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Users Guide for PNSEB

A Program for Rapid Computation of Multioffset
Vertical Seismic Profile Synthetic Seismograms
for Layered Media

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13. Abstract *(Maximum 200 words)*.

PNSEB is a set of FORTRAN programs for calculating the response of a layered elastic medium using the reflectivity method as described in Mallick and Frazer (Practical Aspects of Reflectivity Modeling, *Geophysics* 52, 1355–1364, 1987; Rapid Computation of Multi-offset VSP Synthetic Seismograms for Layered Media, *Geophysics* 53, 479–491, 1988). PNSEB consists of two basic modules, each of which consists of more than one major option. The first module, PNSN, calculates the earth's response (Green's function) in frequency-wavenumber (ω-p) space. Using the proper option, the program can calculate the response at very small or very large offsets. No lateral variability or anisotropy are allowed, but the full response including interface waves is calculated. The second module, PNSYN, in its main form converts the output from PNSN to time-distance (t-x) space, which can then be plotted by the VSPLT module or by other plotting packages. The program has been written and optimized for vector computers, such as a Cray or Convex, but also runs well on scalar computers such as Sun workstations.

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Users Guide for PNSEB

a program for rapid computation of multioffset vertical seismic profile synthetic seismograms for layered media

INTRODUCTION

This document describes a set of FORTRAN programs which can be used to calculate synthetic seismograms and a few other response characteristics of a layered elastic medium. Copies of the programs can be obtained from D. Lindwall at the address on the front page of this report. The method used is the reflectivity method as described in Mallick and Frazer (1987; 1988). These two papers describe the background of the method, the calculations used, and some of the limitations and problems involved. We recommend that the user consult these references for questions concerning the details of these calculations. Another useful reference is Rudman et al. (1993) which reviews the two Mallick and Frazer (1987; 1988) papers, gives some simple examples, and gives the complete FORTRAN listing of the basic modules. In brief, this set of programs uses a rearrangement of the Kennett reflectivity algorithm (Kennett 1983) that is easily vectorizable. The Filon method of quadrature of the slowness integral is used for an additional increase in speed. Complex frequencies are used in a technique to avoid time aliasing. Attenuation is included by using a modified Strick's power law and complex, frequency dependent velocities.

An earlier version of this code was for modeling OBS (ocean bottom seismometer) and OSS (ocean subbottom seismometer) data and was called SEABED. This early code was modified so that it could model the very long range P_n and S_n waves (or P_o and S_o in oceanic crust) and was renamed to PNSEB.

Two packages are used sequentially to give the seismograms or other desired results. Alternative versions of each package give different types of results. The second package produces an ASCII file containing the time series and the model used which can be transported to many other computers and used for making plots. Also included are an ASCII to binary conversion program and a plotting program.

The first package is PNSN. It is the most computationally intensive package. Using a user supplied model, it calculates the earth response over a user defined finite bandwidth for a specified range of receiver offsets and receiver depths from a single source. The calculation is done in frequency-ray parameter (ω-p) space. The ω-p response is transformed to frequency-offset (ω-x) space and written to three files for use by the second package. The pressure, vertical, and horizontal motions are each written to a separate file, each containing the response for all receiver depths and offsets. A version of PNSN, called PNBES uses a trapezoidal integration and a Bessel function instead of a Filon integration and a Hankel function as in PNSN and can be accurate even at zero offset, but has a longer run time than PNSN and gives poor results at large offsets. Other current versions of PNSN calculate only the pressure response (PNSN-P), for quicker

calculation, or write the ω-p response (PNSN-WP) so that it can be transformed to tau-p by a version of the second module.

The second package is PNSYN. It reads one of the w-x response files from PNSN or PNBES, applies filters and windows, convolves the response with a source, transforms the response to the time domain in either time-horizontal offset (t-x) or time-depth (t-z, also called a vertical seismic profile or VSP), and writes an ASCII file which can be used for plotting. It can either write one file for each receiver depth or one file for each receiver offset, depending on whether t-x seismograms are wanted or VSPs are wanted. The version SYNSPEC produces either power spectra or amplitude spectra of the response. It includes the same filters, windows and sources as PNSYN. The version TAUPSYN uses the output from PNSN-WP to generate tau-p synthetics.

The ASCII files produced by PNSYN and SYNSPEC can be transported to other computers and then converted by CON to machine dependent binary files that can then be used by VSPLT to produce plot files. Some users have developed their own plotting routines (which may use commercial graphics software) and new users are urged to consult with old users to learn what is available. ROSECON also reads the ASCII files from PNSYN and SYNSPEC and writes a data file that is similar to ROSE format (LaTraille et al. 1982; LaTraille and Dorman 1983).

PNSN calculates an approximation of the Green's Function (earth response) with numerous limitations caused by the finite sampling and limited bandwidth in both frequency and ray parameter space. This results in a time domain "impulse" response of finite width that always has sidelobes. The shape of the response can be modified by frequency and ray parameter windows and frequency filters. Seismograms of the response may be plotted or the response may be convolved with a user-defined source wavelet. Source wavelets are usually defined to be convolved with a delta function and users are cautioned to use a sufficiently high frequency limit in the response calculation and a smooth window so that the "deltaness" of the calculated response is sufficient so that the source wavelet will be properly reproduced. An additional difficulty with convolving source wavelets occurs when a velocity or acceleration response is calculated rather than a displacement response. A displacement "impulse" or response of sufficiently high frequency with a good window and filters will approximate a delta impulse response. A velocity "impulse" is the derivative of displacement and, in order to follow physical laws, has one positive pulse and one negative pulse and an acceleration "impulse," being the derivative of velocity, has three strong pulses. Measured source functions for velocity and acceleration devices should be corrected (first or second antiderivative) so that they can be convolved with the proper response. Geophones generally measure velocity, or sometimes acceleration, and the proper type of motion must be calculated so that the proper amplitudes are obtained. For a hydrophone, even though it measures pressure, or acceleration, displacement can be used instead to get a simple pulse since the liquid medium is generally uniform. The pressure response is calibrated to give amplitudes relative to the response at a distance of 1 m in a uniform liquid with an explosive source (M1 = 1, M2 = 0, M3 = 1 in the "resp" file) and with a Hanning window (variable IWIND = 2 in the "param" file) in PNSYN. The velocity and acceleration response are calibrated so that their amplitudes are relative to the response at 1 m below a vertical impulse source

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for vertical (M1,M2,M3=0,0,1) and 1 m horizontally away from a horizontal impulse source for horizontal (M1,M2,M3=1,0,0) with a Hanning window (variable IWIND = 2). The amplitudes are calibrated for the Hanning window since it is the most useful and the least frequency and motion type dependent.

A small error in travel times occurs when using very low Q values (high attenuation) as noted by Bromirski et al. (1992). This error comes from using frequency dependent Q and is not changed by different values of the WREF, EPS, and SIG variables in line 3 of the "model" file. The WREF, EPS, and SIG variables do affect the dispersion, however and the user may wish to select your own values rather than use the default values, particularly when Q_p and Q_s are very low.

PNSN

This program uses the reflectivity technique to compute the synthetic seismic response for a laterally homogeneous visco-elastic earth and may be used to model both exploration seismic and earthquake data. This program is especially suitable for modeling very large offset data since it is capable of handling the frequencies and the distances involved. This program is written for use on a Cray X-MP system and is for the most part vectorized. It has been run on a Convex computer using the -cfc option in the FORTRAN compiler and on a Sun workstation using the double precision option on the compiler. We have found that Sun workstations using the IEEE floating point standard have sufficient accuracy that they can be run with single precision resulting in a much shorter run time. This program is also capable of computing the response at multiple receiver depths and, thus, may be used for computing multi-offset synthetic VSP seismograms as well.

This package consists of the main program and six subroutines:

1) pnseb.f, the main module.

2) The subroutine modlin.f, used to read the model file.

3) The subroutine respin.f, used to read the file "resp," which contains computational parameters.

4) The subroutine execut.f, used to compute the synthetics.

5) The subroutine bufout.f, used to write the synthetics to a disc file.

6) The logical functio. cvmgt.f.

7) The subroutine getsecs.f, used to time the program.

On UNIX systems, the compilation and linking is most conveniently done with a makefile. A sample "makefile" is included with the set of sample input files. On a Convex system, the -cfc option must be used with the FORTRAN compiler. An optimization level of 2 (-O2) decreases run time to about a sixth of the unoptimized time. Compilation time using -O2 is about 8 minutes on a Convex C1.

This program can use a large amount of memory. On some machines, the charges and the swap times are partially dependent on the memory size used. To minimize the memory required, some of the array dimensions should be kept to the minimum required for each problem. In the subroutine EXECUT, the memory size can be kept down by specifying array dimensions and parameters that are only as large as necessary for the calculation. In the main common block, the variables CL, QL, CT, QT, RHO, and T have dimensions of maximum number of layers. Be sure to change the dimensions for these variables in the COMMON statements in all of the other subroutines and in the main program. The dimensions for the variables RMODEL and IRM also must be adjusted for the maximum number of layers. The parameters NXMAX, IBLK, NZMAX, IMAX, and ILMAX are used as the dimensions for many complex arrays. NXMAX is the maximum number of offsets allowed. It can be set to one for calculating a single VSP. IBLK is a blocking

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parameter to reduce the memory needed by the program. Program speed is not affected by IBLK unless it is set to a very small value. NZMAX is set to one when there is only one receiver depth. Using multiple receiver depths, as in the case of a VSP, requires setting NZMAX to a number equal to or greater than the number of receiver depths and will turn several one dimensional complex arrays into two dimensional complex arrays. IMAX is set equal to IBLK * NZMAX and ILMAX is set equal to IBLK * the number of layers. Every time that any of the array dimensions or parameters are changed in the program listing, the program must be recompiled.

The maximum number of layers the program can handle is adjustable and affects the program size. This is changed in the dimensions of the arrays ZZ, CL, CT, QL, QT, RHO, T, RMODEL, and IRM in modlin.f and execut.f, the parameter ILMAX in execut.f and CL, . . . ,T in the transf.f module of PNSYN. Most of these arrays have one element per layer and those that don't are documented in the source listing. Increasing the array dimensions will require a larger memory and, on some systems, will slow execution time. Also, be sure that the layer array dimensions in PNSYN are large enough.

