuthal, and (6) VsP azimuthal.
  - *We choose Surface Seismic Grid and with offset range (-2500, 2500) meters and increment 10 m.*

- Choose "Source Type". Choices are explosion, vertical vibrator, radial vibrator, transverse vibrator, 9-component, and earthquake.
  - *Our choice is vertical vibrator to simulate correlated vibroseis data.*

- Choose the "Number of wavenumbers". This is a crucial parameter for all frequency-wavenumber based synthetic seismogram computations. Typical range is between 300 and 3000, with the choice made to avoid certain kinds of artifacts.
  - *We choose a wavenumber count of 800.*

- Choose "Input data type". Choose "land" if you are modeling land data and "marine" if you are modeling marine data. For modeling marine data, you will also need to provide the water-bottom reflection time. ANIVEC will create a water layer with thickness corresponding to that time.
  - *Our input data type is land.*

- Choose start time and number of overburden layers if your input model does not start at time=0. Otherwise set both of them to zero. (This allows us to give the program the reflection time to the first available sonic log value when using LAS files)
  - *Since our source, receiver, and model top all sit at zero depth, this parameter is 0 ms for our test.*

- Choose "Response Type". Choices are:
  - Full response- all events including interbed multiple reflections and mode-conversions are included in the response.
    - *We choose full response.*
  - Primary (P+S)- at every interface all primary and mode-converted reflections are computed, interbed multiples are excluded from the computed synthetics.
  - P-waves- only P-wave reflections including all interbed multiples are computed.
  - P-wave primaries- only P-wave primary reflections are computed.

- Choose yes or no for "Buried Source" and "Buried Receiver" options. If you choose yes, will also need to provide the source and receiver depths. These options are mainly to be used with "Earthquake" sources, but can also simulate marine OBC situations and land dynamite where the source (only) is buried. For land vibroseis data, both source and receiver are at the surface.

  - *We use surface (unburied) source and receiver.*

- Choose yes or no for "Manually override minimum phase velocity". ANIVEC looks at the input model and the source-receiver geometry and attempts to set the ray-parameter window such that all body-wave responses are included in the computed synthetic seismograms. However, ANIVEC is capable of computing surface waves including the ground-roll. For this, include free-surface reflections in the computation, choose "yes" to "Manually override minimum phase velocity" and use a very low value, much lower than the minimum velocity in input model for the minimum phase velocity.
  - *One purpose of this test is to simulate Rayleigh waves. In unlayered media Rayleigh wave speed is approximately 0.92 times the surface shear wave speed (Vs=1600 m/s). To be safe, we set the minimum phase velocity to 800 m/s.*

After choosing these parameters, click the "Next" button. Since our input model is text file, the next dialog box that is like the one in Figure 5. To change some computation parameters or use a different input model, we can also click "Go Back to Previous Step" button. The dialog box of Figure 4 will appear again and we can change computation parameters and/or modify the name of the input model.

At this point the model input and parameter setup is complete. Selecting the "Synthetic Computation" button open a new GUI window named "Computation of Seismograms". In this window we give ANIVEC the necessary file names and other parameters to execute the job.

Note that this program is just the GUI code for running ANIVEC and the final setup dialog creates all the files necessary for running ANIVEC.

- The input model is written as a binary file. Therefore, provide a name of the model file.
  - *Our binary model file name is model.bin*

- ANIVEC GUI code creates a shell-script control file that you execute to run ANIVEC.
  - *Our shell-script file name is control*

- ANIVEC computes the x- y- and z- components of the synthetic seismic responses and saves them as IEEE SEG-Y files. Therefore, input the file names.
  - *Our output SEGY data file names are x.sgy, y.sgy, and z.sgy*

- Choose the location of the ANIVEC executable
  - *Our version of ANIVEC is named anivec_nompi (it resides in a bin directory on our directory path, so we do not need to give the full path).*

- For ANIVEC version 1 and 2, you have the option for running the MPI or the non-MPI code. Choose what you want to run.
  - *We currently only have the nonmpi version compiled, named anivec_nompi*

- After choosing all parameters correctly, click "Proceed to Compute" button. The program will exit and in your directory you will see the model file and the control file created.

Actual execution of the job is done in a Macintosh terminal window using a makefile (see Appendix A) that runs the control script, converts SEGY output to SeismicUnix format, and generates graphics of output data. To run the job, the user simply types 'make' on the command line.

Figure 7 shows the resulting data for this test, on the left (a) is the vertical component of motion and the X horizontal (b) is on the right. ANIVEC defines horizontal X direction as radial from the source, with positive pointing away from the source. The data clearly shows development of dispersive Rayleigh waves, as expected in a layered near-surface model. The other horizontal component (Y) is transverse or perpendicular to the source receiver line. In this test, the Y component was zero (as it should be) and therefore not shown.

In our test, the input model type is unblocked well-log, the model must first be blocked before proceeding further. To block model, click "BLOCK" button (Figure 4). The dialog box that will appear is shown in Figure 6. The blocking factor means the fraction of the wavelength at the dominant seismic frequency at which the model is to be blocked. If original model was isotropic and we created an anisotropic model via "Anisotropy Definition", we will have the option to block either the isotropic or anisotropic log. When we click "Apply" button, the blocked model will be shown on top of original model as shown in Figure 7.

Click "Synthetic Computation" button after set up these functions. The final setup dialog as shown in Figure 8 will appear.

Method and initial results for Humphrey 4-18 well (Dickman Field)

For well-log file, blocked or unblocked, it is assumed that the file format is LAS.

As an example of running ANIVEC using well log input, we will generate synthetic data for the Dickman Field Humphrey 4-18 well. Procedures are similar to those outlined above. Figure 4 applies unchanged.

GUI window 2 for this case is shown in Figure 8. There are several differences, including units, bandpass frequencies, offset range, etc. See the GUI figure for details. When dealing with LAS files, the log curves used for the computation are sonic (DT), shear sonic (DTSM), and density (RHOB), not all of which may be available. But the key log is DT, from which the others can be estimated (though not accurately). For the Humphrey 4-18, the first reliable sonic reading is at 280.5 ft and has a value of 198 μs/ft. This sonic value corresponds to a P-wave velocity of 5050 ft/s (from the relationship Vp = 1,000,000 / sonic). Without further near surface velocity information, we assume this velocity extends to the surface. Therefore, the 2-way reflection time to 280.5 ft is 111 ms (computed using 2 * 280.5 / 5050). This value is entered in the dialog box labeled "Start Time (MS):"

Note that we are not manually looking for low phase velocities as we did in the 3-layer test. Selecting the 'Next >>' button brings up GUI window 3 (Figure 9)

The parameters/choices/actions in this window are:

- Choose the line number where the well data starts. This should be the first line in the LAS file where we have a good sonic value. Sonic logs take a few levels to get up to reliable readings, so this is not always the first nonzero (or non -999.25 value).
    - *Our well data starts at line 471 (corresponding to depth 280.5 ft)*

- Choose the NULL Value as defined in the LAS file.
    - *Our null value is -999.25*

- Choose the well-log index. The choices are Depth (meters) or Depth (feet).
    - *Feet*
- Choose the unit for velocity in the well-log file. The choices are "meters/s", "ft/s", "micro-seconds/meters" and "micro-seconds/ft".
    - *Sonic log input has units of micro-seconds/foot*

- Choose whether or not S-velocity is present in the well-log file.
    - *Our log suite does not include a shear wave sonic, so we choose Absent*

- Choose whether or not density is present in the input well-log file.
    - *Although there is a density log in this well, it is thought to be unreliable and noisy, so we will use a constant density of 2.0 g/cc.*

- Choose the column numbers for depth, Vp, Vs, and density in the input well-log file.
    - *As shown in Figure 9.*

- Choose how you are going to handle the missing Vs and density in the well-log file.
    - *For Vs we use Trend, based on Vp (details below).*
    - *For Density we use a constant of 2.0 g/cc*

- Choose whether or not you have anisotropic logs in the LAS file
    - *Humphrey 4-18 has no anisotropic logs*
- If the well-log file did not have Vs and/or density, we will be required to input the coefficients of polynomial to use for computing Vs and density from Vp. Ignore them if you have Vs and density in well-log input file.
    - *For illustration purposes, it is useful to define Vs as one-half of Vp. This can be done using the equation just below the water velocity definition. The equation has the form Vs = aVs (Vp*Vp) + bVs (Vp) + cVs, where aVs, bVs, and cVs are user-supplied parameters and Vp is the sonic-log Vp at each level in the well. For this example we use aVs=0, bVs=0.5, and cVs=0. In other words, we are using a constant Vp/Vs ratio of 2.*

- Click "DISPLAY MODEL" button. If made a mistake, go back to the previous step by clicking "Go back to previous step" button.

