UNITED STATES DEPARTMENT OF THE INTERIOR

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# Coal-seismic, desktop computer programs in BASIC; part 10: construct and apply one-dimensional synthetic seismograms

by

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## ABSTRACT

Processing of data taken with the U.S. Geological Survey's coal-seismic system is done with a desktop, stand-alone computer. Programs for this computer are written in the extended BASIC language used by the Tektronix 4051 Graphic System. This report discusses and presents a set of computer programs to produce one-dimensional synthetic seismograms, and includes two coal-seismic examples of their application.


## INTRODUCTION

A one-dimensional synthetic seismogram is a computer-generated time series showing what a single trace on a seismic reflection record would look like for a given set of parallel reflection horizons when both the seismic source and receiver are located on a common normal to the horizons. The artificial record is manufactured (Sheriff, 1973, p. 212-213) by convolving a reflectivity function with a specified waveform. An excellent introductory description of the synthetic seismogram is given by Anstey (1982, p. 52-60). Most modern textbooks, for example, Waters (1978, p. 111-118), discuss the fundamental concepts upon which the synthetic seismogram is based.

The programs of this report compute and display one-dimensional synthetic seismograms for a shallow-depth seismic model constructed of a limited number of discrete layers of constant density and velocity. Computations are made in the time domain. Waveforms of different shape and duration can be chosen, multiple reflections can be introduced, and a variety of time-dependent gain functions can be applied.

The computational procedures presented in this report differ from those commonly used in oil and gas exploration in several important aspects:

1. The target depths for coal exploration are shallower, thus the effects of near-surface layers cannot be ignored, a common practice in construction of oil-related synthetic seismograms.

2. Because sonic logs usually are not included in the suite of logs taken in areas considered for coal mine development, the reflectivity series cannot be derived from them. Also, exploratory drill holes generally are not taken to depths much beyond the base of the coal benches and fluid in the holes may not extend to the surface, thus even if a sonic log was taken, its data range would be small relative to that covered by the reflection seismograph.

3. Some question exists as to the applicability of the zero-phase and/or Ricker wavelet for shallow reflecting horizons; therefore, provision is made in the programs of this report for use of an approximation to the minimum-phase wavelet (Sheriff, 1973, p.141-142, 186, 248), an arbitrary wavelet, and a wavelet obtained directly from a downhole-velocity-survey seismogram--these three wavelets may be more appropriate for reflections whose arrival times are less than 100 msec.

4. Because amplitude considerations are of such importance in coal seismics, the programs of this report offer four distinct methods of displaying the synthetic seismogram: (1) fixed gain over the entire record, (2) fixed and/or linear gain within specified time intervals, (3) an AGC (adaptive gain control) procedure based on development of a digital gain-normalization curve (N. S. Neidell, 1979, oral communica-

tion) that smoothly connects rms values within selected windows, and (4) a PGC (programed gain control) of selectable half-value time.

5. Finally, because a desktop computer cannot match the computing power of machines at commercial data processing centers, a smaller number of layers can be handled; therefore, the composite effect of many small acoustic-impedance changes cannot be evaluated by our programs.

Because coals occur in non-marine sections that often do not exhibit extended stratigraphic continuity, one should not expect that a single synthetic seismogram could categorize the seismic response within a specific coal field, particularly for coal fields of the western United States. One of the uses of a set of synthetic seismograms is to gain insight into the anticipated character changes that may occur in the seismic records taken over an entire coal field.

Four programs are required to produce the synthetic seismograms of this report--the functions of these programs are as follows:

1. enter data and develop acoustic impedance and reflection coefficient section,
2. develop time/depth section and reflectivity series,
3. generate and store Fourier coefficients of wavelets, and
4. compute and display synthetic seismogram.

These four programs (the fourth program being divided into two programs because of limited computer memory) are listed at the end of the report. An appendix contains a discussion and listing of a program to compute a sample problem. Results computed by the sample-problem program can be used as input data to the first program listed above.

These data processing procedures were developed as part of the U.S. Geological Survey's coal-seismic system. All computer programs were written in an extended BASIC language developed by Tektronix, Inc. for use with their 4051 Graphic System. Three pieces of Tektronix computing equipment are required by the programs: a 4051 Graphic System with a 32K-byte memory, a 4924 Digital Cartridge Tape Drive, and a 4631 Hard Copy unit. Optionally, the Tektronix 4662 Interactive Digital Plotter may be employed if one wishes to produce a higher quality display.

All programs are self-prompting. In working through a sample problem, the user will notice that the programs print questions and requests followed by a flashing question mark. The computer then waits for a response from the keyboard. Replies entered in order to run the sample problems are enclosed in boxes hand drawn on the figures.

The last part of the report contains an example of the use of synthetic seimograms as a modeling tool to study reflections from two merging coal beds.

The seismic section chosen to illustrate the programs of this report was drawn from fragments of real data and then modified so as to create a sample problem to illustrate the ideal seismic records that for specified wave forms would be observed over a section containing a thin coal bed and a thicker coal bed containing a parting.

With the exception of the simulated sonic log data expressed in microsec/ft, all quantites are in metric units.

## DISCUSSION OF PROGRAM TO ENTER DATA AND CONSTRUCT ACOUSTIC IMPEDANCE AND REFLECTION COEFFICIENT SECTION

Two types of data are entered: those developed from a forward model, and those from field observations. The forward model and a discussion of the program used to generate it are given in the appendix. The "field data" used to demonstrate the program are also derived from the model, but treated as though they were taken in the field.

The first program (instead of using the long title, let us call it program 1) begins by asking if you want to work with sample problem data; that is, results produced by the forward modeling program. If you reply with a Y (fig. 1), then you are prompted to enter the file number in which the sample problem data are stored, the number assigned to the sample problem, and the date on which either the sample problem was computed or the date on which program 1 was run--your choice. Next you are asked if you want to store the results produced by program 1 on a data tape, and if so, within which file. After you reply that you want to plot the results, you are prompted to enter the minimum and maximum values of the variates to be plotted and the tickmark interval for each. Following these entries (fig. 1), the plot is made on the screen, a hard copy of which is shown on figure 2.

```
ENTER DATA AND CONSTRUCT ACOUSTIC IMPEDANCE AND REFL. COEFF. SECTION

DO YOU WANT TO WORK WITH SAMPLE PROBLEM DATA? (Y/N) Y

INSERT DATA TAPE IN 4924   FILE NUMBER = 39
Sample prob no.(2 char,max) = 9
Date computed (12 char,max) = 11 NOV 1982

DO YOU WANT TO STORE RESULTS ON A DATA TAPE? (Y/N) Y
   NUMBER OF FILE ON WHICH DATA ARE TO BE STORED = 40

DO YOU WANT TO PLOT RESULTS? (Y/N) Y

ENTER PLOT-LIMIT VALUES

Depths range from 0 to 140 meters
          Min. depth on plot = 0
          Max. depth on plot = 140
     Depth tickmark interval = 10

Densities range from 1.3 to 2.6 gm/cc
          Min. density on plot = 1.2
          Max. density on plot = 2.7
     Density tickmark interval = .3

Velocities range from 0.3 to 3.6 m/msec
          Min. velocity on plot = 0
          Max. velocity on plot = 4
     Velocity tickmark interval = 1

Refl coeff's range from -0.4375 to 0.4375
          Min. refl coeff on plot = -0.5
          Max. refl coeff on plot = 0.5
     Refl coeff tickmark interval = 0.4

Impedances range from 0.45 to 9.36 x 10↑-9 kg/m↑2s
          Min. impedance on plot = 0
          Max. impedance on plot = 10
     Impedance tickmark interval = 2
```

Figure 1. Copy of screen display of entries made with program 1 when use of forward-model results is selected.

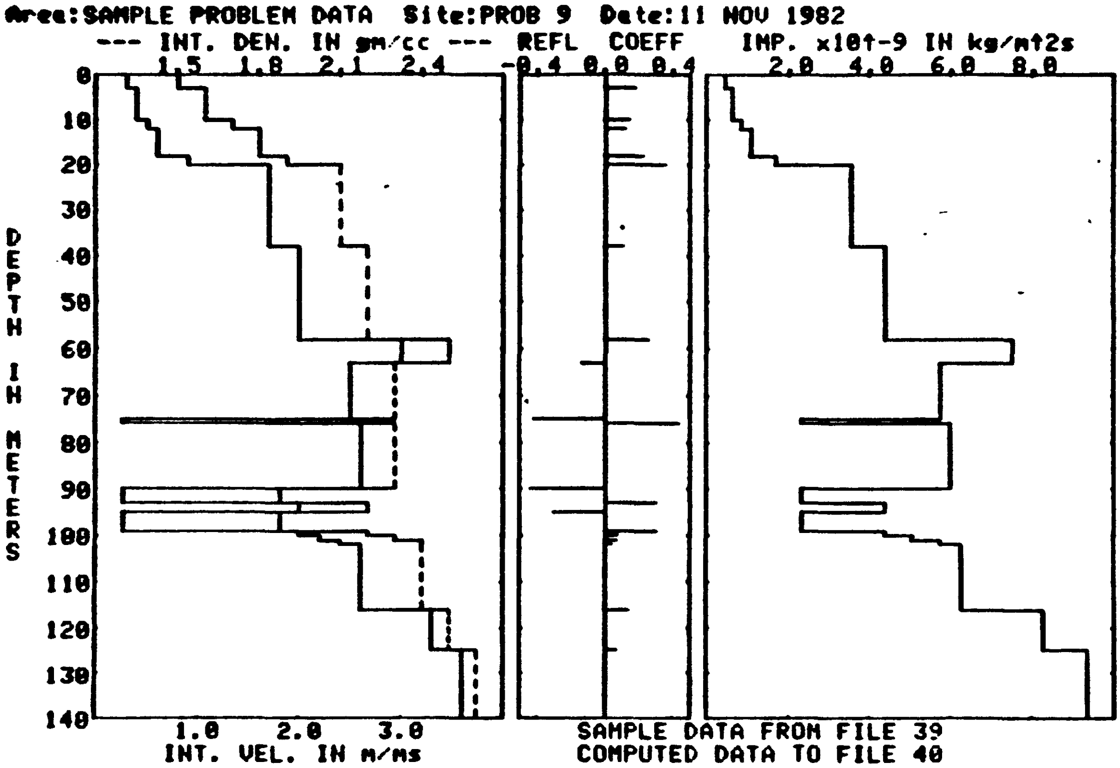



Figure 2. Copy of screen display showing results produced by program 1 when applied to forward-model data. Variate ranges and tickmark intervals are those entered on figure 1.

The normal-incidence reflection coefficients (center panel of fig. 2) are obtained by dividing the difference in acoustic impedance (velocity times density within a discrete layer) between contiguous layers by the sum of their acoustic impedances. Note that the coal layers, identified by their low density and velocity, exhibit large reflection coefficients and thus would be expected to produce strong reflections--this is the basis upon which the hope of using the reflection seismograph to map coals rests. But as we shall see as we continue our study of the synthetic seismogram program, though acoustic impedance mismatch is important, other factors also contribute to reflection strength.

Before leaving inspection of figure 2, note that the change in acoustic impedance between the air and first layer (a mismatch that produces a reflection coefficient almost equal to one) is not displayed. This omission occurs because the source point and detector are coincident on the surface. However, when multiple reflections are considered, a reflection coefficient almost equal to unity is not to be dismissed--unless we choose to suppress its effect. This point is introduced to emphasize that a mathematical model only produces what it has been programed to produce--the real world does not respond as submissively.

Following the making of the plot, you are asked (fig. 3) if you want to replot. If you reply with a Y, you are returned to that part of the program at which you were asked to enter plot-limit values (see fig. 1); if you answer with an N, you are instructed to insert a data tape in the 4924 unit (if you had previously elected, fig. 1, to store results). After data are stored, a read-after-write operation is performed.

```
DO YOU WANT TO REPLOT? (Y/N) N

INSERT DATA TAPE TO STORE RESULTS IN 4924
LENGTH OF FILE REQUIRED = 768
DOES FILE HAVE SUFFICIENT LENGTH? (Y/N) Y
DATA STORED IN AND RETRIEVABLE FROM FILE 48

PROGRAM COMPLETED
```

Figure 3. Copy of screen showing remainder of entries for program 1 when data derived from a forward model have been used.

The procedure to enter field data is initiated if you answer the first question of program 1 with an N (fig. 4). Next you are asked if acoustic and density log data are to be entered. If data from an acoustic and density log are available (a Y response), data entries for three zones are required: zone 1, above the logged interval; zone 2, within the logged interval; and, zone 3, below the logged interval. If you had answered with an N, only data from zone 1 would be entered. In order to illustrate the full procedure, let us assume sonic and density logs had been taken over part of the section.

After prompts are given for entry of information about the area and the site, you are directed to enter data for zone 1 (the section above the logged interval). If the logs extend to the surface, then you would enter a zero for the number of layers in zone 1, following which the program would require you to enter data from zone 2.

The entry of data for zone 1 is straightforward. First you enter the number of layers in zone 1 and then the thickness, density, and velocity of each layer, as shown on figure 4. Values for entry of zone 1 data are obtained from a combination of observed data (from downhole velocity surveys), density-log data, refraction data (with allowance being made for anisotropy), and informed guesses.

At commercial data processing centers, log data generally are read into the programs either through the use of a digitizer (if only analog data are available) or directly from a digital storage medium. In the program of this report, in recognition of the limited memory of the computer, a different approach is used--one in which a balance is struck between decrease in memory and increase in judgment.

Illustration of this procedure is best shown by working through an example. Let us assume the interval from 20 to 104 m (fig 2.) was logged with density and sonic tools. We can proceed in one of two ways: read and enter the density and velocity at every sample interval (for example, every meter) or break the log into segments and then read and

```
ENTER DATA AND CONSTRUCT ACOUSTIC IMPEDANCE AND REFL. COEFF. SECTION

DO YOU WANT TO WORK WITH SAMPLE PROBLEM DATA? (Y/N) [N]

ARE ACOUSTIC AND DENSITY LOG DATA TO BE ENTERED? (Y/N) [Y]

NOTE: ALL QUANTITIES IN METRIC UNITS EXCEPT TRANSIT TIMES
      ON ACOUSTIC LOGS WHERE UNIT IS MICROSECONDS/FOOT.

      Area name (20 char,max) = MARSHALL COAL FIELD
Site designation (7 char,max) = PROB #9
  Date computed (12 char,max) = 11 NOV 1982

  Lat. of site (10 char, max) =  39 11 22
  Long of site (11 char, max) = 105 33 44
County & State  (23 char,max) = BOULDER, COLORADO

     Elevation of site center = 1502


NO. OF LAYERS IN ZONE 1 = 5

LAYER NO.  LAYER THICKNESS   LAYER DENSITY   LAYER VELOCITY
   1             3               1.5             0.3
   2             7               1.6             0.4
   3             2               1.7             0.5
   4             6               1.8             0.6
   5             2               1.9             0.9


ENTER DEPTH-SEGMENT DATA FOR LOGGED INTERVAL

          NUMBER OF SEGMENTS = 6

    Depth to top of segment 1 = 20
   Depth to base of segment 1 = 38
          SI within segment 1 = 18

    Depth to top of segment 2 = 38
   Depth to base of segment 2 = 58
          SI within segment 2 = 20

    Depth to top of segment 3 = 58
   Depth to base of segment 3 = 73
          SI within segment 3 = 5

    Depth to top of segment 4 = 73
   Depth to base of segment 4 = 77
          SI within segment 4 = 1

    Depth to top of segment 5 = 77
   Depth to base of segment 5 = 89
          SI within segment 5 = 12

    Depth to top of segment 6 = 89
   Depth to base of segment 6 = 104
          SI·within segment 6 = 1
```

Figure 4. Copy of first three screen displays showing entries made for program 1 when the use of field data is selected. In this example, data from acoustic and density logs were taken over that part of the section from 20 to 104 ms.

enter data at selected intervals within each segment. Consider, for example, entry of data for a 100-m thick shale section within which the velocity and density are almost constant. Here it would be much faster to enter one density and one velocity than to enter 101 values of density and velocity at an interval of 1 m. But this is a case where compromise caused by lack of computing power may cause loss of significant results--it being well known that layers of alternating acoustic impedance can produce large multiple reflections.

For the sample problem, figure 4, the logged interval was broken into six segments, the first of which begins at the base of zone 1 and extends to a depth of 38 m. Sample interval (SI) within segment 1 is taken to be 18 m; thus, only one transit time and one density are considered (fig. 5). For segment 3, we have elected to enter three sets of time/density data at intervals of 5 m.

ENTER TRANSIT TIMES AND DENSITIES

| DEPTH TOP,M | TRANSIT TIME microsec/ft | VELOCITY M/Msec | DENSITY gm/cc | IMPEDANCE X 10↑-9 kg/(m↑2s) |
|---|---|---|---|---|
| SEGMENT # 1 | | | | |
| 20 | 179 | 1.7028 | 2.1 | 3.5759 |
| SEGMENT # 2 | | | | |
| 38 | 152 | 2.0053 | 2.2 | 4.4116 |
| SEGMENT # 3 | | | | |
| 58 | 102 | 2.9882 | 2.5 | 7.4706 |
| 63 | 122 | 2.4984 | 2.3 | 5.7463 |
| 68 | 122 | 2.4984 | 2.3 | 5.7462 |
| SEGMENT # 4 | | | | |
| 73 | 122 | 2.4984 | 2.3 | 5.7462 |
| 74 | 122 | 2.4984 | 2.3 | 5.7462 |
| 75 | 169 | 1.8036 | 1.3 | 2.3446 |
| 76 | 117 | 2.6051 | 2.3 | 5.9918 |
| SEGMENT # 5 | | | | |
| 77 | 117 | 2.6051 | 2.3 | 5.9918 |
| SEGMENT # 6 | | | | |
| 89 | 117 | 2.6051 | 2.3 | 5.9918 |
| 90 | 169 | 1.8036 | 1.3 | 2.3446 |
| 91 | 169 | 1.8036 | 1.3 | 2.3446 |
| 92 | 169 | 1.8036 | 1.3 | 2.3446 |
| 93 | 152 | 2.0053 | 2.2 | 4.4116 |
| 94 | 152 | 2.0053 | 2.2 | 4.4116 |
| 95 | 169 | 1.8036 | 1.3 | 2.3446 |
| 96 | 169 | 1.8036 | 1.3 | 2.3446 |
| 97 | 169 | 1.8036 | 1.3 | 2.3446 |
| 98 | 169 | 1.8036 | 1.3 | 2.3446 |
| 99 | 152 | 2.0053 | 2.2 | 4.4116 |
| 100 | 139 | 2.1928 | 2.3 | 5.0435 |
| 101 | 127 | 2.4000 | 2.4 | 5.7600 |
| 102 | 117 | 2.6051 | 2.4 | 6.2523 |
| 103 | 117 | 2.6051 | 2.4 | 6.2523 |

Figure 5. Example of entry of density and sonic log data.

After data in the logged interval (zone 2) have been entered, you are prompted (as shown on fig. 6) to enter data for zone 3 following which you are asked if you want to store and plot results.

```
NO. OF LAYERS IN ZONE 3 = 3

LAYER NO.   LAYER THICKNESS   LAYER DENSITY   LAYER VELOCITY
   1              12               2.4             2.6
   2              9                2.5             3.3
   3              15               2.6             3.6

DO YOU WANT TO STORE RESULTS ON A DATA TAPE? (Y/N) Y
   NUMBER OF FILE ON WHICH DATA ARE TO BE STORED = 40

DO YOU WANT TO PLOT RESULTS? (Y/N) Y
```

Figure 6. Example of data entered for zone 3.

Figure 7 shows plot-limit values entered and the resulting plot.

Next you are asked if you want to replot. If you answer with a Y, then you are returned to that section of the program in which you are prompted to enter plot limits; if you reply with an N, then you are instructed as to how to file the data (fig. 8).

```
DO YOU WANT TO REPLOT? (Y/N) N

INSERT DATA TAPE TO STORE RESULTS IN 4924
LENGTH OF FILE REQUIRED = 768
DOES FILE HAVE SUFFICIENT LENGTH? (Y/N) Y
DATA STORED IN AND RETRIEVABLE FROM FILE 40

PROGRAM COMPLETED
```

Figure 8. Copy of screen display showing prompts for storing data.

Data computed from the first program (the impedance and reflection coefficient, Z & RC, program) are stored on tape and are used as data input for the second program (the time/depth and reflectivity series, T/D-RS, program).

ENTER PLOT-LIMIT VALUES

Depths range from 0 to 140 meters
Min. depth on plot = 0
Max. depth on plot = 140
Depth tickmark interval = 10

Densities range from 1.3 to 2.6 gm/cc
Min. density on plot = 1.2
Max. density on plot = 2.7
Density tickmark interval = 0.3

Velocities range from 0.3 to 3.6 m/msec
Min. velocity on plot = 0
Max. velocity on plot = 4
Velocity tickmark interval = 1

Refl coeff's range from -0.4375 to 0.4375
Min. refl coeff on plot = -0.5
Max. refl coeff on plot = 0.5
Refl coeff tickmark interval = 0.4

Impedances range from 0.45 to 9.36 x 10↑-9 kg/m↑2s
Min. impedance on plot = 0
Max. impedance on plot = 10
Impedance tickmark interval = 2

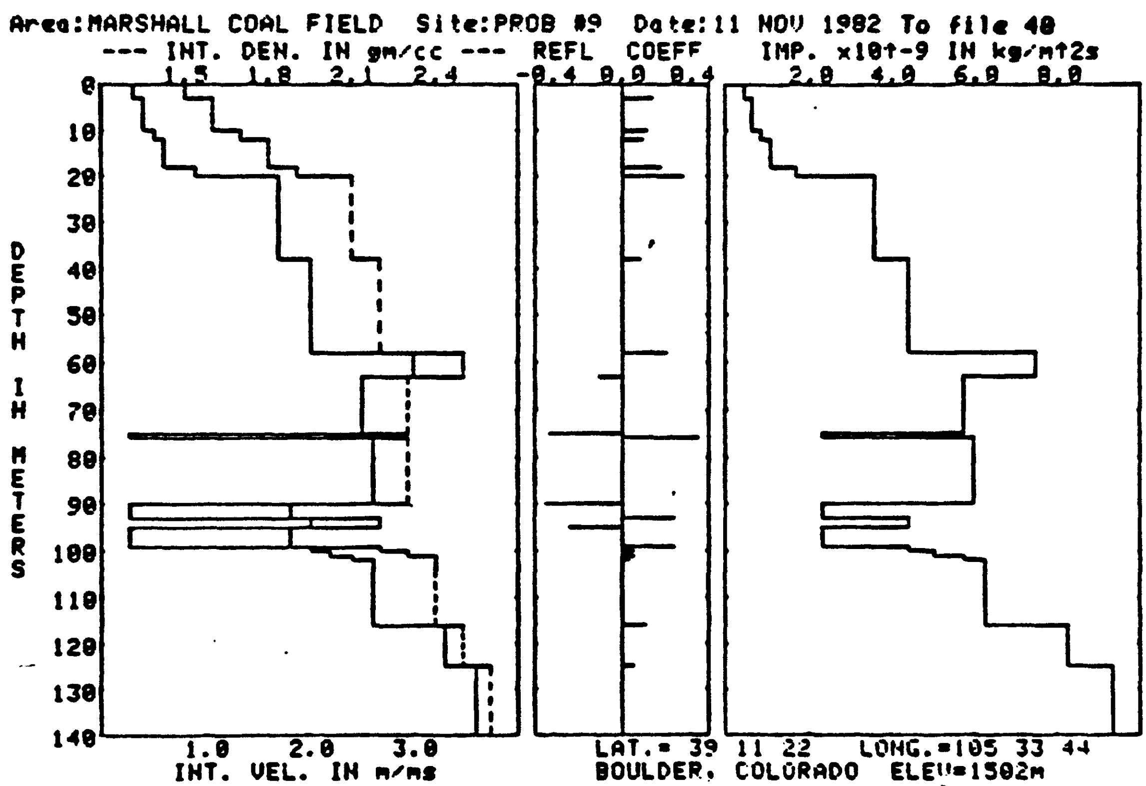



Figure 7. Copy of screen display showing plot-limit values and plot produced when field data are entered into program 1.

## DISCUSSION OF PROGRAM TO DEVELOP TIME/DEPTH SECTION AND REFLECTIVITY SERIES

The program begins (fig. 9) by instructing you to enter the data tape of the first program in the 4924 and then enter the file number in

```
DEVELOP TIME-DEPTH (T/D) SECTION AND REFLECTIVITY SERIES (RS)

INSERT Z & RC DATA TAPE IN 4924      FILE NUMBER = [40]

DO YOU WANT TO STORE RESULTS ON A T/D & RS DATA TAPE? (Y/N) [Y]
   FILE NUMBER = [41]

DO YOU WANT TO INCLUDE TWO-BOUNCE MULTIPLES? (Y/N) [N]

DO YOU WANT PLOT OF VEL, T-D, AND REFL SERIES? (Y/N) [Y]
```

Figure 9. Copy of screen display showing first entries for program 2.

which these data are stored, following which you are prompted to enter the number of the file in which results of the second program are to be stored. Next, you are asked if you want to include two-bounce multiples in the construction of the reflectivity series--to be discussed later in this report. Lastly, you are asked if you want to plot the velocities, the time/depth section, and the reflectivity series.

If your computer has more memory than the 32 K-byte desktop computer for which these programs were developed, then no reason exists for not combining the first and second programs of this report. In this way, one would not need to generate a data tape to carry data from the first to the second program.

Let us begin this second program by developing the reflectivity series without multiple reflections. In the first program, reflection coefficients are developed solely on the basis of acoustic impedance difference between contiguous layers and they are plotted as functions of depth. In the second program, the reflection coefficients are computed as functions of reflection time and the coefficients include across-layer-transmission and spherical-divergence losses.

Figure 10 shows copies of screen displays showing plot-limit values entered and the plot produced using the results of program 1 as input to program 2. Note on comparison of figures 7 and 10 that whereas in figure 7 the largest reflection coefficients occured at the boundaries of the coal seams, on figure 10 the largest reflection coefficient occurs at a reflection time of 20 ms, the reflection time from the base of the first layer. Thus, as stated earlier in this report, although the magnitude of the acoustic-impedance mismatch between layers is an important contributor to the reflectivity series, it is not the only factor to be considered.

Three kind of velocity as functions of reflection time are plotted in the left panel of figure 10: interval velocity, average velocity

```
ENTER PLOT-LIMIT VALUES

Reflection time to top of layer 1 = [0]

Primary reflections range from 20 to 182.064142332
Min. reflection time on plot = [0]
Max. reflection time on plot = [200]
Refl. time tickmark interval = [20]

Velocities range from 0.3 to 3.6
       Min. velocity on plot = [0]
       Max. velocity on plot = [4]
  Velocity tickmark interval = [1]

Refl coeff's range from -0.00198030146247 to 0.0290519877676
     Min. refl coeff on plot = [-0.003]
     Max. refl coeff on plot = [0.035]
Refl coeff tickmark interval = [0.03]

Depths range from 0 to 140
          Min. depth on plot = [0]
          Max. depth on plot = [140]
     Depth tickmark interval = [20]
```

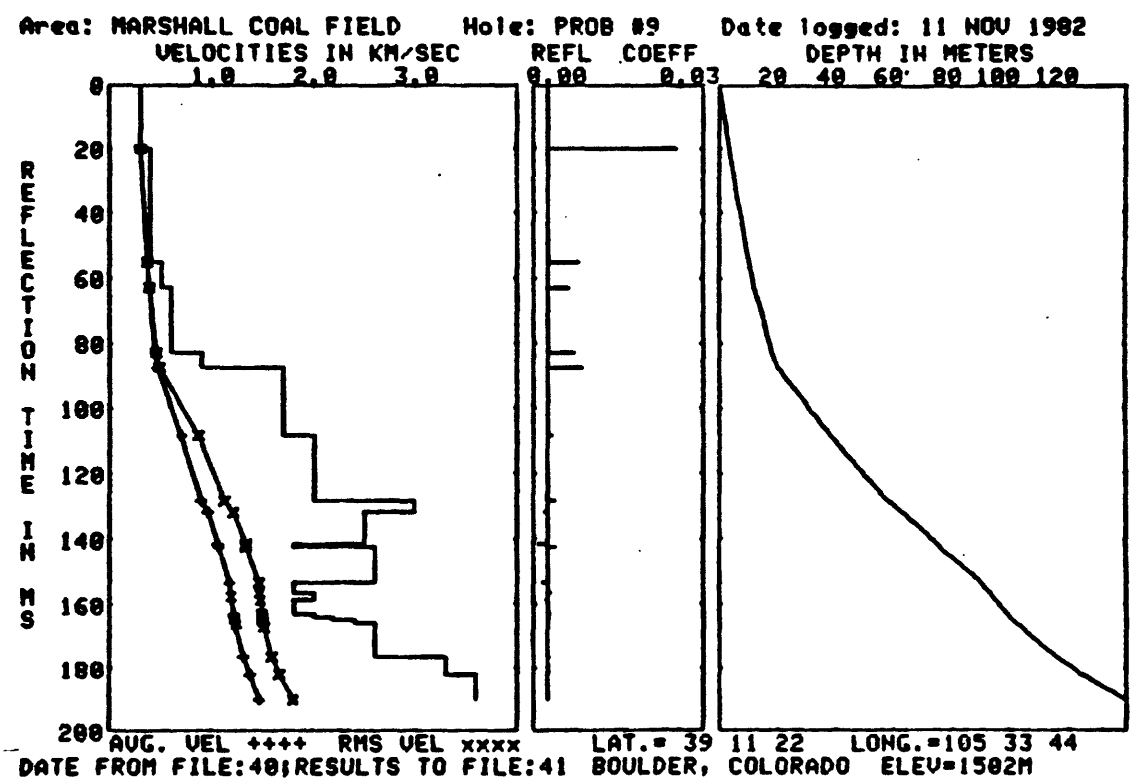



Figure 10. Plot-limit values and plot produced by second program upon entry and computation of data from the first program. The center panel shows the reflectivity series for the illustrative problem whose interval, average, and rms velocities are shown on the left, and whose depth vs. reflection time curve is shown on the right.

(line segments connecting plus signs), and root-mean-square (rms) velocity (line segments joining x's). The reflection-time versus depth function is shown in the right panel. Although these plots are not required in the construction of the synthetic seismogram, they are instructive in that they allow one to anticipate refraction arrivals and their relation to reflection arrivals, and also they offer a quick means of detecting gross errors in data acquisition and entry.

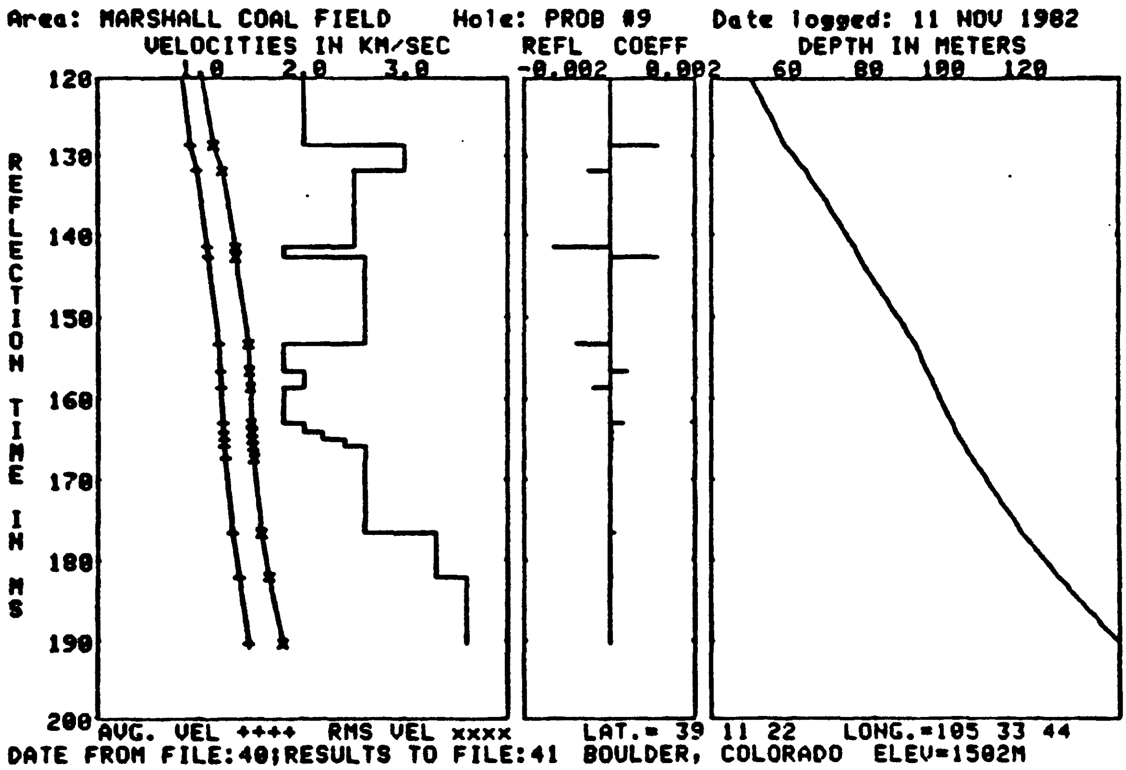
After the plot is made, you are asked if you want to replot. An example of a replot with plot limits chosen so as to detail the reflection-time section from 120 to 200 ms is shown on figure 11.

Much can be learned by study of a plot such as that shown on figure 11. For example, note that though the velocity difference is greater at the base of the thin coal bed (a reflection time of about 142 ms) than at the top of the thin seam, the reflectivity-series display shows that a slightly weaker reflection would be anticipated from the base than from the top of the thin seam. Also it is instructive to examine the transitional reflectivity series developed by the simulated underclay sequence underlying the lower coal seam. Examination of the time/depth (T/D) plot shows that one should not expect to detect a thin coal bed using results obtained with a downhole velocity survey and also that a thick coal section could produce a blind zone in a refraction survey.