INPUTS TO THE PROGRAM

The inputs to the program are in two files; one containing the model and one containing the program parameters. The names of these files at present are "model" and "resp"; however, these names can be changed in the shell script "runpn." The files are written in free format with either commas or single spaces between the numbers. In these input files, the names of integer variables begin with the letters I through N. All others variables are real numbers which must have a decimal point.

The "model" file contains the following in sequence:

Line 1: FS, DECAY, IFLT, LSOUR, IRND, IQOPT Where:

FS is a sampling parameter for the ray parameter, usually between 0.07 and 0.12. Sampling is finer as FS increases. As a rule of thumb, set FS at 0.07 when computing synthetics up to very short ranges (less than 100 km), set it to about 0.09 for computing to the intermediate ranges (less than 1000 km) and set it to 0.12 when going to large distances (say 2000 km).

DECAY is a decay factor used to avoid time series wraparound. A value of N for DECAY means that wrapped around signals are diminished by a factor of N over the length of the time series. A recommended value for DECAY is 50. If the wraparound is in the negative time direction, such as when using a slow reduction velocity, use a DECAY of 1 to avoid enlarging the wraparound.

IFLT is the earth-flattening approximation parameter. If IFLT=1, then the program assumes that the model parameters are for a spherical earth and applies an earth-flattening approximation to them. Otherwise, the model parameters are assumed to be for the flat earth and no approximation is used.

LSOUR is the layer on top of which the source is. If the source is located within a layer, then divide that layer into two layers with the source at the top of the second layer.

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IRND is a flag to implement random layer velocities. If IRND = 1, then line 2 is read.

IQOPT is a flag to reset the parameters used to calculate the frequency dependent velocities that are used to incorporate realistic attenuation into the calculation. If IQOPT = 1, then line 3 is read. Otherwise, the default values are used for all layers. The frequency-dependent complex velocities are calculated with a modified Strick's power law (Mallick and Frazer 1987).

Line 2: (include only if IRND = 1; otherwise, delete this line) LAYER, SDLC, SDCT, ZLAYER where:

LAYER is the layer number for the top layer that has random velocities. All layers (defined in line 4) below this one, except for the bottom layer and the layer LSOUR, have velocities that are randomized over a uniform distribution within the specified limits. Random values are added to, or subtracted from, the values given for the parameters CL and CT in the line 4 list. The parameters QL, QT, RHO, and T are unchanged.

SDLC is the standard deviation of CL for the random velocities.

SDCT is the standard deviation of CT for the random velocities.

ZLAYER is the thickness of the random velocity layers in kilometers. Any layer thicker than this is divided into layers that are ZLAYER thick or less.

Line 3: (include only if IQOPT = 1; otherwise, delete this line) LAYERN, WREFP, WREFS, EPSP, EPSS, SIGP, SIGS. These are values for the variables in equation (28) in Mallick and Frazer (1987) and are used to calculate the frequency dependent velocities as a way of implimenting realistic attenuation.

LAYERN is the top layer which uses the user supplied values. All the layers above this use the default values and all the layers below this use the user applied values.

WREFP is the reference frequency for compressional waves. The default value is 10 Hz.

WREFS is the reference frequency for shear waves. The default value is 10 Hz.

EPSP is the third attenuation parameter for compressional waves. The default value is 0.001.

EPSS is the third attenuation parameter for shear waves. The default value is 0.001.

SIGP is the first attenuation parameter for compressional waves. The default value is 0.1.

SIGS is the first attenuation parameter for shear waves. The default value is 0.1.

Line 4 (repeated): CL,QL,CT,QT,RHO,T (one line for each layer) where:

CL is the compressional wave velocity in kilometers per second.

QL is the compressional Q.

CT is the shear wave velocity in kilometers/second. Note: a value of -1. for CT assumes CT = CL/SQRT(3.).

QT is the shear Q. Note: a value of -1. for QT assumes QT = QL/2.

RHO is the density in grams per cubic centimeter.

T is the absolute thickness of the layer in kilometers.

Note: To get an approximation of a gradient zone between two layers, the user may put in a line with 0,N,T for the first three variables between two regular layer lines. This will automatically insert N layers over the thickness of T km and the elastic values will be linearly interpolated between the layer above and below. In the gradient zone, there should be a sufficient number of layers so that the thickness is equal to half the wavelength of the highest frequency (selected in "resp").

The response file "resp" contains the following in sequence:

Lines 1 and 2: Title cards.

Line 3: NW,NOR,TSEC,P2W where:

NW is the number of frequencies to calculate. The maximum frequency calculated will be NW / TSEC hertz. You should select a maximum frequency about twice that of what you want to observe since a hanning window is usually applied over frequency in PNSYN when a realistic source pulse is used. If a pulse like those in SAFARI (Schmidt 1988) is used (again in PNSYN) be sure to calculate to a frequency high enough for that pulse. NWMAX is not an array dimension parameter in execut.f or any other module of pnsn but it is in transf.f, the largest module of PNSYN. Be sure that NTMAX is at least 2 * NWMAX in transf.f.

NOR is the number of receiver depths for a vertical seismic profile (VSP). Set this to 1 to get a horizontal offset (t-x) seismogram. If more than one depth is used, then change the dimension of NZMAX and IMAX in execut.f and NZMAX in transf.f (one of the PNSYN modules) so that they have the same number of elements in the appropriate dimension as there are receiver depths. The memory space needed and output file sizes are nearly proportional to the number of receiver depths. The run time is only slightly increased when NOR is increased.

TSEC is the time series length in seconds.

P2W is the maximum ray parameter (p) value (in seconds per kilometer) over which the synthetics are computed. The ray parameter is the inverse of the horizontal component of the phase velocity. A value of -1.0 for P2W automatically sets P2W. A user-set value should be large enough so that the window over p will include the arrivals with the slowest horizontal phase velocity. A maximum p of 0.8 seems to be sufficient to include water velocity arrivals.

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Line 4: LOBS(IZ),IZ=1,NOR are the layers on top of which the receivers are located. If any receiver is within a layer, introduce a fictitious layer. (The source layer is specified in the first line of the model file.)

Line 5: BX, FX, DX where:

BX is the initial range in kilometers.

FX is the final range in kilometers.

DX is the range increment in kilometers.

Line 6: PW1, PW2, PW3, PW4

These are ray parameter window settings. Responses are gently tapered between PW2 and PW1 on the lower side (PW1<PW2) and between PW3 and PW4 on the higher side (PW3<PW4) using cosine hanning windows. This is to avoid truncation phases on the seismograms. If PW1, PW2, PW3, and PW4 are all set to zero, then the default taper widths of 15% are used by the program which work quite well. If PW2 is set equal to PW1 or PW3 equal to PW4, then the default values are used to avoid numerical errors. If the user wants to see reflections which have a small ray parameter (such as near vertical incidence), then you may need to use a small value for PW2 such as 0.1, 0.05 or even 0.01.

Line 7: DPMAX

The largest step size in p used. The p step size is set automatically as a function of frequency except when DPMAX is smaller than the automatic value, then DPMAX is used. This avoids very large steps in p at low frequencies and is used when running PNBES since the automatic value is much too big in a trapezoidal integration.

Line 8: ETYPE

Set this source parameter to D if the source input are straight moment tensor and to E if the moment tensor is to be computed from the earthquake focal mechanism solutions. For an explosive source in water, use D.

Line 9: (H(I), I=1,2)

This is the linear part of the source. H(1) denotes the vertical and H(2) denotes the horizontal part. For earthquake sources, both H(1) and H(2) are usually zero. For an explosive source in water, set H(1) and H(2) to zero.

Line 10: M0, DELTA, LAMDA, PHIS, PHI or M1, M2, M3

This can be of two types. If line 8 is E then line 10 contains M0, DELTA, LAMDA, PHIS, PHI, where M0 is the seismic moment, DELTA is the dip, LAMDA is the rake, and PHIS is the azimuth of the fault plane and PHI is the azimuth of the receiver location. If line 8 is D, then line 10 contains M1, M2, M3, where M1, M2, M3 are the (1,1), (1,2), and (2,2) components of the moment tensor. This is a four-component 2-D tensor instead of the nine-component 3-D tensor that you will find in textbooks. The (2,1) component is the same as the

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(1,2) component. For an explosive source in water, set M1 and M? to 1.0 and set M2 to zero (0.0).

OUTPUT OF THE PROGRAM

The program has four output files. The first file is named "pnsnout," and contains the computation information, e.g., model, ray parameters used, total CPU time used in computing etc. This is a text file and may be written to the screen to verify whether the job has executed successfully. The other files are named "denp," "denh," and "denv" and contain the computed pressure and the horizontal and the vertical responses, respectively, in frequency range domain. The amplitude of the response files are relative to the response at 1 m. These files are used as input to the package PNSYN for generating the synthetics. The names of these output files can be changed by modifying the three OPEN statements appearing near the beginning of execut.f.

RUNNING THE VERSION PNBES

PNBES uses exactly the same format for the "model" and "respin" files. In fact, all of the subroutines are the same except for execut.f, which becomes exebes.f, and a new subroutine called bessub.f, which contains the Bessel function. A few of the parameters in the "resp" file must be changed both to take advantage of and to consider some restrictions in the use of the Bessel function. The trapezoidal ray parameter integration in PNBES, which uses a polynomial expansion of a Bessel function, is valid even when the product of the frequency (w), ray parameter (p), and offset (x) (w*p*x) is small while the Filon integration in PNSEB, which uses an asymptotic expansion of a Hankel function is invalid for a small w*p*x than with the Filon integration in PNBES. The big drawback with the trapezoidal integration in PNBES is that many more integration points are needed, especially for large w*p*x. This makes PNBES useful for calculations when w*p*x is small but impractical when w*p*x is large.