Our well model is shown in Figure 10. Before proceeding to the computation step, it is necessary to block the well log.

For unblocked well-log model, it is necessary to block the logs first before proceeding further to compute synthetics. To block logs, just click the "Block" button. The log-blocking dialog box will appear.

The blocking factor is the fraction of the wavelength at the dominant seismic frequency at which the log is to be blocked. Use 1 if you want one wave-length blocking, 0.5 if you want half wave-length blocking and so on. If you created an anisotropic log using the procedures explained as above, you will have the option to block either the original (isotropic) or the anisotropic log. Choose the desired blocking factor and the curve that you would like to block and click the "Apply" button.

For this example, we use a blocking factor of 2λ. The input model display will now show the blocked log in red on top to the original model (Figure 11).

As described before, the job is run on a Macintosh terminal window using a makefile. Compute time for this case was 106 CPU seconds (2X2.93 GHz Quad-Core Intel Xeon). The output data is shown in Figure 12. Note the rich wavefield composed of direct arrivals, reflection events (P, S, and PS), and multiples.

Work is ongoing to investigate the suitability of Humphrey 4-18 as our key simulation well, testing blocking effects, more realistic Vp -> Vs mappings, inclusion of Rayleigh waves, etc. But these early results are very encouraging and the ANIVEC program seems ideally suited to our purposes.

Horizontal rotation of 3D data

Three dimensional (3D) three component (3C) field data are acquired with one horizontal data component aligned with the receiver cable and the other aligned orthogonal to the cable direction.

ANIVEC outputs 3C data in separate SEGY data files typically named z.sgy, x.sgy, and y.sgy. By convention, z is positive down, x is positive to the right looking from source to receiver, and y is positive away from the source. [Need to check this]

To use ANIVEC data to populate a 3D 3C field acquisition design, as we plan, will require rotation of horizontal data components from ANIVEC geometry to the field geometry. We have undertaken initial tests on how to accomplish this.

The program we use to rotate three component data is the SeismicUnix (SU) application is called suhrot. The selfdoc for this program is:

```
SUHROT - Horizontal ROTation of three-component data

 suhrot <stdin >stdout [optional parameters]

 Required parameters:
 none

 Optional parameters:
 angle=rad      unit of angles, choose "rad", "deg", or "gon"
 inv=0          1 = inverse rotation (counter-clockwise)
 verbose=0      1 = echo angle for each 3-C station

 a=...          array of user-supplied rotation angles
 x=0.0,...      array of corresponding header value(s)
 key=tracf      header word defining 3-C station ("x")
```

```
... or input angles from files:
n=0             number of x and a values in input files
xfile=...   file containing the x values as specified by the
                              "key" parameter
afile=...   file containing the a values

Notes:
Three adjacent traces are considered as one three-component
dataset.  By default, the data will be rotated from the Z-North-East
(Z,N,E) coordinate system into Z-Radial-Transverse (Z,R,T).

       If one of the parameters "a=" or "afile=" is set, the data
       are rotated by these user-supplied angles. Specified x values
       must be monotonically increasing or decreasing, and afile and
       xfile are files of binary (C-style) floats.
```

Horizontal rotation was performed to align one of the horizontal components with the source-receiver azimuth (radial component) and the other orthogonal to the source receiver azimuth (transverse component). After rotation, all of the reflected energy should be concentrated onto the radial component, while the transverse component should consist of random noise only.

Here we show one example of many tests we did. A single ANIVEC three component trace in Z, X, Y sequence is shown in Figure 13. The Z and X component traces have strong energy, while the Y component nearly zero (a few small values at shallow time only). We perform a 90 degree clockwise rotation (Figure 14). This has the effect of mapping the components

$$+/-X \;>>\; +/-Y \qquad (1)$$

$$+/-Y \;>>\; -/+X \qquad (2)$$

The first relationship is evidenced in Figures 13 and 14 by the equality of traces X_{before} and Y_{after}. The second mapping is seen by close inspection of Y_{before} and X_{after} which show polarity reversal.

Summary of SEG literature related to CO2

Current work consists of compiling what is being called a CO2 reader. The objective of this task is to conduct a literature search within SEG journals and abstracts to find key papers containing different aspects of Carbon Capture and Sequestration (CCS). The process followed to obtain a complete annotated bibliography are to create a general outline of how the CO2 reader will be set up, conduct a through literature search of SEG materials, read and create no more than a few paragraph summary of each article and finally, compile all written and researched material in the aforementioned outlined format.

The specific outline is rather loose over all. To begin the CO2 reader, a title page and table of contents will be compiled on separate word documents. Following this there will be an introduction given for the topic. This will cover a brief history of CCS and some current topics and techniques being pursued at this time. Following this, the main body of the annotated bibliography will be formed. This will include all papers and abstracts in their pdf format preceded by a short summary of each compiled in a word format.

The literature search was conducted on the SEG website using a very helpful feature allowing the search of all papers from journals and abstracts to be searched at once. To complete this search two journals were searched, Geophysics and The Leading Edge (TLE), as well as the SEG

Expanded Abstracts. Each source was searched for two keywords, CO2 and carbon dioxide. These were selected to allow for a broad range of topics that was then sifted through to determine which papers would be useful and allow the most useful topics.

The goal is to narrow the papers down to a total of 15-20. This is being conducted and summaries are being written. The majority of the papers are useful and current in which they pertain to CO2 monitoring. There are many different areas researchers are exploring in an attempt to find the most effective way to monitor the flow of CO2 once it has been stored. Just as an example of what has been practiced, seismic and gravity tests have been conducted at different areas of the world in both land and marine environments. This is allowing for techniques to be tested and then better fitted for future monitoring uses.

Our working list of references for the CO2 reader includes:

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Sidenote from undergraduate research assistant J. Seals:

As far as other work, the ANIVEC program has been passed to the CO2 group for use. My role in this area is more of a follower with Qiong doing the majority of the main work. She is giving me the processes that are applicable in setting up a computer to be able to use this program, and will eventually have outlined processes for me to test in order to gain a better knowledge of how such a program will operate, and how it is beneficial to our project. Along with this, Dr. Liner has suggested I take on the task of learning Java as well. This will expand the areas and programs that can then be worked with and allow a deeper understanding of concepts that need to be understood in respect to CO2 sequestration and monitoring.

Summary of significant Events

This quarter has seen the introduction of the reflectivity modeling code ANIVEC to our research efforts, for which we are thankful to Prof. Subhashis Mallick of the University of Wyoming. This allows our UH team to do an enormous number of testing cycles, an important capability when using a program with so many parameters and options.

Work Plan for the Next Quarter

Work for the next quarter will be:

1. Continue testing ANIVEC, including anisotropy options for shale (VTI) and vertical fractures (HTI).
2. Decide which well log suite at Dickman will be the key well for our Vp, Vs, density model.
3. Map Vp to Vs in the key well based on earlier reported work relating Vp/Vs ratio to lithology.
4. Work with Geokinetics on how to take the 3D survey design and move that information into SeismicUnix. The goal is to populate trace headers with correct geometry and do horizontal component rotation to correctly orient every trace.