Let us now use program 2 to develop the reflectivity series for a case in which two-bounce multiple reflections are included. I prefer the term "two-bounce multiple", coined by Anstey (1977, p. 2-91,2-94), because to me it is a more descriptive term than either "peg-leg" or "short-path" multiple reflection (Sheriff, 1973, p. 146-147). A two-bounce multiple reflection is one that has bounced twice within a layer; for example, a downward traveling wave that has been reflected upward from the base of a layer, has been reflected downward from the top of the layer, and then has continued its downward travel.

Evidently some restriction must be placed on the number of multiple reflections to be included in the model because each acoustically mismatched layer can contain within it an unlimited number of multiple reflections. The program not only limits the multiple reflections to be of the two-bounce type, but also reduces their number by allowing one to select the lower limit of the reflection coefficient to be used in the calculations. This procedure is illustrated on figure 12 on which several selections are entered for the lower limits of reflection coefficient for the multiple reflections, the quantity being expressed as a percentage of the total range of reflection coefficients.

```
ENTER PLOT-LIMIT VALUES

Reflection time to top of layer 1 = 0

Primary reflections range from 20 to 182.064142332
Min. reflection time on plot = 120
Max. reflection time on plot = 200
Refl. time tickmark interval = 10

Velocities range from 0.3 to 3.6
       Min. velocity on plot = 0
       Max. velocity on plot = 4
  Velocity tickmark interval = 1

Refl coeff's range from -0.00198030146247 to 0.0290519877676
     Min. refl coeff on plot = -0.003
     Max. refl coeff on plot = 0.003
Refl coeff tickmark interval = 0.002

Depths range from 0 to 140
          Min. depth on plot = 40
          Max. depth on plot = 140
     Depth tickmark interval = 20
```




```
DO YOU WANT TO REPLOT? (Y/N) N

INSERT T/D & RS DATA TAPE IN 4924

ARE YOU READY TO PROCEED? (Y/N) Y
    LENGTH OF FILE REQUIRED = 768
    DOES SELECTED FILE HAVE SUFFICIENT LENGTH? (Y/N) Y
DATA STORED IN AND RETRIEVED FROM FILE 41
PROGRAM COMPLETED
```

Figure 11. Plot limits and detail plot produced by program 2 to show velocities, reflectivity series, and depth versus reflection time from 120 to 200 msec.

```
DEVELOP TIME-DEPTH (T/D) SECTION AND REFLECTIVITY SERIES (RS)

INSERT Z & RC DATA TAPE IN 4924      FILE NUMBER = [40]

DO YOU WANT TO STORE RESULTS ON A T/D & RS DATA TAPE? (Y/N) [Y]
   FILE NUMBER = [42]

DO YOU WANT TO INCLUDE TWO-BOUNCE MULTIPLES? (Y/N) [Y]
LOWER LIMIT OF REFL COEFF TO BE USED IN % OF TOTAL RANGE = [0.1]
TOTAL NUMBER OF POSSIBLE TWO-BOUNCE MULTIPLES = 1330
AVAILABLE MEMORY ALLOWS ONLY FIRST 283 MULTIPLES

TOTAL NUMBER OF PRIMARY + MULTIPLE REFLECTIONS = 98

DO YOU WANT TO RESELECT LOWER LIMIT ON MULTIPLES? (Y/N) [Y]
LOWER LIMIT OF REFL COEFF TO BE USED IN % OF TOTAL RANGE = [0.05]

TOTAL NUMBER OF PRIMARY + MULTIPLE REFLECTIONS = 144

DO YOU WANT TO RESELECT LOWER LIMIT ON MULTIPLES? (Y/N) [Y]
LOWER LIMIT OF REFL COEFF TO BE USED IN % OF TOTAL RANGE = [0.2]

TOTAL NUMBER OF PRIMARY + MULTIPLE REFLECTIONS = 58

DO YOU WANT TO RESELECT LOWER LIMIT ON MULTIPLES? (Y/N) [Y]
LOWER LIMIT OF REFL COEFF TO BE USED IN % OF TOTAL RANGE = [0.1]

TOTAL NUMBER OF PRIMARY + MULTIPLE REFLECTIONS = 98

DO YOU WANT TO RESELECT LOWER LIMIT ON MULTIPLES? (Y/N) [N]

DO YOU WANT PLOT OF VEL, T-D, AND REFL SERIES? (Y/N) [Y]
```

Figure 12. Screen copy of entries when two-bounce multiple reflections are considered in the construction of the synthetic seismogram.

Figure 13 shows the plot limits and the plot produced for the illustrative example when multiple reflections are considered. A tabulation of the reflectivity series shows that although 67 multiple reflections above the stated threshold are present, it would take an extremely sharp eye to detect any difference between the reflectivity series displayed on figure 13 (with multiples) and that of figure 10 (without multiples). One reason for the seeming lack of multiple reflections is the intentional suppression of multiples produced by the reflection from the air-ground interface. This omission is standard practice because its inclusion would swamp almost all other arrivals and because with real data (as opposed to model data), the surface-related multiples, though present, are generally not of the large magnitude that a model of limited numbers of layers--and omitted Q factors--would predict.

A replot for the time section from 120 to 200 ms of the reflectivity series with multiples (fig. 14) when compared to the same detailed section without multiples (fig. 11) shows that multiple reflections are included in the reflectivity series, but that their effect is not as large as one might expect given the large acoustic-impedance mismatch between the coal seams and the layers which bound them. From a glance at the reflectivity series containing multiples, one would correctly surmise that the principal effect of two-bounce multiple reflections is to lengthen wavelets by adding a few low-amplitude cycles to them.

ENTER PLOT-LIMIT VALUES

Reflection time to top of layer 1 = 0

Primary reflections range from 20 to 182.064142332
Min. reflection time on plot = 0
Max. reflection time on plot = 200
Refl. time tickmark interval = 20

Velocities range from 0.3 to 3.6
Min. velocity on plot = 0
Max. velocity on plot = 4
Velocity tickmark interval = 1

Refl coeff's range from -0.00198030146247 to 0.0290519877676
Min. refl coeff on plot = -0.003
Max. refl coeff on plot = 0.035
Refl coeff tickmark interval = 0.03

Depths range from 0 to 140
Min. depth on plot = 0
Max. depth on plot = 140
Depth tickmark interval = 20

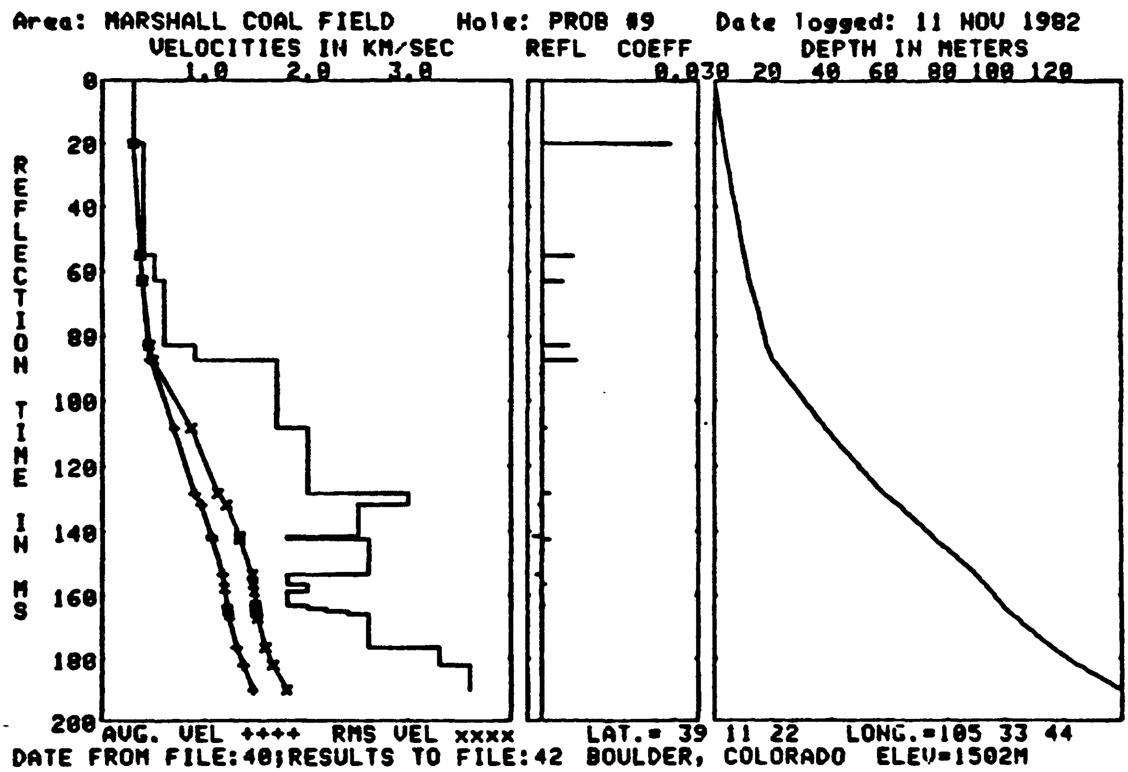



Figure 13. Plot limits and resulting plot for illustrative problem in which multiples are included in the reflectivity series.

```
ENTER PLOT-LIMIT VALUES

Reflection time to top of layer 1 = 0

Primary reflections range from 20 to 182.064142332
Min. reflection time on plot = 120
Max. reflection time on plot = 200
Refl. time tickmark interval = 10

Velocities range from 0.3 to 3.6
        Min. velocity on plot = 0
        Max. velocity on plot = 4
   Velocity tickmark interval = 1

Refl coeff's range from -0.00198830146247 to 0.0290519877676
      Min. refl coeff on plot = -0.003
      Max. refl coeff on plot = 0.003
Refl coeff tickmark interval = 0.002

Depths range from 0 to 140
           Min. depth on plot = 40
           Max. depth on plot = 140
     Depth tickmark interval = 20
```

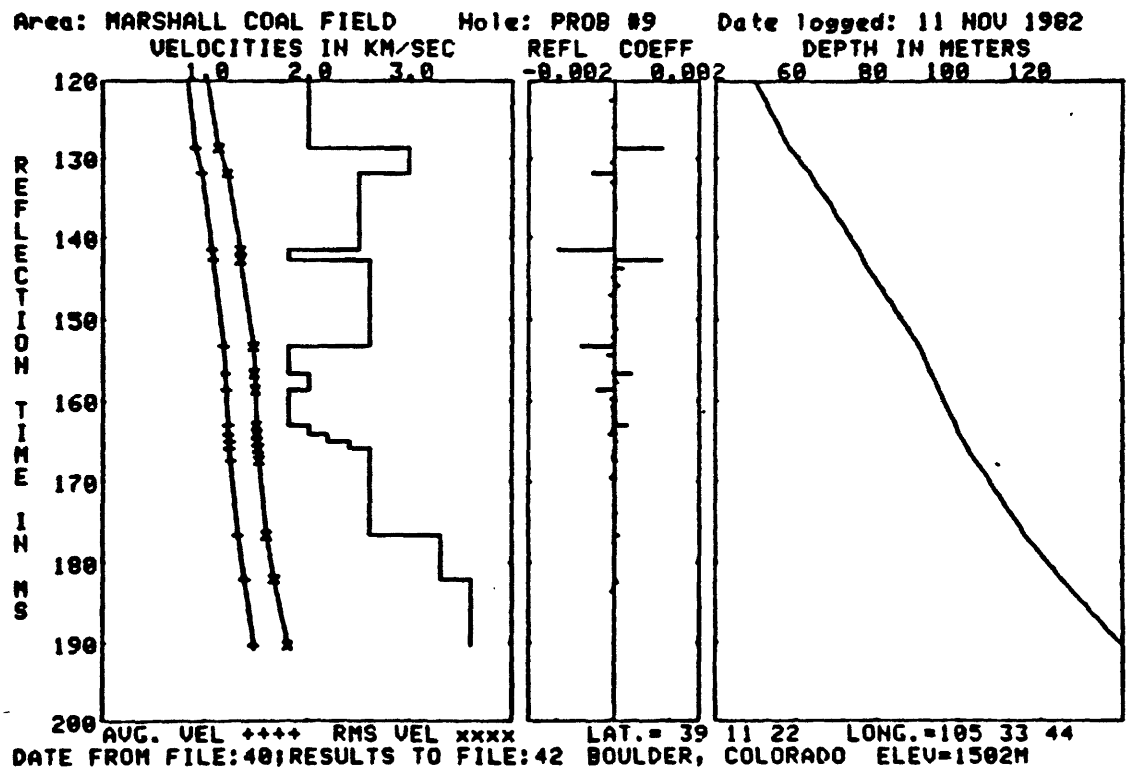



Figure 14. Plot limits and resulting plot from 120 to 200 ms for the illustrative problem for which multiple reflections are included.

After you have replied with an N as to whether you want to replot, you are instructed to insert the T/D & RS (time/depth and reflectivity series) data tape in the 4924 and then you are prompted as to how to store these data. The reflectivity series data together with wavelet data, the next section of this report, will be used later as data input to the final program required to construct a synthetic seismogram.

## DISCUSSION OF PROGRAM TO GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELETS

The purpose of the third program is to generate and store the Fourier coefficients of a wavelet. In the fourth program, these coefficients are used to synthesize a waveform of specific shape and duration. At first glance this seems like a labored process--why not simply develop the wavelet in the time domain? The answer lies in the desire to stretch or shrink a wavelet to a selectable apparent wavelength before convolving it with the reflectivity series.

As shown on figure 15, five wavelet types are available. In this

```
GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELET

DESIRED MAXIMUM ABSOLUTE AMPLITUDE OF WAVELET = [100]

THE FOLLOWING WAVELET TYPES ARE AVAILABLE:
    1. Cosine modulated sine, zero phase approximation, 2.5 cycles
    2. Damped cos mod. sine, minimum phase approximation, 2 cycles
    3. Directly observed--extracted from seismogram .
    4. Arbitrary -- values entered from keyboard
    5. Ricker "far distant" wavelet

NUMBER OF SELECTED WAVELET TYPE = [1]

DO YOU WANT QUICK PLOT OF INPUT WAVELET? (Y/N) [Y]

WAVELET USING A COSINE-MODULATED SINE WAVE
NO. OF VALUES=21      NO. OF CYCLES=2.5      MAX. ABS. AMPL=100
```

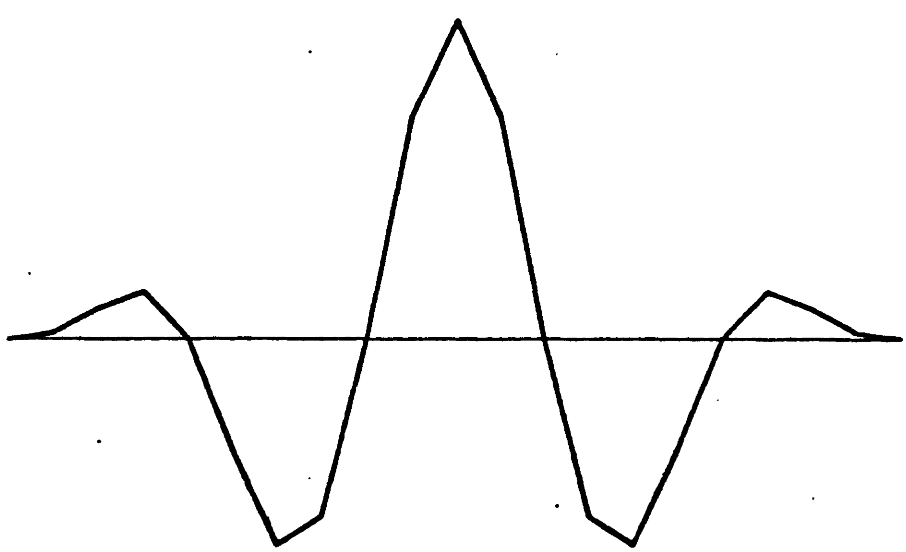


Figure 15. Copy of screen display showing entries to produce a cosine-modulated sine wave approximating a zero-phase wavelet.

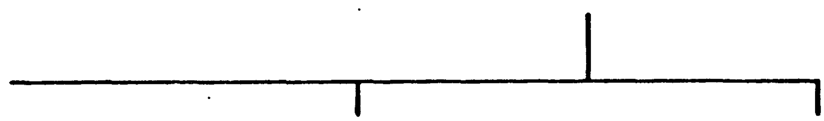
first example, a wave form with the appearance of a zero-phase wavelet was selected, type 1 from the list of five types.

Figure 16 lists the Fourier coefficients of this wavelet and shows the wavelet upon synthesis. Here, only the first seven coefficients are required to exactly reproduce the cosine-modulated sine wavelet from its Fourier coefficients.

FOURIER COEFFICIENTS FOR WAVELET USING A COSINE-MODULATED SINE WAVE

| HARMONIC | FOURIER COEFFICIENT |
|---|---|
| 1 | 0.000000 |
| 2 | 0.000000 |
| 3 | -25.000000 |
| 4 | 0.000000 |
| 5 | 50.000000 |
| 6 | 0.000000 |
| 7 | -25.000000 |

LINE SPECTRA



DO YOU WANT TO SEE FOURIER SYNTHESIZED WAVELET? (Y/N) $\boxed{Y}$

FOURIER SYNTHESIS OF WAVELET USING A COSINE-MODULATED SINE WAVE

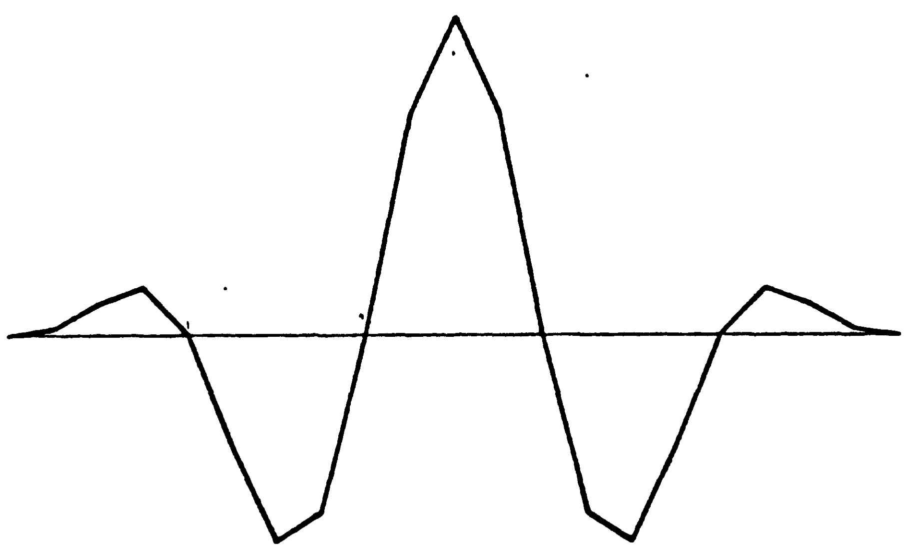


Figure 16. Fourier coefficients and synthesis of first wavelet type.

The third program begins by asking you to enter the desired absolute amplitude of the wavelet. Next you are asked to select the type of wavelet by entering the number of the wavelet type. Wavelets 1, 2, and 5 are developed from equations; wavelet 3 is extracted from observed data, and wavelet 4 is of arbitrary form, being constructed of values entered from the keyboard. In this report, examples are given of all five wavelet types. Display of the input wavelet and the wavelet synthesized from its Fourier coefficients can be elected.

The program ends after the wavelet's Fourier coefficients are stored on a wavelet data tape (WDT) using the procedure as illustrated on figure 17.

```
DO YOU WANT TO STORE FOURIER COEFF. ON WDT? (Y/N) Y
CODE NAME OF WDT = WAVELET#1
FILE NO.=43
LENGTH OF FILE REQUIRED = 256
DOES SELECTED FILE HAVE SUFFICIENT LENGTH? (Y/N) Y
DATA ARE STORED IN FILE 43 OF WDT: WAVELET#1

PROGRAM COMPLETED
```

Figure 17. Copy of screen display showing example of procedure to store Fourier coefficients of the selected wavelet.

Wavelet 1 is an approximation of a zero-phase wavelet of the noncausal type preferred by people at data processing centers for construction of synthetic seismograms to model the deeper seismic section. The second wavelet approximates a minimum-phase wavelet for which the energy is "front loaded" and thus may be more representative of waveforms seen in the shallower seismic section. As shown on figure 18, a choice is given as to the amount of damping to be applied.

Comparison of the wavelet and its form synthesized from its first 20 Fourier coefficients (fig. 19) shows that use of only half the number of coefficients is sufficient to satisfactorily reproduce the wavelet from its Fourier coefficients, as would be expected from inspection of the trail off of higher frequency components as displayed on the line-spectra plot shown near the center of figure 19.

Storage of the Fourier coefficients of this wavelet proceeds in the same manner as for the first wavelet, see figure 17.

```
GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELET

DESIRED MAXIMUM ABSOLUTE AMPLITUDE OF WAVELET = 100

THE FOLLOWING WAVELET TYPES ARE AVAILABLE:
    1. Cosine modulated sine, zero phase approximation, 2.5 cycles
    2. Damped cos mod. sine, minimum phase approximation, 2 cycles
    3. Directly observed--extracted from seismogram
    4. Arbitrary -- values entered from keyboard
    5. Ricker "far distant" wavelet

NUMBER OF SELECTED WAVELET TYPE = 2
           DECREMENT IN PERCENT = 1
                 LOG DECREMENT = -4.60517018599

DO YOU WANT QUICK PLOT OF INPUT WAVELET? (Y/N) Y


WAVELET USING A DAMPED COS-MODULATED SINE
NO. OF VALUES=41 NO. OF CYCLES=2  MAX. ABS. AMPL=100  LOG DEC.=-4.61
```

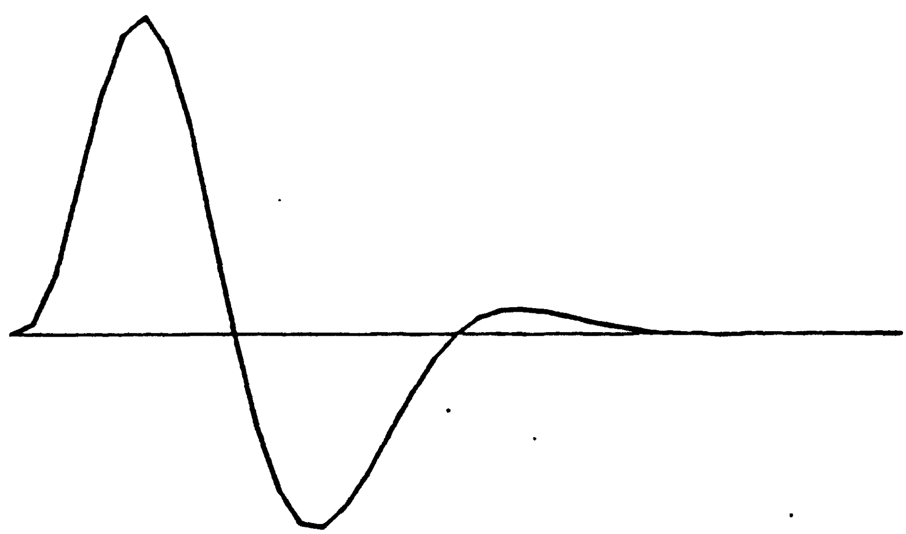


Figure 18. Copy of screen display showing entries to produce a damped cosine modulated sine wave approximating a minimum-phase wavelet.

FOURIER COEFFICIENTS FOR WAVELET USING A DAMPED COS-MODULATED SINE

| HARMONIC | FOURIER COEFFICIENT |
|---|---|
| 1 | -2.679224 |
| 2 | 5.388578 |
| 3 | 25.393874 |
| 4 | 36.945573 |
| 5 | 23.760895 |
| 6 | 1.752759 |
| 7 | -8.983812 |
| 8 | -9.244777 |
| 9 | -6.600114 |
| 10 | -4.277232 |
| 11 | -2.735548 |
| 12 | -1.774939 |
| 13 | -1.179830 |
| 14 | -0.804145 |
| 15 | -0.561860 |
| 16 | -0.401335 |
| 17 | -0.292675 |
| 18 | -0.217276 |
| 19 | -0.164024 |
| 20 | -0.125596 |

LINE SPECTRA 

DO YOU WANT TO SEE FOURIER SYNTHESIZED WAVELET? (Y/N) Y

FOURIER SYNTHESIS OF WAVELET USING A DAMPED COS-MODULATED SINE

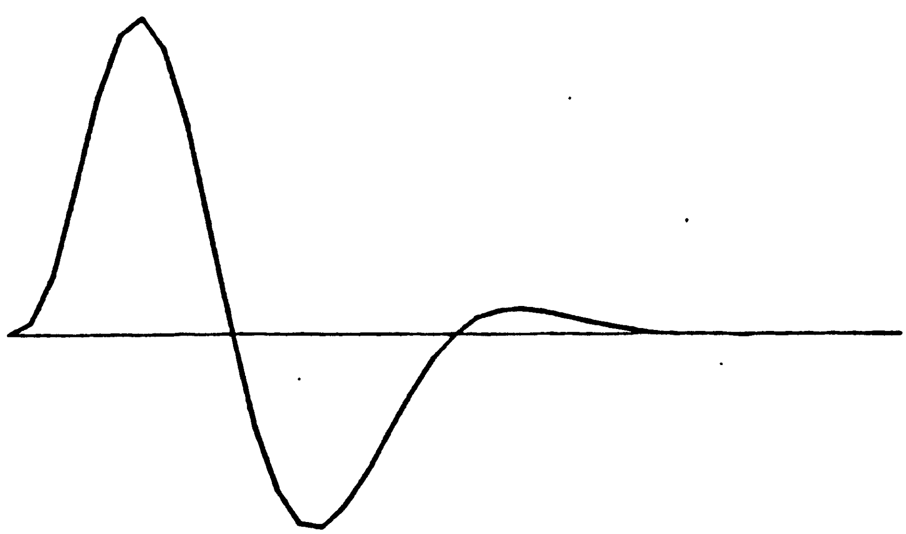


Figure 19. Fourier coefficients and synthesis of second wavelet type.

Figure 20 shows an example of a wavelet extracted directly from a seismogram. As indicated by the boxed quantities, you are required to insert and identify a master data tape (MDT), enter the number of the record of that tape and the trace on the record, and specify the start and end times of the wavelet. After the wavelet is read into memory, it is detrended and end values forced to zero. Fourier coefficients and plot of the synthesized type 3 wavelet are shown on figure 21.

```
GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELET

DESIRED MAXIMUM ABSOLUTE AMPLITUDE OF WAVELET = [100]

THE FOLLOWING WAVELET TYPES ARE AVAILABLE:
   1. Cosine modulated sine, zero phase approximation, 2.5 cycles
   2. Damped cos mod. sine, minimum phase approximation, 2 cycles
   3. Directly observed--extracted from seismogram
   4. Arbitrary -- values entered from keyboard
   5. Ricker "far distant" wavelet

NUMBER OF SELECTED WAVELET TYPE = [3]

INSERT OBSERVED-DATA MDT IN 4924     MDT CODE NO. = [01L2M]
ARE YOU READY TO PROCEED? (Y/N) [Y]
    NO. OF CYCLES IN WAVELET = [1.5]
        RECORD NUMBER ON MDT = [5]
                TRACE NUMBER = [11]
    TIME AT START OF WAVELET = [64]
      TIME AT END OF WAVELET = [104]

DO YOU WANT QUICK PLOT OF INPUT WAVELET? (Y/N) [Y]


OBSERVED WAVELET
FROM MDT:01L2M, REC#:5, TRACE#:11, FROM T=64 to 104
NO. OF VALUES=81  MAX. ABS. AMPL=100
```

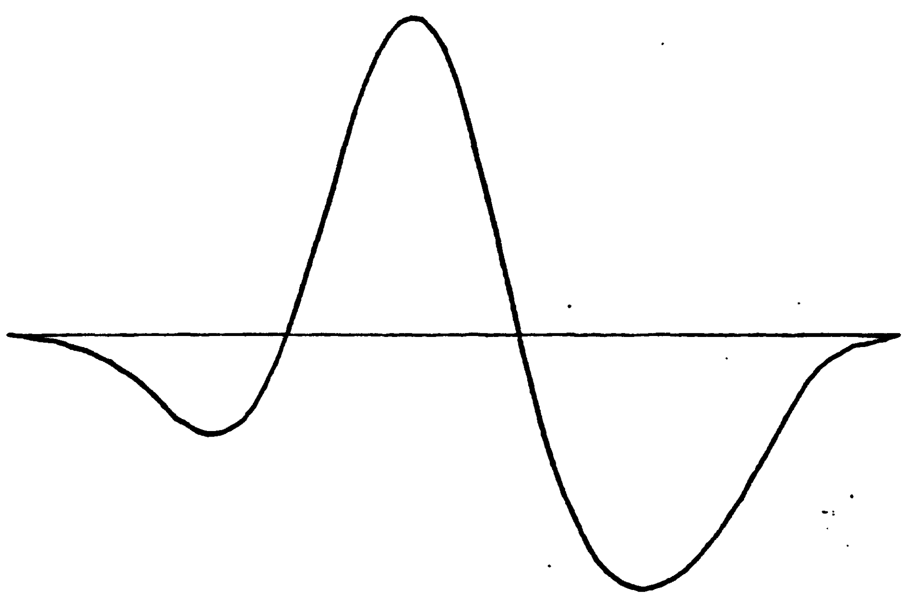


Figure 20. Copy of screen display showing entries to extract a wavelet from a seismogram and a plot of the wavelet selected.

FOURIER COEFFICIENTS FOR OBSERVED WAVELET

| HARMONIC | FOURIER COEFFICIENT |
|---|---|
| 1 | -0.593700 |
| 2 | 33.774604 |
| 3 | -48.107475 |
| 4 | -23.368155 |
| 5 | 29.422905 |
| 6 | 9.939145 |
| 7 | -2.063758 |
| 8 | -4.544261 |
| 9 | 0.795029 |
| 10 | -0.004387 |
| 11 | -0.555224 |
| 12 | 0.155373 |
| 13 | -0.112443 |
| 14 | 0.105008 |
| 15 | -0.258448 |
| 16 | 0.244802 |
| 17 | -0.028662 |
| 18 | 0.111735 |
| 19 | 0.007433 |
| 20 | 0.082617 |

LINE SPECTRA

DO YOU WANT TO SEE FOURIER SYNTHESIZED WAVELET? (Y/N) $\boxed{Y}$

FOURIER SYNTHESIS OF OBSERVED WAVELET
FROM MDT:01L2M, REC#:5, TRACE#:11, FROM T=64 to 104

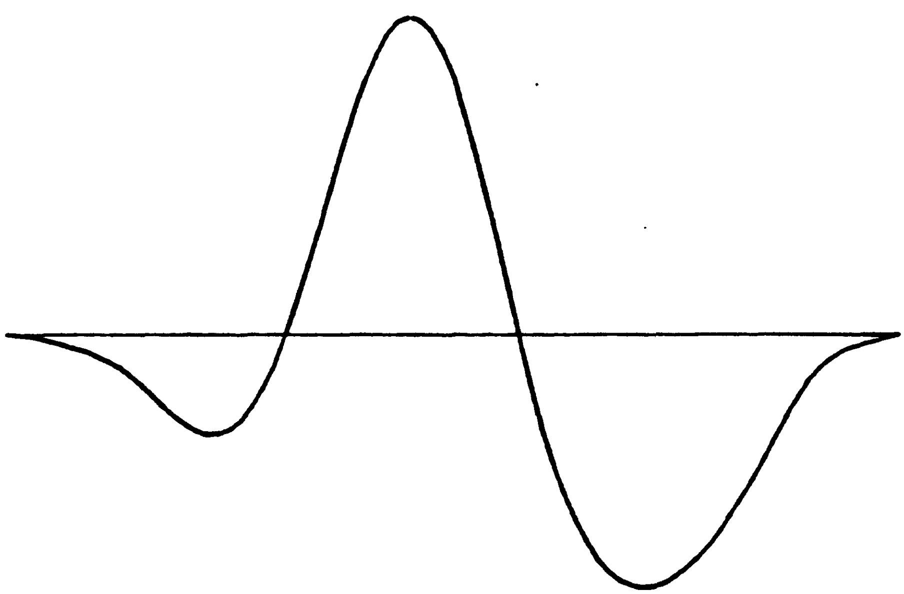


Figure 21. Fourier coefficients and synthesis of third wavelet type.

If the fourth type of wavelet (fig. 22) is selected, values defining the wavelet are entered from the keyboard. With this procedure, one can alter a wavelet shape and thus observe the resulting effect of change of wavelet shape operating on a given reflectivity series. In this example, 21 values were used to describe the wavelet and only the first 10 Fourier coefficients were generated. Comparison of the synthesized wavelet on figure 23 and the input wavelet on figure 22 shows an acceptable match between the two curves.

The fifth selectable wavelet type is the Ricker "far distant" wavelet (fig. 24) of common use at seismic data processing centers. In constructing synthetic seismograms for oil and gas investigations, this wavelet is treated as a non-causal wavelet, its center time being taken as the arrival time. Because our coal studies are focused to shallower depths, we treat this wavelet as if it begins at the spike time of the reflectivity series. If the user prefers to see the Ricker wavelet response in its traditional mode of presentation, all that needs to be done is to shift record times by an amount of time equal to half the wavelet period. For example, if the synthesized Ricker wavelet is 30 ms in duration (an apparent period of 20 ms), then the synthetic seismogram instead of starting at a time of zero would start at a time of -15 ms.

