New developments in the SYNTH algorithm

Jeffrey A. Larsen, Gary F. Margrave and Darren S. Foltinek

ABSTRACT

An upgrade of the SYNTH algorithm has been developed which includes several new features and bug fixes. These new features include the ability to import las (log ASCII standard) logs, a normal moveout and a normal moveout removed option to better simulate the effects of NMO removal. In addition to these options are more realistic attenuation effects including transmission losses, spherical divergence and simple Q attenuation. Further developments to the user interface of SYNTH also make it easier to view the parameters used to generate the synthetic. SYNTH currently uses a robust MATLAB based platform capable of simulating many earth effects to create synthetic P-P or P-SV offset gathers. SYNTH also interacts with other MATLAB based programs for editing well logs (LOGEDIT), creating wavelets (WAVELETED) and creating well log cross sections (LOGSEC).

INTRODUCTION

Previous work in the CREWES project (Lawton and Howell, 1992) describes how converted wave seismograms can be built using the Zoeppritz equations and offset raytracing. These seismograms are not only useful for building P-SV synthetics, but also create more realistic P-P synthetics in regions of significant amplitude variation with offset (AVO). The SYNTH algorithm (both FORTRAN and MATLAB versions) use full Zoeppritz equations with raytraced incident angles to model offset dependent reflectivity effects. A complete description of the SYNTH algorithm is given by Margrave and Foltinek (1995). The basic steps involved with the computation of synthetic seismograms in SYNTH are summarized in figure 1. For implementation of SYNTH, a P-wave velocity log is required for input, with S-wave velocity and density logs as optional. Density logs can be calculated using Gardner's relation between P-wave velocity and density. S-wave logs can be calculated from a constant Vp/Vs ratio input by the user. Density and S-wave sonic logs can also be built by the user in LOGEDIT. After well log input, logs are resampled into constant vertical traveltime layers For each resampled layer, incident angles are raytraced for each user specified offset for either a P-P or P-S offset gather. Next, the Zoeppritz equations are applied to each resampled layer and the free surface effect is calculated for each offset. Finally, reflection coefficients are placed at zero offset traveltime, the wavelet is scaled and phase rotated and convolved giving the resulting output gather.

IMPORT LAS LOGS

Import of LAS or Log ASCII Standard logs is now possible within the confines of SYNTH. The primary benefit of using LAS files is they allow for one file to contain more than one log type. After a filename is selected, a pop-up menu is displayed containing the log mnemonics for each log type. This log mnemonic list will contain all the logs stored within the LAS file. If a log type is not specified at input, for instance a density log, the pop-up menu choice for a density log will display "NONE".