Cost and Milestone Status

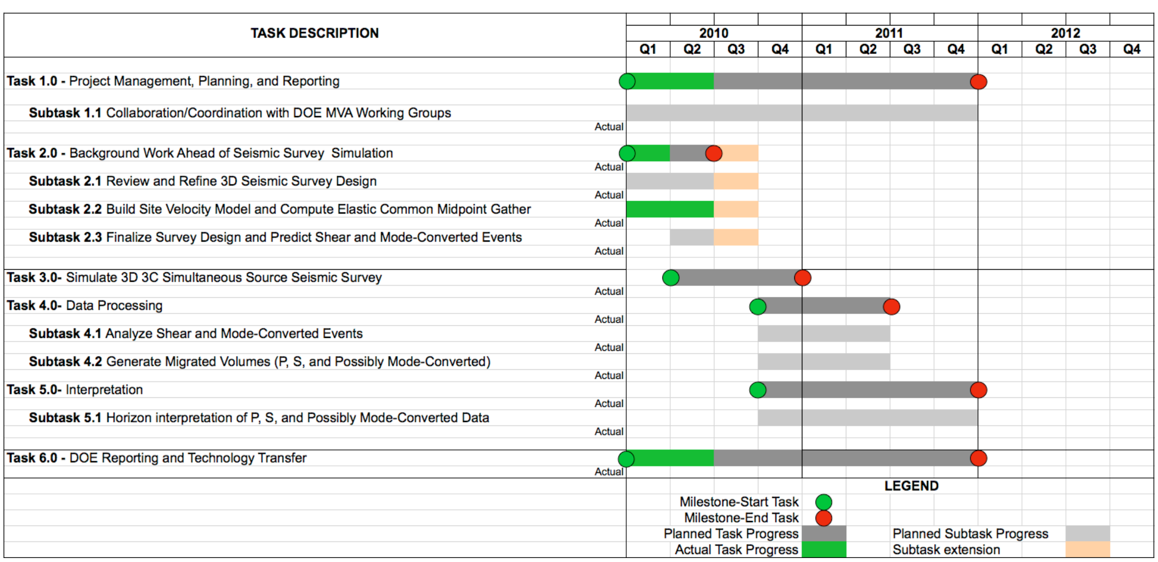
Baseline Costs Compared to Actual Incurred Costs

4/1/10 – 6/30/10	Plan	Costs	Difference
Federal	$36,668	$49,559	($12,892)
Non-Federal	$4,063	$0	$4,063
Total	$40,730	$45,559	($8,829)

Forecasted cash needs Vs. actual incurred costs

Notes:
(1) Federal plan amount based on award of $293,342 averaged over 8 reporting quarters.
(2) Non-Federal plan amount based on cost share of $32,500 averaged as above.
(3) Cost this period reflects salary for J. Zeng (3 mo), Q. Wu (3 mo), J. Seales (3 mo), and C. Liner (1 mo).

Actual Progress Compared to Milestones



Continuing Personnel

Prof. Christopher Liner is Principle Investigator and lead geophysicist. He is a member of the SEG CO_2 Committee, Associate Director of the Allied Geophysical Lab, and has been selected to deliver the 2012 SEG Distinguished Instructor Short Course.

Dr. Jianjun (June) Zeng has been working exclusively on this project since Dec 2007 and is lead geologist.

Ms. Qiong Wu is a graduate PHD student in geophysics who joined the project in January 2010 as a research assistant. She will be funded year-round out of the project.

Mr. Johnny Seales is an undergraduate student majoring in Geology and Geophysics. He is also a U.S. Army veteran, having served in Iraq. He will be funded year-round from the project. He anticipates earning his undergraduate degree in Dec. 2011.

Technology Transfer Activities

Two presentations are accepted for presentation at the SEG Annual Meeting (Oct. 2010) in Denver. These are:

Liner, C., Flynn, B., and Zeng, J., 2010, Case History: Spicing up mid-continent seismic interpretation

Phan, S. and Sen, M., 2010, Porosity estimation from seismic data at Dickman Field, Kansas for carbon sequestration

Contributors

Christopher Liner (P.I, Geophysics)
Jianjun (June) Zeng (Geology and Petrel Modeling)
Qiong Wu (Geophysics PHD candidate)
Johnny Seales (Geology and Geophysics Undergraduate)

Appendix A: Makefile for the 3-layer text model test

```
#***************** begin makefile ********************
xmin=0
dx=10
tmax_pdf=2
perc=99
unit=m

go:
	time control
	make conv
	make x
	make pdf

conv:
	segyread tape=./x.sgy conv=0 \
	| sushw key=offset a=$(xmin) b=$(dx) \
	> x.su
	segyread tape=./y.sgy conv=0 \
	| sushw key=offset a=$(xmin) b=$(dx) \
	> y.su
	segyread tape=./z.sgy conv=0 \
	| sushw key=offset a=$(xmin) b=$(dx) \
	> z.su
	rm binary header

gui:
	anivec-aa &


pdf:
	supsimage < x.su \
	  f2=$(xmin) d2=$(dx) \
	  label2="Offset ($(unit))" label1="Time (s)" \
	  d1s=.2 d2s.2 \
	  grid1=dot grid2=dot x1end=$(tmax_pdf) \
	  perc=$(perc) title=X > x.ps
	ps2pdf x.ps
	supsimage < y.su \
	  f2=$(xmin) d2=$(dx) \
	  label2="Offset ($(unit))" label1="Time (s)" \
	  d1s=.2 d2s.2 \
	  grid1=dot grid2=dot x1end=$(tmax_pdf) \
	  perc=$(perc) title=Y > y.ps
	ps2pdf y.ps
	supsimage < z.su \
	  f2=$(xmin) d2=$(dx) \
	  label2="Offset ($(unit))" label1="Time (s)" \
	  d1s=.2 d2s.2 \
	  grid1=dot grid2=dot x1end=$(tmax_pdf) \
	  perc=$(perc) title=Z > z.ps
	ps2pdf z.ps
	rm *.ps
```

```
x:
        suximage < x.su perc=$(perc) \
          f2=$(xmin) d2=$(dx) \
          label2="Offset ($(unit))" label1="Time (s)" \
          grid1=dot grid2=dot \
          title=X &
        suximage < z.su perc=$(perc) \
          f2=$(xmin) d2=$(dx) \
          label2="Offset ($(unit))" label1="Time (s)" \
          grid1=dot grid2=dot \
          title=Z &

clean:
        rm *.ps binary header *.su *comp.bin

#***************** end makefile *******************
```