The first 20 Fourier coefficients of the Ricker wavelet and a plot of the synthesized wavelet are shown on figure 25. As indicated in the tabulation of coefficients and the plot of line spectra, all even harmonics are equal to zero and harmonics beyond the eleventh would contribute little to the synthesized wavelet.

The Fourier coefficients of wavelet types 1, 2, and 5 only need to be evaluated once and then stored for all subsequent use. For the other wavelets, I suggest building a catalog of their coefficients.

GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELET

DESIRED MAXIMUM ABSOLUTE AMPLITUDE OF WAVELET = $\boxed{100}$

THE FOLLOWING WAVELET TYPES ARE AVAILABLE:

1. Cosine modulated sine, zero phase approximation, 2.5 cycles
2. Damped cos mod. sine, minimum phase approximation, 2 cycles
3. Directly observed--extracted from seismogram
4. Arbitrary -- values entered from keyboard
5. Ricker "far distant" wavelet

NUMBER OF SELECTED WAVELET TYPE = 4
NO. OF VALUES IN WAVELET = 21
NO. OF CYCLES IN WAVELET = 1.5

| INDEX | VALUE |
|---|---|
| 1 | 0 |
| 2 | -1.4 |
| 3 | -5.3 |
| 4 | -12.9 |
| 5 | -25.6 |
| 6 | -30.9 |
| 7 | -16.5 |
| 8 | 22 |
| 9 | 69.6 |
| 10 | 98.7 |
| 11 | 89.3 |
| 12 | 42.5 |
| 13 | -16.3 |
| 14 | -58.8 |
| 15 | -78.5 |
| 16 | -79.3 |
| 17 | -66.6 |
| 18 | -44.6 |
| 19 | -19.5 |
| 20 | -5.3 |
| 21 | 0 |

DO YOU WANT QUICK PLOT OF INPUT WAVELET? (Y/N) $\boxed{Y}$

WAVELET USING ARBITRARY VALUES
NO. OF VALUES=21    NO. OF CYCLES=1.5    MAX. ABS. AMPL=100

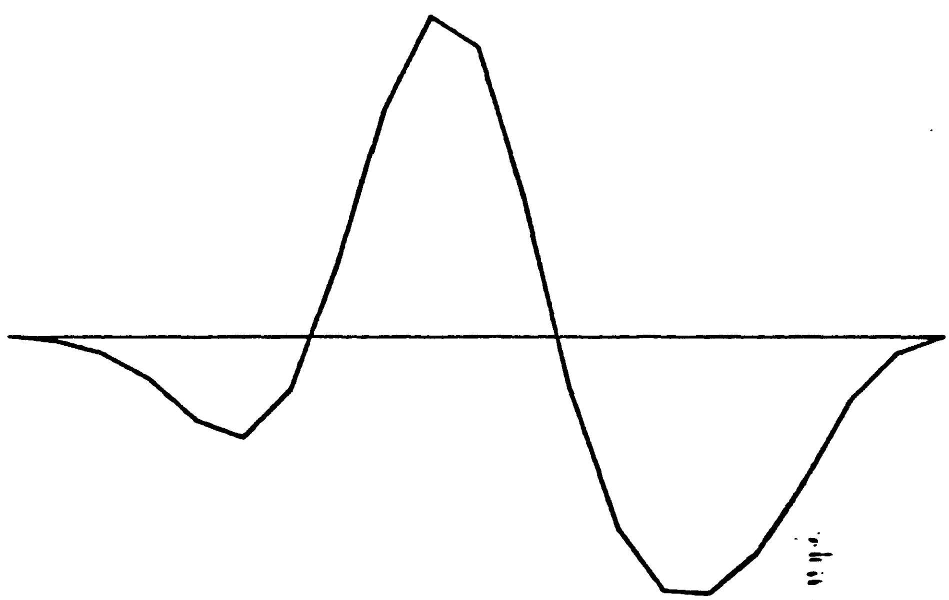
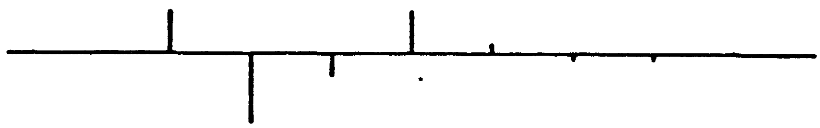


Figure 22. Copy of screen display showing example of entries to produce an arbitrary wavelet.

FOURIER COEFFICIENTS FOR WAVELET USING ARBITRARY VALUES

| HARMONIC | FOURIER COEFFICIENT |
|---|---|
| 1 | 0.291195 |
| 2 | 31.892853 |
| 3 | -52.233730 |
| 4 | -16.005297 |
| 5 | 32.207895 |
| 6 | 7.056252 |
| 7 | -3.972224 |
| 8 | -4.361906 |
| 9 | 1.395121 |
| 10 | -0.405268 |

LINE SPECTRA



DO YOU WANT TO SEE FOURIER SYNTHESIZED WAVELET? (Y/N) $\boxed{Y}$

FOURIER SYNTHESIS OF WAVELET USING ARBITRARY VALUES

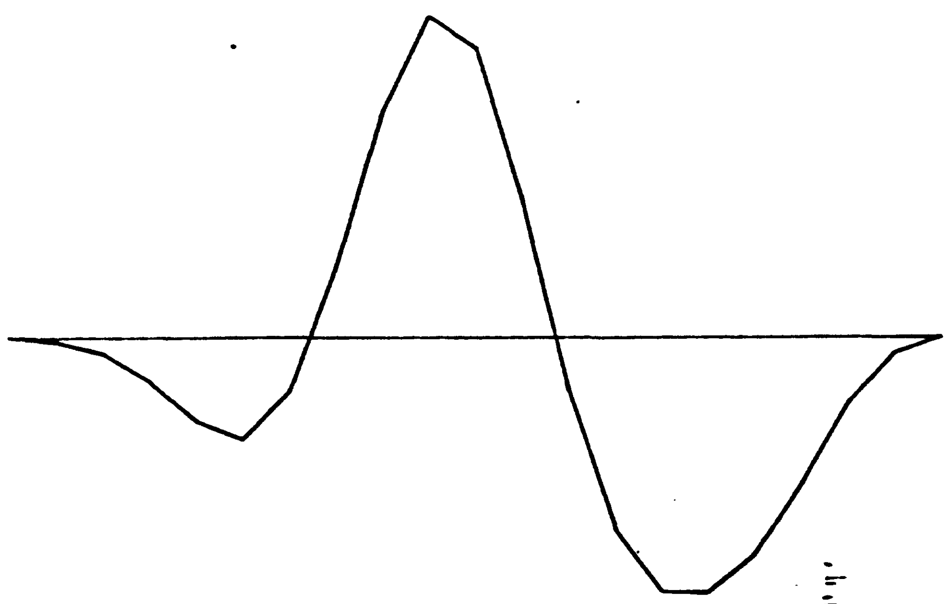


Figure 23. Fourier coefficients and synthesis of fourth wavelet type.

GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELET

DESIRED MAXIMUM ABSOLUTE AMPLITUDE OF WAVELET = $\boxed{100}$

THE FOLLOWING WAVELET TYPES ARE AVAILABLE:
1. Cosine modulated sine, zero phase approximation, 2.5 cycles
2. Damped cos mod. sine, minimum phase approximation, 2 cycles
3. Directly observed--extracted from seismogram
4. Arbitrary -- values entered from keyboard
5. Ricker "far distant" wavelet

NUMBER OF SELECTED WAVELET TYPE = $\boxed{5}$

DO YOU WANT QUICK PLOT OF INPUT WAVELET? (Y/N) $\boxed{Y}$

RICKER "FAR DISTANT" WAVELET
NO. OF VALUES=41     NO. OF CYCLES=1.5     MAX. ABS. AMPL=100

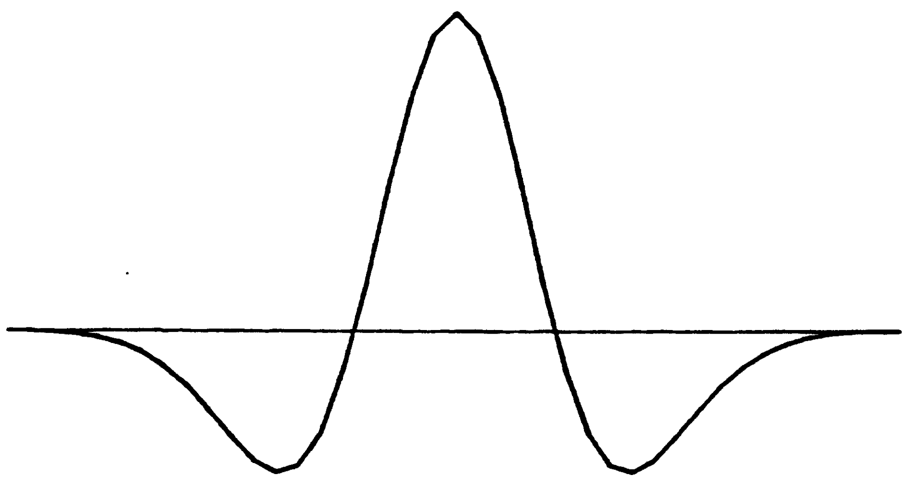


Figure 24. Copy of screen display showing entries to produce a Ricker "far distant" wavelet.

FOURIER COEFFICIENTS FOR RICKER "FAR DISTANT" WAVELET

| HARMONIC | FOURIER COEFFICIENT |
|---|---|
| 1 | 6.624331 |
| 2 | 0.000000 |
| 3 | -36.167040 |
| 4 | 0.000000 |
| 5 | 36.953126 |
| 6 | 0.000000 |
| 7 | -16.166411 |
| 8 | 0.000000 |
| 9 | 3.611321 |
| 10 | 0.000000 |
| 11 | -0.447965 |
| 12 | 0.000000 |
| 13 | 0.026334 |
| 14 | 0.000000 |
| 15 | -0.005505 |
| 16 | 0.000000 |
| 17 | -0.003926 |
| 18 | 0.000000 |
| 19 | -0.003604 |
| 20 | 0.000000 |

LINE SPECTRA

DO YOU WANT TO SEE FOURIER SYNTHESIZED WAVELET? (Y/N) $\boxed{Y}$

FOURIER SYNTHESIS OF RICKER "FAR DISTANT" WAVELET

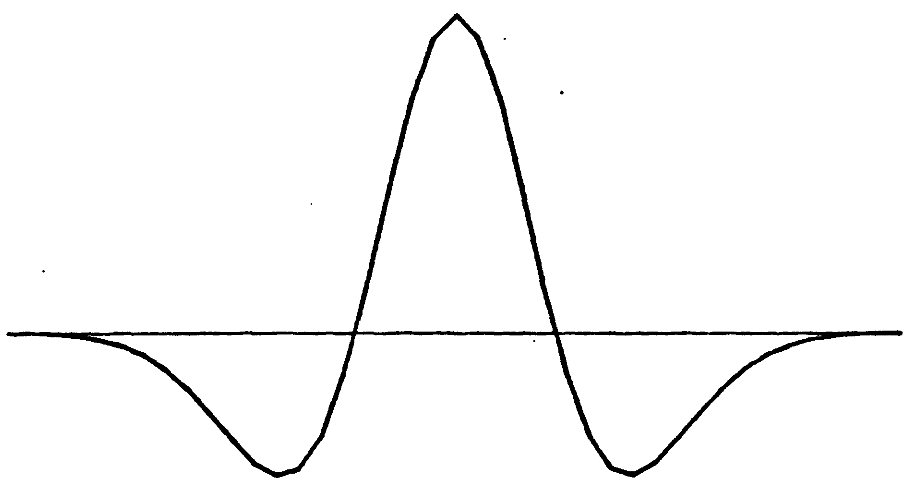


Figure 25. Fourier coefficients and synthesis of fifth wavelet type.

## DISCUSSION OF PROGRAM TO COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

The fourth program begins by asking if you want to use a previously computed synthetic seismogram--an odd way, it might seem, to begin a program to compute a synthetic. However, not too strange if one considers that this program has two main functions: to compute the synthetic and to display the synthetic. A Y response (an example of which will be given later) is entered if one wants to display with a different mode. Let us begin this section of the report by replying to the first question with an N (fig. 26).

You are then instructed to insert the T/D-RS (time/depth-reflectivity series) data tape in the 4924 and to enter the file number of the desired data set. Next you are asked if you want to see the data that have been read from this file, file 41 ( fig. 26).

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) [N]

INSERT T/D-RS DATA TAPE IN 4924    FILE NO. = [41]

DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) [Y]

            DATA READ FROM T/D-RS DATA TAPE

MARSHALL COAL FIELD                    PROB #9              11 NOV 1982
 39 11 22            105 33 44         BOULDER, COLORADO    1502
 21                  REFLECTIVITY SERIES WITHOUT MULTIPLES

REFLECTIVITY SERIES:

 0.02905198776 76  0.0068328598648   0.0047189472503   0.00587635111665
 0.00784602416152  0.00107148498692  0.00170842948788  -7.442478921E-4
 -0.00198030146247 0.00167414351461  -0.00114312611857 6.255135463E-4
 -5.550312 73E-4   4.827555286E-4    9.462825416E-5    9.256988931E-5
 5.639030696E-5    -1.327287476E-6   1.675458362E-4    6.929139822E-5
 0

REFLECTION TIME TO BASE OF LAYER:

 20                55                63                83
 87.4444444444     108.586176728     128.53368329      131.880139983
 141.486439195     142.59536308      153.343394576     156.670166229
 158.664916885     163.180612423     164.097987752     165.810061242
 165.843394576     167.378827647     176.609596877     182.064142332
 198.397475665
```

Figure 26. Copy of screen display showing first set of entries for the fourth program. Here data read from a T/D-RS data tape are listed.

Figure 27 shows a screen copy of the first page of the fourth program when a tabulation of data read from the T/D-RS data tape are not tabulated. After you reply as to whether you want to see the reflectivity series, you are instructed to insert the wavelet data tape (WDT). You are then asked if you want to synthesize a wavelet. Again you are offered a choice. If you answer with an N, as is done on figure 27, you are required to enter the number of the file containing an established wavelet, a much faster procedure than synthesizing a wavelet from its

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM
DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) [N]
INSERT T/D-RS DATA TAPE IN 4924    FILE NO. = [41]
DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) [N]
INSERT WAVELET DATA TAPE (WDT) IN 4924
DO YOU WANT TO SYNTHESIZE WAVELET? (Y/N) [N]
YOU HAVE ELECTED TO USE ESTABLISHED WAVELET    FILE NO. = [61]
DO YOU WANT TO SEE PLOT OF WAVELET? (Y/N) [Y]

20 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.5
WAVELET CONTAINS 41 DATA POINTS
AMPLITUDE OF WAVELET RANGES FROM -60.87 TO 100.34
```

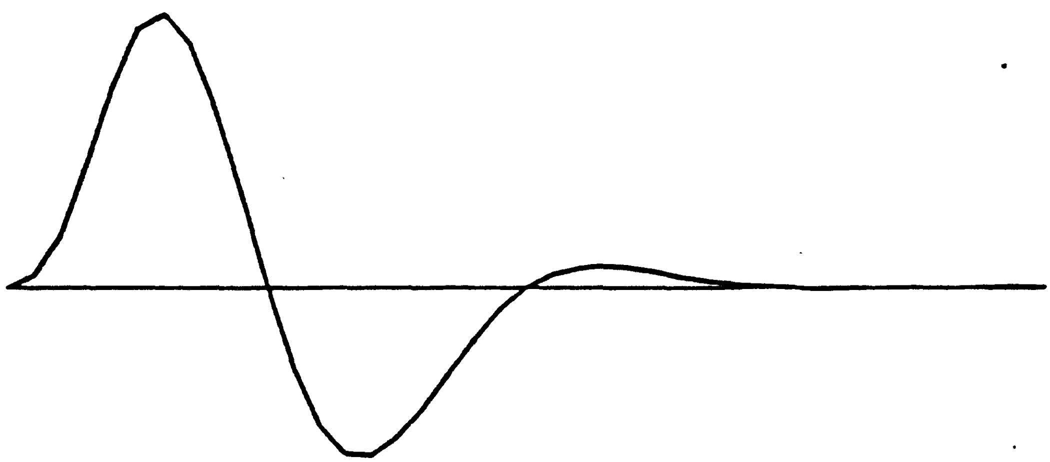


Figure 27. Screen copy of page 1 of the fourth program after one has decided to use an established wavelet, a plot of which is shown.

Fourier coefficients. If you reply with a Y, then the procedure (to be shown later) to synthesize a wavelet is initiated. A description of the wavelet to be used in the construction of the synthetic seismogram is printed above the plot of the selected established wavelet.

After the plot (optional) is made you are asked to enter the start and end times of the synthetic, in this example (fig. 28), 0 and 200 ms respectively. Next you are asked if you want to store the just-computed fixed-gain synthetic seismogram on a synthetic seismogram data tape (SSDT). In this example the reply was an N. Data of this kind are those that would be entered if the first question (fig. 26) of program four had been answered with a Y.

Program four offers three display options, as shown on figure 28. Another method of display, one that uses an AGC (adaptive gain control) procedure, is available; however, because of lack of memory in the computer for which the programs of this report were written, its use calls for a separate program (program five) to be discussed later.

```
START TIME OF SYNTHETIC =[0]
  END TIME OF SYNTHETIC =[200]

DO YOU WANT TO STORE FIXED GAIN SYN SEIS ON SSDT? (Y/N) [N]

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN =[1]

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.76831103218 TO 2.91507204745
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT =[-2]
MAXIMUM AMPLITUDE ON PLOT =[3]
```

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
20 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 61
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM -2.00 TO 3.00 BETWEEN ORDINAL TICKMARKS

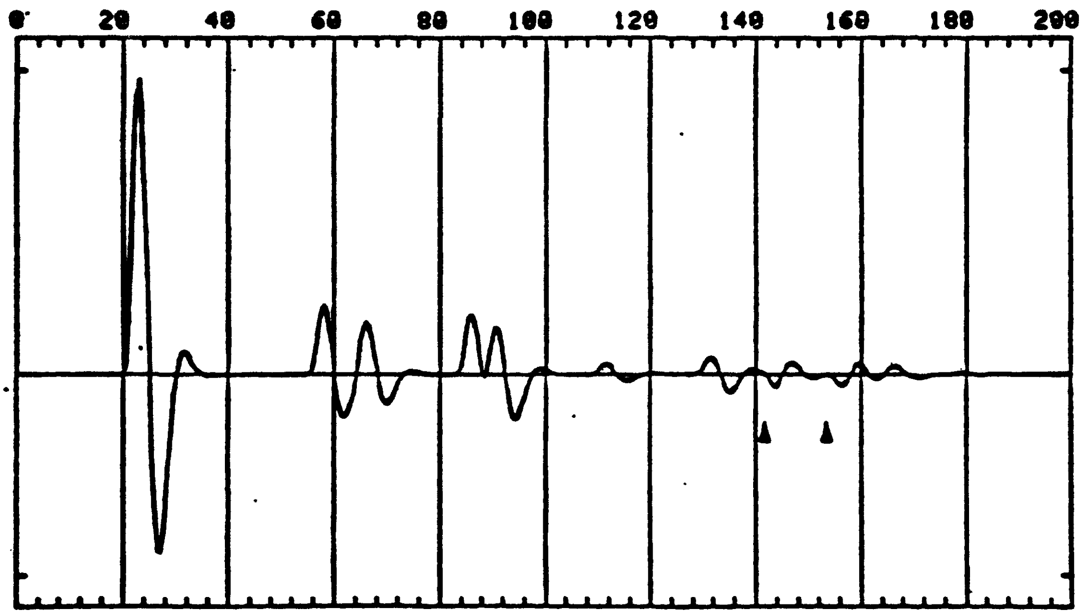



Figure 28. Synthetic seismogram produced upon entry of information as shown on figure 27 and on the top half of this figure.

The display of figure 28 uses a fixed gain applied over the complete record. Since the seismograph used in the coal seismic system has neither an AGC (automatic gain control) nor PGC (programed gain control) capability, display of the synthetic seismogram with fixed gain represents the idealized output from the seismograph.

After the display mode is selected, the amplitude range of the synthetic is computed and printed so as to allow selection of the minimum and maximum amplitudes to be displayed on the plot. On the example of figure 28, these amplitudes are -2 and 3 respectively. Any event whose amplitude exceeds the entered amplitude limits will be truncated at the ordinal tickmark positions on the plot.

Drawn on each of the synthetic seismograms of this report are filled arrowheads pointing to the reflection time (141.6 ms) from the top of the thin coal at a depth of 75 m and to the reflection time (153.4 ms) from the top of parted seam at a depth of 90 m. These reference marks were drawn by the author and are not part of the computer program.

For the first example of a synthetic seismogram (fig. 28), the wavelet has a sharp initial rise time, a severely damped second cycle, and a relatively high apparent frequency (100 Hz)--three wavelet properties conducive to resolution of reflection horizons. Yet, even with this optimum-resolution wavelet, location of the tops of the coal seams from examination of the arrivals on a single-trace seismogram would be a challenging task even for the experienced interpreter. Feasibility studies are one of the main functions of synthetic seismograms.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) N

INSERT T/D-RS DATA TAPE IN 4924    FILE NO. = 41

DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) N

INSERT WAVELET DATA TAPE (WDT) IN 4924

DO YOU WANT TO SYNTHESIZE WAVELET? (Y/N) N

YOU HAVE ELECTED TO USE ESTABLISHED WAVELET    FILE NO. = 37

DO YOU WANT TO SEE PLOT OF WAVELET? (Y/N) Y
```

```
20 MSEC WAVELET USING A COSINE-MODULATED SINE WAVE WITH S.I.=0.5
WAVELET CONTAINS 41 DATA POINTS
AMPLITUDE OF WAVELET RANGES FROM -67.17 TO 100.00
```

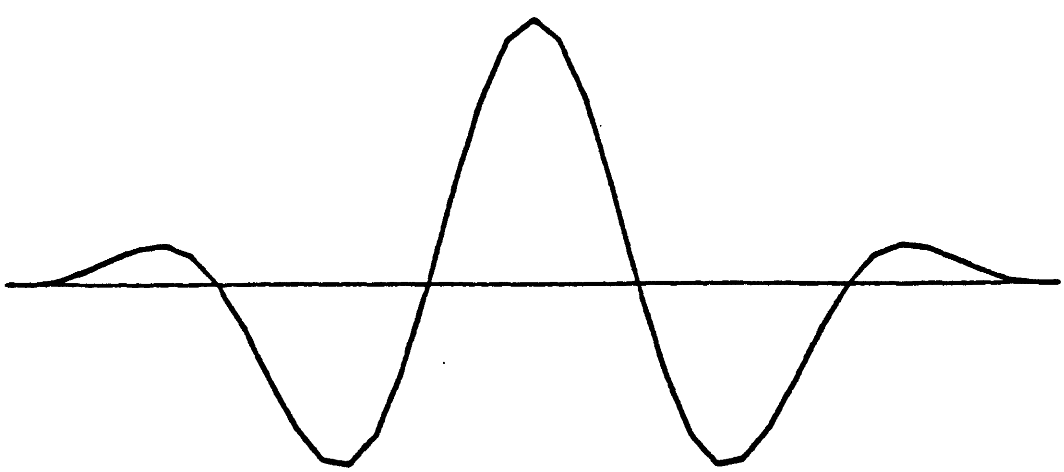


Figure 29. Beginning pages of program four showing entries to use an established wavelet and a plot of that wavelet.

Next, let us examine the synthetic seismogram produced if we keep the same reflectivity series, but introduce a different wavelet. Here we have elected to use the zero-phase-approximation wavelet (fig. 29).

Entries are as before, the only exception being that the estab lished wavelet is taken from file 37. Although this wavelet and the preceding one both have a total duration of 20 ms, the symmetrical wavelet has 2.5 cycles and thus its apparent frequency is 125 Hz. Since it is a higher frequency wavelet, one might expect it to have greater resolving power. However, a glance at figure 30 shows this expectation is

```
START TIME OF SYNTHETIC =[0]
  END TIME OF SYNTHETIC =[200]

DO YOU WANT TO STORE FIXED GAIN SYN SEIS ON SSDT? (Y/N)[N]

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN =[1]

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.95129400971 TO 2.90519866593
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTNETIC: 481

MINIMUM AMPLITUDE ON PLOT =[-2]
MAXIMUM AMPLITUDE ON PLOT =[3]


SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
   20 MSEC WAVELET USING A COSINE-MODULATED SINE WAVE WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 37
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM  -2.00 TO   3.00 BETWEEN ORDINAL TICKMARKS
```

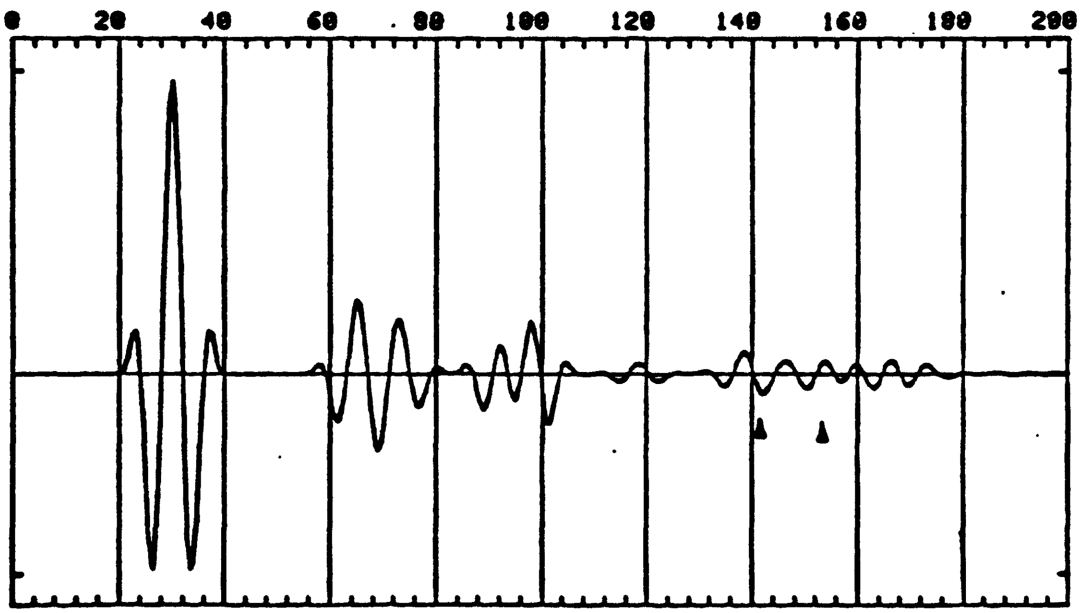



Figure 30. Synthetic seismogram using a zero-phase-approximation wavelet applied to the same reflectivity series as used in figure 28.

unfounded. This synthetic also demonstrates the difficulty of extracting a representative wavelet shape from the seismic record. It also should be remembered in viewing the synthetic seismograms of this report that no waveform distortion, other than that produced by the reflectivity series itself, has been introduced.

After the synthetic seismogram has been plotted, you are asked if you want to replot with a different scale and if you want to store the values of the synthetic on a data tape. Responses to these replies have been shown in earlier programs of this report--to save space, these procedures are not displayed again.

The next three sets of synthetic seismograms are presented to illustrate how the program is used to stretch and compress a wavelet of given form and to show the synthetic seismograms produced with a wavelet of the same shape but of different duration.

As shown on figure 31, once you reply that you want to synthesize a wavelet from its Fourier coefficients, you are asked to enter the number of the file in which these coefficients are stored. The type of wavelet and the number of coefficients are printed following which prompts are given for entry of length of the wavelet (in ms) and sample interval of the wavelet. The sample interval you enter will be the sample interval (S.I.) used in the construction of the synthetic seismogram.

For this example (fig. 31) a 40-ms wavelet sampled at 0.5 ms was selected. Since this wavelet has almost twice the number of data points as the same shape wavelet shown on figure 27, its plot is smoother. Also, the minimum amplitude (because of a filled-in point) is slightly different. The apparent period of the expanded wavelet is 20 ms, an apparent frequency of 50 Hz. In those coal-seismic field studies for which a hammer source is used on the surface, a frequency of 50 Hz is more often seen at a record time of 150 ms than the more desirable but not readily realizable 100 Hz shown on figure 27.

The first nine lines of figure 32 show the procedure for storing the synthesized wavelet. Before storage, you are asked if the intended file is of sufficient length. If not, you are instructed as to the procedure to be followed. After data are stored, a read-after-write operation is performed. The synthetic seismogram produced is displayed on the lower half of figure 32.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) N

INSERT T/D-RS DATA TAPE IN 4924    FILE NO. = 41

DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) N

INSERT WAVELET DATA TAPE (WDT) IN 4924

DO YOU WANT TO SYNTHESIZE WAVELET? (Y/N) Y
 NO. OF FILE CONTAINING FOURIER COEFF. = 44
    TYPE OF WAVELET = WAVELET USING A DAMPED COS-MODULATED SINE
NO. OF COEFFICIENTS = 20
  LENGTH OF WAVELET = 40
WAVELET SAMPLE INT. = 0.5
  POINTS IN WAVELET = 81

DO YOU WANT TO SEE PLOT OF WAVELET? (Y/N) Y


40 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.5
WAVELET CONTAINS 81 DATA POINTS
AMPLITUDE OF WAVELET RANGES FROM -61.34 TO 100.34
```

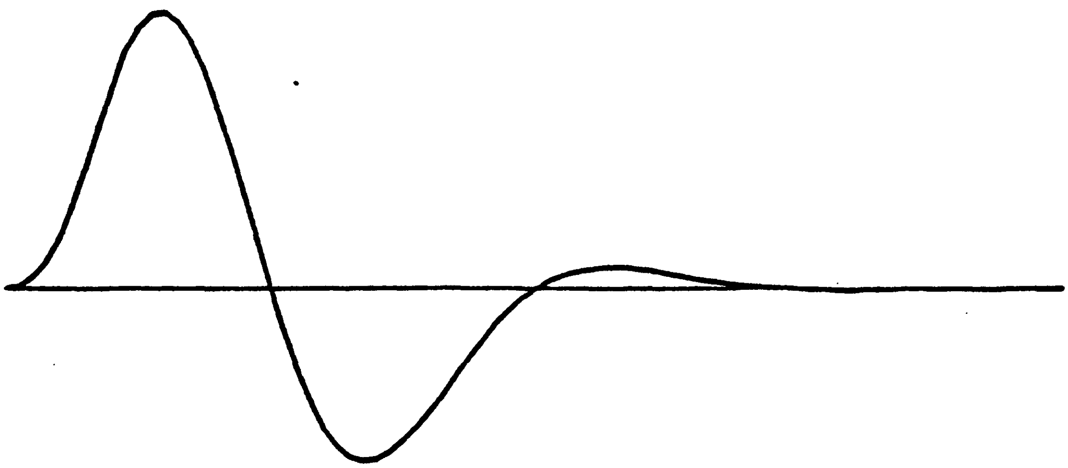


Figure 31. Beginning pages of program four showing procedure to synthesize a 40-ms, minimum-phase wavelet from its Fourier coefficients.

```
DO YOU WANT TO STORE WAVELET ON WDT? (Y/N) Y
INSERT WDT IN 4924     FILE NO. = 63
LENGTH OF FILE REQUIRED = 1024
IS FILE LENGTH SUFFICIENT? (Y/N) N
INSERT WDT IN 4051
ARE YOU READY TO PROCEED? (Y/N) Y
RETURN WDT TO 4924
ARE YOU READY TO PROCEED? (Y/N) Y
DATA ARE STORED AND RETRIEVABLE FROM FILE 63
START TIME OF SYNTHETIC = 0
  END TIME OF SYNTHETIC = 200

DO YOU WANT TO STORE FIXED GAIN SYN SEIS ON SSDT? (Y/N) N

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = 1

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.78799208495 TO 2.91507204745
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT = -2
MAXIMUM AMPLITUDE ON PLOT = 3
```

```
SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
   40 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.5
REFL SERIES FROM FILE 41 AND WAVELET'S FOURIER COMPONENTS FROM FILE 44
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM  -2.00 TO   3.00 BETWEEN ORDINAL TICKMARKS
```

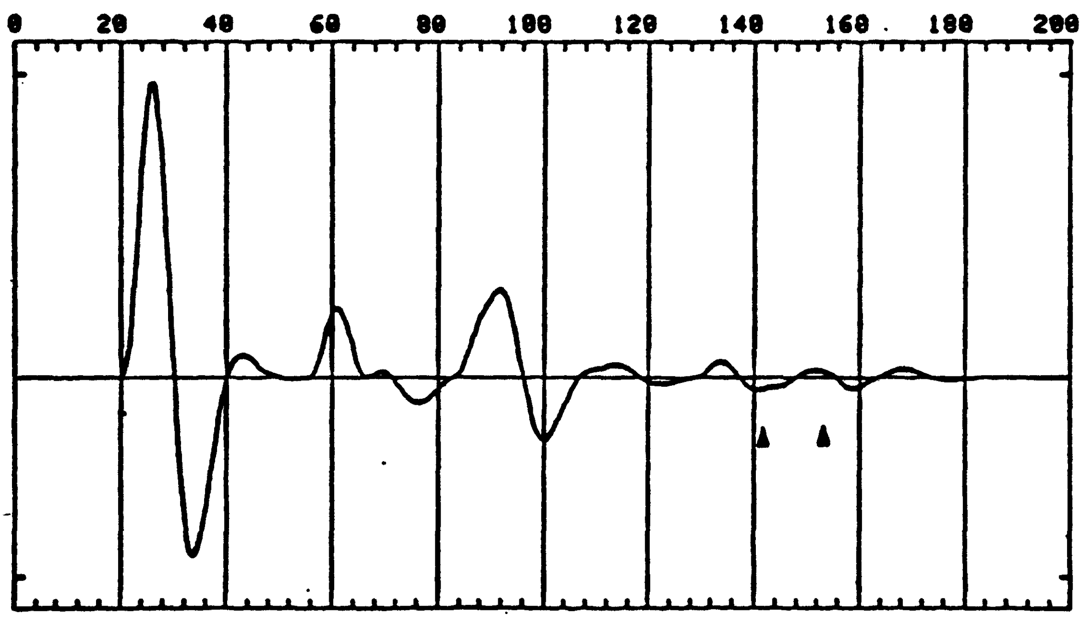



Figure 32. Synthetic seismogram produced using a 40-ms, minimum-phase-approximation wavelet.