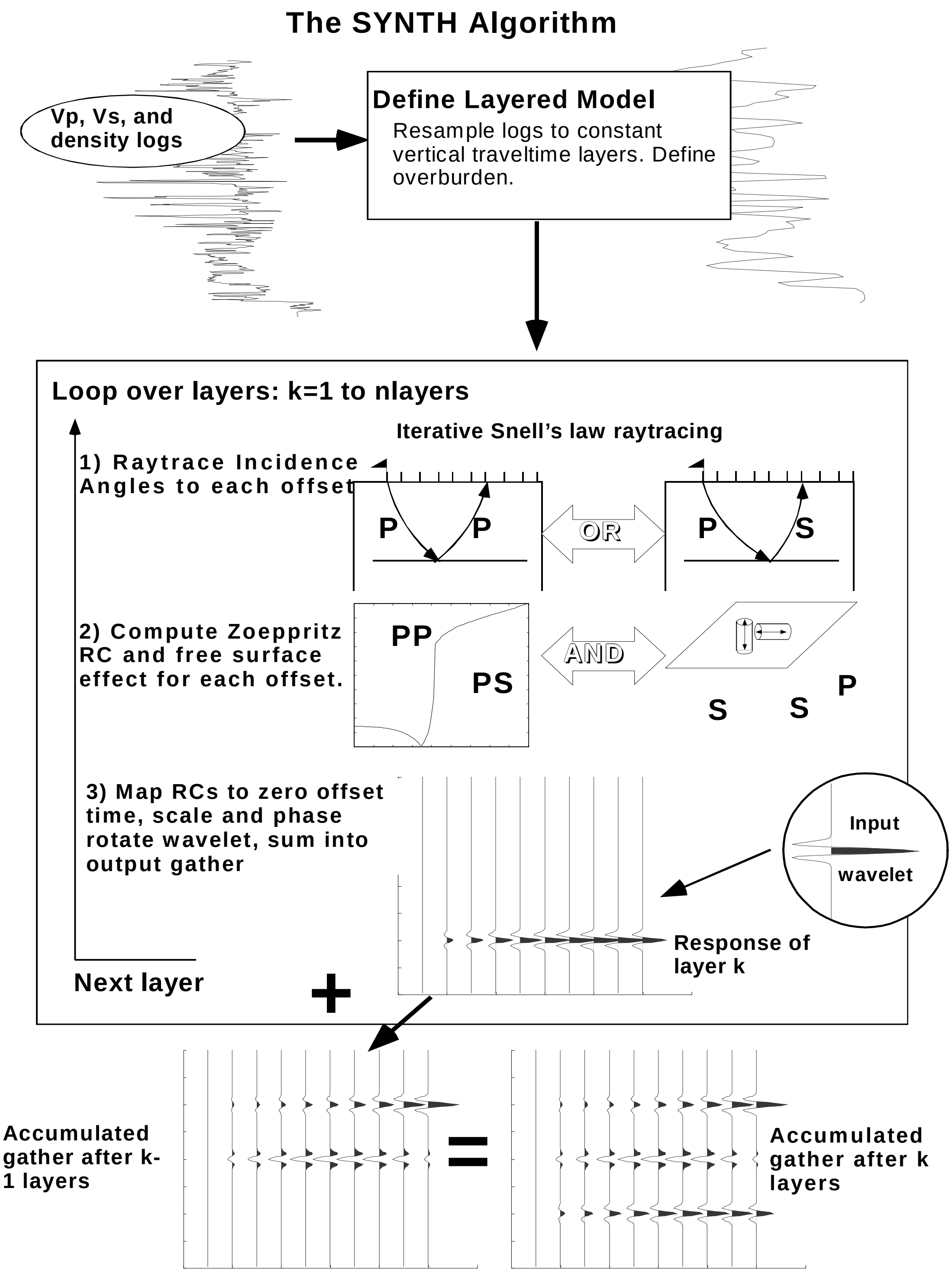

Fig. 1: The SYNTH algorithm

The user must know the type of logs contained within an LAS file, without necessarily knowing the log mnemonics. Logs are re-read from disk every time the synthetic is run to ensure the synthetic is built from the latest version of the logs.

NMO IN OR REMOVED

The normal moveout in option allows for events at offset to contain correct raytraced arrival times. Events at offset will be compressed in time and thus will show a loss in temporal resolution. Previous versions of SYNTH mapped all reflection events at offset to their zero-offset traveltimes, this selection remains an option and is called pseudo-zero offset. The pseudo-zero offset option simulates a perfect removal of NMO with no NMO stretch. Figure 2 shows a comparison between the pseudo-zero offset and nmo in options. NOTE: formation tops are only correct at zero offset for the NMO in option. The normal moveout removed option removes nmo by interpolating events at offset back to their zero-offset time using a sinc interpolation function. This differs from the pseudo-zero offset option because there can be considerable NMO stretch present at offset.