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Figures

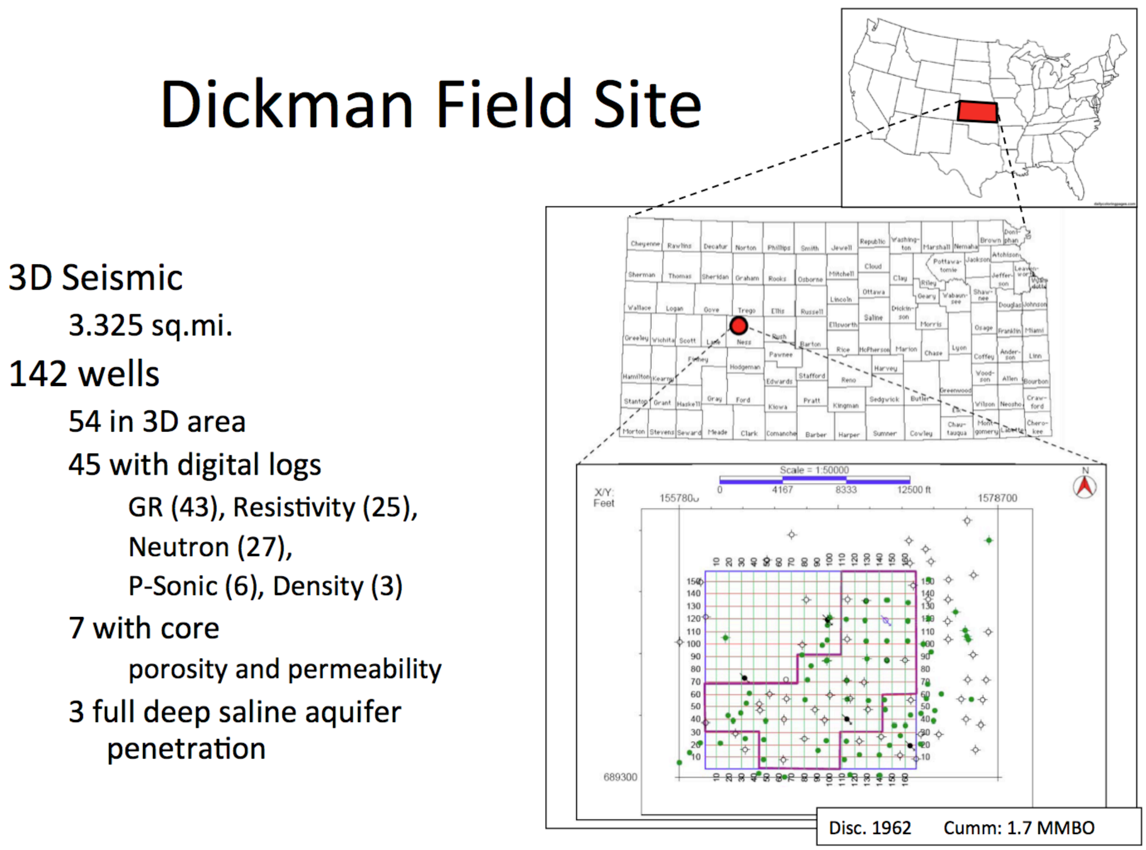

Figure 1. Area map depicting the location of the project area, Dickman field, Ness County, Kansas. On detail map, seismic inline and crossline numbers are shown, as well as the live 3D seismc area (purple polygon).

```
I
2000.0 100.0 1000.0 100.0 2.0 200.0
```
Layer 1

```
H
-1
2200.0 1200.0 0.15 0.05 0.16 2.2 250.0 0.0 90.0 0.0 100.0 100.0 100.0
```
Layer 2

```
H
2
2200 2500
1200 1650
2.2 2.4
0.5 0.5
300.0 0.0 90.0 0.0 100.0 100.0 100.0
```
Layer 3

```
F
0 2
2500 2700
1650 1800
2.4 2.5
0.5 0.5
0.1 0.0 0.0 0.15 0.0 0.18
300.0 0.0 0.0 0.0 90.0 100.0 100.0 100.0
```
Layer 4

```
O
49.454 17.271 18.732 0. 0. 0. 45.621 17.271 0. 0.
0. 49.454 0. 0. 0. 14.713 0. 0. 15.361 0.
14.713 2.55 10. 0. 0. 0. 100.0 100.0 100.0
```
Layer 5

Figure 2. Example five-layer model in text-file format

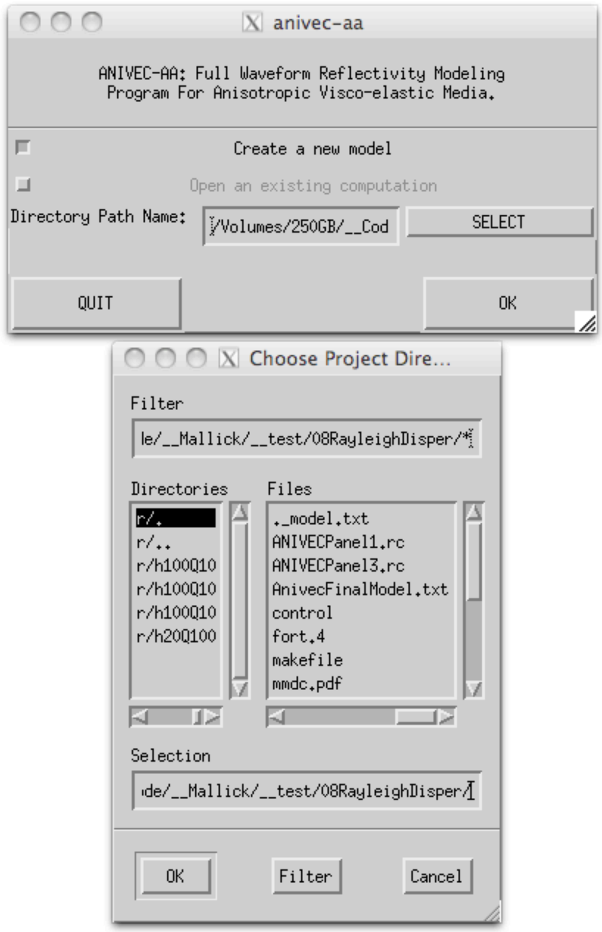

Figure 3. Initial GUI window for 3-layer txt model

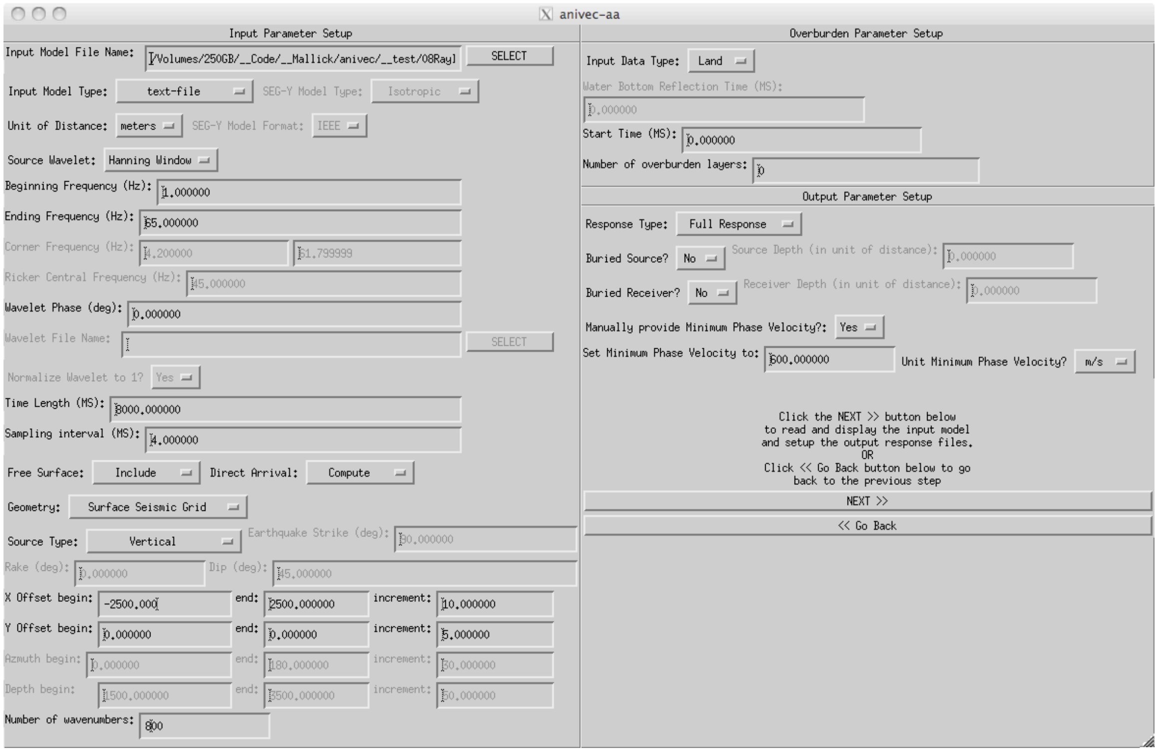

Figure 4. GUI window 2 for 3-layer case.