Let us now compress the wavelet and thereby produce one of higher frequency. Figure 33 shows the required entries to create a minimum-phase-approximation wavelet whose apparent frequency is 200 Hz. A plot of this wavelet is shown on the bottom half of the figure. Because fewer points are used than in figures 18, 27 and 31, the wavelet of figure 33 looks more jagged, and one might question whether this wavelet has a sufficient number of data points to faithfully represent its former shape. That there is little cause for concern can be shown be looking at the listing of Fourier coefficents of this wave shape as displayed on figure 19. Note that for a sample interval of 0.5 ms (a frequency of 1000 Hz at the 20th hoarmonic) that the Fourier coefficient is only about 0.3 percent of the maximum Fourier coefficent at 200 Hz.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) [N]

INSERT T/D-RS DATA TAPE IN 4924    FILE NO. = [41]

DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) [N]

INSERT WAVELET DATA TAPE (WDT) IN 4924

DO YOU WANT TO SYNTHESIZE WAVELET? (Y/N) [Y]
 NO. OF FILE CONTAINING FOURIER COEFF. = [44]
    TYPE OF WAVELET = WAVELET USING A DAMPED COS-MODULATED SINE
NO. OF COEFFICIENTS = 20
  LENGTH OF WAVELET = [10]
WAVELET SAMPLE INT. = [0.5]
  POINTS IN WAVELET = 21

DO YOU WANT TO SEE PLOT OF WAVELET? (Y/N) [Y]
```

```
10 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.5
WAVELET CONTAINS 21 DATA POINTS
AMPLITUDE OF WAVELET RANGES FROM -60.87 TO 100.34
```

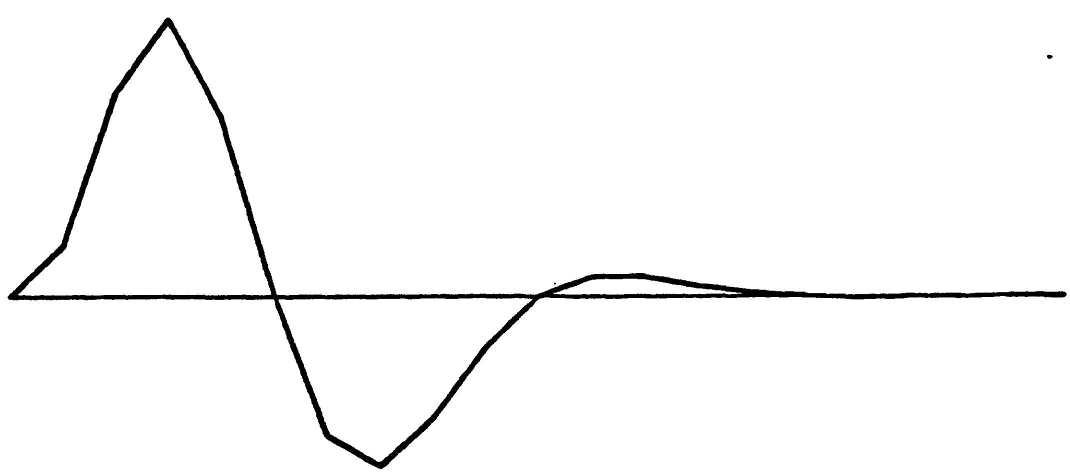


Figure 33. Beginning pages of program four showing procedure to synthesize a 10-ms, minimum-phase wavelet from its Fourier coefficients.

Figure 34 shows the synthetic seismogram using the 10-ms minimum-phase-approximation wavelet applied to the same reflectivity series as used in all previous examples. Comparison of the synthetic seismograms

```
DO YOU WANT TO STORE WAVELET ON WDT? (Y/N) Y
INSERT WDT IN 4924     FILE NO. = 64
LENGTH OF FILE REQUIRED = 512
IS FILE LENGTH SUFFICIENT? (Y/N) N
INSERT WDT IN 4051
ARE YOU READY TO PROCEED? (Y/N) Y
RETURN WDT TO 4924
ARE YOU READY TO PROCEED? (Y/N) Y
DATA ARE STORED AND RETRIEVABLE FROM FILE 64
START TIME OF SYNTHETIC = 0
  END TIME OF SYNTHETIC = 200

DO YOU WANT TO STORE FIXED GAIN SYN SEIS ON SSDT? (Y/N) N

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = 1

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.76831103218 TO 2.91507204745
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT = -2
MAXIMUM AMPLITUDE ON PLOT = 3
```

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
10 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.5
REFL SERIES FROM FILE 41 AND WAVELET'S FOURIER COMPONENTS FROM FILE 44
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM -2.00 TO 3.00 BETWEEN ORDINAL TICKMARKS

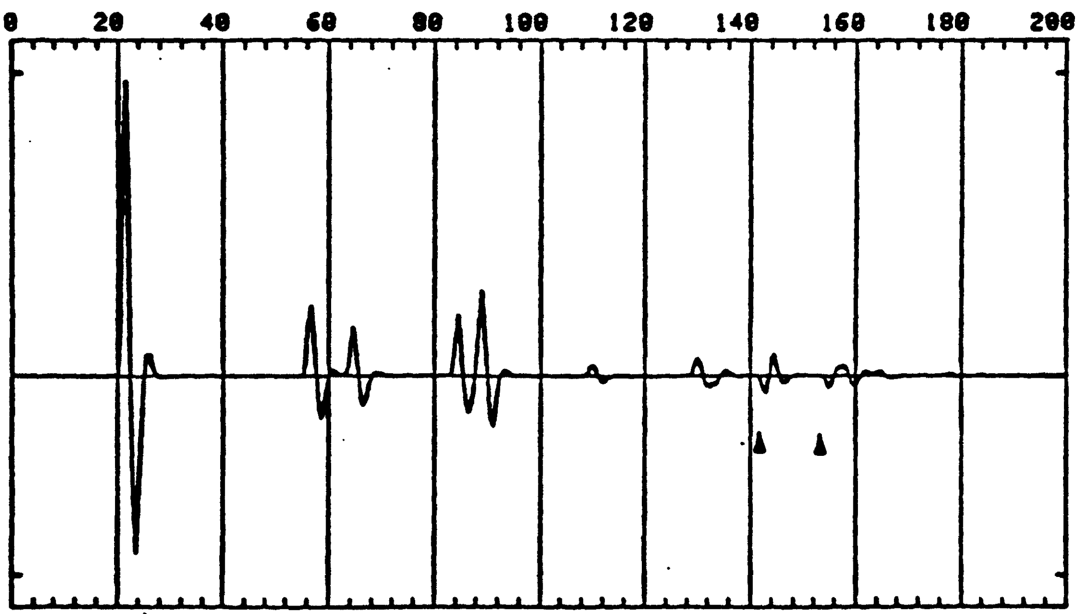



Figure 34. Synthetic seismogram produced using a 10-ms, minimum-phase-approximation wavelet.

of figures 32, 28, and 34 with apparent periods of 20, 10, and 5 ms (apparent frequencies of 50, 100, and 200 Hz) respectively clearly illustrates the need for higher frequency seismic signatures to identify reflections from the tops of the two coal seams.

One consideration of importance in planning field studies is the selection of the sample interval to be used. Let us see how the records might look if we were to decrease the sample interval from 0.5 to 0.25 ms. Again we will use a 10-ms wavelet, but this time use a sample interval of 0.25 in its synthesis. Figure 35 shows the procedure if the previously synthesized wavelet had been stored in file 38. The plot of the wavelet with 41 data points on figure 35 is identical to the plot displayed on figure 27. However, now the wavelet duration is 10 ms instead of 20 ms.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM
DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) [N]
INSERT T/D-RS DATA TAPE IN 4924    FILE NO. = [41]
DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) [N]
INSERT WAVELET DATA TAPE (WDT) IN 4924
DO YOU WANT TO SYNTHESIZE WAVELET? (Y/N) [N]
YOU HAVE ELECTED TO USE ESTABLISHED WAVELET    FILE NO. = [38]
DO YOU WANT TO SEE PLOT OF WAVELET? (Y/N) [Y]

10 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.25
WAVELET CONTAINS 41 DATA POINTS
AMPLITUDE OF WAVELET RANGES FROM -60.87 TO 100.34
```

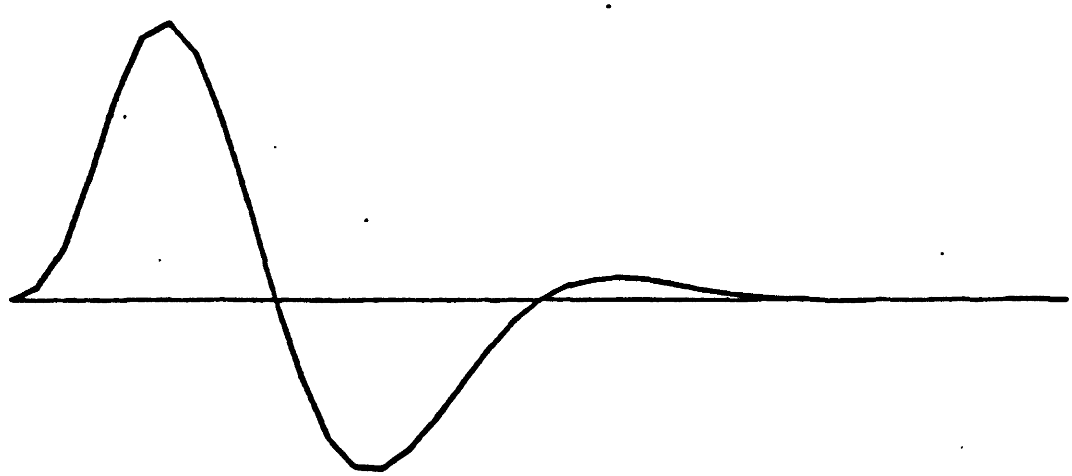


Figure 35. Beginning pages of program four showing entries made to use an established 10-ms wavelet of 0.25 ms sample interval.

The synthetic seismogram with the 10-ms wavelet and a sample interval of 0.25 ms is shown on figure 36. Close examination of the fixed-gain displays of figures 34 and 36 reveals at a reflection time of about 158 ms a slight difference in waveform following the trough at 155 ms. Could it be that the slight dip and flattening of the waveform across the deeper coal seam is an indication of the parting that we built into the model? And could we see this nuance in the presence of noise, in particular, wind-generated noise which can often be in the same range of frequencies? Is it worth the cost in changing from a half-millisecond to a quarter-millisecond seismograph to see this event? These are questions that the synthetic seismogram may help us answer.

```
START TIME OF SYNTHETIC = [0]
  END TIME OF SYNTHETIC = [200]

DO YOU WANT TO STORE FIXED GAIN SYN SEIS ON SSDT? <Y/N> [N]

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = [1]

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.76830950798 TO 2.91507121614
SAMPLE INTERVAL FOR SYNTHETIC: 0.25 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 801

MINIMUM AMPLITUDE ON PLOT = [-2]
MAXIMUM AMPLITUDE ON PLOT = [3]
```

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
10 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.25
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 30
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM -2.00 TO 3.00 BETWEEN ORDINAL TICKMARKS

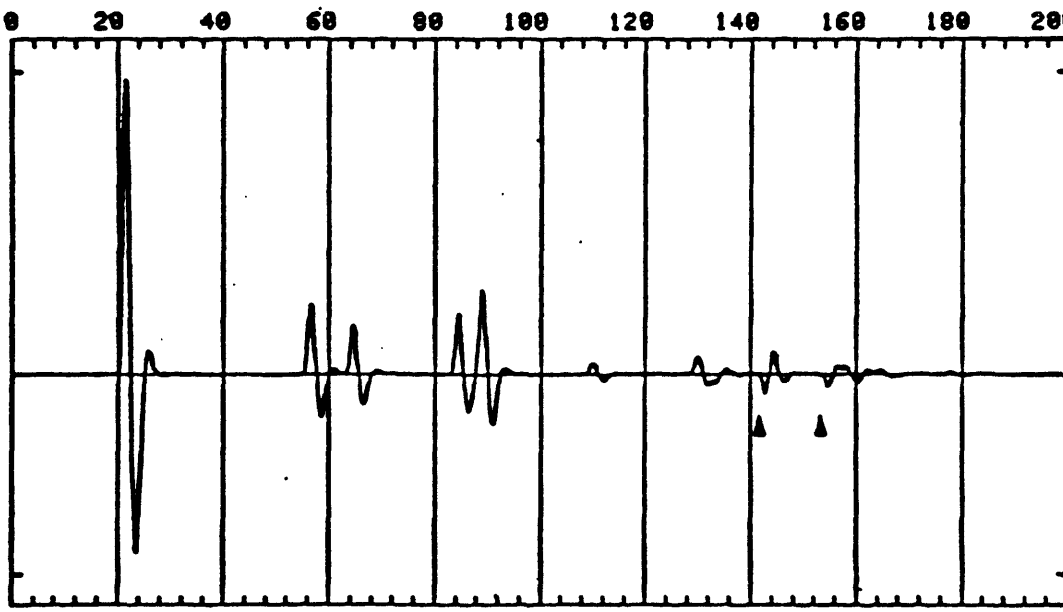



Figure 36. Synthetic seismogram produced using a 10-ms, 0.25-ms sample interval, minimum-phase-approximation wavelet.

After the synthetic seismogram has been displayed, viewed, and the screen cleared, you are asked if you want to replot with a different scale. To better see the waveforms from deeper in the section, let us replot with the minimum and maximum amplitudes ranging from -0.8 to 0.8. In doing so (fig. 37), the early arrivals near 20 ms are truncated. Methods to keep all excursions within bounds will be illustrated later in this report. With an increased plot gain applied, the reflections from the tops of the coal seams and the character (relative amplitude) of the waveforms near 158 ms are easier to distinguish.

```
DO YOU WANT TO REPLOT WITH DIFFERENT SCALE? (Y/N) Y

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.76830950708 TO 2.91507121614
SAMPLE INTERVAL FOR SYNTHETIC: 0.25 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 801

MINIMUM AMPLITUDE ON PLOT = -0.8
MAXIMUM AMPLITUDE ON PLOT = 0.8
```

```
SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
   10 MSEC WAVELET USING A DAMPED COS-MODULATED SINE WITH S.I.=0.25
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 38
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM  -0.80 TO   0.80 BETWEEN ORDINAL TICKMARKS
```

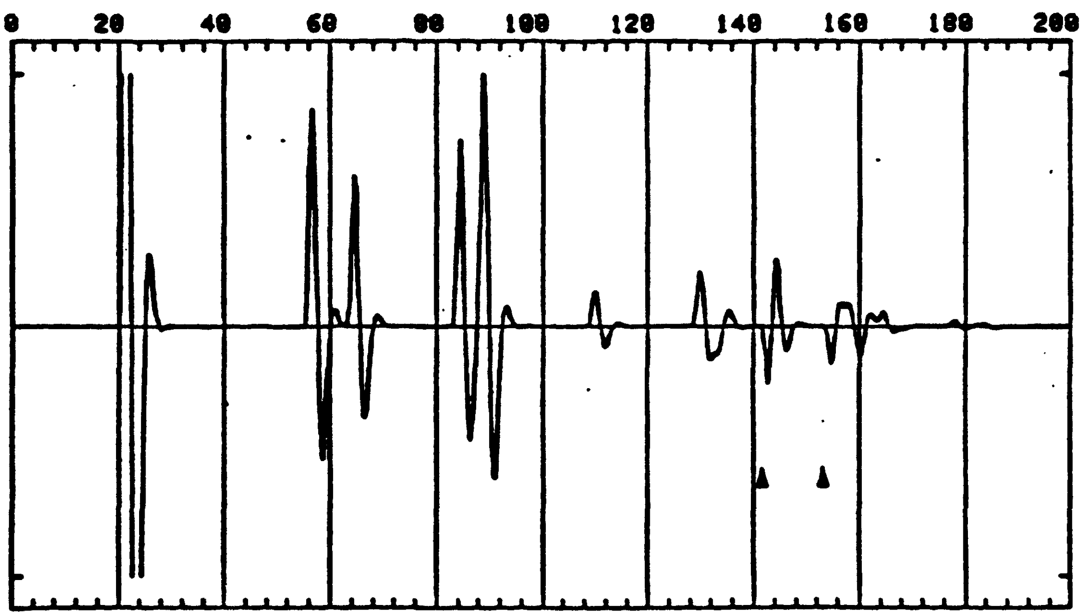
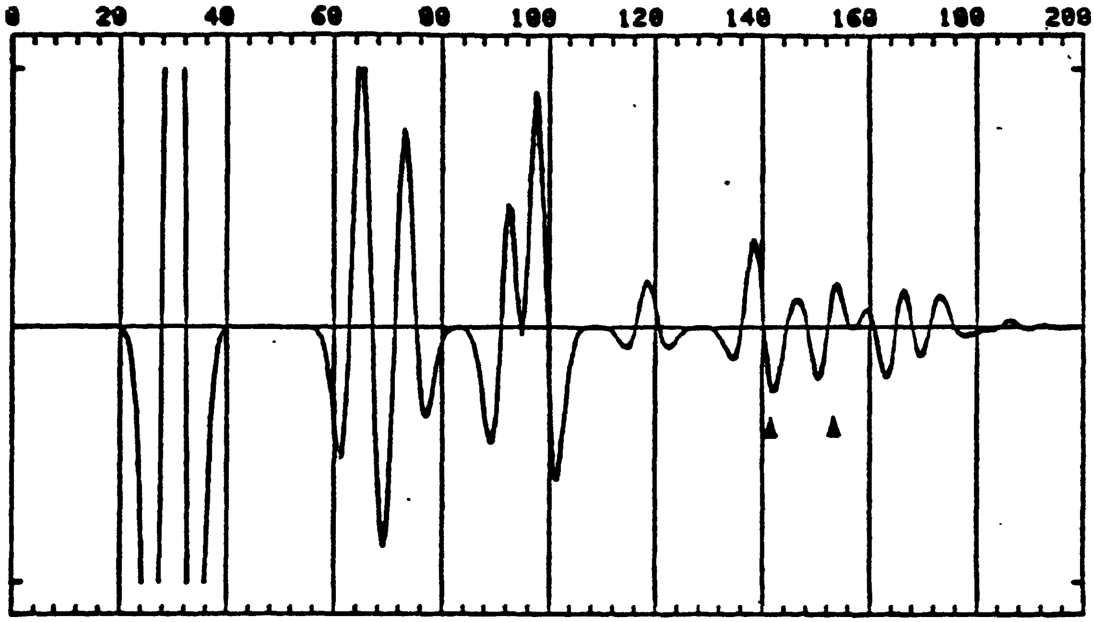



Figure 37. Synthetic seismogram of figure 36 replotted with increased amplitudes to better see the coal-bed reflections.

Let us now compare synthetic seismograms without and with two-bounce multiple reflections using the reflectivity series developed earlier in this report, a minimum and maximum amplitude on the plots (fig. 38) ranging from -0.6 to 0.6, and a zero-phase-approximation wavelet. Multiple reflections from the air/surface interface are suppressed. As one would expect upon comparison of the reflectivity series without and with multiples, the synthetic seismograms look similar. The

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
20 MSEC RICKER "FAR DISTANT" WAVELET WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 40
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM -0.60 TO 0.60 BETWEEN ORDINAL TICKMARKS




SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES INCLUDES 2-BOUNCE MULTIPLES
20 MSEC RICKER "FAR DISTANT" WAVELET WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 42 AND WAVELET'S VALUES FROM FILE 40
AMPLITUDE MODE: FIXED GAIN OVER ENTIRE RECORD
PLOT AMPLITUDES RANGE FROM -0.60 TO 0.60 BETWEEN ORDINAL TICKMARKS

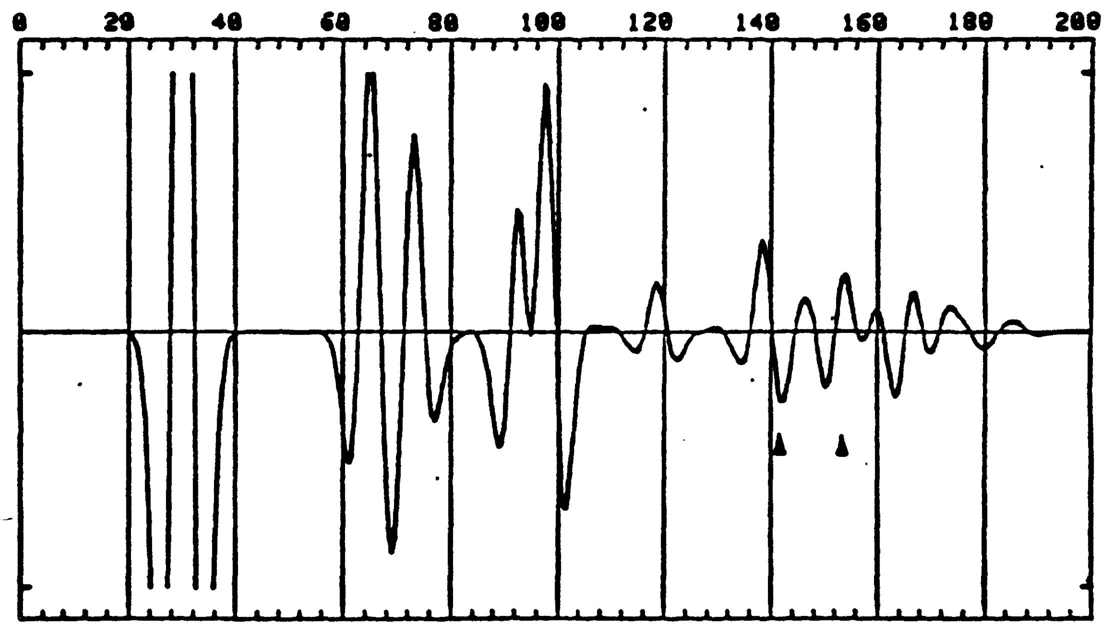



Figure 38. Comparison of synthetic seismograms developed using a wavelet of same shape and amplitude but with reflectivity series without (above) and with (below) two-bounce multiple reflections.

main difference between the two synthetics is an extension of the tails of waveforms and an increase in the amplitude of some later arrivals.

In all previous displays of synthetic seismograms in this report, a fixed gain was applied over the entire record. However, when later parts of the record were plotted at increased gain, one did so at the expense of truncating some early events. Figure 39 shows a synthetic

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) Y
INSERT SYN SEIS DATA TAPE IN 4924     FILE NO. = 49

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = 2

NUMBER OF SEGMENTS = 2
SEGMENT    START TIME   END TIME    START GAIN   END GAIN
   1           0           50           1           1
   2          50          200          10          10

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -5.13845393189 TO 6.73247575664
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT = -6
MAXIMUM AMPLITUDE ON PLOT = 9
```

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
20 MSEC RICKER "FAR DISTANT" WAVELET WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 40
AMPLITUDE MODE: SEGMENTED GAIN IN 2 SEGMENTS
PLOT AMPLITUDES RANGE FROM -6.00 TO 9.00 BETWEEN ORDINAL TICKMARKS

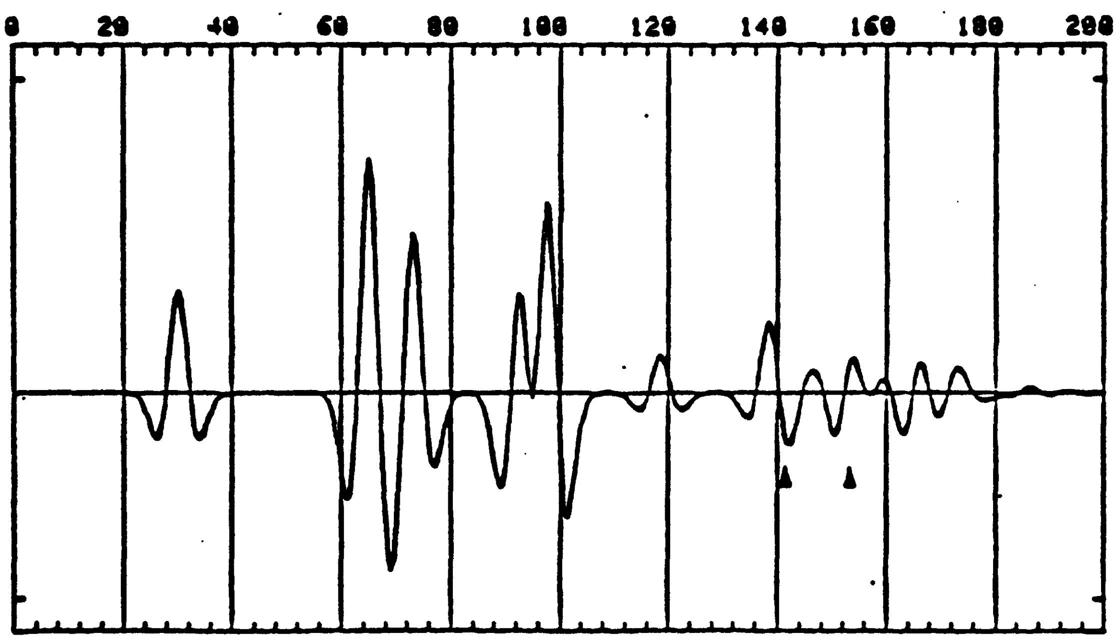



Figure 39. Synthetic seismogram displayed by using different gains in two segments, as indicated by the boxed entries shown above.

seismogram for which a constant plot-gain function is applied within record-time segments of selected length. In this example, data were read from file 49 of a synthetic seismogram data tape (SSDT)--the same data that were used in the preparation of the upper record on figure 38.

After the data are read, you are requested to enter the number of the display option that you have chosen (option 2), and then you are asked to supply the number of segments (2 in this example). Next you are prompted to enter the start time, end time, start gain, and end gain for each segment. If start and end gains are equal, then a constant gain is applied to all values within the specified segment.

In the example shown on figure 39, the segment boundary was selected at a low-amplitude time on the record (50 ms), and the plot gain was made to be ten times greater in the second segment than in the first segment. The ten-fold jump in plot gain if not taken at a quiet time on the record would produce a marked change in the slope of the arrival at the segment boundary.

Option 2 also can be used to produce a linear gain from the beginning to the end of the record by using one segment and specifying the start and end gains. For example, if the start gain was equal to zero, and the end gain was equal to ten, then the record would be displayed with a gain of five at its middle time.

Figure 40 shows the synthetic seismogram produced by application of two linear gain functions with start and end times and gains as shown by the boxed quantities. This plot exhibits a more balanced appearance for the arrivals beyond 50 ms; however, as it is with any non-fixed-gain display, distortion in the waveforms occurs. Note that the second trough at 34 ms is shown to be deeper than the first trough at 26 ms--a result of increased plot gain as a function of record time.

Selection of display option 3 allows a programed gain control (PGC) function to be applied to the synthetic seismogram. This plot-gain procedure uses an exponential function whose start and half-gain times are specified by the user. Half-gain time is the time on the seismogram at which the gain is 50 percent of the ultimate gain of unity. Final gain is the gain at the end of the record. In the example shown on figure 41, start time was at the beginning of the record (0 ms), half-gain time was at a record time of 100 ms, and the gain at the end of the record (200 ms) was 0.75. The plot of the PGC function shows the form of the gain function over the complete time of the record. Since the function is exponential, the rate of increasing gain will be greater during the earlier part of the record; therefore, one would expect waveform distortion to be more pronounced for the early arrivals. The synthetic seismogram on figure 42 was made using the PGC function of figure 41. As anticipated, the early arrival beginning at 20 ms shows severe distortion--note the greater amplitude of the second trough relative to the first trough resulting from application of the PGC function.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) Y
INSERT SYN SEIS DATA TAPE IN 4924     FILE NO. = 49

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = 2

NUMBER OF SEGMENTS = 2
SEGMENT    START TIME   END TIME    START GAIN   END GAIN
   1           0           110          1            2
   2          110          200          2            10

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -1.69171918371 TO 3.69642355577
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT = -2
MAXIMUM AMPLITUDE ON PLOT = 4
```

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
20 MSEC RICKER "FAR DISTANT" WAVELET WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 40
AMPLITUDE MODE: SEGMENTED GAIN IN 2 SEGMENTS
PLOT AMPLITUDES RANGE FROM -2.00 TO 4.00 BETWEEN ORDINAL TICKMARKS

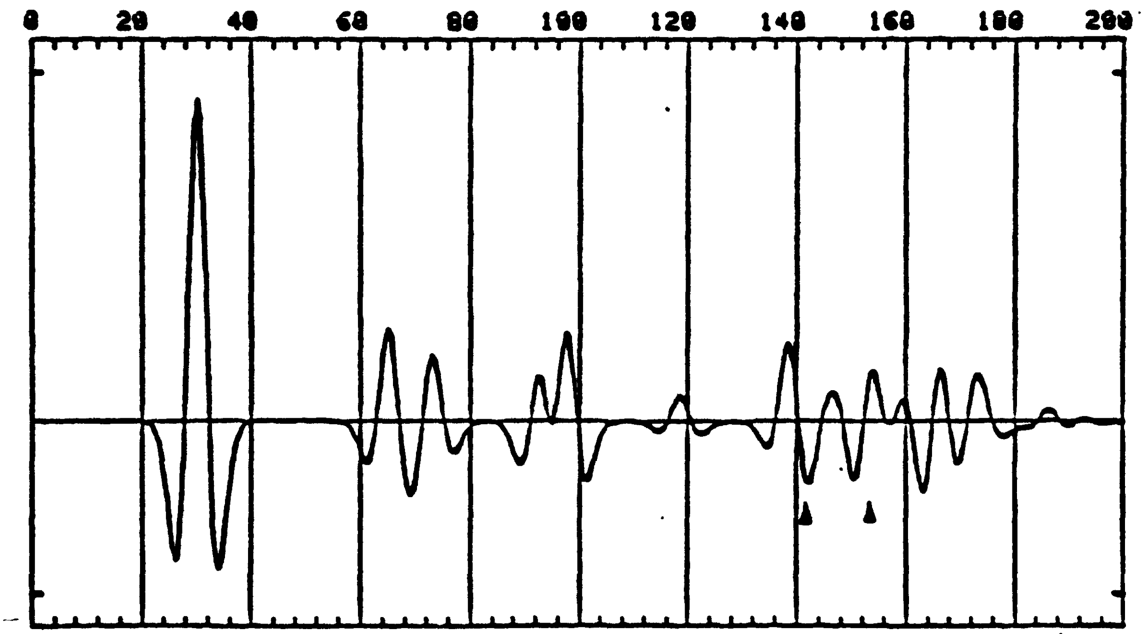



Figure 40. Synthetic seismogram produced after application of linear-gain functions in two segments using values entered on figure 39.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) Y
INSERT SYN SEIS DATA TAPE IN.4924     FILE NO. = 49

THREE DISPLAY OPTIONS ARE AVAILABLE:
   1. FIXED GAIN OVER ENTIRE RECORD,
   2. SELECTED GAIN WITHIN SEGMENTS, AND
   3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = 3

    START TIME = 0

HALF GAIN TIME = 100

    FINAL GAIN = 8.75

DO YOU WANT TO PLOT PGC GAIN FUNCTION? (Y/N) Y

  PGC FUNCTION FROM T=0 TO 200 WITH FINAL GAIN = 8.75
PROGRAMED GAIN CONTROL (PGC) WITH HALF GAIN AT T = 100
```

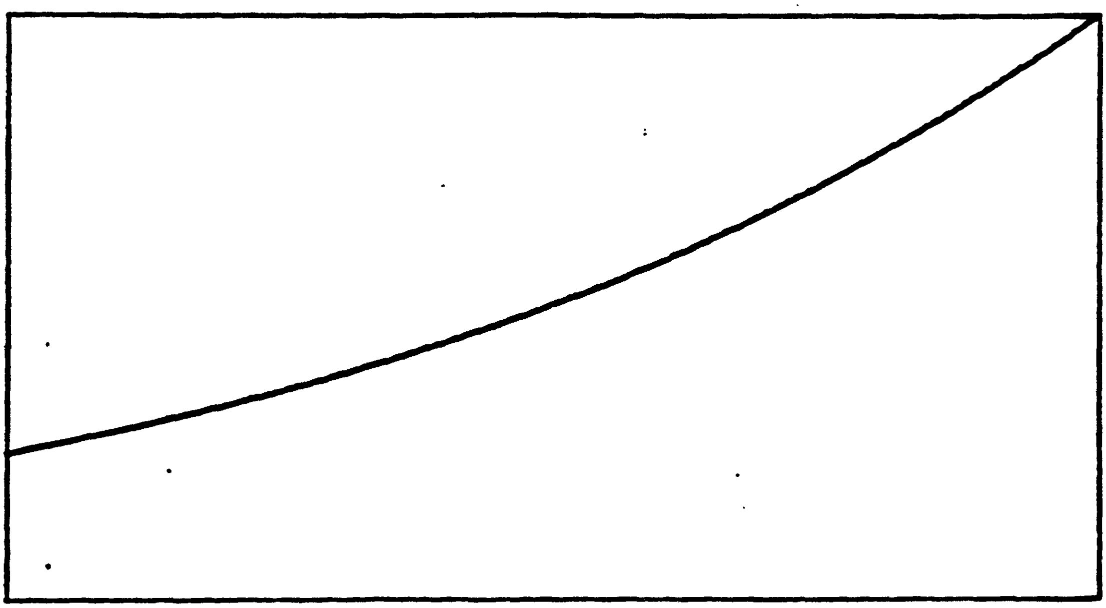


Figure 41. Beginning pages of program four showing entries for PGC function whose plot is shown on the lower half of the figure.