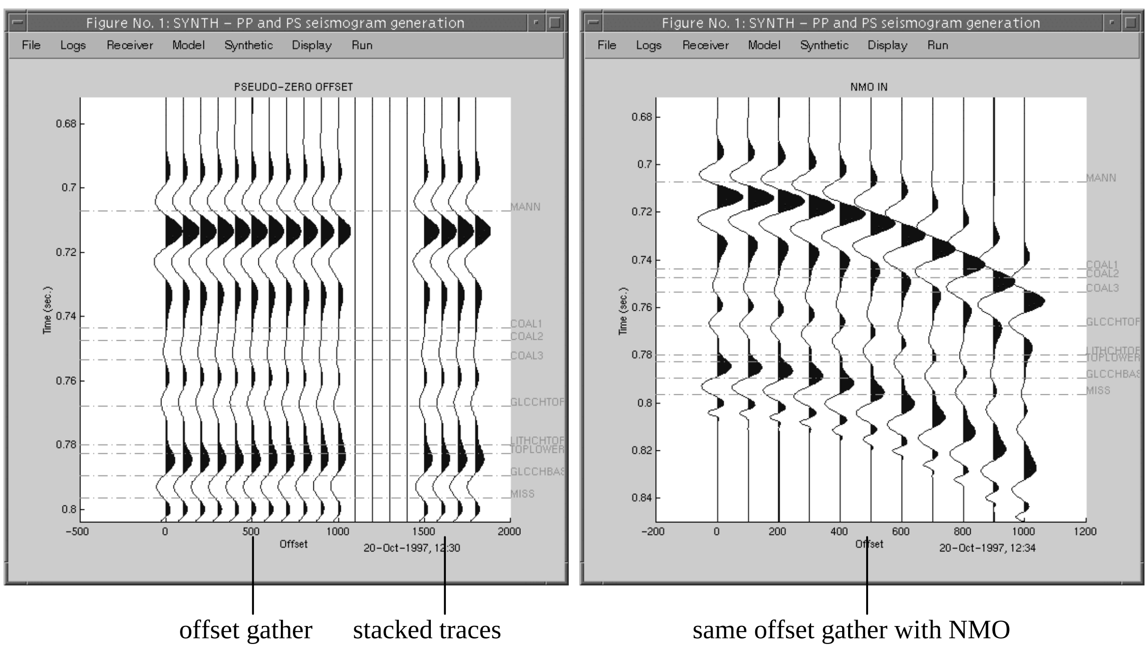

Fig. 2: “Pseudo-zero offset” and “nmo in” options on well 08-08-023W4 using a zero phase wavelet with a dominant frequency of 35Hz on a P-P offset gather.

TRANSMISSION LOSSES

Transmission losses due to reflection are an important factor when considering attenuation effects. With a minor alteration, the Zoeppritz equations can be used to find transmission coefficients, as well as reflection coefficients. The apparent reflection coefficient measured at the surface is equal to:

$$R = R_n \cdot \left(\prod_{j=1}^{n-1} T_{j(down)} \cdot T_{j(up)}\right)$$

where R_n is the reflection coefficient of layer n, and $T_{j(down)}$ is the transmission coefficient of layer j for the downgoing P-wave and $T_{j(up)}$ is the transmission coefficient of layer j for the reflected P or S wave.

This new attenuation model significantly reduces the amplitude of reflection coefficients at deeper traveltime layers. For instance, an incident wave travelling through 50 layers with reflection coefficients equal to .2 will have an apparent reflection coefficient of 0.1299 as recorded at surface. This effect is typically accounted for in seismic data processing by applying a db/sec correction.