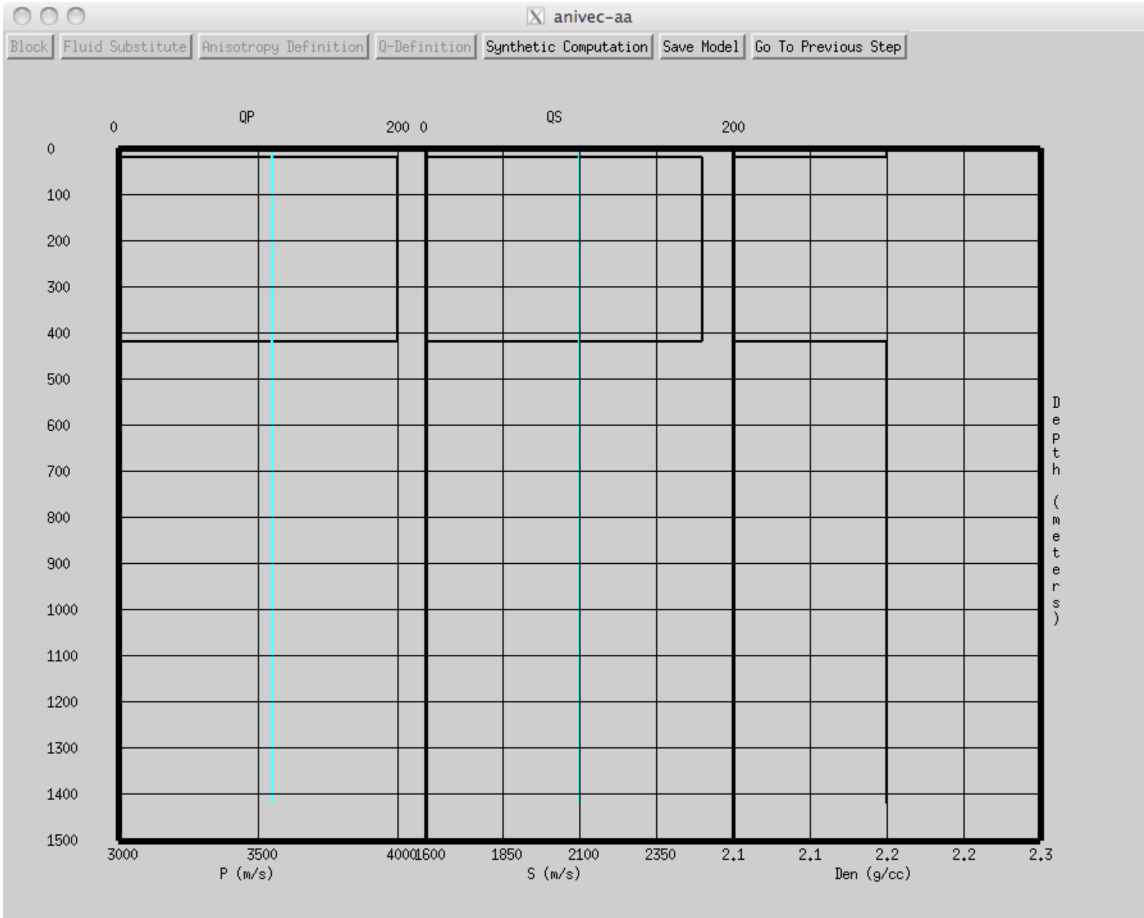

Figure 5. GUI window 3 for 3-layer case.

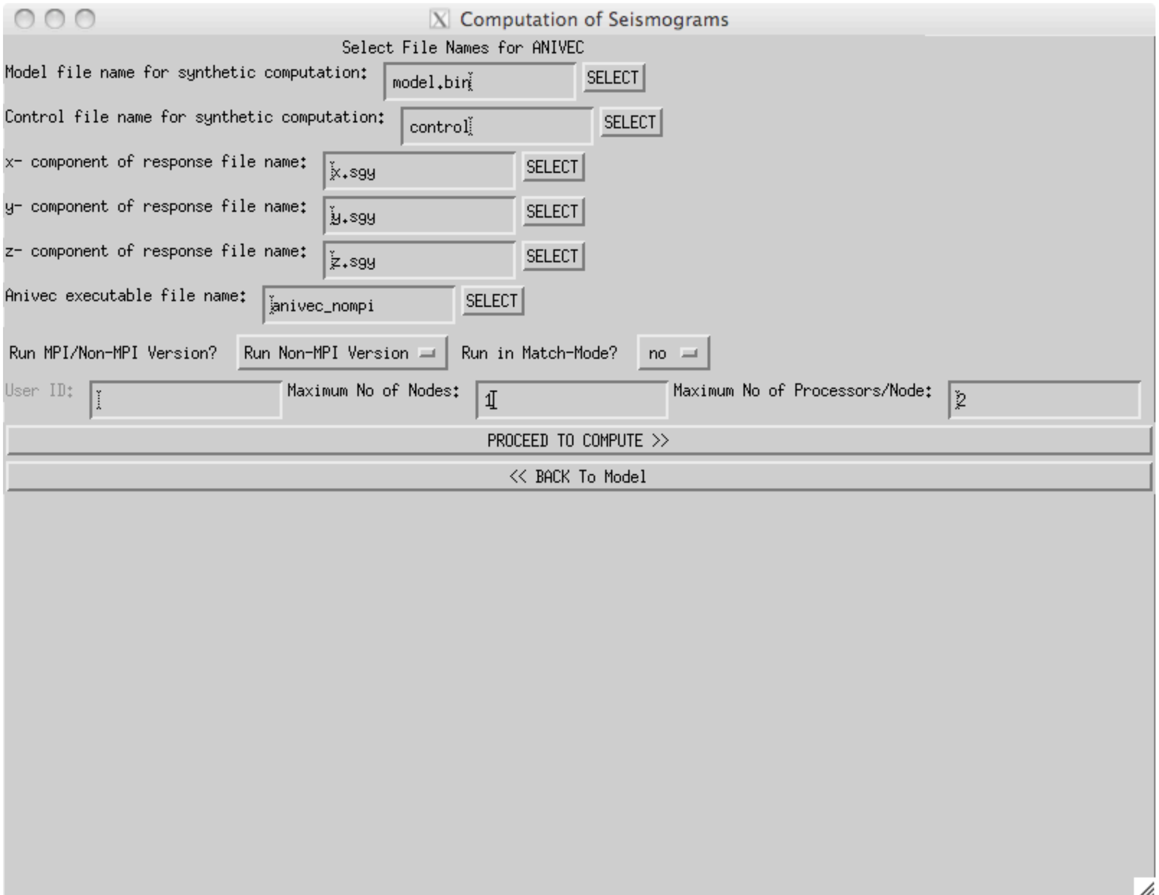

Figure 6. GUI window 4 for 3-layer case.

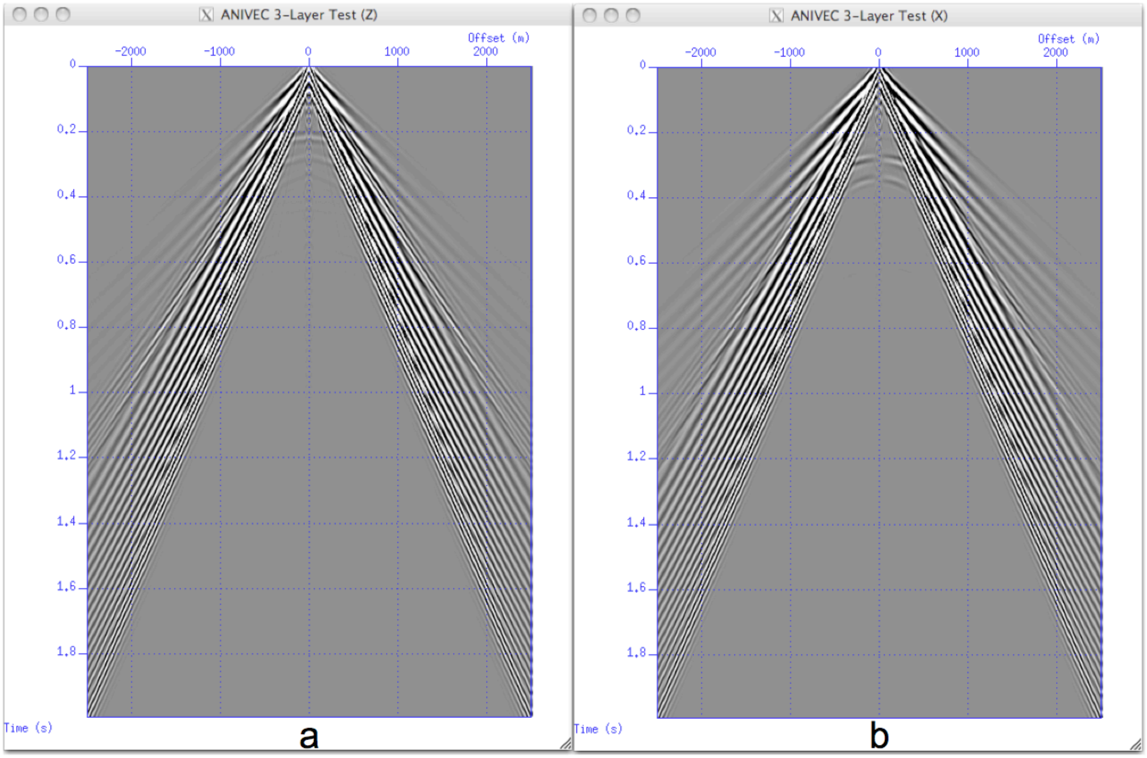

Figure 7. ANIVEC synthetic data for 3-layer text model. a) Vertical (Z) component of motion. b) Horizontal (X) component of motion.