```
SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -0.271326563663 TO 0.545281522223
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT = -0.3
MAXIMUM AMPLITUDE ON PLOT = 0.6
```

```
SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
   20 MSEC RICKER "FAR DISTANT" WAVELET WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 40
AMPLITUDE MODE: PROGRAMED GAIN CONTROL (PGC) WITH HALF GAIN AT T = 100
PLOT AMPLITUDES RANGE FROM  -0.30 TO   0.60 BETWEEN ORDINAL TICKMARKS
```

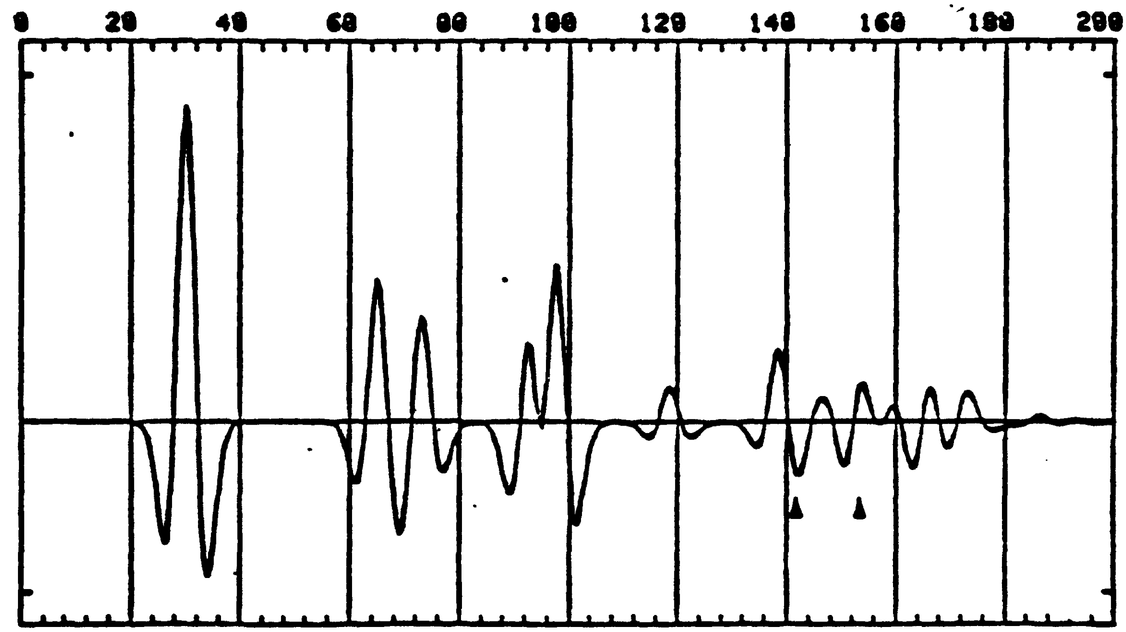



Figure 42. Synthetic seismogram produced using the PGC function specified and plotted on figure 41.

Next, let us examine a PGC function whose start time is not zero. In the example shown on figure 43, a start time of 40 ms and a half-gain time of 80 ms were used. As shown by the plot of the PGC function on the lower half of figure 43, the PGC parameters entered cause all values between times of 0 and 40 to be muted, and the choice of a half-gain time of 80 ms causes the function to rise more rapidly than in figure 41; thus, the final gain (at a time of 200 ms) is greater than it was on figure 41. Figure 44 shows the synthetic seismogram produced when the PGC function specified on figure 43 is applied. Note that the early arrival beginning at a record time of 20 ms has been muted.

```
COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) Y
INSERT SYN SEIS DATA TAPE IN 4924    FILE NO. = 49

THREE DISPLAY OPTIONS ARE AVAILABLE:
    1. FIXED GAIN OVER ENTIRE RECORD,
    2. SELECTED GAIN WITHIN SEGMENTS, AND
    3. PROGRAMED GAIN CONTROL (PGC).

NUMBER OF DISPLAY OPTION CHOSEN = 3

     START TIME = 40

HALF GAIN TIME = 80

     FINAL GAIN = 0.9375

DO YOU WANT TO PLOT PGC GAIN FUNCTION? (Y/N) Y


   PGC FUNCTION FROM T=0 TO 200 WITH FINAL GAIN = 0.9375
PROGRAMED GAIN CONTROL (PGC) WITH HALF GAIN AT T = 80
```

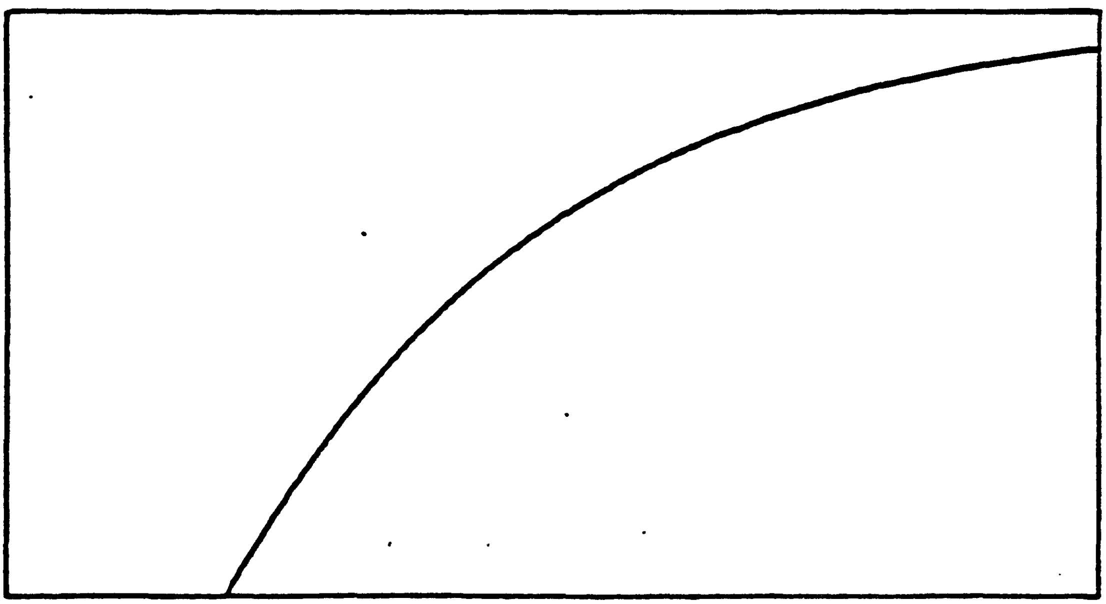


Figure 43. Beginning pages of program four showing entry of a PGC function with a non-zero start time.

SYNTHETIC STARTS AT 0 AND ENDS AT 200 MSEC
AMPLITUDES RANGE FROM -0.232914184351 TO 0.344313156646
SAMPLE INTERVAL FOR SYNTHETIC: 0.5 MSEC
TOTAL NUMBER OF VALUES IN SYNTHETIC: 401

MINIMUM AMPLITUDE ON PLOT = $\boxed{-0.3}$
MAXIMUM AMPLITUDE ON PLOT = $\boxed{0.4}$

SYNTHETIC SEISMOGRAM--REFLECTIVITY SERIES WITHOUT MULTIPLES
20 MSEC RICKER "FAR DISTANT" WAVELET WITH S.I.=0.5
REFLECTIVITY SERIES FROM FILE 41 AND WAVELET'S VALUES FROM FILE 40
AMPLITUDE MODE: PROGRAMED GAIN CONTROL (PGC) WITH HALF GAIN AT T = 80
PLOT AMPLITUDES RANGE FROM -0.30 TO 0.40 BETWEEN ORDINAL TICKMARKS

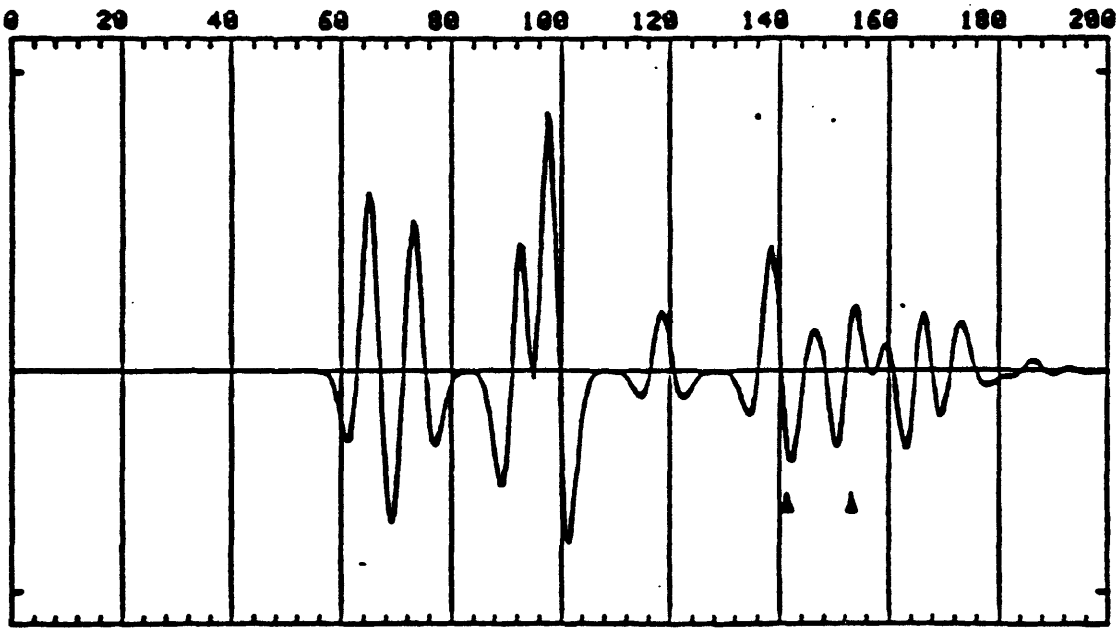



Figure 44. Synthetic seismogram produced upon application of the PGC function specified on figure 43.

Although the three display options shown so far in this report are included as part of the synthetic seismogram program, these procedures also could be applied to observed data, as could the AGC (adaptive gain control) methods to be discussed in the next section.

## DISCUSSION OF PROGRAM TO COMPUTE AND APPLY AGC FUNCTION TO SYNTHETIC SEISMOGRAM

The adaptive gain control function of this report uses a gain normalization curve derived from a set of rms values obtained over windows whose intervals (shift times), lag times, lead times, and start time of the first window are specified by the user. Figure 45 illustrates the entry of these quantities and a plot of the AGC gain function applied to the values of the fixed-gain synthetic seismogram stored in file 49. A Lanczos-conditioned, folded (sin x)/x interpolator is used to obtain

```
APPLY AGC TO SYNTHETIC SEISMOGRAM
INSERT SYN SEIS DATA TAPE IN 4924     FILE NO. = 49

NOTE: GAINS EXTERIOR TO AGC INTERVAL ARE CONSTANTS WITH
START GAIN = FIRST AGC GAIN AND END GAIN = LAST AGC GAIN

    AGC START TIME = 50
   WINDOW LAG TIME = 20
  WINDOW LEAD TIME = 10
     WINDOW LENGTH = 30
     VALUES/WINDOW = 61
   WINDOW INTERVAL = 50
    NO. OF WINDOWS = 3
      AGC END TIME = 150
  NO.OF AGC VALUES = 201

DO YOU WANT TO PLOT AGC GAIN FUNCTION? (Y/N) Y

NORMALIZED AGC GAIN FUNCTION FROM T=50 TO 150
NO. OF VALUES=201   MIN VALUE=0.172012819881
```

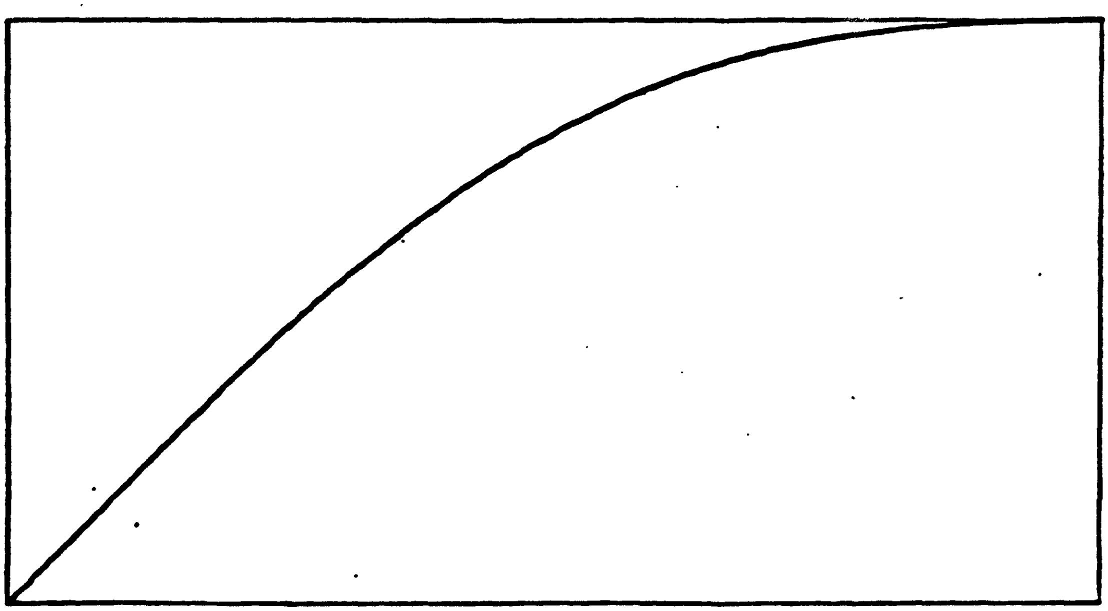


Figure 45. Beginning pages of program five showing entry of values used to develop AGC function.

gain-function values interior to those at the window times. The synthetic seismogram resulting from application of the AGC function specified on figure 45 is shown on figure 46.

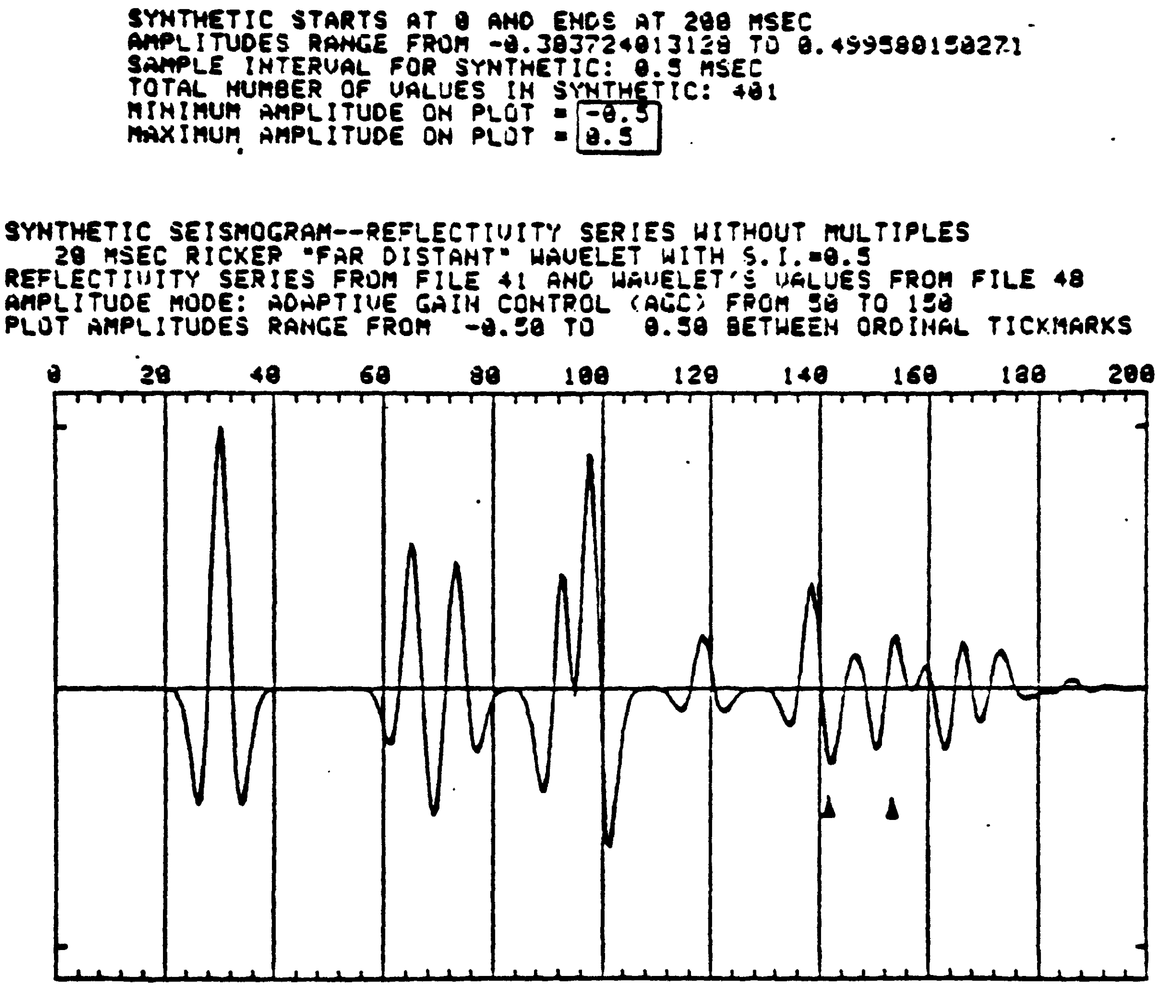



Figure 46. Synthetic seismogram produced upon application of the AGC function specified on figure 45.

In the examples on figures 45 and 46, the AGC function begins at 50 ms and ends at 150 ms. Gain from 0 to 50 ms equals that computed at 50 ms; unity gain is applied from 150 to 200 ms. Thus, no distortion of waveforms occurs in the intervals from 0 to 50 and 150 to 200 ms.

## EXAMPLE OF SYNTHETIC SEISMOGRAM SECTION

So far we have produced and examined synthetic seismograms developed for one location. Let us now construct a set of synthetic seismograms at several locations at which the depth to one of the horizons varies--in effect, construct a seismic section. Because the synthetic seismograms of this report are one dimensional, we are forced to assume the dip of the horizons is small at each location.

Figure 47 shows interpreted depths and thickness of two coal seams at six widely spaced locations. What we want to examine is the variation in seismic response as the lower coal seam approaches and then merges with the upper seam.

Respective velocities (m/ms) and densities (gm/cc) used in the model are as follows: overburden--1.8/2.0; coal--1.5/1.3; interburden--2.0/2.2; bottom layer--2.5/2.5. Depth to the 2-m thick coal is 10 m and depths to the 6-m thick coal at locations 1 through 6 are 62, 32, 22, 17, 14, and 12 m respectively.

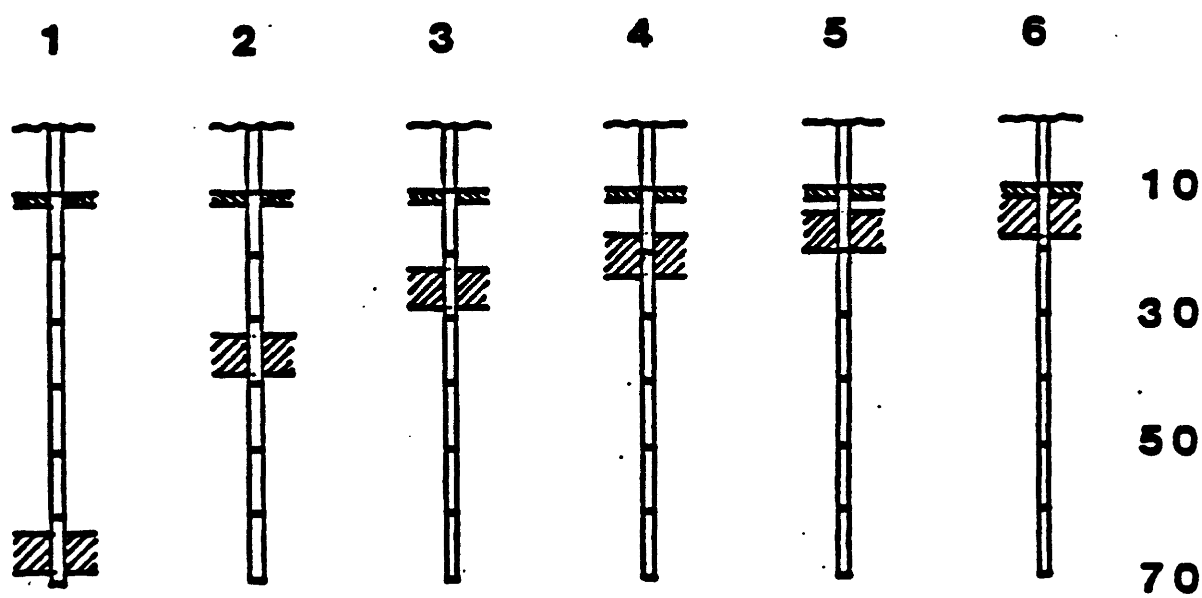



Figure 47. Coal seam thicknesseses and depths at the six locations for which synthetic seismograms are constructed.

Four synthetic seismogram sections are presented: a pair using a 20-ms wavelet of the zero-phase-approximation form with an apparent frequency of 125 Hz, and a pair using a 10-ms wavelet of the minimum-phase-approximation form with an apparent frequency of 200 Hz. Each pair shows the section both with and without two-bounce multiple reflections. All synthetic seismograms are displayed with the same fixed gain.

Figure 48 shows synthetic seismogram sections using an approximate zero-phase wavelet whose apparent frequency is 125 Hz. The upper section includes two-bounce multiples, the lower section is without multiples.

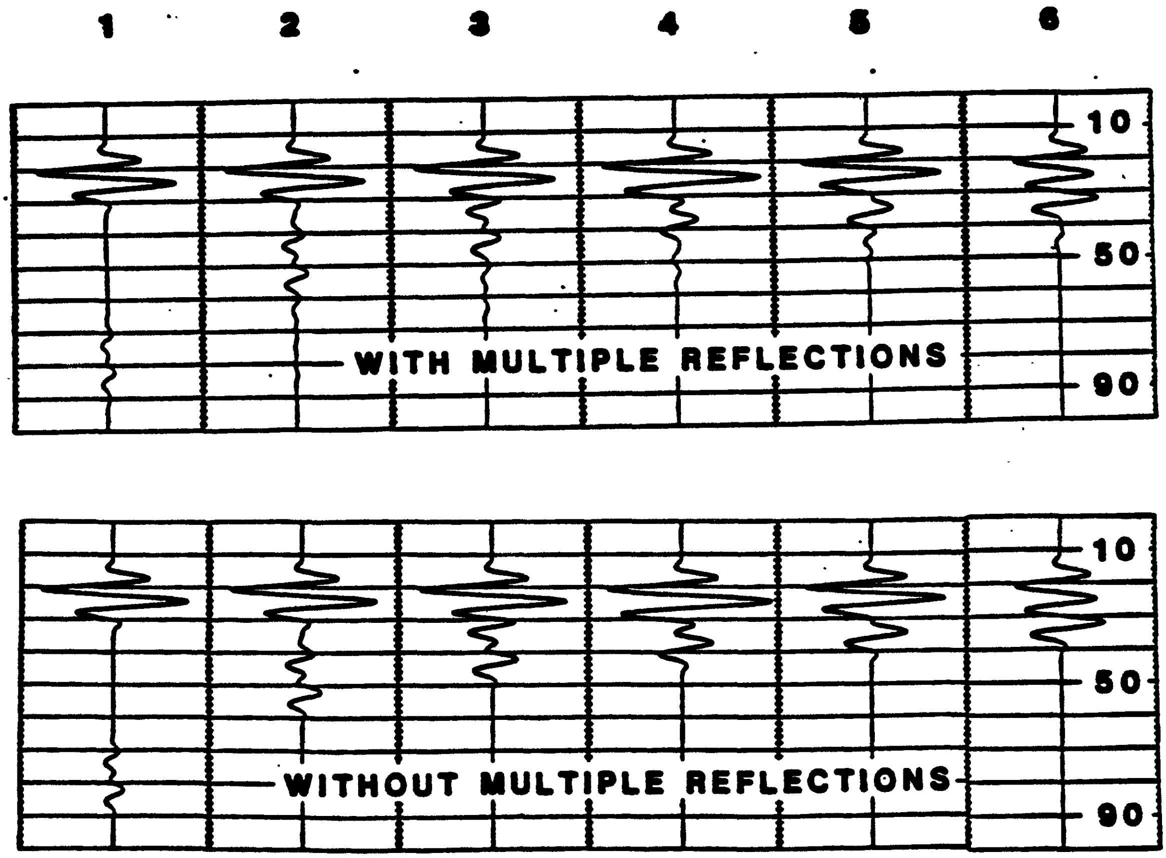



Figure 48. Synthetic seismogram sections with (upper) and without (lower) two-bounce multiple reflections. Wavelet is an approximate-zero-phase wavelet whose apparent frequency is 125 Hz.

Figure 49 shows synthetic seismogram sections using an approximate-minimum-phase wavelet whose apparent frequency is 200 Hz. The upper section includes two-bounce multiples; the lower section is without multiples.

Although the synthetic seismograms displayed on these sections were derived from a highly simplistic model, much can be learned from examination of these sections. For example, one can determine the conditions for resolution of bed and interburden thicknesses as functions of wavelet shape and duration and one can see bed-thickness tuning effects.

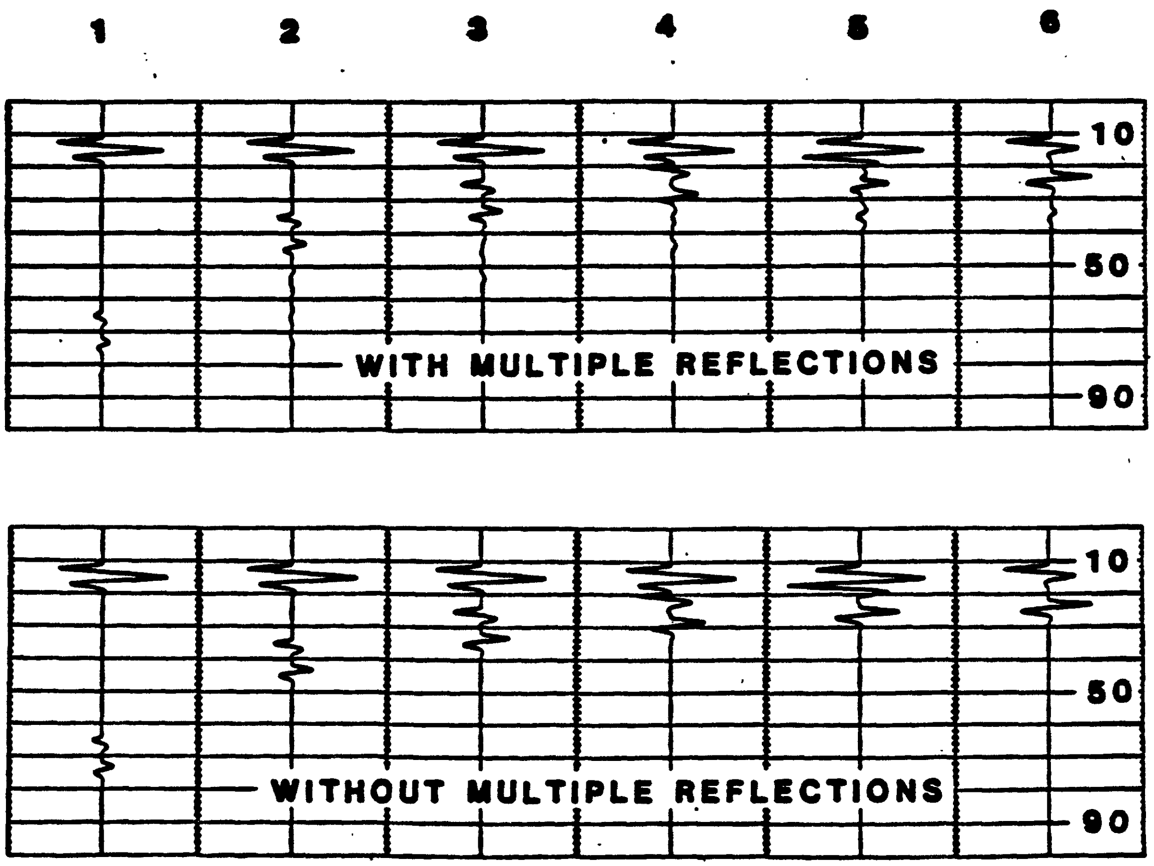



Figure 49. Synthetic seismogram sections with (upper) and without (lower) two-bounce multiple reflections. Wavelet is an approximate-minimum-phase wavelet whose apparent frequency is 200 Hz.

## ADDITIONAL COMMENTS ON THE PROGRAMS

In order to put the programs of this report to work, you must know how to perform the following operations:

1. transcribe the programs into the computer,
2. store the programs on magnetic tape,
3. retrieve the programs from magnetic tape,
4. enter information from the keyboard, and
5. copy the screen display.

These tasks are documented in the computer's operator's manuals.

Four control characters (ones requiring the holding down of the control key as the letter is entered) are used in the programs: G (ring bell), K (move cursor up one line), L (erase screen and move cursor to the HOME position), and the RUB OUT (move cursor to the left margin and down one line). In the printed listing these control characters are shown as G_, K_, L_, and __, respectively.

To achieve maximum data packing on master data tapes, all record data are stored as three-byte hexadecimal values. A specially designed ROM is used to convert MDT (master-data-tape) data from hexadecimal to digital values and later to convert digital values to hexadecimal prior to storing them on a master data tape. The occurrences of these ROMs can be recognized in the programs by the statements of the form: CALL "HEXDEC",B$,V,LEN (B$),3 (where B$ is the string variable containing data in hexadecimal and V is the array containing the data in decimal), and CALL "DECHEX",B$,V,1001,3 (where 1001 is the size of the V array). ROMs also are used to speed the finding of the minimum and maximum values of a function--recognizeable in the program listings by statements of the form: CALL "MIN",V,R1,I1 and CALL "MAX",V,R2,I2G--and to plot a function--identifiable by a statement of the form: CALL "DISP",V. All of the above operations can be performed by BASIC programs; however, it is considerably faster to employ ROMs.

As a convenience to the reader who may wish to copy and store the programs of this report separately, the five programs used in the computation and display of synthetic seismograms and the sample-problem program are listed following the appendix.

## REFERENCES

Anstey, N. A., 1977, Seismic interpretation: the physical aspects: International Human Resources Development Corporation, Boston, Mass, 637 p.

------ 1982, Simple seismics: International Human Resources Development Corporation, Boston, Mass, 168 p.

Sheriff, R. E., 1973, Encyclopedic dictionary of exploration geophysics: Society of Exploration Geophysicists, Tulsa, Okla., 266 p.

Waters, K. E., 1978, Reflection seismology: John Wiley & Sons, New York, 377 p.

## APPENDIX--DISCUSSION OF PROGRAM TO GENERATE FORWARD-MODEL DATA

In the belief that the best way to learn the use of a computer program is by working through examples, a program to generate sample-problem data is included in this report. With its use, the user can simulate data as if they had been obtained from a density and acoustic log. Sample problem data entered on figure 1 were obtained in this way.

The program begins by asking you if you want to work in the metric system. If you answer with a Y (as is done on figure A-1), then you are told the metric units to use; if you reply with an N, then distance data are entered in ft and velocities in ft/sec, but densities (in keeping with standard practice) are entered in grams/cubic centimeter. Regardless of which system of units you elect, the transit time on the sonic log will be expressed in microseconds per foot.

Next you are asked to enter the number of layers in the model. The computer program is designed only to handle layers within which the density and velocity are constant and whose thickness is an integer. Upon completion of the computations, you are asked if you want to store the results on a master data tape (MDT) and then are prompted as to the procedure to be followed to store these data.

SYNTHETIC SEISMOGRAM: GENERATE SAMPLE PROBLEM DATA

DO YOU WANT TO WORK IN THE METRIC SYSTEM? (Y OR N) Y

NOTE: ENTER DIST.=INTEGER M; VEL.=M/MS ; DEN.=GM/CC

NUMBER OF LAYERS IN THE MODEL = 21

| LAYER NO. | LAYER THICKNESS | LAYER DENSITY | LAYER VELOCITY |
|---|---|---|---|
| 1 | 3 | 1.5 | .3 |
| 2 | 7 | 1.6 | .4 |
| 3 | 2 | 1.7 | .5 |
| 4 | 6 | 1.8 | .6 |
| 5 | 2 | 1.9 | .9 |
| 6 | 10 | 2.1 | 1.7 |
| 7 | 20 | 2.2 | 2 |
| 8 | 5 | 2.5 | 3 |
| 9 | 12 | 2.3 | 2.5 |
| 10 | 1 | 1.3 | 1.8 |
| 11 | 14 | 2.3 | 2.6 |
| 12 | 3 | 1.3 | 1.8 |
| 13 | 2 | 2.2 | 2 |
| 14 | 4 | 1.3 | 1.8 |
| 15 | 1 | 2.2 | 2 |
| 16 | 1 | 2.3 | 2.2 |
| 17 | 1 | 2.4 | 2.4 |
| 18 | 7 | 2.4 | 2.6 |
| 19 | 7 | 2.4 | 2.6 |
| 20 | 9 | 2.5 | 3.3 |
| 21 | 15 | 2.6 | 3.6 |

DO YOU WANT TO STORE RESULTS ON HDT? (Y OR N) Y

INSERT MDT IN 4924     NUMBER OF SELECTED FILE = 39
LENGTH OF FILE REQUIRED = 4688
DOES FILE HAVE SUFFICIENT LENGTH? (Y OR N) N

NUMBER OF FILE TO BE MARKED = 39

INSERT MDT IN 4051
ARE YOU READY TO PROCEED? (Y OR N) Y

INSERT MDT IN 4924
ARE YOU READY TO PROCEED? (Y OR N) Y
DATA STORED IN AND RETRIEVABLE FROM FILE 39

DO YOU WANT TO SEE MODEL AND SAMPLE PROBLEM DATA? (Y OR N) Y
DO YOU WANT TO PRINT ON 4642? (Y OR N) Y

DO YOU WANT TO TABULATE LOG DATA? (Y OR N) Y

DO YOU WANT TO PLOT SIMULATED LOG DATA? (Y OR N) Y

Figure A-1. Screen copy of beginning pages of sample-problem program showing examples of data and replies entered.

Figures A-2a and A-2b show tabulations made on a printer (optional: display could have been made and then copied from the screen) of the sample-problem data. If in reply to the question as to whether you want to tabulate log data you enter a Y, then a listing such as partially shown by on figure A-3 is made.