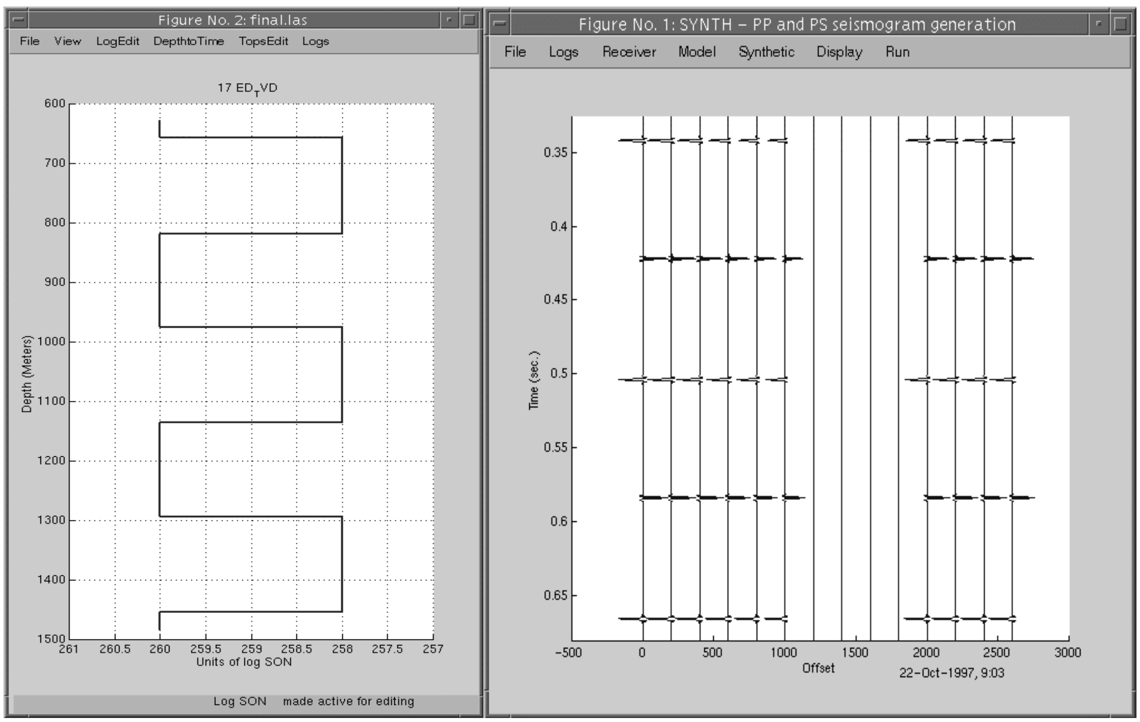

Fig. 3: Simple log model showing P-wave slowness (left). P-P offset synthetic gather using a “spike” wavelet, based on well log model using a constant density and Vp/Vs ratio (right).

SPHERICAL DIVERGENCE

Spherical divergence simulates the effect of energy conservation over an increasing surface area as the wavefield propagates through the earth. Spherical divergence is calculated using a simple formula relating displacement amplitude to the original amplitude times a decay term proportional to 1/r. The formula used is as follows:

$$u(t) = u(t_o) \cdot \frac{r_o}{r(t)}, \quad r(t) = \sum_{i=1}^{n} v_{RMS\,i}^{\;2} \cdot t_i$$

where u is the displacement amplitude of the wave, r_o is the radius of the spherical wavefront at the first log sample and r is the radius of the spherical wavefront at time t. Wavefront radius r is calculated using the method of Newman (1973) for a horizontally layered earth.

Q ATTENUATION

A simple Q attenuation model now exists for the SYNTH algorithm. This model incorporates the “constant Q model” of Kjartansson (1979), where Q is independent of frequency. This is generally considered a reasonable assumption over the seismic bandwidth. The formula for this model is:

$$u(t) = u_o \cdot \exp(-\pi \cdot f_{dom} \cdot t / \sum_{i=1}^{N} Q_i)$$

where u is displacement wave amplitude, f_{dom} is the dominant frequency, t is the traveltime and Q is the quality factor of each log layer. This formula simulates a bulk attenuation effect, without accounting for phase changes due to anelastic dispersion. Current development is focusing on creating a more complex Q attenuation model based on the constant Q theory of Kjartansson.