The window over ray parameter (p) must be changed from the default values to get the correct amplitudes from the arrivals with a small w*p*x. The default p window is a 15% cosine taper on both sides. This minimizes the artifacts but also eliminates any real arrivals with a small p. The variables PW1, PW2, PW3, and PW4 on line 6 of the "resp" file control the p window. Values of 0.0, 0.01, 0.7, and 0.8 with an oceanic crustal model give a good compromise between minimizing the truncation phase and keeping most of the amplitude at small x. A value of 0.0 cannot be used for PW2 because it will result in a numerical error and halt the program. A very small PW2 will give truncation phases with an infinite phase velocity from the stronger arrivals appearing at x = 0 km. These truncation phases are very small when PW2 is 0.1 or larger.

The parameter DPMAX on line 7 of the "resp" file must be sufficiently small so that the trapezoidal integration has sufficient sampling. A value of 0.001 or smaller may be needed. Decreasing DPMAX increases the run time. TSEC (line 3) should be at least twice as long as the desired time section to avoid some strong, time-aliased artifacts, which appear at time TSEC-T in the record where T is the true arrival time. There are also some very strong artifacts in the last 2 s of the time series. Remember to increase NW proportional to TSEC so that the maximum frequency calculated will remain constant. Increasing NW also increases the run time.

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SAMPLE FILES:

Following this paragraph are, in order, a "makefile" for PNSN, a shell script file to run PNSN, a "model" file, and a "resp" file. For PNBES, change execut.o to exebes.o and change pnsn.O2 to pnbes.O2 in the makefile and change pnsn.O2 to pnbes.O2 in the shell script file. PNBES uses the same "model" and "resp" files as PNSN.

```
#                    Makefile for pnsn
#        Makefiles are used in UNIX based systems and are
#  system dependent.  The best way for you to make such a
#  file is with the "makemake" command and then edit it to
#  include the options that you want.  This makefile is for
#  a CONVEX system and includes some vectorization and
#  optimization options.

OBJ =\
        pnseb.o modlin.o respin.o execut.o bufout.o cvmgt.o
getsec.o

FC = fc -vn

OPT = -O1 -cfc

PROF =

LINKPROF =

LIB = -lveclib

.f.o:
        $(FC)  $(OPT)  $(PROF)  -c $*.f

pnsn.O2:              $(OBJ)
        $(FC)  $(LINKPROF)  -O2 -o pnsn.O2 $(OBJ)  $(LIB)

#  cvmgt.fil: cvmgt.f
#        $(FC)  $(OPT)  -il cvmgt.f

execut.o:
        $(FC)  $(PROF)  -O2 -nlp -cfc -c execut.f

getsecs.o:
        $(FC)  $(PROF)  -c getsecs.f
```

The next file is a shell script (UNIX) for running the program PNSN. It assigns logical numbers to files and directs error listing to "pnsn.out."

```
# model is the model input file
# resp is the response parameter file
setenv FOR010 /io2way/lindwall/pn/pnsn/model
setenv FOR011 /io2way/lindwall/pn/pnsn/resp
setenv FOR013 /io2way/lindwall/pn/pnsnout
/io2way/lindwall/pn/pnsn/pnsn.02 >&! pnsn.out
# the output files with the w-p domain synthetics are:
# denp with the pressure
# denv with the vertical
# denh with the horizontal
```

The next file is a sample model file for PNSN. The first line contains some parameters. The second line is the first model layer, 10 m thick. The receivers are at the top of the second layer (variable lobs set in the "resp" file below) and the source is at the top of the third layer as set by the variable LSOUR in the first line of this file. Note that the first three layers have identical physical properties and are specified as different layers, since the receivers and source are at the top of layers two and three, respectively. The seventh line specifies a "gradient," which is approximated by 12 thin layers with a total thickness of 1.8 km. The last layer is set to be thick to avoid reflections from its bottom but a default built into the code makes it much thicker than this.

```
0.07,50.,0,3,0,0
1.5,5000.,0.,0.,1.03,0.01
1.5,5000.,0.,0.,1.03,0.02
1.5,5000.,0.,0.,1.03,4.47
2.0,100.,0.7,10.,1.5,0.22
5.3,450.,2.8,100.,2.4,0.7
0.,12.,1.8
6.8,1000.,3.7,600.,3.3,0.6
7.5,1000.,4.05,1000.,3.0,0.1
8.3,1000.,4.56,1000.,3.3,20.0
```

The next file is a sample "resp" file for running the program PNSN. The 10-s long time series and 512 frequencies mean that the program will calculate the response at every 0.0195 Hz (10/512) up to a maximum of 51.2 Hz.

```
:MODEL CRUST1
:PVH
512,1,10.0,0.8              !nw,nor,tsec,p2w
2                          !lobs(nor)
5.0,20.,5.0                !bx,fx,dx
0.,0.1,0.7,0.8             !pw1,pw2,pw3,pw4
0.002                     !dpmax
D                         !etype
0.,0.,0.                  !h(1),h(2)
1.,0.0,1.                 !m1,m2,m3
```

PNSYN

This program is to be used to process output from the package PNSN/PNBES. PNSYN reads one of the frequency-ray parameter domain (w-p) output files (such as denp) of PNSEB, filters and windows the data, convolves it with a source function, adds noise, and transformes it to the time domain, generating the synthetic seismograms. This program is written for running on a Cray X-MP system and modified to run on a CONVEX using the -cfc option. The program consists of the main program and eight subroutines:

1) pnsyn.f, the main program.

2) subroutine parmsin.f, reads the parameter file.

3) subroutine transf.f, generates synthetics.

4) subroutine filter.f, filters the data.

5) subroutine fft.f, does a fast Fourier transform.

6) subroutine bufin.f, reads the unformatted (binary) files.

7) subroutine source5.f, bubble source function.

8) subroutine pulse1.f, SAFARI pulse type 1.

9) subroutine getsecs.f, times the program.

10) subroutine makenoise.f, makes noise then shapes it by filtering.

11) subroutine filtern.f, filters the noise.

12) subroutine ran2.f, a random number generator from "Numerical Recepies."

13) subroutine gasdev.f, turns "ran2" into a Gaussian (normal) distribution.

INPUTS TO THE PROGRAM

There are two input files to this program:

1) The parameter file "param." This file can be written as a free format file, where the variable type is the default taken from the variable name with integer names starting with the letters I through N and the rest are real numbers. Real numbers must have a decimal point but integers must not. The name of this file is assumed to be "param" but the name can be changed in the shell script "runsyn."

2) The response file, which is the output from PNSN, is one of three files. The pressure response is "denp," the horizontal displacement is "denh," and the vertical displacement is "denv." The file to be transformed must be renamed to "synin" (or copied to "synin"). The name of the input file is assumed to be "synin" but can be changed in the OPEN statement in the subroutine transf.f. This is a large binary file and cannot be written to the screen.

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PARAMETER FILE STRUCTURE

Line 1: RED, which is the reduction velocity in kilometers per second. If RED is set to zero, then there is no velocity reduction. A nonzero reduction velocity gives plots that have plotted times (P) equal to the true travel time (T) less the product of the reduction velocity (RED) and the offset (X), or $P = T - (RED * X)$. A good choice for this value is the velocity of the fastest refracting layer in the model so that the refractions from that layer will appear flat.

Line 2: TLAG, which is the time lag in seconds, to be used in the computed synthetics if you want a time offset.

Line 3: JF, which is the number of frequencies to be used from the input response file ("synin"). If using all the frequencies present in the response file (output of PNSEB), set JF=0.

Line 4: NF, which denotes the number of complex numbers used in the fft. NF must be an integral power of 2 greater than or equal to JF. There are 2*NF time samples per trace on the synthetics. Normally, NF is set equal to JF, but a larger value can be used to give smoother wave forms.

Line 5: IFLT, which is 1 if earth flattening is used and 0 otherwise.

Line 6: IVSP, which is set to 1 for VSPs (NOR > 1).

Line 7: INRES, which is set to 1 for an automatic band pass filter. This filter does not preserve the amplitudes. The filters available with lines 13 and 14 are preferable.

Line 8: IFSOURCE, which is set to 5 for a bubble source function taken from Spudich and Orcutt (1980; 1987) which is not calibrated for amplitude; set to 1 for Schmidt's #1 pulse (Schmidt 1988), which has an amplitude twice that of a simple impulse. Set to 0 for no source, but the calibrated band-limited response. Note that the calibrated amplitudes are only for the displacement motion and are relative to the response at 1 m in any direction for the pressure response in a liquid, 1 m directly below a vertical impulse source (M1,M2,M3 = 1,0,0 in the "resp" file), and 1 m horizontally away from a horizontal impulse source (M1,M2,M3 = 0,0,1). Note that an impulse source of M1,M2,M3 = 1,0,1 in an elastic medium also gives a unit response at 1 m either directly horizontally or directly vertically.

Line 9: IWIND, which specifies the frequency window:

0 = a rectangular window (strongest sidelobes)

1 = a triangular window

2 = a Hanning window (weak sidelobes and the preferred window)

3 = another Hanning window

4 = a Hamming window

5 = a Nuttall window (weakest side lobes but widest central peak)

Line 10: IFF AD, which is set to 1 to write the file header to the file "pnsyn.out." This gives diagnostics for debugging.

Line 11: IFRHEAD, which is set to 1 to write each record header to the file "pnsyn.out." This gives diagnostics for debugging.

Line 12: IDVA, which is set to 1 to calculate displacements, 2 for velocity, and 3 for acceleration. Since displacements have a simpler pulse, they can be used for hydrophone pressure synthetics since the uniform media (water) will not change the relative amplitudes. The simple displacement pulse, is also easier to convolve with a known source.

Line 13: RUTE1, which is the low side of a mute window in seconds. If a mute is applied, then all values before RUTE1 are set equal to the value at time RUTE1.

Line 14: RUTE2, which is the end of the mute window in seconds. If RUTE2 is set to 0.0, then there is no mute applied. If a mute is applied, then all values after RUTE2 are set equal to the value at time RUTE2. This mute is designed to eliminate artifacts that sometimes appear before and after the arrivals of interest.