```
QUICK PRINT OF MODEL AND SAMPLE  PROBLEM DATA
SYN SEIS -- SAMPLE PROB DATA FROM MODEL SECTION   NO. OF LAYERS = 21
LAYER THICKNESS IN m:
 3                 7                 2                 6
 2                 18                20                5
 12                1                 14                3
 2                 4                 1                 1
 1                 7                 7                 9
 15
LAYER DENSITY IN gm/cc:
 1.5               1.6               1.7               1.8
 1.9               2.1               2.2               2.5
 2.3               1.3               2.3               1.3
 2.2               1.3               2.2               2.3
 2.4               2.4               2.4               2.5
 2.6
LAYER VELOCITY IN m/mS:
 0.3               0.4               0.5               0.6
 0.9               1.7               2                 3
 2.5               1.8               2.6               1.8
 2                 1.8               2                 2.2
 2.4               2.6               2.6               3.3
 3.6
LAYER ACOUSTIC IMPEDANCE IN kg/m↑2sx10↑6:
 0.45              0.64              0.85              1.08
 1.71              3.57              4.4               7.5
 5.75              2.34              5.98              2.34
 4.4               2.34              4.4               5.06
 5.76              6.24              6.24              8.25
 9.36
REFLECTION TIME TO BASE OF LAYER IN msec:
 20                55                63                83
 87.4444444444     108.620915033     128.620915033     131.954248366
 141.554248366     142.665359477     153.434590246     156.76792258
 158.76792358      163.212368024     164.212368024     165.121458933
 165.954792267     171.339407651     176.724023036     182.17856849
 190.511901824
REFLECTION COEFFICIENT:
 0.174311926606    0.140939597315    0.119170984456    0.225806451613
 0.352272727273    0.104140526976    0.260504201681    -0.132075471698
 -0.421508034611   0.4375            -0.4375           0.305637982196
 -0.305637982196   0.305637982196    0.0697674418605   0.0646950092421
 0.04              0                 0.138716356108    0.063032367972
 0
```

Figure A-2a. Tabulation of entered and computed values for the sample problem used as data input on figure 1.

DEPTH TO BASE OF LAYER IN m.

| | | | |
|---|---|---|---|
| 3 | 10 | 12 | 18 |
| 20 | 38 | 58 | 63 |
| 75 | 76 | 90 | 93 |
| 95 | 99 | 100 | 101 |
| 102 | 109 | 116 | 125 |
| 140 | | | |

INTRA-LAYER SONIC-LOG TRANSIT TIME IN microsec/ft

| | | | |
|---|---|---|---|
| 1016 | 762 | 609.6 | 508 |
| 338.666666667 | 179.294117647 | 152.4 | 101.6 |
| 121.92 | 169.333333333 | 117.230769231 | 169.333333333 |
| 152.4 | 169.333333333 | 152.4 | 138.545454545 |
| 127 | 117.230769231 | 117.230769231 | 92.3636363636 |
| 84.6666666667 | | | |

TRANSIT TIME/m FOR EACH m OF DEPTH

| | | | |
|---|---|---|---|
| 1016 | 1016 | 1016 | 762 |
| 762 | 762 | 762 | 762 |
| 762 | 762 | 609.6 | 609.6 |
| 508 | 508 | 508 | 508 |
| 508 | 508 | 338.666666667 | 338.666666667 |
| 179.294117647 | 179.294117647 | 179.294117647 | 179.294117647 |
| 179.294117647 | 179.294117647 | 179.294117647 | 179.294117647 |
| 179.294117647 | 179.294117647 | 179.294117647 | 179.294117647 |
| 179.294117647 | 179.294117647 | 179.294117647 | 179.294117647 |
| 179.294117647 | 179.294117647 | 152.4 | 152.4 |
| 152.4 | 152.4 | 152.4 | 152.4 |
| 152.4 | 152.4 | 152.4 | 152.4 |
| 152.4 | 152.4 | 152.4 | 152.4 |
| 152.4 | 152.4 | 152.4 | 152.4 |
| 152.4 | 152.4 | 101.6 | 101.6 |
| 101.6 | 101.6 | 101.6 | 121.92 |
| 121.92 | 121.92 | 121.92 | 121.92 |
| 121.92 | 121.92 | 121.92 | 121.92 |
| 121.92 | 121.92 | 121.92 | 169.333333333 |
| 117.230769231 | 117.230769231 | 117.230769231 | 117.230769231 |
| 117.230769231 | 117.230769231 | 117.230769231 | 117.230769231 |
| 117.230769231 | 117.230769231 | 117.230769231 | 117.230769231 |
| 117.230769231 | 117.230769231 | 169.333333333 | 169.333333333 |
| 169.333333333 | 152.4 | 152.4 | 169.333333333 |
| 169.333333333 | 169.333333333 | 169.333333333 | 152.4 |
| 138.545454545 | 127 | 117.230769231 | 117.230769231 |
| 117.230769231 | 117.230769231 | 117.230769231 | 117.230769231 |
| 117.230769231 | 117.230769231 | 117.230769231 | 117.230769231 |
| 117.230769231 | 117.230769231 | 117.230769231 | 117.230769231 |
| 92.3636363636 | 92.3636363636 | 92.3636363636 | 92.3636363636 |
| 92.3636363636 | 92.3636363636 | 92.3636363636 | 92.3636363636 |
| 92.3636363636 | 84.6666666667 | 84.6666666667 | 84.6666666667 |
| 84.6666666667 | 84.6666666667 | 84.6666666667 | 84.6666666667 |
| 84.6666666667 | 84.6666666667 | 84.6666666667 | 84.6666666667 |
| 84.6666666667 | 84.6666666667 | 84.6666666667 | 84.6666666667 |

DATA STORED IN FILE 29

Figure A-2b. Continuation of tabulation of entered and computed values for the sample problem used as data input on figure 1.

In the example, the density, transit time, and computed interval velocity are tabulated only for the first 50 m of the section. If you elect to plot the simulated log data, you are given the ranges of depths, densities, and transit times and then prompted (fig. A-4) to enter minimum and maximum values and tickmark intervals for the plots. Although the practiced eye can detect entry errors on a tabulation of a large mass of data, a plot such as that of figure A-4 makes it much easier to see a mistake in entry of model parameters. Note that in the selection of the transit-time plot range on figure A-4 that the maximum transit time was entered as 200. This was done so that the coal section would show in more detail than if the full range were displayed.

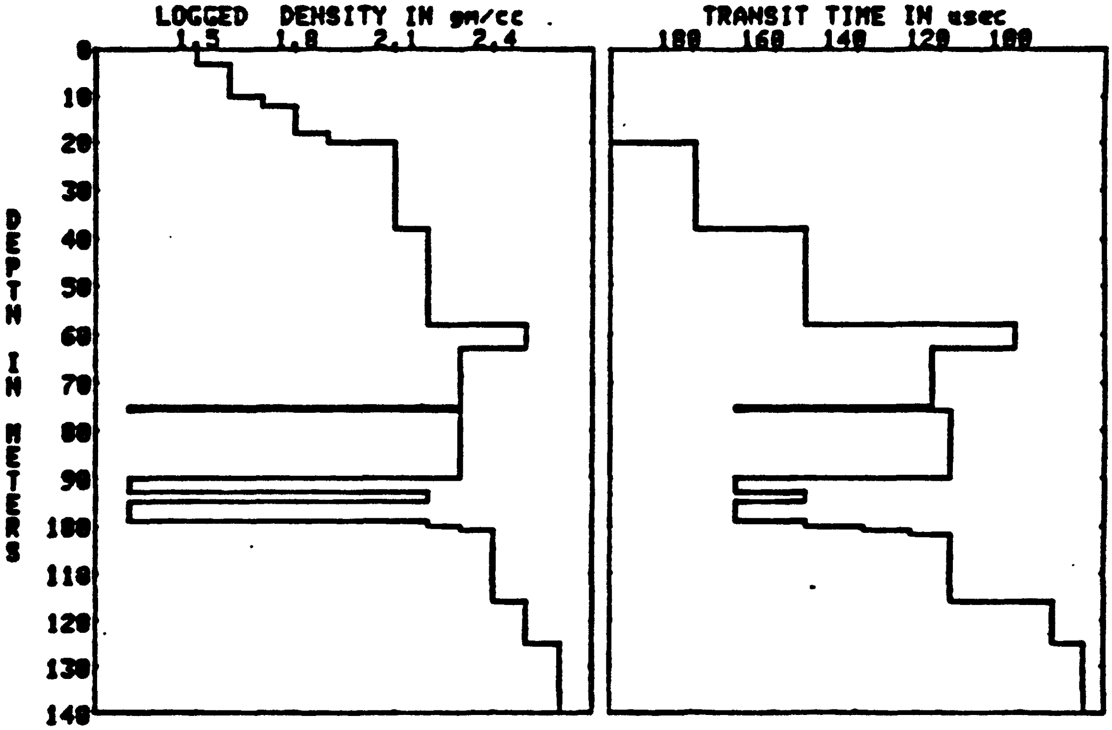
DATA AS IF A LOG HAD BEEN RUN

| DEPTH (m) | DENSITY(gm/cc) | TT(usec/ft) | VEL(m/mS) |
|---|---|---|---|
| 1 | 1.50 | 1016 | 0.3 |
| 2 | 1.50 | 1016 | 0.3 |
| 3 | 1.50 | 1016 | 0.3 |
| 4 | 1.60 | 762 | 0.4 |
| 5 | 1.60 | 762 | 0.4 |
| 6 | 1.60 | 762 | 0.4 |
| 7 | 1.60 | 762 | 0.4 |
| 8 | 1.60 | 762 | 0.4 |
| 9 | 1.60 | 762 | 0.4 |
| 10 | 1.60 | 762 | 0.4 |
| 11 | 1.70 | 610 | 0.5 |
| 12 | 1.70 | 610 | 0.5 |
| 13 | 1.80 | 508 | 0.6 |
| 14 | 1.80 | 508 | 0.6 |
| 15 | 1.80 | 508 | 0.6 |
| 16 | 1.80 | 508 | 0.6 |
| 17 | 1.80 | 508 | 0.6 |
| 18 | 1.80 | 508 | 0.6 |
| 19 | 1.90 | 339 | 0.9 |
| 20 | 1.90 | 339 | 0.9 |
| 21 | 2.10 | 179 | 1.7 |
| 22 | 2.10 | 179 | 1.7 |
| 23 | 2.10 | 179 | 1.7 |
| 24 | 2.10 | 179 | 1.7 |
| 25 | 2.10 | 179 | 1.7 |
| 26 | 2.10 | 179 | 1.7 |
| 27 | 2.10 | 179 | 1.7 |
| 28 | 2.10 | 179 | 1.7 |
| 29 | 2.10 | 179 | 1.7 |
| 30 | 2.10 | 179 | 1.7 |
| 31 | 2.10 | 179 | 1.7 |
| 32 | 2.10 | 179 | 1.7 |
| 33 | 2.10 | 179 | 1.7 |
| 34 | 2.10 | 179 | 1.7 |
| 35 | 2.10 | 179 | 1.7 |
| 36 | 2.10 | 179 | 1.7 |
| 37 | 2.10 | 179 | 1.7 |
| 38 | 2.10 | 179 | 1.7 |
| 39 | 2.20 | 152 | 2.0 |
| 40 | 2.20 | 152 | 2.0 |
| 41 | 2.20 | 152 | 2.0 |
| 42 | 2.20 | 152 | 2.0 |
| 43 | 2.20 | 152 | 2.0 |
| 44 | 2.20 | 152 | 2.0 |
| 45 | 2.20 | 152 | 2.0 |
| 46 | 2.20 | 152 | 2.0 |
| 47 | 2.20 | 152 | 2.0 |
| 48 | 2.20 | 152 | 2.0 |
| 49 | 2.20 | 152 | 2.0 |
| 50 | 2.20 | 152 | 2.0 |

Figure A-3. Tabulation of first 50 m of simulated density and acoustic log data (with computed interval velocities) for sample problem.

```
ENTER PLOT LIMITS

Depths range from 0 to 140
            Min. depth on plot = 0
            Max. depth on plot = 140
       Depth tickmark interval = 10

Densities range from 1.3 to 2.6
          Min. density on plot = 1.2
          Max. density on plot = 2.7
     Density tickmark interval = .3

Transit times range from 84.6666666667 to 1016
Min. transit time on plot = 80
Max. transit time on plot = 200
Transit time tickmark int = 20
```

SYN SEIS -- SAMPLE PROB DATA FROM MODEL SECTION DATA IN FILE 39




```
DO YOU WANT TO REPLOT WITH DIFFERENT PLOT LIMITS? (Y OR N) N
PROGRAM COMPLETED: 11-NOV-82 13:19:33
```

Figure A-4. Plot limits and resulting plot of sample problem data.

LISTING OF PROGRAM TO ENTER DATA AND CONSTRUCT ACOUSTIC IMPEDANCE AND REFLECTION COEFFICIENT SECTION

```
100 PRINT "L_ENTER DATA AND CONSTRUCT ACOUSTIC IMPEDANCE AND REFL. ";
110 PRINT "COEFF. SECTION".
120 INIT
130 DIM A$(22),C$(25),D$(14),F$(2),G$(1),L$(12),N$(17),O$(13),U$(14)
140 DATA 1,1000,1000,1,1.806,2.857,1,1,0,5,1
150 READ K1,K2,K3,K4,K5,K6,K7,K8,N4,N7,Q1
160 PRINT "__DO YOU WANT TO WORK WITH SAMPLE PROBLEM DATA? (Y/N) ";
170 INPUT G$
180 IF G$="N" THEN 220
190 Q1=2
200 GOSUB 5700
210 GO TO 390
220 PRINT "__ARE ACOUSTIC AND DENSITY LOG DATA TO BE ENTERED? (Y/N) ";
230 INPUT G$
240 IF G$="N" THEN 280
250 N4=1
260 PRINT "__NOTE: ALL QUANTITIES IN METRIC UNITS EXCEPT TRANSIT TIMES"
270 PRINT "      ON ACOUSTIC LOGS WHERE UNIT IS MICROSECONDS/FOOT."
280 REM ** ENTER LOCATION DATA
290 GOSUB 880
300 REM ** ENTER DATA & COMPUTE FOR ZONE 1 (ABOVE LOGGED INTERVAL)
310 GOSUB 1040
320 REM ** ENTER ACOUSTIC AND DENSITY LOG RANGES ,ZONE 2
330 IF N4=0 THEN 370
340 GOSUB 1230
350 REM ** ENTER & COMPUTE DATA FOR ZONE 2 (LOGGED INTERVAL)
360 GOSUB 1570
370 REM ** ENTER & COMPUTE DATA FOR ZONE 3 (BELOW LOGGED INTERVAL)
380 GOSUB 1970
390 REM **.COMP. INT V, INT D, IMPEDANCE AND REFL. COEFF AS F(DEPTH)
400 GOSUB 2140
410 GOSUB 2510
420 GOSUB 2570
430 GOSUB 2870
440 PRINT "__DO YOU WANT TO STORE RESULTS ON A DATA TAPE? (Y/N) ";
450 INPUT G$
460 IF G$="Y" THEN 490
470 F1=0
480 GO TO 510
490 PRINT "   NUMBER OF FILE ON WHICH DATA ARE TO BE STORED = ";
500 INPUT F1
510 PRINT "__DO YOU WANT TO PLOT RESULTS? (Y/N) ";
520 INPUT G$
530 IF G$="N" THEN 820
540 REM ** PLOT RESULTS ON CRT
550 RESTORE 560
560 DATA 10,58,60,80,82,130,10,92
570 READ B1,B2,B4,B5,B7,B8,C1,C2
580 GOSUB 2970
590 Z=Z0-Z
600 GOSUB 3350
610 GOSUB 3800
620 GOSUB 4130
630 GOSUB 4350
640 GOSUB 4490
650 GOSUB 4710
660 GOSUB 4920
670 GOSUB 5150
680 GOSUB 5240
690 GOSUB 5350
700 WINDOW 0,130,0,100
710 VIEWPORT 0,130,0,100
720 MOVE 0,0
730 PRINT
740 PRINT "L_DO YOU WANT TO REPLOT? (Y/N) ";
```

```
750 INPUT G$
760 IF G$="N" THEN 820
770 WINDOW 0,130,0,100
780 VIEWPORT 0,130,0,100
790 Z=Z0-Z
800 Z7=Z0-Z7
810 GO TO 580
820 IF F1=0 THEN 860
830 REM ** STORE RESULTS ON MDT
840 Z=Z7-Z
850 GOSUB 5450
860 PRINT "G_G_G___PROGRAM COMPLETED"
870 END
880 REM ** SUB: ENTER LOCATION DATA
890 PRINT "__      Area name (20 char,max) = ";
900 INPUT A$
910 PRINT "Site designation (7 char,max) = ";
920 INPUT U$
930 PRINT "  Date computed (12 char,max) = ";
940 INPUT D$
950 PRINT "__  Lat. of site (10 char, max) = ";
960 INPUT L$
970 PRINT "  Long of site (11 char, max) = ";
980 INPUT O$
990 PRINT "County & State  (23 char,max) = ";
1000 INPUT C$
1010 PRINT "__      Elevation of site center = ";
1020 INPUT E1
1030 RETURN
1040 REM ** SUB: ENTER VEL-DEN DATA FOR ZONE 1 (ABOVE LOGGED INTERVAL)
1050 PRINT "L_NO. OF LAYERS IN ZONE 1 = ";
1060 INPUT N0
1070 IF N0=0 THEN 1220
1080 DIM A1(N0),D1(N0),V1(N0),Z1(N0),Z8(N0)
1090 Z6=0
1100 PRINT "LAYER NO.  LAYER THICKNESS   LAYER DENSITY   LAYER VELOCITY"
1110 FOR J=1 TO N0
1120 PRINT "    ";J;"              ";
1130 INPUT Z1(J)
1140 Z6=Z6+Z1(J)
1150 Z8(J)=Z6
1160 PRINT "K_                                ";
1170 INPUT D1(J)
1180 PRINT "K_                                                    ";
1190 INPUT V1(J)
1200 A1(J)=D1(J)*V1(J)
1210 NEXT J
1220 RETURN
1230 REM ** SUB: ENTER DATA FROM DENSITY AND ACOUSTIC LOGS
1240 PRINT "L_ENTER DEPTH-SEGMENT DATA FOR LOGGED INTERVAL"
1250 PRINT "__             NUMBER OF SEGMENTS = ";
1260 INPUT N1
1270 DIM N2(N1),S2(N1),S3(N1),S4(N1)
1280 IF N0=0 THEN 1320
1290 S2(1)=Z8(N0)
1300 PRINT "__   Depth to top of segment 1 = ";S2(1)
1310 GO TO 1340
1320 PRINT "__   Depth to top of segment 1 = ";
1330 INPUT S2(1)
1340 PRINT "  Depth to base of segment 1 = ";
1350 INPUT S3(1)
1360 PRINT "           SI within segment 1 = ";
1370 INPUT S4(1)
1380 N2(1)=INT((S3(1)-S2(1)+1.0E-3)/S4(1))
1390 IF N1=1 THEN 1490
1400 FOR J=2 TO N1
```

```
1410 S2(J)=S3(J-1)
1420 PRINT "__   Depth to top of segment ";J;" = ";S2(J)
1430 PRINT "  Depth to base of segment ";J;" = ";
1440 INPUT S3(J)
1450 PRINT "            SI within segment ";J;" = ";
1460 INPUT S4(J)
1470 N2(J)=INT((S3(J)-S2(J)+1.0E-3)/S4(J))
1480 NEXT J
1490 CALL "MAX",N2,N3,I3
1500 DIM A2(N1,N3),D2(N1,N3),T2(N1,N3),V2(N1,N3),Z2(N1,N3)
1510 A2=0
1520 D2=0
1530 T2=0
1540 V2=0
1550 Z2=0
1560 RETURN
1570 REM ** SUB: ENTER TRANSIT TIMES AND DENSITIES FROM KEYBOARD
1580 IMAGE "K_",48X,2D.4D
1590 IMAGE "K_",24X,D.4D
1600 FOR J=1 TO N1
1610 Z2(J,1)=S2(J)
1620 FOR K=2 TO N2(J)
1630 Z2(J,K)=Z2(J,K-1)+S4(J)
1640 NEXT K
1650 NEXT J
1660 PRINT "L_ENTER TRANSIT TIMES AND DENSITIES"
1670 K3=304.8
1680 PRINT "DEPTH   TRANSIT TIME   VELOCITY   DENSITY   IMPEDANCE";
1690 PRINT " X 10↑-9"
1700 PRINT "TOP,m   microsec/ft      m/msec      gm/cc        kg/(m↑2s)__"
1710 L=3
1720 FOR J=1 TO N1
1730 PRINT "SEGMENT # ";J
1740 L=L+1
1750 FOR K=1 TO N2(J)
1760 L=L+1
1770 IF L<33 THEN 1810
1780 MOVE 0,0
1790 PRINT
1800 L=0
1810 PRINT "  ";Z2(J,K);"          ";
1820 INPUT T2(J,K)
1830 V2(J,K)=K3/T2(J,K)
1840 PRINT USING 1590:V2(J,K)
1850 PRINT "K_                                   ";
1860 INPUT D2(J,K)
1870 A2(J,K)=K4*D2(J,K)*V2(J,K)
1880 PRINT USING 1580:A2(J,K)
1890 NEXT K
1900 NEXT J
1910 N4=N2(1)
1920 IF N1=1 THEN 1960
1930 FOR J=2 TO N1
1940 N4=N4+N2(J)
1950 NEXT J
1960 RETURN
1970 REM ** SUB: ENTER VEL-DEN DATA FOR ZONE 3 (BELOW LOGGED INTERVAL)
1980 PRINT "L_NO. OF LAYERS IN ZONE 3 = ";
1990 INPUT N5
2000 IF N5=0 THEN 2130
2010 DIM A3(N5),D3(N5),V3(N5),Z3(N5)
2020 A3=0
2030 PRI "__LAYER NO.  LAYER THICKNESS   LAYER DENSITY   LAYER VELOCITY"
2040 FOR J=1 TO N5
2050 PRINT "   ";J;"             ";
2060 INPUT Z3(J)
```

```
2070 PRINT "K_                                    ";
2080 INPUT D3(J)
2090 PRINT "K_                                                          ";
2100 INPUT V3(J)
2110 A3(J)=V3(J)*D3(J)
2120 NEXT J
2130 RETURN
2140 REM ** SUB: COMBINE ZONAL VALUES AS FUNCTION OF DEPTH
2150 N6=N0+N4+N5
2160 DIM A(N6),D(N6),R(N6),V(N6),Z(N6)
2170 L=0
2180 IF N0=0 THEN 2270
2190 REM ** ZONE 1
2200 FOR J=1 TO N0
2210 L=L+1
2220 A(J)=A1(J)
2230 D(J)=D1(J)
2240 V(J)=V1(J)
2250 Z(J)=Z8(J)
2260 NEXT J
2270 IF N4=0 THEN 2380
2280 REM ** ZONE 2
2290 FOR J=1 TO N1
2300 FOR K=1 TO N2(J)
2310 L=L+1
2320 A(L)=A2(J,K)
2330 D(L)=D2(J,K)
2340 V(L)=V2(J,K)
2350 Z(L)=Z2(J,K)+S4(J)
2360 NEXT K
2370 NEXT J
2380 REM ** ZONE 3
2390 IF N5=0 THEN 2490
2400 Z5=Z(L)
2410 FOR J=1 TO N5
2420 L=L+1
2430 A(L)=A3(J)
2440 D(L)=D3(J)
2450 V(L)=V3(J)
2460 Z5=Z5+Z3(J)
2470 Z(L)=Z5
2480 NEXT J
2490 DELETE A1,A2,A3,D1,D2,D3,V1,V2,V3,Z1,Z2,Z3
2500 RETURN
2510 REM ** SUB: COMPUTE REFLECTION COEFFICIENTS
2520 R=0
2530 FOR J=2 TO N6
2540 R(J-1)=(A(J)-A(J-1))/(A(J)+A(J-1))
2550 NEXT J
2560 RETURN
2570 REM ** SUB: COMPRESS LENGTH OF REFLECTIVITY SERIES
2580 DIM A4(N6),D4(N6),V4(N6),Z4(N6),R4(N6)
2590 A4=A
2600 A=0
2610 D4=D
2620 D=0
2630 V4=V
2640 V=0
2650 Z4=Z
2660 Z=0
2670 R4=R
2680 R=0
2690 L=0
2700 FOR J=1 TO N6-1
2710 IF R4(J)=0 THEN 2780
```

```
2720 L=L+1
2730 A(L)=A4(J)
2740 D(L)=D4(J)
2750 V(L)=V4(J)
2760 Z(L)=Z4(J)
2770 R(L)=R4(J)
2780 NEXT J
2790 A(L+1)=A4(N6)
2800 D(L+1)=D4(N6)
2810 V(L+1)=V4(N6)
2820 Z(L+1)=Z4(N6)
2830 R(L+1)=R4(N6)
2840 N6=L+1
2850 DIM A(N6),D(N6),V(N6),Z(N6),R(N6)
2860 RETURN
2870 REM ** SUB: COMPUTE RANGES OF VARIATES
2880 CALL "MIN",A,A7,I1
2890 CALL "MAX",A,A8,I2
2900 CALL "MIN",D,D7,I1
2910 CALL "MAX",D,D8,I2
2920 CALL "MIN",R,R7,I1
2930 CALL "MAX",R,R8,I2
2940 CALL "MIN",V,V7,I1
2950 CALL "MAX",V,V8,I2
2960 RETURN
2970 REM ** SUB: ENTER PLOT LIMITS
2980 PRINT "L_ENTER PLOT-LIMIT VALUES"
2990 PRINT "__Depths range from ";Z7;" to ";Z(N6);" meters"
3000 PRINT "           Min. depth on plot = ";
3010 INPUT Z9
3020 PRINT "           Max. depth on plot = ";
3030 INPUT Z0
3040 PRINT "      Depth tickmark interval = ";
3050 INPUT M1
3060 PRINT "__Densities range from ";D7;" to ";D8;" gm/cc"
3070 PRINT "         Min. density on plot = ";
3080 INPUT D9
3090 PRINT "         Max. density on plot = ";
3100 INPUT D0
3110 PRINT "    Density tickmark interval = ";
3120 INPUT M2
3130 PRINT "__Velocities range from ";V7;" to ";V8;" m/msec"
3140 PRINT "        Min. velocity on plot = ";
3150 INPUT V9
3160 PRINT "        Max. velocity on plot = ";
3170 INPUT V0
3180 PRINT "   Velocity tickmark interval = ";
3190 INPUT M3
3200 PRINT "__Refl coeff's range from ";R7;" to ";R8
3210 PRINT "      Min. refl coeff on plot = ";
3220 INPUT R9
3230 PRINT "      Max. refl coeff on plot = ";
3240 INPUT R0
3250 PRINT "Refl coeff tickmark interval = ";
3260 INPUT M4
3270 PRINT "__Impedances range from ";A7;" to ";A8;" x 10↑-9 kg/m↑2s"
3280 PRINT "       Min. impedance on plot = ";
3290 INPUT A9
3300 PRINT "       Max. impedance on plot = ";
3310 INPUT A0
3320 PRINT " Impedance tickmark interval = ";
3330 INPUT M5
3340 RETURN
3350 REM ** SUB: PRINT HEADING, PLOT BORDERS, AND LABEL AXES
3360 PRINT "L_Area:";A$;"  Site:";U$;"  Date:";D$;" To file ";F1
3370 N$="DEPTH IN METERS"
```

```
3380 B3=B2-B1
3390 B6=B5-B4
3400 B9=B8-B7
3410 C3=C2-C1
3420 MOVE B1,C2
3430 RDRAW B3,0
3440 RDRAW 0,-C3
3450 RDRAW -B3,0
3460 RDRAW 0,C3
3470 MOVE B4,C2
3480 RDRAW B6,0
3490 RDRAW 0,-C3
3500 RDRAW -B6,0
3510 RDRAW 0,C3
3520 MOVE B7,C2
3530 RDRAW B9,0
3540 RDRAW 0,-C3
3550 RDRAW -B9,0
3560 RDRAW 0,C3
3570 MOVE 0.5*(B1+B2)-13*K5,C2+K6
3580 PRINT "--- INT. DEN. IN gm/cc ---"
3590 MOVE 0.5*(B4+B5)-5.5*K5,C2+K6
3600 PRINT "REFL  COEFF"
3610 MOVE 0.5*(B7+B8)-11*K5,C2+K6
3620 PRINT "IMP. x10↑-9 IN kg/m↑2s"
3630 MOVE 0,0.5*(C1+C2)+6.5*K6
3640 FOR I=1 TO LEN(N$)
3650 F$=SEG(N$,I,1)
3660 PRINT F$
3670 NEXT I
3680 MOVE 0.5*(B1+B2)-8.5*K5,C1-2*K6
3690 PRINT "INT. VEL. IN m/ms"
3700 MOVE B4+4*K5,C1-K6
3710 IF Q1=2 THEN 3760
3720 PRINT "LAT.=";L$;"    LONG.=";O$
3730 MOVE B4+4*K5,C1-2*K6
3740 PRINT C$;"  ELEV=";E1;"m"
3750 RETURN
3760 PRINT "SAMPLE DATA FROM FILE ";F0
3770 MOVE B4+4*K5,C1-2*K6
3780 PRINT "COMPUTED DATA TO FILE ";F1
3790 RETURN
3800 REM ** SUB: PLOT AND LABEL DEPTH TICKMARKS
3810 C4=C3/(Z0-Z9)
3820 H1=M1*(INT(Z9/M1)+1)
3830 G1=(H1-Z9)*C4
3840 MOVE B1,C2
3850 RMOVE -5.4,-0.5*K6
3860 PRINT USING "3D":Z9
3870 RMOVE 5.4,0.5*K6
3880 RMOVE 0,-G1
3890 GOSUB 3970
3900 FOR I=1 TO INT((Z0-Z9)/M1)
3910 RMOVE 0,-M1*C4
3920 H1=H1+M1
3930 IF H1>Z0 THEN 3960
3940 GOSUB 3970
3950 NEXT I
3960 RETURN
3970 REM ** SUB: TICKMARK PLOTTING
3980 RDRAW 0.2,0
3990 RMOVE B3-0.4,0
4000 RDRAW 0.2,0
4010 RMOVE 2,0
4020 RDRAW 0.2,0
4030 RMOVE B6-0.4,0
```

```
4040 RDRAW 0.2,0
4050 RMOVE 2,0
4060 RDRAW 0.2,0
4070 RMOVE B9-0.4,0
4080 RDRAW 0.2,0
4090 RMOVE B1-B8-5.4,-0.5*K6
4100 PRINT USING "3D":H1
4110 RMOVE 5.4,0.5*K6
4120 RETURN
4130 REM ** SUB: PLOT AND LABEL DENSITY TICKMARKS
4140 C4=B3/(D0-D9)
4150 H1=M2*(INT(D9/M2)+1)
4160 G1=(H1-D9)*C4
4170 MOVE B1,C2
4180 RMOVE G1,0
4190 GOSUB 4210
4200 GO TO 4280
4210 REM ** SUB: TICKMARK PLOTTING ACROSS TOP OF PLOT
4220 RDRAW 0,-0.2
4230 RDRAW 0,0.2
4240 RMOVE -1.2*K5,0
4250 PRINT USING "D.D":H1
4260 RMOVE 1.2*K5,0
4270 RETURN
4280 FOR I=1 TO INT((D0-D9)/M2)
4290 H1=H1+M2
4300 IF H1=>D0 THEN 4340
4310 RMOVE M2*C4,0
4320 GOSUB 4210
4330 NEXT I
4340 RETURN
4350 REM ** SUB: PLOT AND LABEL REFL COEFF TICKMARKS
4360 C4=B6/(R0-R9)
4370 H1=M4*(INT(R9/M4)+1)
4380 G1=(H1-R9)*C4
4390 MOVE B4,C1
4400 RMOVE G1,0
4410 GOSUB 4630
4420 FOR I=1 TO INT((R0-R9)/M4)
4430 H1=H1+M4
4440 IF H1=>R0 THEN 4480
4450 RMOVE M4*C4,0
4460 GOSUB 4630
4470 NEXT I
4480 RETURN
4490 REM ** SUB: PLOT AND LABEL IMPEDANCE TICKMARKS
4500 C4=B9/(A0-A9)
4510 H1=M5*(INT(A9/M5)+1)
4520 G1=(H1-A9)*C4
4530 MOVE B7,C1
4540 RMOVE G1,0
4550 GOSUB 4630
4560 FOR I=1 TO INT((A0-A9)/M5)
4570 H1=H1+M5
4580 IF H1=>A0 THEN 4620
4590 RMOVE M5*C4,0
4600 GOSUB 4630
4610 NEXT I
4620 RETURN
4630 REM ** SUB: TICKMARK PLOTTING ACROSS TOP AND BOTTOM.
4640 RDRAW 0,0.2
4650 RMOVE 0,C3-0.4
4660 RDRAW 0,0.2
4670 RMOVE -2.2*K5,0
4680 PRINT USING "2D.D":H1
4690 RMOVE 2.2*K5,-C3
```