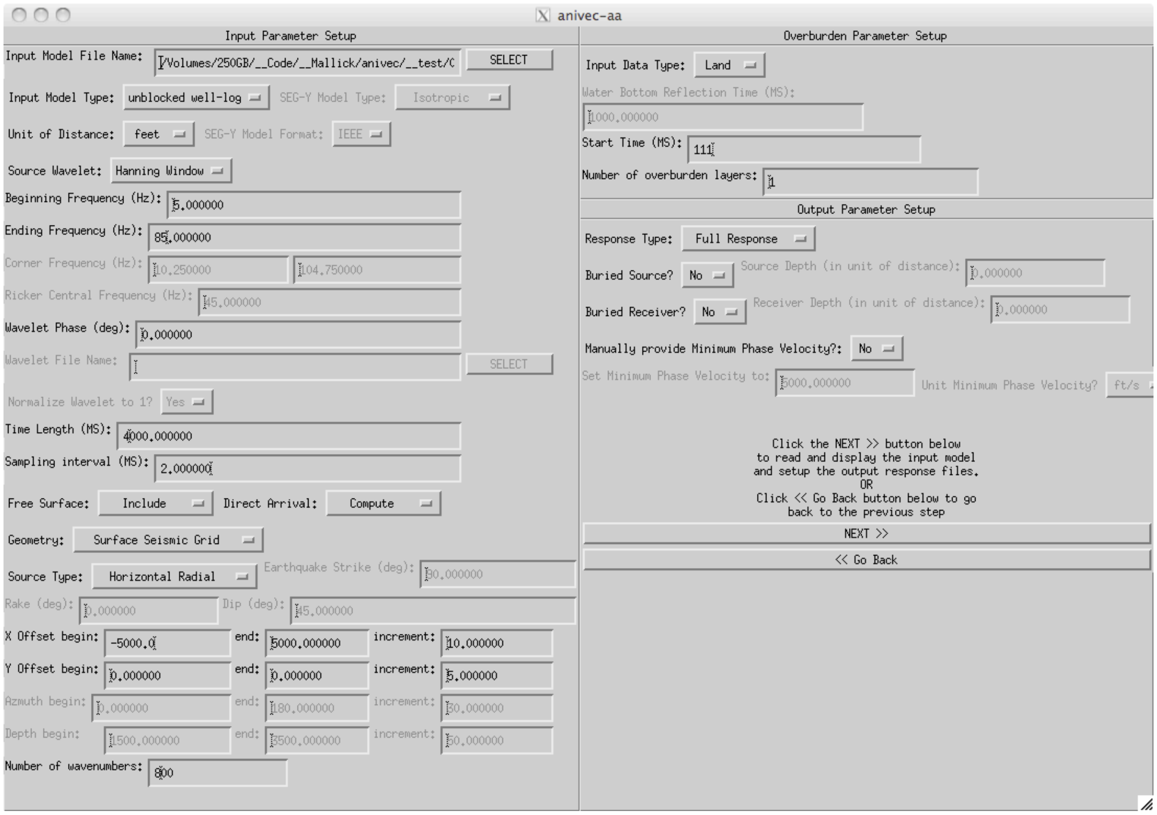

Figure 8. GUI window 2 for Humphrey 4-18 LAS model

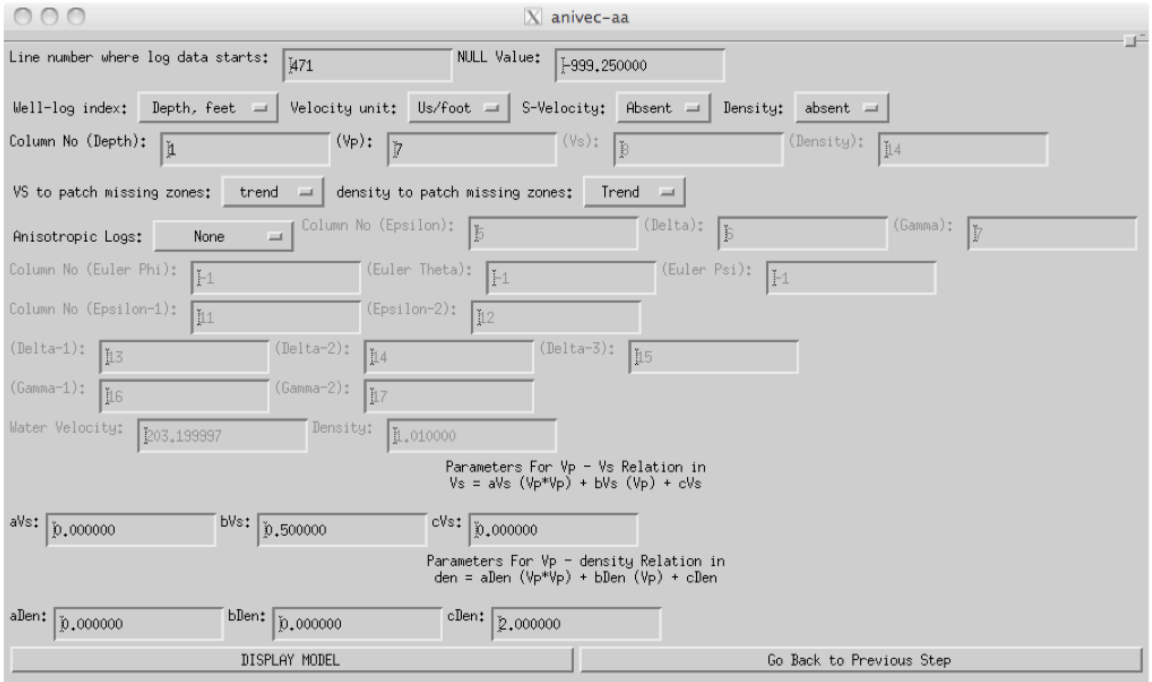

Figure 9. GUI window 3 for Humphrey 4-18 LAS model

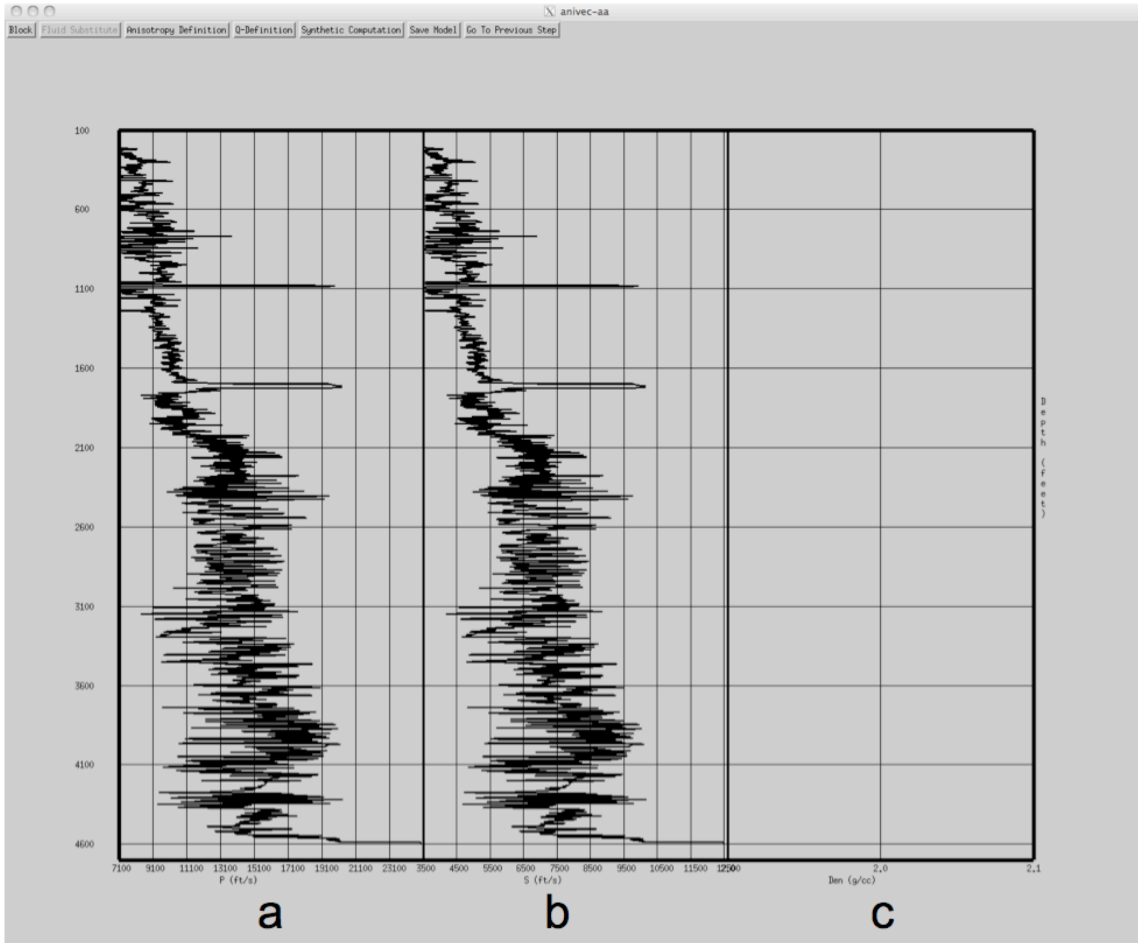

Figure 10. GUI window 4 for Humphrey 4-18 LAS model. a) Vp from sonic, b) Vs computed from Vp, c) constant density.