Line 15a: (only if IFSOURCE (line 8) is 1:) WEIGHT,0.,0.,0.,0.,0.,0.

WEIGHT is the central frequency, which should be about one-third of the maximum frequency. The rest of the variables are not used for the SAFARI source. A rectangular window (IWIND = 0) should be used with this source. The following zeroes are dummy values, since line 13a is read by the same command as 13b.

Line 15b: (only if IFSOURCE (line 8) is 5:) WEIGHT, CONV, DEPTH, RANGE, BDEC, BRAT, DRAT, where:

WEIGHT is the weight of an explosive charge in kilograms or the pressure times volume in pounds per square inch and cubic inches of an airgun for source number 5.

CONV is the conversion factor for different sources

= 1.0 for TNT in kilograms,
= 0.639 for TOVEX in kilograms,
= 3884330.0 for airguns in pounds per square inch and cubic inches.

DEPTH is the depth of the shot below the water surface in meters.

RANGE is the range from the source in meters for unit amplitude. This number is purely arbitrary and does not affect the wave form or its amplitude.

BDEC is the bubble decay speed. A larger number makes the peaks sharper, and 10.0 works well.

BRAT is the bubble ratio or the amplitude ratio between one peak and the preceeding peak, and 1.5 to 2.0 works well.

DRAT is the dilatation ratio, how much smaller the amplitude for the negative pressure parts of the waves are, and 3.0 to 5.0 works well. The best values for

BDEC, BRAT, and DRAT will depend on each users situation and can be determined from experimentation.

Line 16: IFNOISE, NFILTN, where:

IFNOISE is 1 to add noise to the seismogram and 0 to not add noise.

NFILTN is the number of filters used on the noise and can be anywhere from 0 to 10. Filtering the noise changes its spectrum and can be used to make the noise match the characteristics of the receiving system, the environment, or whatever else may be the source of the simulated noise.

Line 17: AMPN, which is the amplitude of the noise. This is an absolute value, is not relative to the signal strength which depends on the range and the elastic model used, and may be changed by filtering. To get a specific signal to noise ratio, several trials may be necessary using inspection of the seismograms to determine the current signal to noise ratio.

Lines 18 and 19 are filter specification cards used with the noise option and are repeated depending on number of filters used as determined by NFILTN and always appear in pairs. If no filters are to be used, then these lines must not be present, not even carriage returns.

Line 18: M for a minimum-phase type filter and Z for a zero-phase type filter. Minimum-phase filters are physically realizable and are good for high-cut filters. Zero-phase filters produce no phase distortion and are good for low-cut filters, but are not physically realizable.

Line 19: IFILTYP, IDB, F1, F2, where:

IFILTYP is the filter type. Use 1 for high-cut Butterworth, 2 for low-cut Butterworth, and 3 for notch.

IDB is the slope in dB/octave and can be any integer. A slope of 6 dB/octave or less gives a gentle filter, while a slope of 24 dB/octave gives a hard filter.

F1 is the corner frequency in hertz. For a notch filter, this is the lower corner frequency.

F2 is the upper corner frequency of a notch filter in hertz. This variable is not used for other filter types.

Lines 20 and 21 are filter specification cards and are repeated depending on number of filters used, up to a maximum of 10 and appear in pairs in the identical format as lines 18 and 19. If no filters are to be used, then these lines must not be present, not even carriage returns. The program reads lines until none are left. A zero-phase, low-cut filter with a corner frequency of 10 to 20% of the maximum frequency calculated (NW/TSEC from line 3 of the "resp" file) is highly recommended to remove many of the low-frequency p integration artifacts. The automatic filter on line 7 will do this but it does not preserve the amplitudes. These artifacts are also greatly reduced by increasing the number of frequencies calculated in PNSN.

OUTPUT OF THE PROGRAM

There are three output files of the program:

1) The output file, which gives such computational details as the beginning range, the final range, range increment, cpu time, etc. The name of this file is "fort.3."

2) The synthetics file. This is the desired file which can be plotted to generate synthetic seismograms. The name of this file at present defaults to "fort.30" and is a large ASCII file which can be written to the terminal screen.

3) Further diagnostic output appears in "pnsyn.out."

NOTE: All the output files are in ASCII.

STRUCTURE OF THE SYNTHETICS FILE ("fort.30")

Line 1: NL, KW, NP, NT; in (1X,2I5,2I8) format where:

NL is the number of layers.

KW is the number of (complex) frequencies calculated.

NP is the number of complex frequencies used in the FFT. If NP > KW, then the FFT series is padded with zeroes before the transform is made.

NT is the number of time samples in the time series.

Line 2; BW, FW, TLAG, DECAY, BEGP, FINP, PW1, PW4, PW2, PW3; in (1X,10E14.7) format where:

BW is the starting frequency in hertz.

FW is the ending frequency in hertz.

TLAG is the time lag in seconds.

DECAY is the decay factor over the time series length.

BEGP is the beginning ray parameter.

FINP is the final ray parameter.

PW1 is the lower edge of the ray parameter (p) window.

PW4 is the upper edge of the p window.

PW2 is the start of the taper for the lower part of the p window.

PW3 is the start of the taper for the upper part of the p window.

Line 3: T(I), CL(I), CT(I), QL(I), QT(I), RHO(I); in (1X,6E14.7) format and appears once for each layer.

T(I) is the thickness of layer I in kilometers.

CL(I) is the compressional wave velocity for layer I in kilometers per second.

CT(I) is the shear wave velocity for layer I in kilometers per second.

QL(I) is the compressional Q for layer I.

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QT(I) is the shear Q for layer I.

RHO(I).is the density for layer I in grams per cubic centimeter.

Line 4: NFILT, MINPHASE, VSP, LSOUR, NOR, NX, ZS, RV, BX, FX, DX in (1X,I2,2L1,3I3,5E14.7) format where:

NFILT is the number of filters (maximum of 10).

MINPHASE is true if the filters are minimum phase, else false.

VSP is true if there is more than one receiver depth.

LSOUR is the layer number that contains the source.

NOR is the number of receiver depths. (1 for normal seismograms)

NX is the number of receiver offsets.

ZS is the depth of the receiver in kilometers.

RV is the reducing velocity in kilometers per second.

BX is the offset of the first receiver.

FX is the offset of the last receiver.

DX is the difference in offset between receivers.

Line 5: IFILTYP(10), IDB(10) in (1X,10I1,10I3) format where:

IFILTYP are the filter types for all 10 filters; 1 for high cut, 2 for low cut, 3 for notch.

IDB are the filter slopes in dB/octave for all 10 filters.

Line 6: F1(10) in (1X,10F10.4) format where:

F1 are the frequencies in hertz for all 10 filters. For a notch filter, this is the lower frequency.

Line 7: F2(10) in (1X,10F10.4) format where:

F2 are the upper frequency in hertz for notch filters.

Lines 8 and 9 are repeated in sequence once for each trace (or offset) in the computed synthetics.

Line 8; ISS, NT, DT, X, Z; in (1X,2I8,3E14.7) FORMAT where:

ISS is a flag for the end of the file. It is 0 for every trace except for the last trace when it is 1.

NT is the number of time samples.

DT is the sampling interval in seconds.

X is the range in kilometers for this trace.

Z is the depth in kilometers for this receiver.

Line 9 is repeated NT/8 times for each trace and contains the time series values, 8 at a time, of the trace in 8(1X,E14.7) format. The amplitude of the time series is relative to a direct arrival at one meter.

RUNNING THE VERSION SYNSPEC

SYNSPEC uses the same format for the "param" file. In fact, all of the subroutines are the same except for pnsyn.f, which becomes synspec.f. The makefile and the runfile for SYNSPEC are the same as for PNSYN except that "synspec" is used in place of "pnsyn."

SAMPLE FILES:

Following are, in order, a "makefile"for PNSYN, a shell script file to run PNSYN, and two "param" files to show cases with and without sources and filters.

```
#                    Makefile for pnsyn
#          Makefiles are used in UNIX based systems and are
#     system dependent.  The best way for you to make such a
#     file is with the "makemake" command and then edit it to
#     include the options that you want.  This makefile is for
#     a CONVEX system and includes some vectorization and
#     optimization options.

OBJ =\
pnsyn.o parmsin.o transf.o source5.o pulse1.o filter.o bufin.o \
fft.o getsecs.o

FC = fc -vn

OPT = -O1 -cfc

PROF =

LINKPROF =

LIB = -lveclib

.f.o:
        $(FC) $(OPT) $(PROF) -c $*.f

pnsyn.O1:      $(OBJ)
        $(FC) $(LINKPROF) -O1 -o pnsyn.O1 $(OBJ) $(LIB)

getsecs.o:
        $(FC) $(PROF) -c getsecs.f
```

```
#               Makefile for synspec

OBJ =\
pnsyn.o parmsin.o transf.o source5.o filter.o bufin.o bufout.o\
fft.o getsecs.o

FC = fc -vn

OPT = -O1 -cfc

PROF =

LINKPROF =

LIB = -lveclib

.f.o:
        $(FC) $(OPT) $(PROF) -c $*.f

synspec.01:          $(OBJ)
        $(FC) $(LINKPROF) -O1 -o synspec.01 $(OBJ) $(LIB)

getsecs.o:
        $(FC) $(PROF) -c getsecs.f
```

The next file is a shell script (UNIX) for running the program PNSYN. It assigns logical numbers to files and directs error listing to "pnsn.out." Note that the data file produced by pnsn (denp, denh, or denv) has been renamed "synin."

```
# 11 is a parameter input file
setenv for011 /io2way/lindwall/pn/syn/param
# 20 is the w-x domain synthetics from pnsn
setenv FOR020 /io2way/lindwall/pn/synin
unalias rm
rm syn.out
/io2way/lindwall/pn/syn/pnsyn.01 >&! syn.out
# fort.30 is the time domain output file
# fort.3 is the diagnostic output file
```