```
4700 RETURN
4710 REM ** SUB: PLOT AND LABEL VELOCITY TICKMARKS
4720 C4=B3/(V0-V9)
4730 H1=M3*(INT(V9/M3)+1)
4740 G1=(H1-V9)*C4
4750 MOVE B1,C1
4760 RMOVE G1,0
4770 GOSUB 4850
4780 FOR I=1 TO INT((V0-V9)/M3)
4790 H1=H1+M3
4800 IF H1=>V0-0.01 THEN 4840
4810 RMOVE M3*C4,0
4820 GOSUB 4850
4830 NEXT I
4840 RETURN
4850 REM ** SUB: TICKMARK PLOTTING ACROSS BOTTOM OF PLOT
4860 RDRAW 0,0.2
4870 RDRAW 0,-0.2
4880 RMOVE -1.2*K5,-K6
4890 PRINT USING "D.D":H1
4900 RMOVE 1.2*K5,K6
4910 RETURN
4920 REM ** SUB: PLOT DENSITY VS. DEPTH
4930 DELETE Z8
4940 N8=2*N7-1
4950 WINDOW D9,D0,Z9,Z0
4960 VIEWPORT B1,B2,C1,C2
4970 Z7=Z0-Z7
4980 MOVE D(1),Z7
4990 Z8=(Z(1)-Z7)/N8
5000 FOR K=1 TO N7
5010 RDRAW 0,Z8
5020 RMOVE 0,Z8
5030 NEXT K
5040 RMOVE 0,-Z8
5050 FOR J=2 TO N6
5060 RDRAW D(J)-D(J-1),0
5070 Z8=(Z(J)-Z(J-1))/N8
5080 FOR K=1 TO N7
5090 RDRAW 0,Z8
5100 RMOVE 0,Z8
5110 NEXT K
5120 RMOVE 0,-Z8
5130 NEXT J
5140 RETURN
5150 REM ** SUB: PLOT VELOCITY VS. DEPTH
5160 WINDOW V9,V0,Z9,Z0
5170 MOVE V(1),Z7
5180 RDRAW 0,Z(1)-Z7
5190 FOR J=2 TO N6
5200 RDRAW V(J)-V(J-1),0
5210 RDRAW 0,Z(J)-Z(J-1)
5220 NEXT J
5230 RETURN
5240 REM ** SUB: PLOT REFLECTION COEFF VS DEPTH
5250 WINDOW R9,R0,Z9,Z0
5260 VIEWPORT B4,B5,C1,C2
5270 MOVE 0,Z7
5280 RDRAW 0,Z(1)-Z7
5290 FOR J=1 TO N6-1
5300 RDRAW R(J),0
5310 RDRAW -R(J),0
5320 RDRAW 0,Z(J+1)-Z(J)
5330 NEXT J
5340 RETURN
```

```
5350 REM ** SUB: PLOT ACOUSTIC IMPEDANCE VS. DEPTH
5360 WINDOW A9,A0,Z9,Z0
5370 VIEWPORT B7,B8,C1,C2
5380 MOVE A(1),Z7
5390 RDRAW 0,Z(1)-Z7
5400 FOR J=2 TO N6
5410 RDRAW A(J)-A(J-1),0
5420 RDRAW 0,Z(J)-Z(J-1)
5430 NEXT J
5440 RETURN
5450 REM ** SUB: STORE VALUES ON MDT
5460 PRINT "G_G_G___INSERT DATA TAPE TO STORE RESULTS IN 4924"
5470 N9=100+30*N6
5480 N9=INT(N9/256+1)*256
5490 PRINT "LENGTH OF FILE REQUIRED = ";N9
5500 PRINT "DOES FILE HAVE SUFFICIENT LENGTH? (Y/N) ";
5510 INPUT G$
5520 IF G$="Y" THEN 5590
5530 PRINT "G_G_G___INSERT DATA TAPE TO BE MARKED IN 4051"
5540 GOSUB 5960
5550 FIND F1
5560 MARK 1,N9
5570 PRINT "G_G_G___RETURN DATA TAPE TO 4924"
5580 GOSUB 5960
5590 FIND @2:F1
5600 WRITE @2:A$,U$,D$,L$,O$,C$,E1,N6,R,V,Z
5610 PRINT @2,2:
5620 REM ** CHECK ON READABILITY OF STORED DATA
5630 DELETE A$,U$,D$,L$,O$,C$,E1,N6,R,V,Z
5640 FIND @2:F1
5650 READ @2:A$,U$,D$,L$,O$,C$,E1,N6
5660 DIM R(N6),V(N6),Z(N6)
5670 READ @2:R,V,Z
5680 PRINT "DATA STORED IN AND RETRIEVABLE FROM FILE ";F1
5690 RETURN
5700 REM ** SUB: INPUT & CONDITION SAMPLE PROBLEM DATA FROM MDT
5710 PRINT "G_G_G___INSERT DATA TAPE IN 4924   FILE NUMBER = ";
5720 INPUT F0
5730 DELETE N1,N6,A1,D1,D,R1,T,T1,T2,V1,Z,Z4
5740 DIM H$(51),S$(16)
5750 FIND @2:F0
5760 READ @2:H$,S$,N1,N6
5770 DIM A1(N1),D1(N1),D(N6),R1(N1),T(N1),T1(N1),T2(N6),V1(N1)
5780 DIM Z(N1),Z8(N1)
5790 READ @2:A1,D1,D,R1,T,T1,T2,V1,Z,Z8
5800 DELETE D,R,T,T1,T2
5810 N0=N1
5820 Z7=0
5830 A$="SAMPLE PROBLEM DATA"
5840 PRINT "Sample prob no. (2 char,max) = ";
5850 INPUT U$
5860 U$="PROB "&U$
5870 PRINT "Date computed (12 char,max) = ";
5880 INPUT D$
5890 N4=0
5900 N5=0
5910 L$="LATITUDE"
5920 O$="LONGITUDE"
5930 C$="CO. $ STATE"
5940 E1=0
5950 RETURN
5960 REM ** SUB: READY TO PROCEED
5970 PRINT "__ARE YOU READY TO PROCEED? (Y/N) ";
5980 INPUT G$
5990 IF G$="N" THEN 5970
6000 RETURN
```

LISTING OF PROGRAM TO DEVELOP TIME/DEPTH
SECTION AND REFLECTIVITY SERIES

```
100 PRI "L_DEVELOP TIME-DEPTH (T/D) SECTION AND REFLECTIVITY SERIES (RS)"
110 INIT
120 DATA 1,10,50,60,80,82,130,10,92,0,1,81,2,86,0,1
130 READ B0,B1,B2,B4,B5,B7,B8,C1,C2,F1,K5,K6,M1,Q1
140 DIM A$(22),C$(25),D$(14),G$(1),L$(12),O$(13),U$(14),R$(50)
150 R$="REFLECTIVITY SERIES WITHOUT MULTIPLES"
160 PRINT "__G_G_G_INSERT Z & RC DATA TAPE IN 4924     FILE NUMBER = ";
170 INPUT F0
180 FIND @2:F0
190 READ @2:A$,U$,D$,L$,O$,C$,E1,N6
200 DIM R(N6),R5(N6),T1(N6),T2(N6),V(N6),V1(N6),V2(N6),Z(N6),Z1(N6)
210 READ @2:R,V,Z
220 PRI "__DO YOU WANT TO STORE RESULTS ON A T/D & RS DATA TAPE? (Y/N) ";
230 INPUT G$
240 IF G$="N" THEN 270
250 PRINT "   FILE NUMBER = ";
260 INPUT F1
270 GOSUB 790
280 GOSUB 980
290 GOSUB 1210
300 GOSUB 1120
310 PRINT "__DO YOU WANT TO INCLUDE TWO-BOUNCE MULTIPLES? (Y/N) ";
320 INPUT G$
330 IF G$="N" THEN 420
340 R$="REFLECTIVITY SERIES WITH MULTIPLES"
350 PRINT "LOWER LIMIT OF REFL COEFF TO BE USED IN % OF TOTAL RANGE = ";
360 INPUT E2
370 GOSUB 1330
380 GOSUB 4570
390 GOSUB 4740
400 GOSUB 5050
410 GO TO 450
420 DIM R9(N6),T9(N6)
430 R9=R5
440 T9=T2
450 PRINT "__DO YOU WANT PLOT OF VEL, T-D, AND REFL SERIES? (Y/N) ";
460 INPUT G$
470 IF G$="N" THEN 750
480 DIM F$(2),N$(21)
490 N$="REFLECTION TIME IN MS"
500 GOSUB 1770
510 GOSUB 1910
520 GOSUB 2240
530 GOSUB 2700
540 GOSUB 3030
550 GOSUB 3300
560 GOSUB 3460
570 T2=D3+D2-T2
580 GOSUB 3610
590 GOSUB 3730
600 GOSUB 3810
610 T9=D3+D2-T9
620 GOSUB 3890
630 GOSUB 4110
640 WINDOW 0,130,0,100
650 VIEWPORT 0,130,0,100
660 MOVE 0,0
670 PRINT
680 PRINT "L_DO YOU WANT TO REPLOT? (Y/N) ";
690 INPUT G$
700 IF G$="N" THEN 750
710 T2=D3+D2-T2
720 T9=D3+D2-T9
730 T5=D3+D2-T5
740 GO TO 510
```

```
750 IF F1=0 THEN 770
760 GOSUB 4200
770 PRINT "G_G_G_PROGRAM COMPLETED"
780 END
790 REM ** SUB: COMPUTE AVG AND RMS VELOCITIES AT INTERFACES
800 Z1(1)=Z(1)
810 FOR J=2 TO N6
820 Z1(J)=Z(J)-Z(J-1)
830 T1(J)=Z1(J)/V(J)
840 NEXT J
850 T1(1)=Z1(1)/V(1)
860 P3=0
870 T3=0
880 Z3=0
890 FOR J=1 TO N6
900 T3=T1(J)+T3
910 T2(J)=2*T3
920 Z3=Z1(J)+Z3
930 V1(J)=Z3/T3
940 P3=V(J)*V(J)*T1(J)+P3
950 V2(J)=SQR(P3/T3)
960 NEXT J
970 RETURN
980 REM ** SUB: COMPUTE TWO-WAY T/D FUNCTION IN METER INCREMENTS
990 DIM T5(Z(N6)),Z5(Z(N6))
1000 L=0
1010 T4=0
1020 FOR J=1 TO N6
1030 FOR K=1 TO Z1(J)
1040 L=L+1
1050 Z5(L)=L
1060 T4=1/V(J)+T4
1070 T5(L)=T4
1080 NEXT K
1090 NEXT J
1100 T5=2*T5
1110 RETURN
1120 REM ** SUB: COMPUTE AND APPLY SPHERICAL DIVERGENCE FACTOR
1130 DIM S(N6)
1140 S=1
1150 IF Q1=2 THEN 1200
1160 FOR J=1 TO N6
1170 S(J)=0.5/Z(J)
1180 R5(J)=S(J)*R5(J)
1190 NEXT J
1200 RETURN
1210 REM ** SUB: DEVELOP REFLECTIVITY SERIES WITH TRANSMISSION LOSSES
1220 DIM R6(N6)
1230 R6=1
1240 R3=1
1250 R5(1)=R(1)
1260 FOR J=2 TO N6
1270 R2=1-R(J-1)*R(J-1)
1280 R6(J-1)=R2
1290 R3=R2*R3
1300 R5(J)=R3*R(J)
1310 NEXT J
1320 RETURN
1330 REM ** SUB: DEVELOP REFLECTIVITY SERIES WITH TWO-BOUNCE MULTIPLES
1340 DIM R0(N6)
1350 R0=0
1360 R8=1
1370 R0(1)=R(1)
1380 FOR J=2 TO N6-1
1390 R8=R8*R6(J-1)
1400 R0(J)=R(J)*R8
```

```
1410 NEXT J
1420 R$="REFLECTIVITY SERIES INCLUDES TWO-BOUNCE MULTIPLES"
1430 REM ** DETERMINE NUMBER (M1) OF MULTIPLE REFLECTION
1440 M1=0
1450 FOR M=1 TO N6-2
1460 M1=M1+(N6-1-M)*M
1470 NEXT M
1480 PRINT "TOTAL NUMBER OF POSSIBLE TWO-BOUNCE MULTIPLES = ";M1
1490 M1=INT((MEMORY-18)/35)
1500 PRINT "AVAILABLE MEMORY ALLOWS ONLY FIRST ";M1;" MULTIPLES"
1510 DIM R1(M1),T6(M1),Z6(M1)
1520 J1=0
1530 FOR J=1 TO N6-2
1540 L1=1
1550 K1=J+1
1560 K2=K1-1
1570 FOR K=K1 TO N6-1
1580 K2=K2+1
1590 J1=J1+1
1600 IF J1=M1+1 THEN 1750
1610 T6(J1)=T2(K1)-T2(L1)+T2(K2)
1620 Z6(J1)=2*(Z(K1)-Z(L1)+Z(K2))
1630 R4=1
1640 IF K1=L1+1 THEN 1680
1650 FOR L=L1+1 TO K1-1
1660 R4=R6(L)*R4
1670 NEXT L
1680 R1(J1)=-R(K1)*R(L1)*R4*R0(K2)/Z6(J1)
1690 NEXT K
1700 L1=L1+1
1710 K1=K1+1
1720 IF K1=N6 THEN 1740
1730 GO TO 1560
1740 NEXT J
1750 DELETE Z6
1760 RETURN
1770 REM ** SUB: PLOT TIME-DEPTH, VELOCITES, AND REFL SERIES AS F(T)
1780 CALL "MIN",V2,V3,I1
1790 CALL "MAX",V2,V4,I2
1800 CALL "MIN",V1,V5,I1
1810 CALL "MAX",V1,V6,I2
1820 CALL "MIN",R9,C7,I1
1830 CALL "MAX",R9,C8,I2
1840 CALL "MIN",V,V7,I1
1850 CALL "MAX",V,V8,I2
1860 V3=V3 MIN V5
1870 V7=V3 MIN V7
1880 V4=V4 MAX V6
1890 V8=V4 MAX V8
1900 RETURN
1910 REM ** SUB: ENTER PLOT LIMITS
1920 PRINT "L_ENTER PLOT-LIMIT VALUES"
1930 PRINT "__Reflection time to top of layer 1 = ";
1940 INPUT D1
1950 PRINT "__Primary reflections range from ";T2(1);" to ";T2(N6-1)
1960 PRINT "Min. reflection time on plot = ";
1970 INPUT D2
1980 PRINT "Max. reflection time on plot = ";
1990 INPUT D3
2000 PRINT "Refl. time tickmark interval = ";
2010 INPUT D4
2020 PRINT "__Velocities range from ";V7;" to ";V8
2030 PRINT "        Min. velocity on plot = ";
2040 INPUT V9
2050 PRINT "        Max. velocity on plot = ";
2060 INPUT V0
```

```
2070 PRINT "  Velocity tickmark interval = ";
2080 INPUT M2
2090 PRINT "__Refl coeff's range from ";C7;" to ";C8
2100 PRINT "      Min. refl coeff on plot = ";
2110 INPUT C9
2120 PRINT "      Max. refl coeff on plot = ";
2130 INPUT C0
2140 PRINT "Refl coeff tickmark interval = ";
2150 INPUT M3
2160 PRINT "__Depths range from 0 to ";Z(N6)
2170 PRINT "           Min. depth on plot = ";
2180 INPUT D9
2190 PRINT "           Max. depth on plot = ";
2200 INPUT D0
2210 PRINT "      Depth tickmark interval = ";
2220 INPUT M4
2230 RETURN
2240 REM ** SUB: PRINT HEADING, PLOT BORDERS, AND LABEL AXES
2250 PRINT "L_Area: ";A$;"    Hole: ";U$;"    Date logged: ";D$
2260 RESTORE 2270
2270 DATA 1,10,58,60,80,82,130,10,92,1.81,2.86
2280 READ B0,B1,B2,B4,B5,B7,B8,C1,C2,K5,K6
2290 DIM F$(2),N$(21)
2300 N$="REFLECTION TIME IN MS"
2310 B3=B2-B1
2320 B6=B5-B4
2330 B9=B8-B7
2340 C3=C2-C1
2350 MOVE B1,C2
2360 RDRAW B3;0
2370 RDRAW 0,-C3
2380 RDRAW -B3,0
2390 RDRAW 0,C3
2400 MOVE B4,C2
2410 RDRAW B6,0
2420 RDRAW 0,-C3
2430 RDRAW -B6,0
2440 RDRAW 0,C3
2450 MOVE B7,C2
2460 RDRAW B9,0
2470 RDRAW 0,-C3
2480 RDRAW -B9,0
2490 RDRAW 0,C3
2500 MOVE 0.5*(B1+B2)-10*K5,C2+K6
2510 PRINT "VELOCITIES IN KM/SEC"
2520 MOVE 0.5*(B4+B5)-5.5*K5,C2+K6
2530 PRINT "REFL  COEFF"
2540 MOVE 0.5*(B7+B8)-7.5*K5,C2+K6
2550 PRINT "DEPTH IN METERS"
2560 MOVE 0,0.5*(C1+C2)+10*K6
2570 FOR I=1 TO LEN(N$)
2580 F$=SEG(N$,I,1)
2590 PRINT F$
2600 NEXT I
2610 MOVE 0.5*(B1+B2)-13*K5,C1-1*K6
2620 PRINT "AVG. VEL ++++  RMS VEL xxxx"
2630 MOVE 0,C1-2*K6
2640 PRINT "DATE FROM FILE:";F0;";RESULTS TO FILE:";F1
2650 MOVE B4+4*K5,C1-K6
2660 PRINT "LAT.=";L$;"   LONG.=";O$
2670 MOVE B4+4*K5,C1-2*K6
2680 PRINT C$;"  ELEV=";E1;"M"
2690 RETURN
2700 REM ** SUB: PLOT AND LABEL REFLECTION TIME TICKMARKS
2710 C4=C3/(D3-D2)
2720 H1=D4*(INT(D2/D4)+1)
```

```
2730 G1=(H1-D2)*C4
2740 MOVE B1,C2
2750 RMOVE -4*K5,-0.5*K6
2760 PRINT USING "4D":D2
2770 RMOVE 4*K5,0.5*K6
2780 RMOVE 0,-G1
2790 GOSUB 2870
2800 FOR I=1 TO INT((D3-D2)/D4)
2810 RMOVE 0,-D4*C4
2820 H1=H1+D4
2830 IF H1>D3 THEN 2860
2840 GOSUB 2870
2850 NEXT I
2860 RETURN
2870 REM ** SUB: TICKMARK PLOTTING
2880 RDRAW 0.2,0
2890 RMOVE B3-0.4,0
2900 RDRAW 0.2,0
2910 RMOVE 2,0
2920 RDRAW 0.2,0
2930 RMOVE B6-0.4,0
2940 RDRAW 0.2,0
2950 RMOVE 2,0
2960 RDRAW 0.2,0
2970 RMOVE B9-0.4,0
2980 RDRAW 0.2,0
2990 RMOVE B1-B8-4*K5,-0.5*K6
3000 PRINT USING "4D":H1
3010 RMOVE 4*K5,0.5*K6
3020 RETURN
3030 REM ** SUB: PLOT AND LABEL VELOCITY TICKMARKS
3040 J$="D.D"
3050 J1=1.2
3060 C4=B3/(V0-V9)
3070 H1=M2*(INT(V9/M2)+1)
3080 G1=(H1-V9)*C4
3090 MOVE B1,C2
3100 RMOVE G1,0
3110 GOSUB 3130
3120 GO TO 3230
3130 REM ** SUB: TICKMARK PLOTTING ACROSS TOP AND BOTTOM
3140 RDRAW 0,-0.2
3150 RMOVE 0,-C3+0.4
3160 RDRAW 0,-0.2
3170 RMOVE 0,C3
3180 IF H1=0 THEN 3220
3190 RMOVE -J1*K5,0
3200 PRINT USING J$:H1
3210 RMOVE J1*K5,0
3220 RETURN
3230 FOR I=1 TO INT((V0-V9)/M2)
3240 H1=H1+M2
3250 IF H1=>V0 THEN 3290
3260 RMOVE M2*C4,0
3270 GOSUB 3130
3280 NEXT I
3290 RETURN
3300 REM ** SUB: PLOT AND LABEL REFL COEFF TICKMARKS
3310 J$="2D.3D"
3320 J1=2.2
3330 C4=B6/(C0-C9)
3340 H1=M3*(INT(C9/M3)+1)
3350 G1=(H1-C9)*C4
3360 MOVE B4,C2
3370 RMOVE G1,0
3380 GOSUB 3130
```

```
3390 FOR I=1 TO INT((C0-C9)/M3)
3400 H1=H1+M3
3410 IF H1>C0 THEN 3450
3420 RMOVE M3*C4,0
3430 GOSUB 3130
3440 NEXT I
3450 RETURN
3460 REM ** SUB: PLOT AND LABEL DEPTH TICKMARKS
3470 J$="3D"
3480 C4=B9/(D0-D9)
3490 H1=M4*(INT(D9/M4)+1)
3500 G1=(H1-D9)*C4
3510 MOVE B7,C2
3520 RMOVE G1,0
3530 GOSUB 3130
3540 FOR I=1 TO INT((D0-D9)/M4)
3550 H1=H1+M4
3560 IF H1=>D0 THEN 3600
3570 RMOVE M4*C4,0
3580 GOSUB 3130
3590 NEXT I
3600 RETURN
3610 REM ** SUB: PLOT INTERVAL VELOCITY VS. REFLECTION TIME
3620 WINDOW V9,V0,D2,D3
3630 VIEWPORT B1,B2,C1,C2
3640 K7=B0*(V0-V9)/B3
3650 K8=B0*(D3-D2)/C3
3660 MOVE V(1),D3-D1
3670 RDRAW 0,T2(1)-D3+D1
3680 FOR J=2 TO N6
3690 RDRAW V(J)-V(J-1),0
3700 RDRAW 0,T2(J)-T2(J-1)
3710 NEXT J
3720 RETURN
3730 REM ** SUB: PLOT AVERAGE VELOCITY VS. REFLECTION TIME
3740 MOVE V1(1),T2(1)
3750 GOSUB 4410
3760 FOR J=2 TO N6
3770 DRAW V1(J),T2(J)
3780 GOSUB 4410
3790 NEXT J
3800 RETURN
3810 REM ** SUB: PLOT RMS VELOCITY VS. REFLECTION TIME
3820 MOVE V2(1),T2(1)
3830 GOSUB 4490
3840 FOR J=2 TO N6
3850 DRAW V2(J),T2(J)
3860 GOSUB 4490
3870 NEXT J
3880 RETURN
3890 REM ** SUB: PLOT REFLECTION COEFF VS REFLECTION TIME
3900 WINDOW C9,C0,D2,D3
3910 VIEWPORT B4,B5,C1,C2
3920 MOVE 0,D3-D1
3930 IF M1=0 THEN 4030
3940 DRAW 0,T9(1)
3950 RDRAW R9(1),0
3960 RDRAW -R9(1),0
3970 FOR J=2 TO N1
3980 RDRAW 0,T9(J)-T9(J-1)
3990 RDRAW R9(J),0
4000 RDRAW -R9(J),0
4010 NEXT J
4020 RETURN
4030 DRAW 0,T2(1)
4040 FOR J=1 TO N6-1
```

```
4050 RDRAW R9(J),0
4060 RDRAW -R9(J),0
4070 RDRAW 0,T2(J+1)-T2(J)
4080 DELETE R7,T7
4090 NEXT J
4100 RETURN
4110 REM ** SUB: PLOT DEPTH VS. REFLECTION TIME
4120 WINDOW D9,D0,D2,D3
4130 VIEWPORT B7,B8,C1,C2
4140 MOVE 0,D3
4150 T5=D3+D2-T5
4160 FOR J=1 TO Z(N6)
4170 DRAW Z5(J),T5(J)
4180 NEXT J
4190 RETURN
4200 REM ** SUB: STORE RESULTS ON MDT
4210 PRINT "G_G_G___INSERT T/D & RS DATA TAPE IN 4924"
4220 GOSUB 5180
4230 T9=D3+D2-T9
4240 IF M1=0 THEN 4280
4250 N7=N1
4260 GOSUB 5230
4270 GO TO 4300
4280 N7=N6
4290 GOSUB 5230
4300 FIND @2:F1
4310 WRITE @2:A$,U$,D$,L$,O$,C$,E1,N7,R$,R9,T9
4320 PRINT @2,2:
4330 REM ** CHECK ON READABILITY OF STORED DATA
4340 DELETE A$,U$,D$,L$,O$,C$,E1,N7,R$,R9,T9
4350 FIND @2:F1
4360 READ @2:A$,U$,D$,L$,O$,C$,E1,N7
4370 DIM R9(N7),T9(N7)
4380 READ @2:R$,R9,T9
4390 PRINT "DATA STORED IN AND RETRIEVED FROM FILE ";F1
4400 RETURN
4410 REM ** SUB: CROSS SYMBOL
4420 RDRAW -0.5*K7,0
4430 RDRAW K7,0
4440 RDRAW -0.5*K7,0
4450 RDRAW 0,-0.5*K8
4460 RDRAW 0,K8
4470 RDRAW 0,-0.5*K8
4480 RETURN
4490 REM ** SUB: X SYMBOL
4500 RDRAW -0.5*K7,0.5*K8
4510 RDRAW K7,-K8
4520 RDRAW -0.5*K7,0.5*K8
4530 RDRAW -0.5*K7,-0.5*K8
4540 RDRAW K7,K8
4550 RDRAW -0.5*K7,-0.5*K8
4560 RETURN
4570 REM ** SUB: COMBINE PRIMARY AND MULTIPLE REFLECTIVITY SERIES
4580 N7=N6+M1-1
4590 DIM R7(N7),T7(N7)
4600 FOR N=1 TO N6-1
4610 T7(N)=T2(N)
4620 R7(N)=R5(N)
4630 NEXT N
4640 DELETE R5
4650 L=0
4660 FOR N=N6 TO M1+N6-1
4670 L=L+1
4680 T7(N)=T6(L)
4690 R7(N)=R1(L)
4700 NEXT N
```

```
4710 N1=N-1
4720 DELETE T6,R1
4730 RETURN
4740 REM ** SUB: ELIMINATE REFLECTION COEFFICIENTS < E2% OF RANGE
4750 DIM A1(N1),A2(N1)
4760 A1=0
4770 A2=0
4780 E2=0.01*E2
4790 CALL "MIN",R7,M7,I7
4800 CALL "MAX",R7,M8,I8
4810 M9=ABS(E2*(M8-M7))
4820 L=0
4830 FOR J=1 TO N1
4840 IF ABS(R7(J))<M9 THEN 4880
4850 L=L+1
4860 A1(L)=R7(J)
4870 A2(L)=T7(J)
4880 NEXT J
4890 PRINT "__TOTAL NUMBER OF PRIMARY + MULTIPLE REFLECTIONS = ";L
4900 PRINT "__DO YOU WANT TO RESELECT LOWER LIMIT ON MULTIPLES? (Y/N) ";
4910 INPUT G$
4920 IF G$="N" THEN 4960
4930 PRI "LOWER LIMIT OF REFL COEFF TO BE USED IN % OF TOTAL RANGE = ";
4940 INPUT E2
4950 GO TO 4760
4960 N1=L
4970 DELETE R7,T7
4980 DIM R7(N1),T7(N1)
4990 FOR J=1 TO N1
5000 R7(J)=A1(J)
5010 T7(J)=A2(J)
5020 NEXT J
5030 DELETE A1,A2
5040 RETURN
5050 REM ** ORDER REFLECTIVITY SERIES IN VALUES OF INCREASING TIME
5060 DIM R9(N1),T9(N1)
5070 CALL "MAX",T7,M3,I3
5080 J1=M3+10
5090 L=0
5100 FOR J=1 TO N1
5110 L=L+1
5120 CALL "MIN",T7,M2,I2
5130 T9(L)=T7(I2)
5140 R9(L)=R7(I2)
5150 T7(I2)=J1
5160 NEXT J
5170 RETURN
5180 REM ** SUB: READY TO PROCEED?
5190 PRINT "__ARE YOU READY TO PROCEED? (Y/N) ";
5200 INPUT G$
5210 IF G$="N" THEN 5190
5220 RETURN
5230 REM ** SUB: ESTABLISH DATA FILE
5240 N9=120+20*N7
5250 N9=INT(N9/256+1)*256
5260 PRINT "   LENGTH OF FILE REQUIRED = ";N9
5270 PRINT "   DOES SELECTED FILE HAVE SUFFICIENT LENGTH? (Y/N) ";
5280 INPUT G$
5290 IF G$="Y" THEN 5360
5300 PRINT "G_G_G___INSERT T/D & RS DATA TAPE TO BE MARKED IN 4051"
5310 GOSUB 5180
5320 FIND F1
5330 MARK 1,N9
5340 PRINT "G_G_G___RETURN T/D & RS DATA TAPE TO 4924"
5350 GOSUB 5180
5360 RETURN
```

# LISTING OF PROGRAM TO GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELETS

```
100 PRINT "L_GENERATE AND STORE FOURIER COEFFICIENTS OF WAVELET"
110 INIT
120 PRINT "__DESIRED MAXIMUM ABSOLUTE AMPLITUDE OF WAVELET = ";
130 INPUT M4
140 DIM G$(1),M$(5),N$(10)
150 PRINT "__THE FOLLOWING WAVELET TYPES ARE AVAILABLE:"
160 PRINT "   1. Cosine modulated sine, zero phase approximation";
170 PRINT ", 2.5 cycles"
180 PRINT "   2. Damped cos mod. sine, minimum phase approximation";
190 PRINT ", 2 cycles"
200 PRINT "   3. Directly observed--extracted from seismogram"
210 PRINT "   4. Arbitrary -- values entered from keyboard"
220 PRINT "   5. Ricker ""far distant"" wavelet"
230 PRINT "__NUMBER OF SELECTED WAVELET TYPE = ";
240 INPUT N9
250 GO TO N9 OF 260,280,300,320,340
260 GOSUB 470
270 GO TO 350
280 GOSUB 610
290 GO TO 350
300 GOSUB 840
310 GO TO 350
320 GOSUB 1480
330 GO TO 350
340 GOSUB 1630
350 REM ** SCALE TO SELECTED MAX ABS AMPL OF WAVELET
360 GOSUB 3190
370 REM ** PLOT WAVELET
380 GOSUB 2580
390 REM ** COMPUTE FIRST N2 FOURIER COEFFICIENTS
400 GOSUB 1800
410 REM ** FOURIER SYNTHESIZE AND PLOT SYNTHESIZED WAVELET
420 GOSUB 2160
430 REM ** STORE FOURIER COEFFICIENTS ON WAVELET DATA TAPE (WDT)
440 GOSUB 2880
450 PRINT "__G_G_G_PROGRAM COMPLETED"
460 END
470 REM ** SUB: GENERATE WAVELET USING A COSINE-MODULATED SINE WAVE
480 T$="WAVELET USING A COSINE-MODULATED SINE WAVE"
490 N1=21
500 DIM V(N1)
510 Q3=1
520 N4=2.5
530 K1=2*PI/(N1-1)
540 FOR K=1 TO N1
550 V(K)=0.5*(1-COS(K1*(K-1)))
560 K2=N4*K1
570 V(K)=V(K)*SIN(K2*(K-1))
580 NEXT K
590 N2=7
600 RETURN
610 REM ** SUB: GENERATE WAVELET USING A DAMPED COS-MODULATED SINE
620 T$="WAVELET USING A DAMPED COS-MODULATED SINE"
630 N1=41
640 Q3=2
650 DIM V(N1)
660 N3=N1-1
670 N4=2
680 PRINT "            DECREMENT IN PERCENT = ";
690 INPUT N6
700 IF N6<>100 THEN 720
710 N6=1.0E-3
720 N5=LOG(N6/100)
730 PRINT "                    LOG DECREMENT = ";N5
```

```
740 K1=2*PI*N4/N3
750 A1=N5*N4/N3
760 V(1)=0
770 FOR J=1 TO N1
780 K6=J-1
790 K3=EXP(A1*K6)
800 V(J)=K3*SIN(K1*K6)*(1-COS(K1/N4*K6))
810 NEXT J
820 N2=(N1-1)/2
830 RETURN
840 REM ** SUB: OBSERVED WAVELET FROM SEISMOGRAM
850 T$="OBSERVED WAVELET"
860 Q3=3
870 PRINT "G_G_G___INSERT OBSERVED-DATA MDT IN 4924    MDT CODE NO.  = ";
880 INPUT M$
890 GOSUB 3320
900 PRINT "     NO. OF CYCLES IN WAVELET = ";
910 INPUT N4
920 PRINT "          RECORD NUMBER ON MDT = ";
930 INPUT R3
940 R1=12*R3-10
950 PRINT "                     TRACE NUMBER = ";
960 INPUT R2
970 F0=R1+R2-1
980 REM ** FIND, RETRIEVE, AND DECODE HEADER FILE
990 DIM H$(10), I$(3), L$(4)
1000 FIND @2:R1
1010 READ @2:H$
1020 I$=SEG(H$,4,1)
1030 L$=SEG(H$,5,2)
1040 S1=VAL(I$)
1050 L=VAL(L$)*10
1060 GO TO S1 OF 1070,1090,1110,1130,1150,1170
1070 S1=0.05
1080 GO TO 1180
1090 S1=0.1
1100 GO TO 1180
1110 S1=0.2
1120 GO TO 1180
1130 S1=0.5
1140 GO TO 1180
1150 S1=1
1160 GO TO 1180
1170 S1=2
1180 PRINT "    TIME AT START OF WAVELET = ";
1190 INPUT T9
1200 PRINT "      TIME AT END OF WAVELET = ";
1210 INPUT T0
1220 T1=T0-T9
1230 J1=3*INT((T9-L)/S1)+1
1240 N1=INT(T1/S1+1)
1250 J3=3*N1
1260 DIM D$(3005), V(N1)
1270 REM ** FIND, RETRIEVE, CONVERT AND SCALE DATA -
1280 FIND @2:F0
1290 IF F0=R1 THEN 1320
1300 READ @2:D$
1310 GO TO 1330
1320 READ @2:H$, D$
1330 D$=SEG(D$, J1, J3)
1340 V=0
1350 CALL "HEXDEC", D$, V, LEN(D$), 3
1360 DELETE D$
1370 V=V-511
1380 REM ** DETREND WAVELET
1390 C1=(V(N1)-V(1))/(N1-1)
```