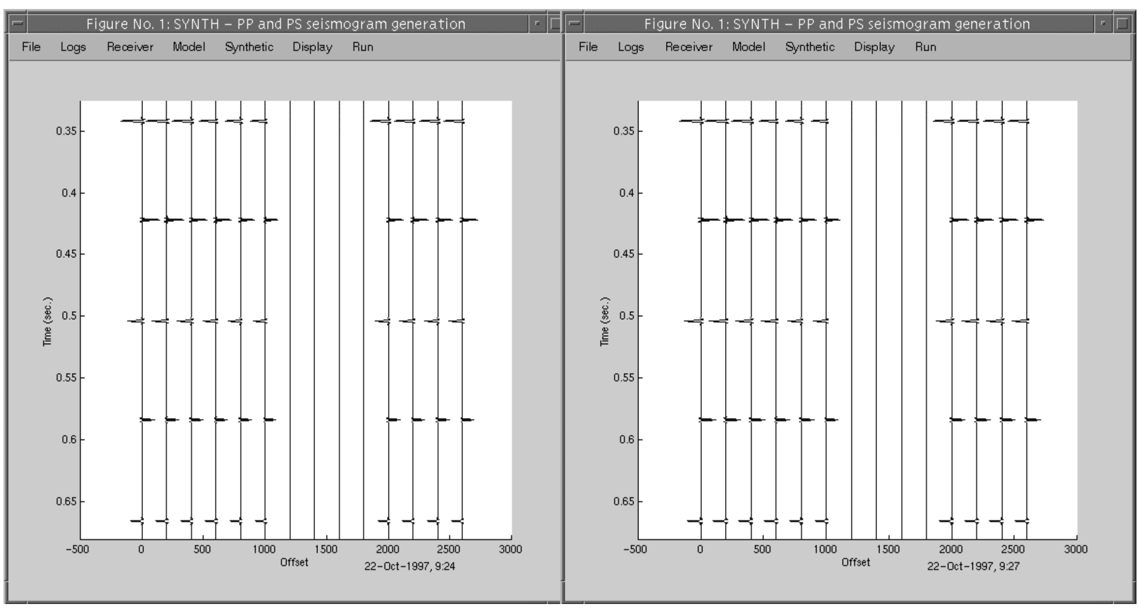

Fig. 4: Simple synthetic model incorporating spherical divergence (left), synthetic showing simple Q attenuation with Q = 70 and dominant frequency = 35Hz (right). Note the relative loss in amplitude with respect to traveltime compared with figure 3.

NEW DISPLAY OPTIONS

Two new options are available in the display menu. The first called “Current parameters” lists all relevant optional parameters for synthetic generation such as wavelet names, survey geometry, P-P or P-S offset gathers, etc. All values in this menu are read only and cannot be changed from within this menu. The second option is a figure cloning capability called “Clone figure”. This parameter copies the SYNTH window exactly, without copying the menu. A new menu is created in the cloned figure called “Parameters”, which displays the parameters used to create the synthetic gather.

SUMMARY AND CONCLUSIONS

The new features added to SYNTH incorporate more realistic earth effects than previous versions. NMO in and removed options more accurately simulate the effects of NMO stretch on real seismic data. The effect of NMO stretch is most significant for traces at far offset, and may significantly affect the appearance of the stacked section. Transmission losses incorporate the effects of energy loss due to reflection of wavefield energy and can be quite significant for real data. Spherical divergence accounts for the effect of energy conservation over an increasing surface area and is proportional to 1/r where r is the radius of the wavefront. Q attenuation currently includes a simple model that accounts for amplitude decay due to anelastic absorbtion. Future developments to the SYNTH Q model will account for phase effects as well.

ACKNOWLEDGEMENTS

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APPENDIX: SYNTH USERS GUIDE

Creating a synthetic section in SYNTH is essentially a six-step process.

I. Select the type of well logs available for import. This selection is made in the “Logs” menu under the “log types” sub menu. This step requires the user to know the contents of the well logs, but not necessarily the log mnemonics. The user must import a P-wave sonic log, with S-wave sonic logs and bulk density logs as optional. If no S-wave sonic log is selected, the S-wave velocities are derived from a constant Vp/Vs ratio set by the user. If no bulk density log is selected, densities are derived from P-wave velocities using Gardner’s relation. NOTE: more complex log models can be built using LOGEDIT if density and/or S-wave sonic logs are not available.

II. Select the file(s) for log import. The current version of SYNTH can import logs of LAS or GMA/QCD format. This step is located in the “File” menu under the sub menu “Import Logs”. To import logs in LAS format, click the “Import Logs” sub menu and then select “LAS file”. The user will then be prompted to select a file name from a pop-up menu. This LAS file should contain all the logs needed for import. Editing of well logs can also be done using LOGEDIT, a MATLAB based software package freely available to CREWES sponsors. Using LOGEDIT and LAS files is the preferred method for importing well logs in SYNTH. After selecting a filename, the user will be given another menu selection from which to select the log mnemonics for the logs selected in step one. To import logs in a GMA/QCD format, select “GMA/QCD files” from the “Import Logs” sub menu. The user will then be prompted to import the filenames for each log selected in step 1. NOTE: GMA/QCD files cannot contain more than one log.

III. Import a wavelet file. SYNTH supports an interactive wavelet editor called WAVELETED in the MATLAB environment. . To create a new wavelet, go to the “File” menu, then select the “Start wavelet editor” sub menu. This opens up WAVELETED, from which the user can select a variety of wavelet options. To open a saved wavelet file select “Load wavelet file” in the same menu. After loading a wavelet file, select the “Synthetic” menu, then the “Wavelet” sub menu and finally select the desired wavelet. NOTE: the sample rate of the wavelet now determines the sample rate of the final seismogram.