The next two files are sample "param" files. The first is for PNSYN and includes a filter and a source function line. The source function is for the bubble pulse from 27 kg of TOVEX. This file is set for a PNSYN input file ("synin") calculated with 512 frequencies. NF is set to 1024 rather than 512 so that the waveforms will appear smoother in the plots. A 2-Hz, high-pass filter is used to remove some of the very low frequency artifacts. The second "param" file is for a SYNSPEC input file. This file could also include filters and a source but does not.

```
6.0                 ! reduction velocity in km/s
0.                  ! time lag in sec.
512                 ! number of frequencies to use
1024                ! number of points to use in the fft
0                   ! set to 1 if earth flatening is used
0                   ! set to 1 for VSPs
0                   ! set to 1 for automatic band pass filter
5                   ! specifies source, 0 is no source
2                   ! specifies frequency window, 2 is hanning
0                   ! set to 1 to write file header
0                   ! set to 1 to write record headers
1                   ! 1-displacement, 2-velocity, 3-acceleration
1.1                 ! mute window 1, seconds
0.0                 ! mute window 2, if 0.0, then no mute
27.3.0,0.639,78.,10000.,10.,1.5,5.
z
2,12,2.
```

```
0.0                 ! reduction velocity (km/s)
0.                  ! time lag
512                 ! length of time series to read
512                 ! length of fft time series
0                   ! 1 to use earth flatening
0                   ! 1 for VSPs
0                   ! 1 for band pass filter
0                   ! source type, 0 for no source
0                   ! 0 for amplitude, 1 for power spectra
0                   ! set to 1 to write file header
0                   ! set to 1 to write record headers
1                   ! 1-displacement, 2-velocity, 3-acceleration
1.1                 ! mute window 1, seconds
0.0                 ! mute window 2, if 0.0, then no mute
```

VSPLT

The files from PNSYN or SYNSPEC are ASCII files and can be transported to many other computers. Once the files are on the computer to do the plotting, the data must be converted to a binary file with the program CONVRT. CONVRT requires no user parameter file. It reads the "fort.30" file and a title file "synhead" and writes a binary "fort.81" data file and a binary "synhead" file, which contains some header information. After running CONVRT, the plotting is done by running VSPLT. Several lines in the FORTRAN program VSPLT are plotter dependent and plotting software dependent and may need to be changed for the users system. This code has been run on many machines and the initializing calls for several types of plotters are still in the code as comment lines.

The package VSPLT consists of the main program and four subroutines:

1) vsplt.f, the main module.

2) The subroutine axis.f, which plots the axis for the section.

3) The subroutine plottr.f, which plots the time series traces.

4) The subroutine step.f.

5) The subroutine modplt.f, which plots the geophysical model before the time series.

On UNIX systems, the compilation and linking is most conveniently done with a makefile. A sample "makefile" is included with the set of sample input files.

ROSECON reads a file from PNSYN and writes an ASCII file in ROSE format (LaTraille and Dorman 1982; LaTraille et al. 1983) which can be plotted by several programs designed for that purpose. While CONVRT has no input file, ROSECON does to specify certain variable parameters.

INPUTS TO VSPLT

The inputs to the program VSPLT are in one file, "param5". The name can be changed in the shell script "runplot." In this input file, the names of integer variables begin with the letters I-N. All others variables are real numbers which must have a decimal point.

The "param5" file contains the following in sequence:

Line 1: IPLOTYP specifies the receiver type; 1 is for pressure, 2 is for horizontal and 3 is for vertical. This is used for information only and does not affect the plot.

Line 2: RMIN is the minimum range on the plot or the origin of the x axis in kilometers.

Line 3: RAMX is the maximum range on the plot in kilometers. Occasionally the program will plot to a slightly greater range.

Line 4: RSF is the range scaling factor. This is in units of inches per 100 km.

Line 5: TMIN is the minimum time on the plot in seconds. This can either be the origin or the top of the plot, depending on the sign of TSF.

Line 6: NET is the number of seconds to plot, an integer. The maximum time on the plot is TMIN + NET.

Line 7: TSF is the time scaling factor with units of inches per second. When this factor has a negative sign, TMIN will be at the top of the plot and time will increase downward.

Line 8: AMP is the gain variable. All data values are multiplied by this factor before plotted.

Line 9: D1R is the depth to the first reflector used by the mute. When this value is 0, no mute is used.

Line 10: V1R is the velocity overlying the first reflector and is used to mute the noise in front of the first reflector hyperbola.

Line 11: GPS is the gain per second after the first reflector. When GPS = 0.0, no time-varying gain is used.

Line 12: ALPHA is the exponent used for a range dependent gain. When ALPHA = 0.0, no range dependent gain is used. Also, be sure to set ALPHA to 0.0 if there is a record at zero offset.

Line 13: XXO is the reference distance for range dependent gain. The default value is 1 km.

Line 14: ISCALE selects a trace dependent amplitude scaling. If ISCALE = 1, then the maximum amplitude of each trace is scaled to the maximum amplitude of the first trace. If ISCALE = 2, then each trace is scaled to its own maximum amplitude. If ISCALE = 3, then no trace scaling is done and each trace is multiplied only by the AMP factor and the range scaling factor.

Line 15: IOPT is the switch for shading. Setting IOPT = 1 gives a variable area plot (with shading) while setting IOPT = 0 gives a wiggle line plot.

Line 16: ISGN selects which side is shaded when using the variable area plot option (IOPT = 1). 1 shades the + side while -1 shades the - side.

Line 17: MODPLOT selects the option of plotting the geophysical model in front of the record section. MODPLOT = 1 plots the model while MODPLOT = 0 does not.

Line 18: ICLIP selects whether or not to clip the traces. This is highly recommended. Set ICLIP = 1 to clip the traces.

Line 19: CLAMP which is the maximum amplitude from positive peak to negative peak in inches allowed by the clipper.

Line 20: TDELAY adds TDELAY time in seconds to the front of the traces.

Line 21: JDB selects the logarithmic plotting option. If JDB = 1 then the plot is in decibels, if JDB = 0, then the traces are plotted linearly.

Line 22: DBOFF is the DC offset added to each trace when plotted in decibels.

Line 23: ISTART is the first trace to be plotted.

Line 24: IJUMP is the interval between traces to plot. Every IJUMPth trace is plotted.

Line 25: NTOPLOT is the number of traces to plot. NTOPLOT = 0 plots all traces.

OUTPUT OF THE PROGRAM

The program produces a vector file which must be converted to something readable by your machine. This may be a system software command like "raster," which makes a raster file for a dot-matrix plotter.

RUNNING ROSECON

ROSECON reads the same data file as CONVRT but requires a parameter file "roseconin." The first six lines of the "roseconin" file have one parameter each, which are, in order: instrument number, event number, channel number, instrument ID number, source type, and receiver type. The last two lines are shot time and first sample time with six parameters on each line being, in order: year, month, day, hour, minute, second. A "roseconin" file is included with the sample files.

OTHER PLOTTING PROGRAMS

Other plotting programs will inevitably be written as printers and software are updated and may not use CONVRT. Contact other users to see what is currently available.

SAMPLE FILES:

On the following pages are, in order, a "makefile" for VSPLT, a shell script file to run VSPLT, a "param5" file, makefiles for CONVRT and ROSECON, shell script files to run CONVRT and ROSECON, and a "roseconin" file.

```
#                 Makefile for vsplt

OBJ =\
vsplt.o axis.o plottr.o step.o modplt.o

FC = fc -vn

OPT = -O1

PROF =

LINKPROF =

LIB = -lvpltlib -lveclib

.f.o:
          $(FC) $(OPT) $(PROF) -c $*.f

vsplt.O1:        $(OBJ)
          $(FC) $(LINKPROF) -O1 -o vsplt.O1 $(OBJ) $(LIB)


# Sample script to run plotting code.  These commands are
# mashine and software dependent.  Consult your local
# computer gurus
unalias rm
rm /io2way/lindwall/pn/V9INT.DAT
rm /io2way/lindwall/pn/VERSATEC
# assign lun 11 to plot parameter file (you generate)
setenv FOR011 /io2way/lindwall/pn/plot/param5
# assign model parameter file (lun 11 generated by convrt) to
# lun 12
setenv FOR012 /io2way/lindwall/pn/synhead
# assign lun 10 to the fort.xx (xx = 81,82,..) generated by
# the convrt program
setenv FOR010 /io2way/lindwall/pn/fort.81
/io2way/lindwall/pn/plot/vsplt.O1 >&! vsplt.out
#
# the next two commands plot the record section
raster
dd if=VERSATEC of = /dev/pb5 bs=528
```

The next file is a sample "param5" file which specifies all of the plot specifications.

```
1              ! iplotyp, 1=pres, 2=horiz, 3=vert
0.0            ! rmin, minimum range in km.
20.0           ! rmax, maximum range in km.
20.0           ! rsf, inches/100 km
0.0            ! tmin, minimum time on plot
2              ! net, number of seconds to plot
5.0            ! tsf, inches/sec; when <0, time increases downward
1.0            ! amp
0.0            ! dlr, depth to first reflector
0.             ! vlr, velocity overlying first reflector
0.             ! gps, gain per second after first reflector
1.0            ! alpha, range exponent, use 0 if there is an x=0 trace
0.             ! xx0
3              ! iscale, 1=first trace, 2=max of each, 3=not scaled
0              ! iopt, set to one (1) for shading (variable area)
-1             ! isgn, 1 shades the + side, -1 shades the - side.
0              ! modplt, set to 1 to get plot of model.
1              ! iclip, if = 1, clips at "clamp" inches
2.0            ! clamp
0.0            ! tdelay, delays record by tdelay seconds
0              ! jdb, if 1, plot in dB instead of linear amplitude
-00.           ! dboff, dc offset for dB values
1              ! istart, first trace to plot
1              ! ijump, plot every "ijump"th trace
0              ! ntoplot, number of traces to plot.  0 plots all
```

```
#               Makefile for convrt

OBJ =\
convrt.o

FC = fc -vn

OPT = -O1

PROF =

LINKPROF =

LIB = -lveclib

.f.o:
        $(FC) $(OPT) $(PROF) -c $*.f

convrt.O1:          $(OBJ)
        $(FC) $(LINKPROF) -O1 -o convrt.O1 $(OBJ) $(LIB)


#               Makefile for rosecon

OBJ =\
convrt.o

FC = fc -vn

OPT = -O1

PROF =

LINKPROF =

LIB = -lveclib

.f.o:
        $(FC) $(OPT) $(PROF) -c $*.f

rosecon.O1:         $(OBJ)
        $(FC) $(LINKPROF) -O1 -o rosecon.O1 $(OBJ) $(LIB)
```