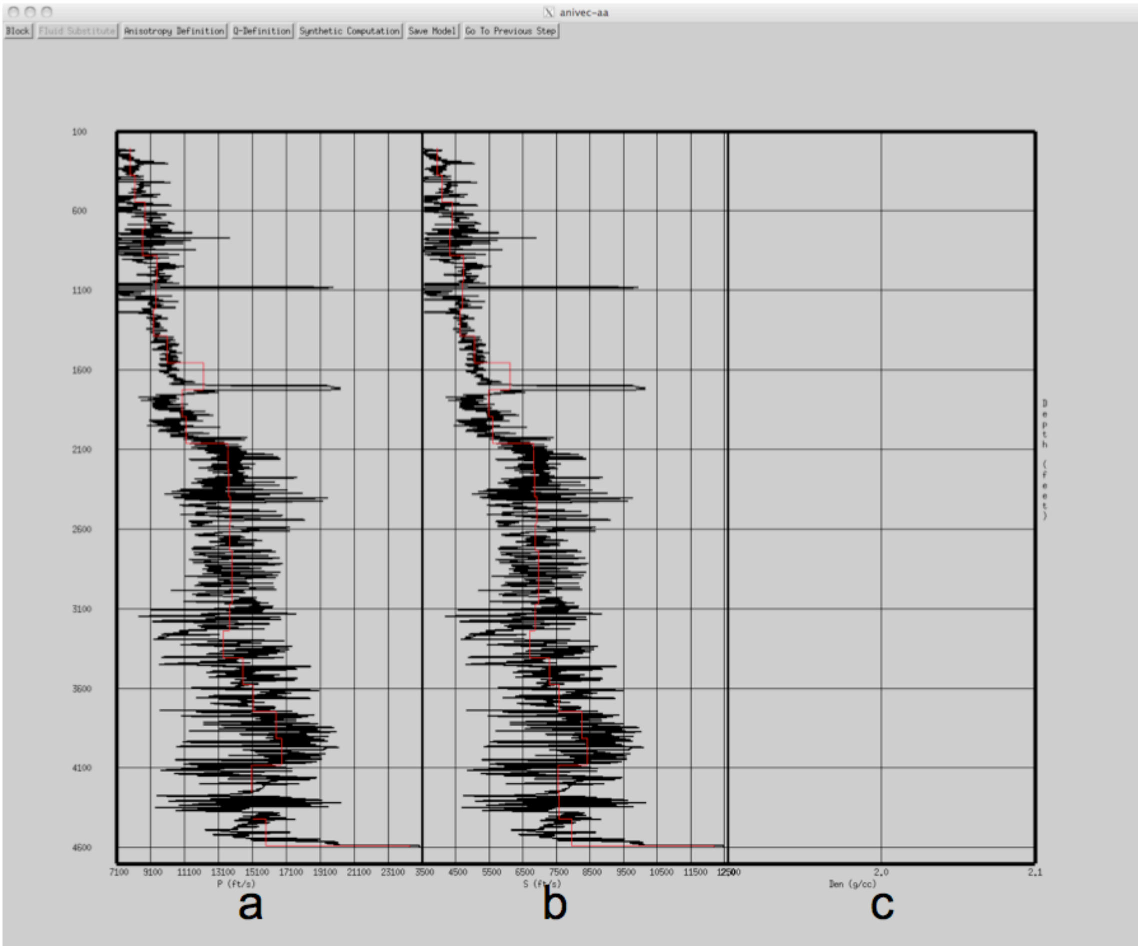

Figure 11. GUI window 4 for Humphrey 4-18 LAS model after blocking (2λ). a) Vp from sonic, b) Vs computed from Vp, c) constant density.

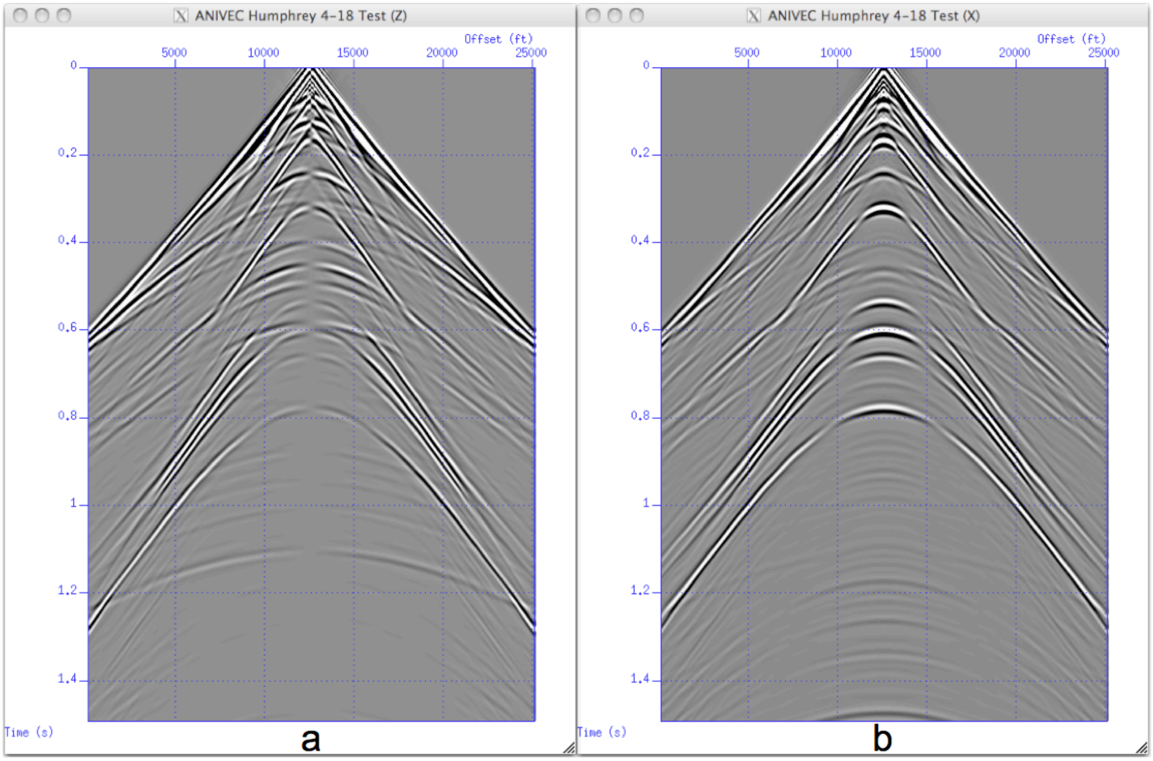

Figure 12. ANIVEC synthetic data for Humphrey 4-18 LAS model. a) Vertical (Z) component of motion. b) Horizontal (X) component of motion.