IV. Select the optional parameters for the synthetic. Some parameters can be loaded from a saved session by going to the “File” menu and selecting “Load Parameters”. Parameters can be saved during a session by selecting “Save Parameters” in the same menu. Optional parameters are summarized as follows:

> 1. Log integration interval - This allows for the selection of an integration interval in time for the well log. Raytrace based synthetic algorithms are destabilized by rapid fluctuations in velocity. Log re-sampling essentially time averages the logs over a traveltime equivalent to the sample rate. This causes high velocity portions of the log to be averaged more than lower velocity regions. The default log integration interval is 2ms.

2. Receiver options - Under the menu “Receiver” and the sub menu “Type”, vertical, horizontal and total receiver components can be displayed. The component selected should be appropriate to either a P-P or P-S reflection type. A second option in this menu is the receiver geometry. By selecting the “Geometry” sub menu, a pop-up menu will be displayed which allows for the selection of the number of receivers, receiver interval, near offset and capture radius. Capture radius is the distance interval around a geophone where a given wavefront will be recorded.

3. Earth model options - In the menu “Model” several sub menu options can be selected. “Top layer specs” allows for the user to input P and S wave velocities and density for the top layer. The default for this parameter is the first value in each well log, or the derived values from Vp/Vs ratios and/or Gardner's relation. “Vp/Vs” ratio is only used when no S-wave sonic log is available. This sets a single Vp/Vs ratio for the entire well interval, which is used to derive values for the S-wave sonic log. More detailed Vp/Vs models can be built using LOGEDIT. “Transmission losses” includes amplitude decay due to the reflection of wavefield energy at each layer interface. “Spherical divergence” includes the effect of amplitude decay due to spreading of wavefield energy. When “Q attenuation” is selected, a pop-up menu will be displayed asking for a single Q value or an LAS log containing Q values for the entire section, as well as a dominant frequency. Q defaults to infinity, which suits the model for a perfectly elastic, layered earth medium.

4. Synthetic options - In the menu “Synthetic”, several options are available for the synthetic type. Under the sub menu “Section type”, a pseudo-zero offset, normal moveout or normal moveout removed option can be selected. A P-P or P-S gather can be selected in the “Reflection type” sub menu.

5. Check current parameters - In the “Display” menu, “Current parameters” lists all the currently selected parameters inclusive of this third step. This option can be used before or after running the synthetic. NOTE: the value displayed in this menu can be changed at any time, and may not necessarily be current to the actual synthetic displayed.

V. Run the synthetic algorithm. Simply select “Run” once all the desired options have been selected.

VI. The final step is to select any display or output parameters for the synthetic. NOTE: options 4 to 7 below can be set before running SYNTH.

1. Saving output seismogram - In the “File” menu, select “Save seismogram to SEGY” from which a pop-up menu will ask for a file name.

2. Printing a figure - In the “File” menu, select “Print figure” , from which a pop-up menu will ask for the desired print options.

3. Cloning a figure - In the “Display” menu, select “Clone figure” to exactly copy the output of the figure window. This is useful when more than one seismogram is desired for output. After selection, an exact copy of the figure

is made and a menu called "Parameters" lists all the current parameters at the time the figure was cloned. NOTE: if this option is used, it is recommended the figure is cloned immediately after run since the parameters menu only displays the values current at the time of figure cloning.

4. Show tops - In the "Display" menu, select "Show tops" to display formation tops. NOTE: formation tops must be included in the log input, or tops cannot be displayed. See option 9.

5. Spread top labels - In the "Display" menu, select "Spread tops" to either display names at top times or at an even interval. See option 9.

6. Stack display - In the "Display" menu, select "Stack display" to show a display of only the stacked section. NOTE: this option only works for the pseudo-zero offset and normal moveout removed section type options. See option 9.

7. Drawing scale - In the "Display" menu, select "Drawing scale" which creates a pop-up menu to input an overall plot scale (default = 1:1). See option 9.

8. Specify title - In the "Display" menu, select "Specify title", which will create a pop-up menu that asks for a title to be placed at the top of the figure.

9. Redraw plot - In the "Display" menu, select "Redraw plot" to redraw the seismogram in the figure window. This will not run the seismogram again, but will only redraw the figure window. This option must be selected when any of 4 to 7 above are changed.