The next two files are sample shell scripts for running CONVRT and ROSECON.

```
#
unalias rm
rm convrt.out synhead fort.81 fort.82
#
# 10 is the input synthetics
setenv FOR010 fort.30
# 11 is the heading output file
setenv FOR011 synhead
# 12 is the title input file
setenv FOR012 stitle
# following are files of traces, one file per offset for VSP
# or one file per receiver depth otherwise.  Start with unit
# 81, but don't exceed unit 98.
#
# setenv FOR081 synrec
#
/io2way/lindwall/pn/con/convrt.01 >&! convrt.out
```

```
#
unalias rm
rm convrt.out synhead fort.81 fort.82
#
# 10 is the input synthetics
setenv FOR010 fort.30
# 11 is the heading output file
setenv FOR011 synhead
# 12 is the title input file
setenv FOR012 stitle
# 21 is an input file with rose format information
setenv FOR021 /io2way/lindwall/pn/con/roseconin
# following are files of traces, one file per offset for VSP
# or one file per receiver depth otherwise.  Start with unit
# 81, but don't exceed unit 98.
#
# setenv FOR081 synrec
#
/io2way/lindwall/pn/con/rosecon.01 >&! rose.out
```

This is a "roseconin" file.

```
1               ! instrument number
1               ! event number
1               ! channel number
1               ! instrument ID number
2               ! 1 for earthquake, 2 for shot
4               ! 1 vertical; 2 radial; 4 hydrophone
90,1,1,0,0,0    !y,m,d,h,m,s for shot and first sample time
```

EXAMPLES

Following are several examples calculated and plotted to show what the synthetic seismograms should look like. Each example consists of a "model" file in the upper left corner, a "resp" file in the upper right corner, followed by a "param" file for running PNSYN, and then the seismic record section. The examples shown are:

1) A horizontal, near sea-surface line with a simple subbottom. The strong arrivals at about 3 to 5 km offset and 9 s reduced travel time are artifacts of the calculation.

2) A horizontal, near sea-surface line with a simplified ocean crustal model.

3) A horizontal, near sea-surface line with an ocean crustal model including gradients. The record section is plotted with a different reduction velocity than those above to better show the long range refraction arrivals that are typical in marine seismic refraction lines.

4) A line of near sea-surface shots to an ocean bottom seismometer (OBS). This includes a record section each for the pressure, horizontal, and vertical components. The feature seen at 20 km and about 2 s is a wraparound artifact.

5) A vertical seismic profile (VSP). The receivers are placed at the top of layers 3 through 12 (the variable LOBS in the "resp" file), and the source is at the top of layer 13 at a range of 500 m (variable BX). The program will not work correctly if the source is in the same layer as one of the receivers.

The surface lines (examples 1, 2, and 3) can be either a single shot to a line of receivers or a line of shots to a single receiver. In these calculations, the problems are reciprocal. Likewise, the OBS line could alternatively be thought of as a single surface shot to a line of OBSs.

ACKNOWLEDGMENTS

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```
0.07,50.,0,3,0,0                    :MODEL HSP 1
1.5,5000.,0.,0.,1.03,0.01           :PVH
1.5,5000.,0.,0.,1.03,0.005          256,1,10.0,0.8        !nw,nor,tsec,p2w
1.5,5000.,0.,0.,1.03,3.985          2                     !lobs(nor)
1.8,100.,0.6,6.,1.4,0.5             1.0,20.0,1.0          !bx,fx,dx
4.5,100.,2.2,50.,2.3,50.0           0.,0.1,0.7,0.8        !pw1,pw2,pw3,pw4
                                    0.005                 !dpmax
                                    D                     !etype
                                    0.,0.,0.              !h(1),h(2)
                                    1.,0.0,1.             !m1,m2,m3
```

```
4.0              ! reduction velocity in km/s
0.0               ! time lag in sec.
256              ! number of frequencies to use
512              ! number of points to use in the fft (power of 2)
0                ! set to 1 if earth flatening is used
0                ! set to 1 for VSPs
0                ! set to 1 for automatic band pass filter
0                ! specifies source, 0 is no source
2                ! specifies frequency window, 0 is rectangle, 2 is hanning
0                ! set to 1 to write file header
0                ! set to 1 to write record headers
1                ! 1-displacement, 2-velocity, 3-acceleration (pressure)
1.1              ! mute window, seconds
0.0              ! end of mute window, if 0, then no mute
0,0              ! 1 for noise, number of noise filters
0.020            ! noise amplitude
z
2,12,2.
M
1,12,13.
```
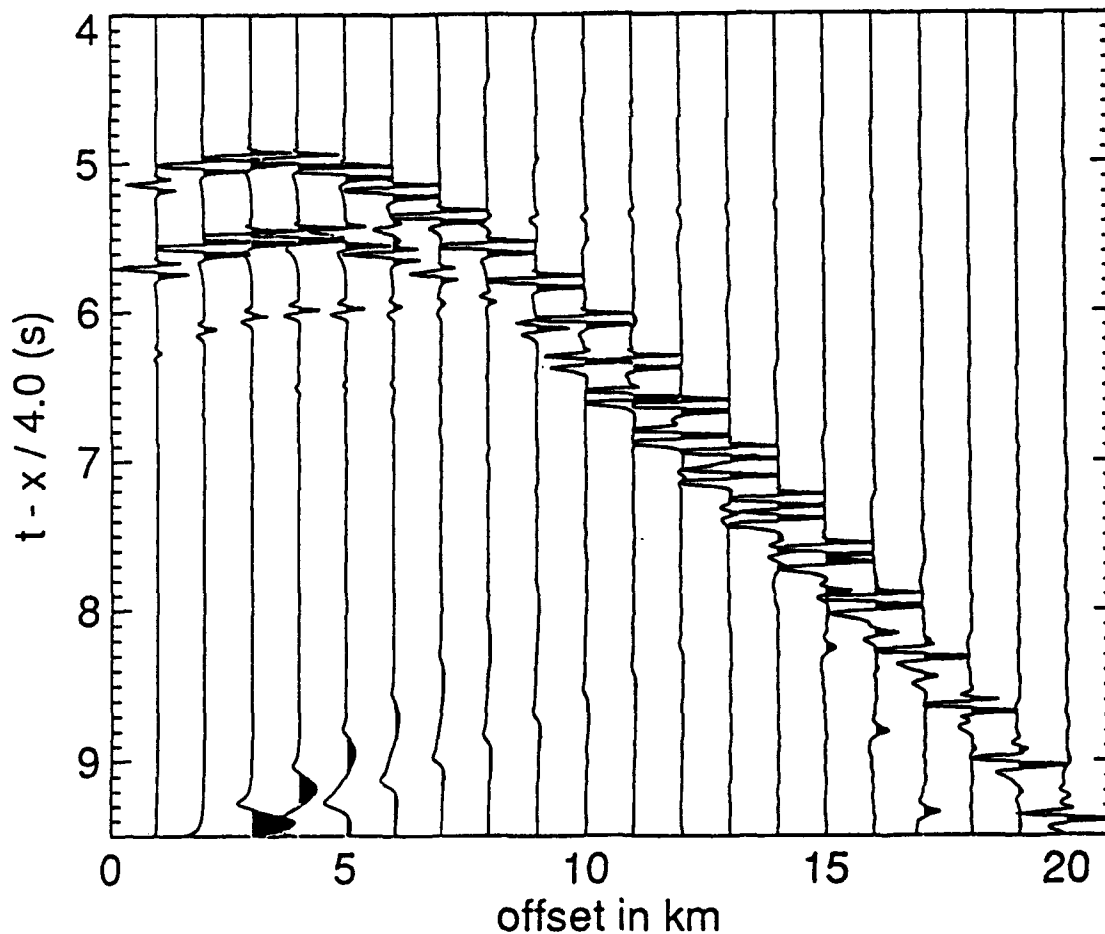
horizontal profile # 1

```
0.07,50.,0,3,0,0                          :MODEL HSP 2
1.5,5000.,0.,0.,1.03,0.01                 :PVH
1.5,5000.,0.,0.,1.03,0.005                256,1,10.0,0.8            !nw,nor,tsec,p2w
1.5,5000.,0.,0.,1.03,3.985                2                        !lobs(nor)
1.8,100.,0.6,6.,1.4,0.5                    1.0,20.0,1.0             !bx,fx,dx
4.5,100.,2.2,50.,2.3,0.5                   0.,0.1,0.7,0.8           !pw1,pw2,pw3,pw4
5.7,100.,2.2,50.,2.3,1.0                   0.005                    !dpmax
6.8,100.,3.6,50.,3.0,4.50                  D                        !etype
8.0,200.,4.5,100.,4.5,50.00                0.,0.,0.                 !h(1),h(2)
                                           1.,0.0,1.                !m1,m2,m3