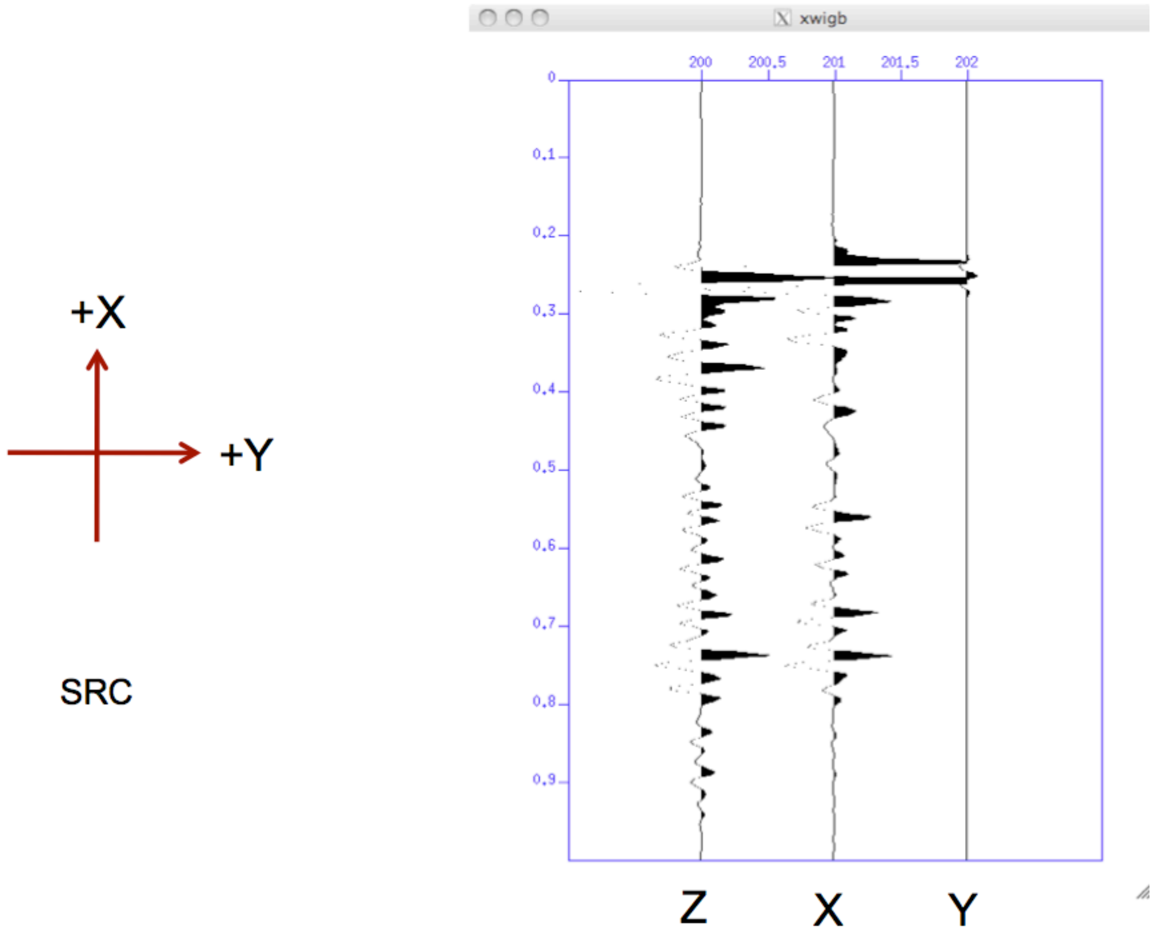

Figure 13. ANIVEC 3-component (3C) trace Z, X, Y before 90 degree horizontal rotation.

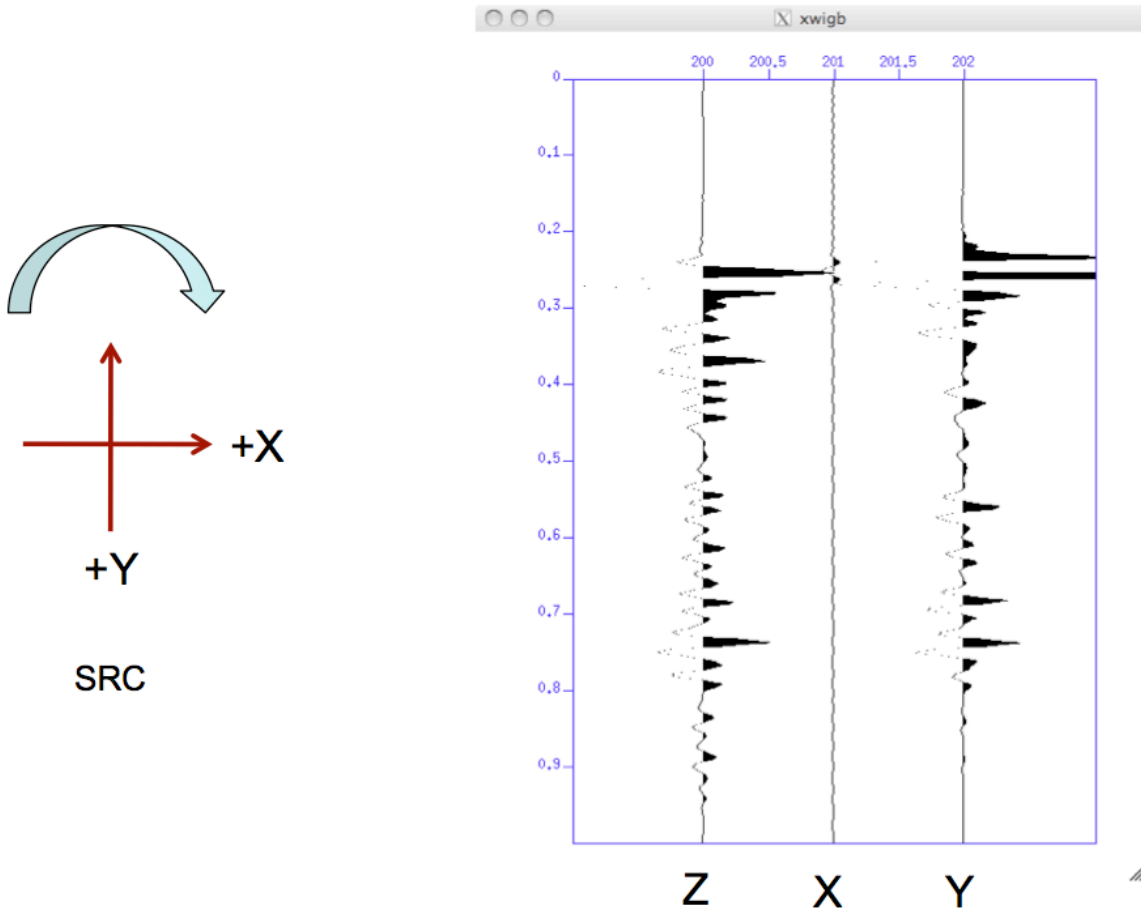

Figure 14. ANIVEC 3C trace after 90 degree horizontal rotation.