4.0            ! reduction velocity in km/s
0.0            ! time lag in sec.
256            ! number of frequencies to use
512            ! number of points to use in the fft (power of 2)
0              ! set to 1 if earth flatening is used
0              ! set to 1 for VSPs
0              ! set to 1 for automatic band pass filter
0              ! specifies source, 0 is no source
2              ! specifies frequency window, 0 is rectangle, 2 is hanning
0              ! set to 1 to write file header
0              ! set to 1 to write record headers
1              ! 1-displacement, 2-velocity, 3-acceleration (pressure)
1.1            ! mute window, seconds
0.0            ! end of mute window, if 0, then no mute
0,0            ! 1 for noise, number of noise filters
0.020          ! noise amplitude
Z
2,12,2.
M
1,12,13.
```
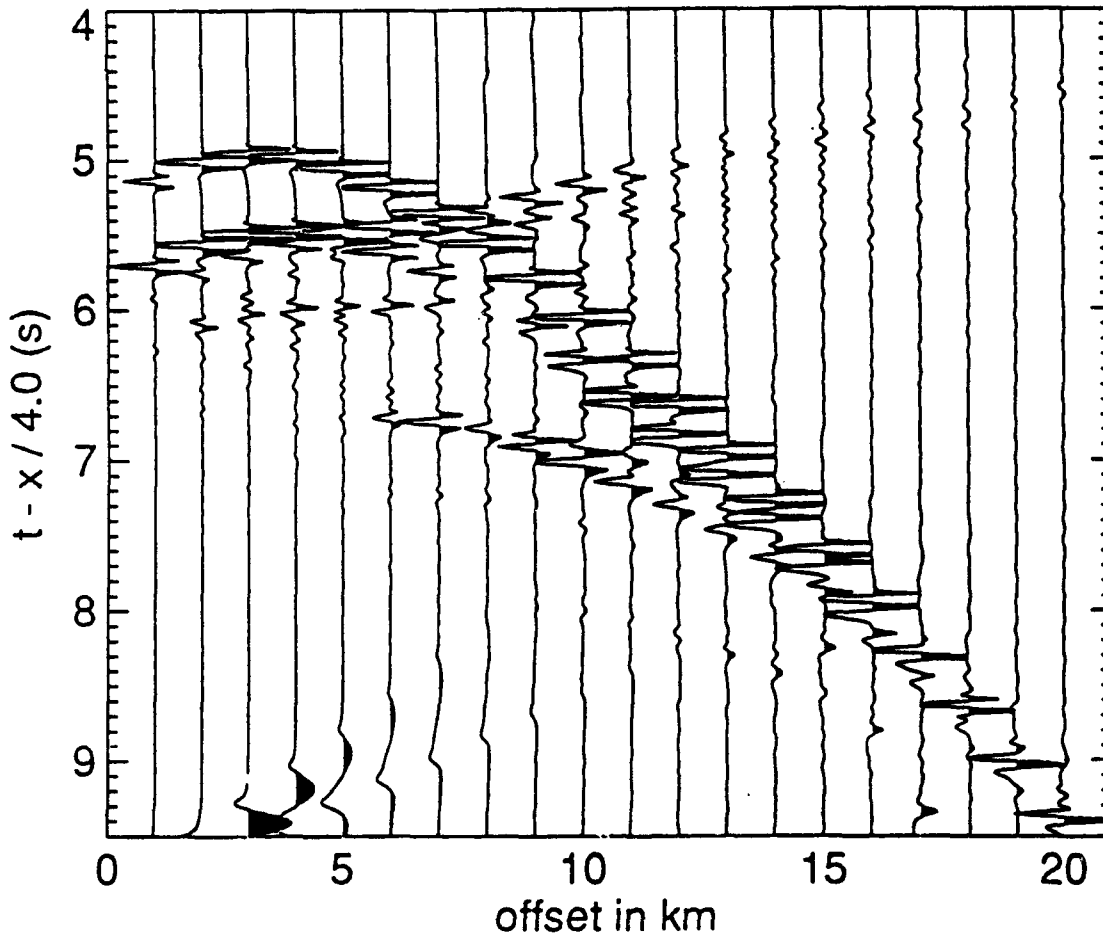
horizontal profile # 2

```
0.07,50.,0,3,0,0                    :MODEL HSP 2-GRAD
1.5,5000.,0.,0.,1.03,0.01           :PVH
1.5,5000.,0.,0.,1.03,0.005          256,1,10.0,0.8         !nw,nor,tsec,p2w
1.5,5000.,0.,0.,1.03,3.985          2                      !lobs(nor)
1.7,100.,0.5,6.,1.4,0.1             1.0,40.0,1.0           !bx,fx,dx
0.,3.,0.3                           0.,0.1,0.7,0.8         !pw1,pw2,pw3,pw4
1.9,100.,0.8,6.,1.4,0.1             0.005                  !dpmax
4.0,100.,2.0,50.,2.3,0.1            D                      !etype
0.,5.,1.2                           0.,0.,0.               !h(1),h(2)
5.7,100.,3.2,50.,2.3,0.2            1.,0.0,1.              !m1,m2,m3
0.,5.,2.0
6.8,100.,3.6,50.,3.0,0.20
0.,5.,2.1
7.2,100.,3.8,50.,3.0,0.20
8.0,200.,4.5,100.,4.5,50.00


6.0           ! reduction velocity in km/s
0.0           ! time lag in sec.
256           ! number of frequencies to use
512           ! number of points to use in the fft (power of 2)
0             ! set to 1 if earth flatening is used
0             ! set to 1 for VSPs
0             ! set to 1 for automatic band pass filter
0             ! specifies source, 0 is no source
2             ! specifies frequency window, 0 is rectangle, 2 is hanning
0             ! set to 1 to write file header
0             ! set to 1 to write record headers
1             ! 1-displacement, 2-velocity, 3-acceleration (pressure)
1.1           ! mute window, seconds
0.0           ! end of mute window, if 0, then no mute
0,0           ! 1 for noise, number of noise filters
0.020         ! noise amplitude
z
2,12,2.
M
1,12,13.
```
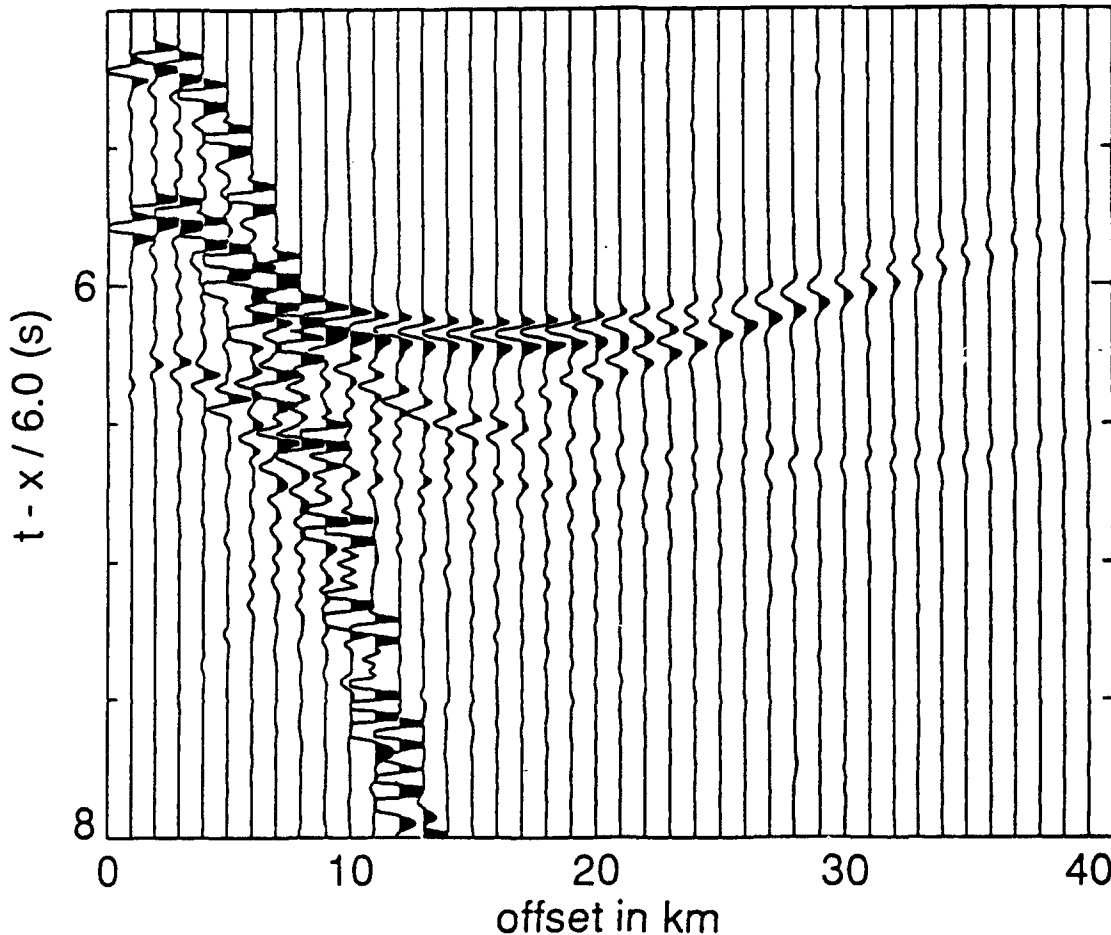
HSP # 2 with gradients

```
0.07,50.,0,2,0,0              :OBS MODEL 2
1.5,5000.,0.,0.,1.03,0.01     :PVH
1.5,5000.,0.,0.,1.03,3.99     256,1,10.0,0.8        !nw,nor,tsec,p2w
1.8,100.,0.6,6.,1.4,0.5       3                     !lobs(nor)
4.5,100.,2.2,50.,2.3,0.5      1.0,20.0,1.0          !bx,fx,dx
5.7,100.,2.2,50.,2.3,1.0      0.,0.1,0.7,0.8        !pw1,pw2,pw3,pw4
6.8,100.,3.6,50.,3.0,4.50     0.005                 !dpmax
8.0,200.,4.5,100.,4.5,50.00   D                     !etype
                              0.,0.,0.              !h(1),h(2)
                              1.,0.0,1.             !m1,m2,m3

6.0         ! reduction velocity in km/s
0.0         ! time lag in sec.
256         ! number of frequencies to use
512         ! number of points to use in the fft (power of 2)
0           ! set to 1 if earth flatening is used
0           ! set to 1 for VSPs
0           ! set to 1 for automatic band pass filter
0           ! specifies source, 0 is no source
2           ! specifies frequency window, 0 is rectangle, 2 is hanning
0           ! set to 1 to write file header
0           ! set to 1 to write record headers
1           ! 1-displacement, 2-velocity, 3-acceleration (pressure)
1.1         ! mute window, seconds
0.0         ! end of mute window, if 0, then no mute
0,0         ! 1 for noise, number of noise filters
0.020       ! noise amplitude
2
2,12,2.
M
1,12,13.
```
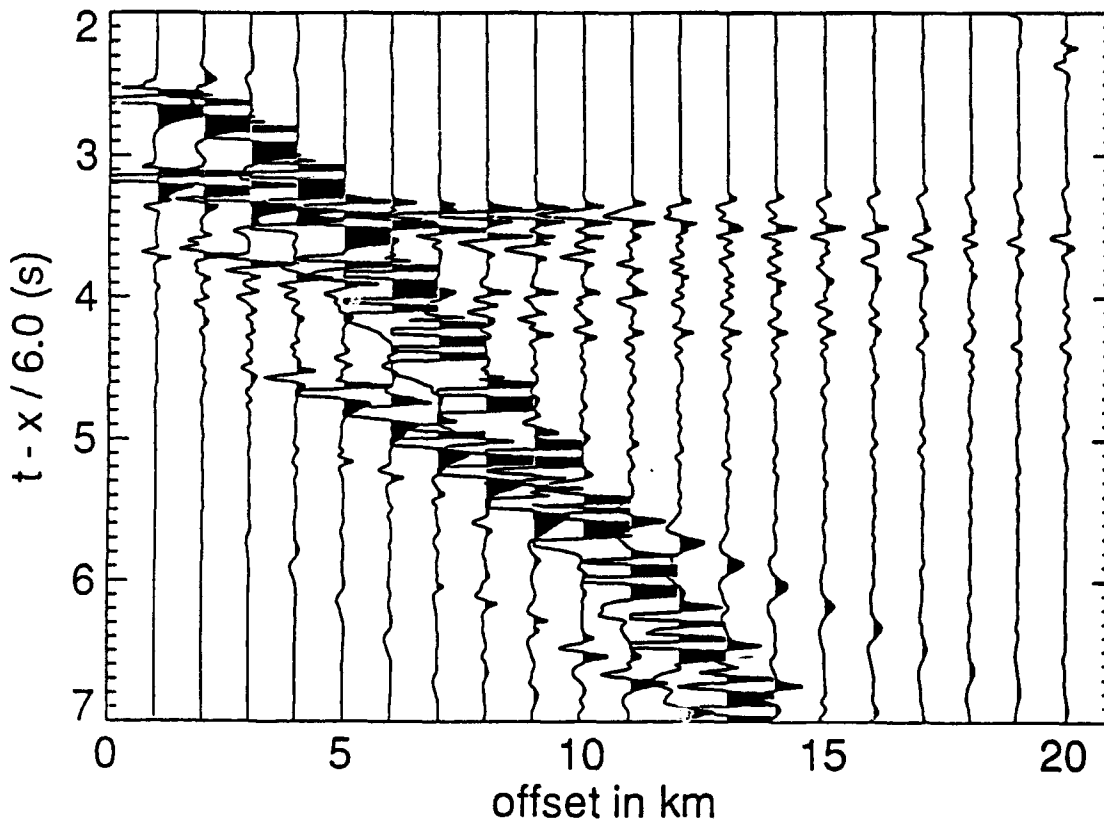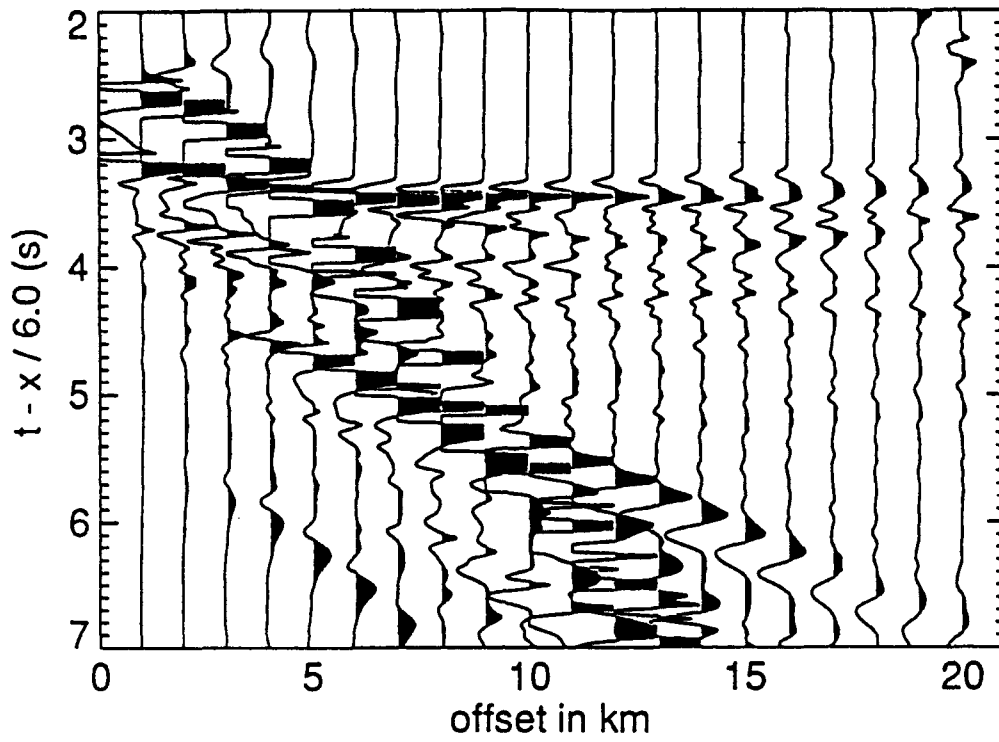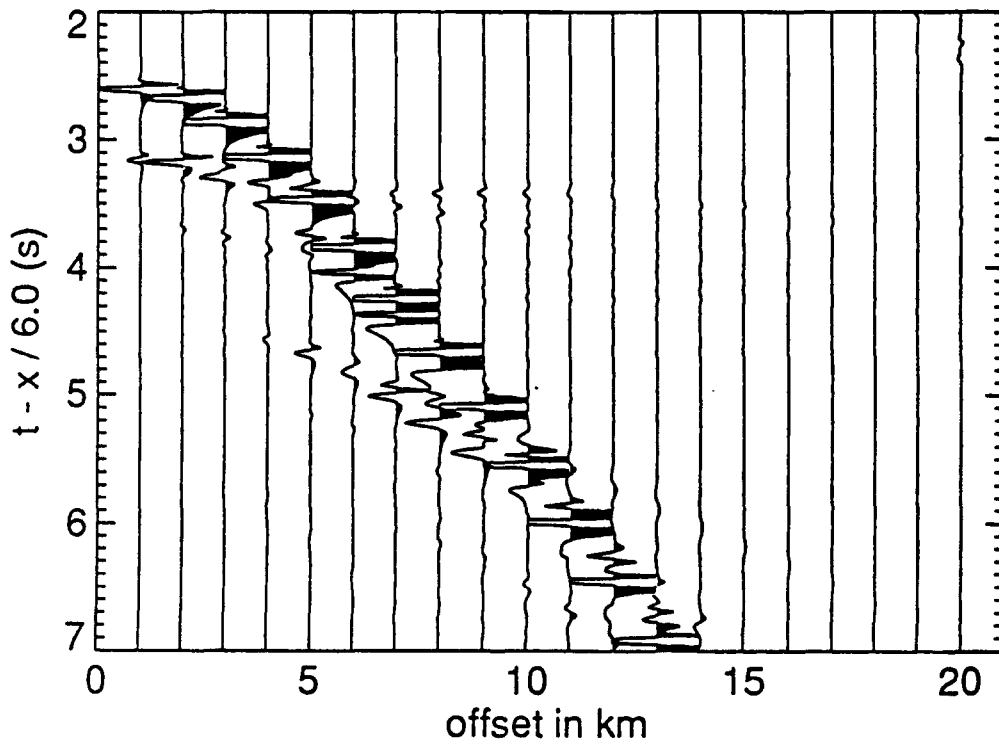
OBS - pressure

OBS - vertical

OBS - horizontal

```
0.07,50.,0,13,0,0              :MODEL 2
1.5,5000.,0.,0.,1.03,0.01      :PVH
1.5,5000.,0.,0.,1.03,0.99      256,10,10.0,0.8           !nw,nor,tsec,p2w
1.8,100.,0.6,6.,1.4,0.05       3,4,5,6,7,8,9,10,11,12              !lobs(nor)
1.8,100.,0.6,6.,1.4,0.05       0.5,0.5,0.5               !bx,fx,dx
1.8,100.,0.6,6.,1.4,0.05       0.,0.1,0.7,0.8            !pw1,pw2,pw3,pw4
1.8,100.,0.6,6.,1.4,0.05       0.005                     !dpmax
1.8,100.,0.6,6.,1.4,0.05       D                         !etype
1.8,100.,0.6,6.,1.4,0.05       0.,0.,0.                  !h(1),h(2)
1.8,100.,0.6,6.,1.4,0.05       1.,0.0,1.                 !m1,m2,m3
1.8,100.,0.6,6.,1.4,0.05
1.8,100.,0.6,6.,1.4,0.05
4.5,100.,2.2,50.,2.3,0.5
5.7,100.,2.2,50.,2.3,1.0
6.8,100.,3.6,50.,3.0,4.50
8.0,200.,4.5,100.,4.5,50.00

0.0             ! reduction velocity in km/s
0.0             ! time lag in sec.
256             ! number of frequencies to use
512             ! number of points to use in the fft (power of 2)
0               ! set to 1 if earth flatening is used
1               ! set to 1 for VSPs
0               ! set to 1 for automatic band pass filter
0               ! specifies source, 0 is no source
2               ! specifies frequency window, 0 is rectangle, 2 is hanning
0               ! set to 1 to write file header
0               ! set to 1 to write record headers
1               ! 1-displacement, 2-velocity, 3-acceleration (pressure)
1.1             ! mute window, seconds
0.0             ! end of mute window, if 0, then no mute
0,0             ! 1 for noise, number of noise filters
0.020           ! noise amplitude
Z
2,12,2.
M
1,12,13.
```

VSP - vertical