```
1400 FOR K=2 TO N1
1410 V(K)=V(K)-C1*(K-1)
1420 NEXT K
1430 V=V-V(1)
1440 N2=(N1-1)/2
1450 IF N2<=20 THEN 1470
1460 N2=20
1470 RETURN
1480 REM ** SUB: GENERATE WAVELET USING ARBITRARY VALUES FROM KEYBOARD
1490 T$="WAVELET USING ARBITRARY VALUES"
1500 Q3=4
1510 PRINT "        NO. OF VALUES IN WAVELET = ";
1520 INPUT N1
1530 DIM V(N1)
1540 PRINT "        NO. OF CYCLES IN WAVELET = ";
1550 INPUT N4
1560 PRINT "INDEX   VALUE"
1570 FOR J=1 TO N1
1580 PRINT "  "; J; "        ";
1590 INPUT V(J)
1600 NEXT J
1610 N2=(N1-1)/2
1620 RETURN
1630 REM ** SUB: GENERATE "FAR DISTANT" RICKER WAVELET
1640 T$="RICKER ""FAR DISTANT"" WAVELET"
1650 N1=41
1660 DIM V(N1)
1670 N4=1.5
1680 Q3=5
1690 P3=0.05*PI
1700 P2=0.5*(N1+1)
1710 FOR J=1 TO N1
1720 P4=P3*(J-P2)*P3*(J-P2)
1730 IF P4>9.8 THEN 1750
1740 V(J)=(1-2*P4)*EXP(-P4)
1750 NEXT J
1760 V(1)=0
1770 V(N1)=0
1780 N2=20
1790 RETURN
1800 REM ** SUB: GENERATE FIRST N2 FOURIER COEFFICIENTS
1810 N3=N1-1
1820 Q1=PI/N3
1830 DIM B(N2),C(N3)
1840 B=0
1850 C=0
1860 FOR K=1 TO N2
1870 FOR I=2 TO N3
1880 C(I)=A(I)*SIN(Q1*K*(I-1))
1890 NEXT I
1900 B(K)=SUM(C)*2/N3
1910 NEXT K
1920 DELETE A,C
1930 PRINT "__FOURIER COEFFICIENTS FOR "; T$
1940 PRINT "__HARMONIC    FOURIER COEFFICIENT"
1950 IMAGE 2X,3D,10X,4D.6D
1960 FOR K=1 TO N2
1970 PRINT USING 1950:K,B(K)
1980 NEXT K
1990 REM ** SUB: PLOT LINE SPECTRA
2000 WINDOW 0,N2,-M4,M4
2010 VIEWPORT 0,120,6,40
2020 MOVE 0,0
2030 PRINT "LINE SPECTRA"
2040 VIEWPORT 25,120,6,40
2050 MOVE 0,0
```

```
2060 FOR J=1 TO N2
2070 RMOVE 1,0
2080 RDRAW 0,B(J)
2090 RDRAW 0,-B(J)
2100 NEXT J
2110 RDRAW -N2,0
2120 WINDOW 0,130,0,100
2130 VIEWPORT 0,130,0,100
2140 MOVE 0,6
2150 RETURN
2160 REM ** SUB: FOURIER SYNTHESIS OF FIRST N2 HARMONICS
2170 PRINT "DO YOU WANT TO SEE FOURIER SYNTHESIZED WAVELET? (Y/N) ";
2180 INPUT G$
2190 IF G$="N" THEN 2570
2200 DELETE S
2210 DIM Z(N2)
2220 Z=ABS(B)
2230 CALL "MAX",Z,Z1,Z2
2240 DELETE Z
2250 M5=1.0E-3*Z1
2260 Q1=PI/N3
2270 DIM S(N2,N1)
2280 S=0
2290 B2=ABS(B(1))
2300 IF B2<M5 THEN 2350
2310 REM ** COMPUTE CONTRIBUTION OF FUNDAMENTAL
2320 FOR K=2 TO N1
2330 S(1,K)=B(1)*SIN(Q1*(K-1))
2340 NEXT K
2350 REM ** COMPUTE CONTRIBUTION OF HARMONICS
2360 FOR J=2 TO N2
2370 B2=ABS(B(J))
2380 FOR K=2 TO N1
2390 IF B2<M5 THEN 2420
2400 S(J,K)=B(J)*SIN(Q1*J*(K-1))
2410 GO TO 2430
2420 S(J,K)=0
2430 S(J,K)=S(J-1,K)+S(J,K)
2440 NEXT K
2450 NEXT J
2460 DELETE A
2470 DIM A(N1)
2480 FOR K=1 TO N1
2490 A(K)=S(N2,K)
2500 NEXT K
2510 REM ** PLOT FOURIER SYNTHESIZED WAVELET
2520 PRINT "L_FOURIER SYNTHESIS OF ";T$
2530 IF Q3<>3 THEN 2560
2540 PRI "FROM MDT:";M$;", REC#:";R3;", TRACE#:";R2;", FROM T=";T9;" ";
2550 PRINT "to ";T0
2560 GOSUB 2780
2570 RETURN
2580 REM ** SUB: QUICK PLOT OF WAVELET
2590 PRINT "__DO YOU WANT QUICK PLOT OF INPUT WAVELET? (Y/N) ";
2600 INPUT G$
2610 IF G$="N" THEN 2870
2620 IMAGE 54X,"K_LOG DEC. =",2D.2D
2630 PRINT "L_";T$
2640 GO TO Q3 OF 2650,2680,2720,2760
2650 PRINT "NO. OF VALUES=";N1;"      NO. OF CYCLES=";N4;"       MAX. ";
2660 PRINT " ABS. AMPL=";M4
2670 GO TO 2780
2680 PRINT "NO. OF VALUES=";N1;" NO. OF CYCLES=";N4;"  MAX. ABS. ";
2690 PRINT " AMPL=";M4
2700 PRINT USING 2620:N5
2710 GO TO 2780
```

```
2720 PRI "FROM MDT:";M$;", REC#:";R3;", TRACE#:";R2;", FROM T=";T9;" ";
2730 PRINT "to ";T0
2740 PRINT "NO. OF VALUES=";N1;"  MAX. ABS. AMPL=";M4;"  ";
2750 GO TO 2780
2760 PRINT "NO. OF VALUES=";N1;"    NO. OF CYCLES=";N4;"     MAX. ";
2770 PRINT " ABS. AMPL=";M4
2780 WINDOW 1,N1,-M4,M4
2790 VIEWPORT 10,120,6,86
2800 MOVE 0,0
2810 RDRAW N1,0
2820 CALL "DISP",A
2830 WINDOW 0,130,0,100
2840 VIEWPORT 0,130,0,100
2850 MOVE 0,0
2860 PRINT
2870 RETURN
2880 REM ** SUB: STORE FOURIER COEFFICIENTS ON WAVELET DATA TAPE (WDT)
2890 PRINT "DO YOU WANT TO STORE FOURIER COEFF. ON WDT? (Y/N) ";
2900 INPUT G$
2910 IF G$="N" THEN 3180
2920 PRINT "CODE NAME OF WDT = ";
2930 INPUT N$
2940 PRINT "FILE NO.=";
2950 INPUT F0
2960 N6=50+10*N2
2970 N6=INT(N6/256+1)*256
2980 PRINT "LENGTH OF FILE REQUIRED = ";N6
2990 PRINT "DOES SELECTED FILE HAVE SUFFICIENT LENGTH? (Y/N) ";
3000 INPUT G$
3010 IF G$="Y" THEN 3080
3020 PRINT "G_G_G_  INSERT WDT TO BE MARKED IN 4051"
3030 GOSUB 3320
3040 FIND F0
3050 MARK 1,N6
3060 PRINT "G_G_G_  RETURN WDT TO 4924"
3070 GOSUB 3320
3080 FIND @2:F0
3090 WRITE @2:N2,T$,B
3100 PRINT @2,2:
3110 REM ** CHECK ON READABILITY OF DATA STORED ON MDT
3120 DELETE N2,T$,B
3130 FIND @2:F0
3140 READ @2:N2
3150 DIM T$(50),B(N2)
3160 READ @2:T$,B
3170 PRINT "DATA ARE STORED IN FILE ";F0;" OF WDT: ";N$
3180 RETURN
3190 REM ** SUB: SCALE TO ABSOLUTE MAXIMUM VALUE
3200 DELETE A
3210 DIM A(N1)
3220 A=V
3230 DELETE V
3240 CALL "MIN",A,M1,I1
3250 CALL "MAX",A,M2,I2
3260 M1=ABS(M1)
3270 M2=ABS(M2)
3280 M3=M1 MAX M2
3290 S2=M4/M3
3300 A=S2*A
3310 RETURN
3320 REM ** SUB: READY TO PROCEED?
3330 PRINT "ARE YOU READY TO PROCEED? (Y/N) ";
3340 INPUT G$
3350 IF G$="N" THEN 3330
3360 RETURN
```

LISTING OF PROGRAM TO COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM

```
100 PRINT "L_COMPUTE AND DISPLAY SYNTHETIC SEISMOGRAM"
110 INIT
120 Q1=1
130 Q2=1
140 DIM A$(22),C$(25),D$(14),F$(4),G$(1),L$(12),M$(29)
150 DIM O$(13),P$(60),Q$(28),R$(50),S$(41),U$(14),W$(50)
160 S$="SYNTHETIC SEISMOGRAM DATA"
170 REM ** OPTION TO READ PREVIOUSLY COMPUTED SYN SEIS DATA
180 GOSUB 500
190 REM ** READ REFLECTIVITY SERIES DATA FROM T/D-RS DATA TAPE
200 GOSUB 600
210 REM ** READ WAVELET DATA FROM WDT
220 GOSUB 770
230 IF Q2=1 THEN 260
240 GOSUB 1740
250 GO TO 320
260 REM ** SYNTHESIZE WAVELET
270 GOSUB 1050
280 REM ** PLOT WAVELET
290 GOSUB 1740
300 REM ** STORE WAVELET
310 GOSUB 1450
320 REM ** ENTER START AND END TIMES OF RECORD
330 GOSUB 1950
340 REM ** COMPUTE FIXED GAIN SYNTHETIC SEISMOGRAM
350 GOSUB 2030
360 REM ** STORE FIXED GAIN SYNTHETIC SEISMOGRAM
370 GOSUB 2210
380 REM ** SELECT TYPE AND COMPUTE GAIN FUNCTION
390 GOSUB 2270
400 REM ** DISPLAY SYNTHETIC SEISMOGRAM
410 GOSUB 2410
420 GOSUB 2540
430 GOSUB 3220
440 REM ** REPLOT SYNTHETIC SEISMOGRAM
450 GOSUB 3340
460 REM ** STORE ADJUSTED GAIN SYNTHETIC SEISMOGRAM
470 GOSUB 3400
480 PRINT "G_G_G___PROGRAM COMPLETED"
490 END
500 REM ** SUB: READ PREVIOUSLY COMPUTED SYN SEIS DATA
510 PRINT "__DO YOU WANT TO USE PREVIOUSLY COMPUTED SYNTHETICS? (Y/N) ";
520 INPUT G$
530 IF G$="N" THEN 590
540 Q1=2
550 PRINT "G_G_G_INSERT SYN SEIS DATA TAPE IN 4924    FILE NO. = ";
560 INPUT F2
570 GOSUB 3710
580 GO TO 380
590 RETURN
600 REM ** SUB: READ REFLECTIVITY SERIES DATA FROM T/D-RS DATA TAPE
610 PRINT "__G_G_G_INSERT T/D-RS DATA TAPE IN 4924   FILE NO. = ";
620 INPUT F0
630 FIND @2:F0
640 READ @2:A$,U$,D$,L$,O$,C$,E1,N1,R$
650 DIM R(N1),T(N1)
660 READ @2:R,T
670 PRINT "__DO YOU WANT TO SEE REFLECTIVITY SERIES DATA? (Y/N) ";
680 INPUT G$
690 IF G$="N" THEN 760
700 PRINT "__          DATA READ FROM T/D-RS DATA TAPE__"
710 PRINT A$,U$,D$,L$,O$,C$,E1,N1,R$
720 PRINT "__REFLECTIVITY SERIES:"
730 PRINT R
740 PRINT "REFLECTION TIME TO BASE OF LAYER:"
```

```
750 PRINT T
760 RETURN
770 REM ** SUB: READ WAVELET DATA FROM WDT
780 PRINT "__G_G_G_INSERT WAVELET DATA TAPE (WDT) IN 4924"
790 PRINT "__DO YOU WANT TO SYNTHESIZE WAVELET? (Y/N) ";
800 INPUT G$
810 IF G$="Y" THEN 900
820 Q2=2
830 PRINT "__YOU HAVE ELECTED TO USE ESTABLISHED WAVELET    FILE NO. = ";
840 INPUT F1
850 FIND @2:F1
860 READ @2:N2,L1,W$,S1
870 DIM W1(N2)
880 READ @2:W1
890 RETURN
900 PRINT " NO. OF FILE CONTAINING FOURIER COEFF. = ";
910 INPUT F1
920 FIND @2:F1
930 READ @2:N3,W$
940 DIM B(N3)
950 READ @2:B
960 PRINT "     TYPE OF WAVELET = ";W$
970 PRINT "NO. OF COEFFICIENTS = ";N3
980 PRINT "  LENGTH OF WAVELET = ";
990 INPUT L1
1000 PRINT "WAVELET SAMPLE INT. = ";
1010 INPUT S1
1020 N2=INT(L1/S1+1)
1030 PRINT "  POINTS IN WAVELET = ";N2
1040 RETURN
1050 REM ** SUB: FOURIER SYNTHESIS OF FIRST N3 HARMONICS
1060 CALL "MAX",B,M3,I3
1070 M5=0.01*M3
1080 N4=N2-1
1090 Q1=PI/N4
1100 DIM S(N3,N2)
1110 S=0
1120 B2=ABS(B(1))
1130 IF B2<M5 THEN 1180
1140 REM ** COMPUTE CONTRIBUTION OF FUNDAMENTAL
1150 FOR K=2 TO N2
1160 S(1,K)=B(1)*SIN(Q1*(K-1))
1170 NEXT K
1180 REM ** COMPUTE CONTRIBUTION OF HARMONICS
1190 FOR J=2 TO N3
1200 B2=ABS(B(J))
1210 FOR K=2 TO N2
1220 IF B2<M5 THEN 1250
1230 S(J,K)=B(J)*SIN(Q1*J*(K-1))
1240 GO TO 1260
1250 S(J,K)=0
1260 S(J,K)=S(J-1,K)+S(J,K)
1270 NEXT K
1280 NEXT J
1290 DELETE W1
1300 DIM W1(N2)
1310 FOR K=1 TO N2
1320 W1(K)=S(N3,K)
1330 NEXT K
1340 DELETE S
1350 RETURN
1360 REM ** SUB: ENTER START AND END TIMES OF RECORD
1370 PRINT "__  NUMBER OF REFLECTIONS = ";N1
1380 PRINT "START TIME OF SYNTHETIC = ";
1390 INPUT T0
```

```
1400 T7=T0
1410 PRINT "  END TIME OF SYNTHETIC = ";
1420 INPUT T9
1430 N5=(T9-T7)/S1+1
1440 RETURN
1450 REM ** SUB: STORE WAVELET
1460 PRINT "__DO YOU WANT TO STORE WAVELET ON WDT? (Y/N) ";
1470 INPUT G$
1480 IF G$="N" THEN 1750
1490 PRINT "G_G_G_INSERT WDT IN 4924    FILE NO. = ";
1500 INPUT F3
1510 L2=50+10*N2
1520 L2=INT(L2/256+1)*256
1530 PRINT "LENGTH OF FILE REQUIRED = ";L2
1540 PRINT "IS FILE LENGTH SUFFICIENT? (Y/N) ";
1550 INPUT G$
1560 IF G$="Y" THEN 1630
1570 PRINT "G_G_G_INSERT WDT IN 4051"
1580 GOSUB 3490
1590 FIND F3
1600 MARK 1,L2
1610 PRINT "G_G_G_RETURN WDT TO 4924"
1620 GOSUB 3490
1630 FIND @2:F3
1640 WRITE @2:N2,L1,W$,S1,W1
1650 PRINT @2,2:
1660 REM ** VERIFY TAPE WRITE
1670 DELETE N2,L1,W$,S1,W1
1680 FIND @2:F3
1690 READ @2:N2
1700 DIM W1(N2)
1710 READ @2:L1,W$,S1,W1
1720 PRINT "DATA ARE STORED AND RETRIEVABLE FROM FILE ";F3
1730 RETURN
1740 REM ** SUB: PLOT WAVELET
1750 PRINT "__DO YOU WANT TO SEE PLOT OF WAVELET? (Y/N) ";
1760 INPUT G$
1770 IF G$="N" THEN 2030
1780 REM ** PLOT OF WAVELET
1790 PRINT "L_";L1;" MSEC ";W$;" WITH S. I. =";S1
1800 PRINT "WAVELET CONTAINS ";N2;" DATA POINTS"
1810 CALL "MIN",W1,M1,I3
1820 CALL "MAX",W1,M2,I4
1830 IMAGE"AMPLITUDE OF WAVELET RANGES FROM ",3D.2D," TO ",3D.2D
1840 PRINT USING 1830:M1,M2
1850 WINDOW 1,N2,M1,M2
1860 VIEWPORT 5,125,30,85
1870 MOVE 0,0
1880 RDRAW N2,0
1890 CALL "DISP",W1
1900 WINDOW 0,130,0,100
1910 VIEWPORT 0,130,0,100
1920 MOVE 0,0
1930 PRINT
1940 RETURN
1950 REM ** SUB: ENTER START AND END TIMES OF RECORD
1960 PRINT "START TIME OF SYNTHETIC = ";
1970 INPUT T0
1980 T7=T0
1990 PRINT "  END TIME OF SYNTHETIC = ";
2000 INPUT T9
2010 N5=(T9-T7)/S1+1
2020 RETURN
2030 REM ** SUB: COMPUTE FIXED GAIN SYNTHETIC SEISMOGRAM
2040 DIM I1(N1),S(N5)
```

```
2050 S=0
2060 FOR J=1 TO N1
2070 IF T(J)<T7 THEN 2180
2080 I1(J)=(T(J)-T7)/S1+1
2090 NEXT J
2100 FOR J=1 TO N1
2110 FOR K=1 TO N2
2120 L=I1(J)-1+K
2130 IF L>T9/S1+1 THEN 2170
2140 S(L)=R(J)*W1(K)+S(L)
2150 NEXT K
2160 NEXT J
2170 RETURN
2180 PRINT "G_G_G___ERROR: START TIME GREATER THAN REFLECTION TIME TO BASE";
2190 PRINT " OF FIRST LAYER"
2200 GO TO 260
2210 REM ** SUB: STORE FIXED GAIN SYN SEIS
2220 PRINT "__DO YOU WANT TO STORE FIXED GAIN SYN.SEIS ON SSDT? (Y/N) ";
2230 INPUT G$
2240 IF G$="N" THEN 2260
2250 GOSUB 3530
2260 RETURN.
2270 REM ** SUB: SELECT GAIN FUNCTION
2280 PRINT "__THREE DISPLAY OPTIONS ARE AVAILABLE:"
2290 PRINT "    1. FIXED GAIN OVER ENTIRE RECORD,"
2300 PRINT "    2. SELECTED GAIN WITHIN SEGMENTS, AND"
2310 PRINT "    3. PROGRAMED GAIN CONTROL (PGC)."
2320 PRINT "__NUMBER OF DISPLAY OPTION CHOSEN = ";
2330 INPUT O1
2340 GO TO O1 OF 2350,2370,2390
2350 GOSUB 3820
2360 GO TO 2400
2370 GOSUB 3860
2380 GO TO 2400
2390 GOSUB 4270
2400 RETURN
2410 REM ** SUB: RANGES OF SYNTHETIC
2420 PRINT "__SYNTHETIC STARTS AT ";T7;" AND ENDS AT ";T9;" MSEC"
2430 CALL "MIN",S,M1,I3
2440 CALL "MAX",S,M2,I4
2450 PRINT "AMPLITUDES RANGE FROM ";M1;" TO ";M2
2460 PRINT "SAMPLE INTERVAL FOR SYNTHETIC: ";S1;" MSEC"
2470 N6=(T9-T7)/S1+1
2480 PRINT "TOTAL NUMBER OF VALUES IN SYNTHETIC: ";N6
2490 PRINT "__MINIMUM AMPLITUDE ON PLOT = ";
2500 INPUT M1
2510 PRINT "MAXIMUM AMPLITUDE ON PLOT = ";
2520 INPUT M2
2530 RETURN
2540 REM ** SUB: DRAW BORDER AND PLOT TICKMARKS
2550 WINDOW 0,130,0,100
2560 VIEWPORT 0,130,0,100
2570 M$="PLOT AMPLITUDES RANGE FROM "
2580 Q$=" BETWEEN ORDINAL TICKMARKS"
2590 MOVE 0,95
2600 PRINT "L_SYNTHETIC SEISMOGRAM--";R$
2610 PRINT "    ";L1;" MSEC ";W$;" WITH S.I.=";S1
2620 IF Q2=2 THEN 2660
2630 PRINT "REFL SERIES FROM FILE ";F0;" AND WAVELET'S ";
2640 PRINT "FOURIER COMPONENTS FROM FILE ";F1
2650 GO TO 2680
2660 PRINT "REFLECTIVITY SERIES FROM FILE ";F0;" AND WAVELET'S ";
2670 PRINT "VALUES FROM FILE ";F1
2680 PRINT "AMPLITUDE MODE: ";P$
2690 IMAGE 27A,3D.2D," TO ",3D.2D.26A
```

```
2700 PRINT USING 2690:M$,M1,M2,Q$
2710 RESTORE 2720
2720 DATA 1,5,125,10,80
2730 READ B0,C0,C1,D0,D1
2740 C2=C1-C0
2750 C3=C2/50
2760 D2=D1-D0
2770 D3=0.5*D2
2780 MOVE C0,D1
2790 RDRAW C2,0
2800 RDRAW 0,-D2
2810 RDRAW -C2,0
2820 RDRAW 0,D2
2830 REM ** ORDINAL TICKMARKS
2840 D4=4
2850 MOVE C0,D1-D4
2860 RDRAW 1,0
2870 RMOVE C2-2,0
2880 RDRAW 1,0
2890 MOVE C0,D0+D4
2900 RDRAW 1,0
2910 RMOVE C2-2,0
2920 RDRAW 1,0
2930 MOVE C0,D1
2940 GOSUB 2960
2950 GO TO 3080
2960 REM ** SUB: TICKMARKS AND TIME LINES
2970 FOR J=1 TO 10
2980 FOR K=1 TO 4
2990 RMOVE C3,0
3000 RDRAW 0,-B0
3010 RDRAW 0,B0
3020 NEXT K
3030 RMOVE C3,0
3040 RDRAW 0,-D3
3050 RDRAW 0,D3
3060 NEXT J
3070 RETURN
3080 MOVE C0,D0
3090 D3=-D3
3100 B0=-B0
3110 GOSUB 2960
3120 REM ** LABEL TIME LINES
3130 IMAGE 3D
3140 B4=(T9-T7)/10
3150 MOVE C0-4.1,D1+1
3160 PRINT USING 3130:T7
3170 FOR K=1 TO 10
3180 RMOVE C2/10,0
3190 PRINT USING 3130:T7+K*B4
3200 NEXT K
3210 RETURN
3220 REM ** SUB: PLOT SYNTHETIC SEISMOGRAM
3230 WINDOW 1,N6,M1,M2
3240 VIEWPORT C0,C1,D0+D4,D1-D4
3250 MOVE 0,0
3260 RDRAW N6,0
3270 MOVE 0,0
3280 CALL "DISP",S
3290 WINDOW 0,130,0,100
3300 VIEWPORT 0,130,0,100
3310 MOVE 0,0
3320 PRINT
3330 RETURN
3340 REM ** SUB: REPLOT SYNTHETIC SEIS WITH DIFFERENT SCALE
```

```
3350 PRINT "DO YOU WANT TO REPLOT WITH DIFFERENT SCALE? (Y/N) ";
3360 INPUT G$
3370 IF G$="N" THEN 3390
3380 GO TO 400
3390 RETURN
3400 REM ** SUB: STORE ADJUSTED-GAIN SYN SEIS
3410 PRINT "__DO YOU WANT TO STORE GAIN-ADJUSTED SYNTHETIC? (Y/N) ";
3420 INPUT G$
3430 IF G$="N" THEN 3460
3440 S$="GAIN ADJUSTED "&S$
3450 GOSUB 3530
3460 RETURN
3470 REM ** SUB: READY TO PROCEED
3480 MOVE 0,6
3490 PRINT "ARE YOU READY TO PROCEED? (Y/N) ";
3500 INPUT G$
3510 IF G$="N" THEN 3490
3520 RETURN
3530 REM ** SUB: STORE SYNTHETIC ON TAPE
3540 PRINT "G_G_G_INSERT SSDT IN 4924    FILE NO. = ";
3550 INPUT F2
3560 L2=200+10*(N2+N5+L1)
3570 L2=INT(L2/256+1)*256
3580 PRINT "LENGTH OF FILE REQUIRED = ";L2
3590 PRINT "IS FILE LENGTH SUFFICIENT? (Y/N) ";
3600 INPUT G$
3610 IF G$="Y" THEN 3450
3620 PRINT "G_G_G_INSERT SSDT IN 4051"
3630 GOSUB 3490
3640 FIND F2
3650 MARK 1,L2
3660 PRINT "G_G_G_RETURN SSDT TO 4924"
3670 GOSUB 3490
3680 FIND @2:F2
3690 WRITE @2:N2,N5,R$,S$,W$,F0,F1,L1,Q2,S1,T0,T9,W1,S
3700 PRINT @2,2:
3710 REM ** VERIFY TAPE WRITE
3720 DELETE N2,N5,R$,S$,W$,F0,F1,L1,Q2,S1,T0,T9,W1,S
3730 DIM R$(50),S$(41),W$(50)
3740 FIND @2:F2
3750 READ @2:N2,N5
3760 DIM S(N5),W1(N2)
3770 READ @2:R$,S$,W$,F0,F1,L1,Q2,S1,T0,T9,W1,S
3780 T7=T0
3790 IF Q1=2 THEN 3810
3800 PRINT "DATA ARE STORED AND RETRIEVABLE FROM FILE ";F2
3810 RETURN
3820 REM ** SUB: DISPLAY USING FIXED GAIN OVER ENTIRE RECORD
3830 P$="FIXED GAIN OVER ENTIRE RECORD"
3840 T7=T0
3850 RETURN
3860 REM ** SUB: DISPLAY USING SEGMENTED GAINS
3870 DELETE T1,T2
3880 PRINT "__NUMBER OF SEGMENTS = ";
3890 INPUT N7
3900 DIM F$(3),G1(N5),J1(N7),J2(N7),J3(N7),T1(N7),T2(N7)
3910 P$="SEGMENTED GAIN IN"
3920 F$=STR(N7)
3930 P$=P$&F$
3940 P$=P$&" SEGMENTS"
3950 G1=0
3960 J1=0
3970 J2=0
3980 J3=0
3990 T1=0
```

```
4000 T2=0
4010 PRINT "SEGMENT    START TIME  END TIME    START GAIN  END GAIN"
4020 FOR J=1 TO N7
4030 PRINT "    ";J;"          ";
4040 INPUT T1(J)
4050 PRINT "K_                         ";
4060 INPUT T2(J)
4070 J1(J)=(T1(J)-T0)/S1+1
4080 J2(J)=(T2(J)-T0)/S1+1
4090 J3(J)=J2(J)-J1(J)
4100 PRINT "K_                                         ";
4110 INPUT G1(J1(J))
4120 PRINT "K_                                                   ";
4130 INPUT G1(J2(J))
4140 G2=(G1(J2(J))-G1(J1(J)))/J3(J)
4150 FOR K=1 TO J3(J)
4160 G1(J1(J)+K)=G2*K+G1(J1(J))
4170 NEXT K
4180 NEXT J
4190 L=0
4200 FOR J=J1(1) TO J2(N7)
4210 L=L+1
4220 S(L)=G1(J)*S(J)
4230 NEXT J
4240 T7=T1(1)
4250 T9=T2(N7)
4260 RETURN
4270 REM ** SUB: DISPLAY USING PGC
4280 DELETE W1
4290 DIM B$(4),W1(N5)
4300 W1=0
4310 PRINT "__    START TIME = ";
4320 INPUT T8
4330 J8=(T8-T7)/S1+1
4340 PRINT "__HALF GAIN TIME = ";
4350 INPUT T3
4360 B$=STR(T3)
4370 T3=(T3-T8)/S1
4380 K5=LOG(2)/T3
4390 FOR J=J8 TO N5
4400 N=K5*(J-J8)
4410 W1(J)=1-EXP(-N)
4420 NEXT J
4430 PRINT "__    FINAL GAIN = ";W1(N5)
4440 P$="PROGRAMED GAIN CONTROL (PGC) WITH HALF GAIN AT T ="
4450 P$=P$&B$
4460 PRINT "__DO YOU WANT TO PLOT PGC GAIN FUNCTION? (Y/N) ";
4470 INPUT G$
4480 IF G$="N" THEN 4640
4490 PRINT "L_    PGC FUNCTION FROM T=";T7;" TO ";T9;" WITH FINAL GAIN";
4500 PRINT " = ";W1(N5)
4510 PRINT P$
4520 MOVE 5,80
4530 RDRAW 120,0
4540 RDRAW 0,-70
4550 RDRAW -120,0
4560 RDRAW 0,70
4570 WINDOW 1,N5,0,1
4580 VIEWPORT 5,125,10,80
4590 CALL "DISP",W1
4600 REM ** APPLY GAIN FUNCTION
4610 FOR J=1 TO N5
4620 S(J)=W1(J)*S(J)
4630 NEXT J
4640 RETURN
```

LISTING OF PROGRAM TO COMPUTE AND APPLY
AGC FUNCTION TO SYNTHETIC SEISMOGRAM

```
100 PRINT "L_APPLY AGC TO SYNTHETIC SEISMOGRAM"
110 INIT
120 DIM A$(22),B$(8),C$(25),D$(14),F$(4),G$(1),L$(12),M$(29)
130 DIM O$(13),P$(60),Q$(28),R$(50),S$(41),U$(14),W$(50)
140 S$="SYNTHETIC SEISMOGRAM DATA"
150 REM ** READ PREVIOUSLY COMPUTED SYN SEIS DATA
160 GOSUB 290
170 REM ** COMPUTE AND APPLY AGC GAIN FUNCTION
180 GOSUB 350
190 REM ** DISPLAY SYNTHETIC SEISMOGRAM
200 GOSUB 1990
210 GOSUB 2120
220 GOSUB 2800
230 REM ** REPLOT SYNTHETIC SEISMOGRAM
240 GOSUB 2920
250 REM ** STORE SYNTHETIC SEISMOGRAM WITH AGC APPLIED
260 GOSUB 2980
270 PRINT "G_G_G___PROGRAM COMPLETED"
280 END
290 REM ** SUB: READ PREVIOUSLY COMPUTED SYN SEIS DATA
300 Q1=2
310 PRINT "G_G_G_INSERT SYN SEIS DATA TAPE IN 4924    FILE NO. = ";
320 INPUT F2
330 GOSUB 3290
340 RETURN
350 REM ** SUB: COMPUTE AND APPLY AGC GAIN FUNCTION
360 PRINT "__NOTE: GAINS EXTERIOR TO AGC INTERVAL ARE CONSTANTS WITH"
370 PRINT "START GAIN = FIRST AGC GAIN AND END GAIN = LAST AGC GAIN"
380 P$="ADAPTIVE GAIN CONTROL (AGC) FROM"
390 REM ** SET WINDOW PARAMETERS
400 J5=(T9-T0)/S1+1
410 PRINT "__  AGC START TIME = ";
420 INPUT T1
430 J1=(T1-T0)/S1+1
440 PRINT " WINDOW LAG TIME = ";
450 INPUT W2
460 IF T1-W2=>T0 THEN 490
470 PRINT "G_G_G_ERROR: AGC START TIME TOO SMALL FOR SELECTED LAG TIME"
480 GO TO 410
490 PRINT "WINDOW LEAD TIME = ";
500 INPUT W3
510 W4=W2+W3
520 PRINT "    WINDOW LENGTH = ";W4
530 N8=W4/S1+1
540 PRINT "    VALUES/WINDOW = ";N8
550 PRINT " WINDOW INTERVAL = ";
560 INPUT W5
570 W6=W5/S1
580 N7=INT((T9-T1)/W5)
590 T2=T1+W5*(N7-1)
600 IF T2<=T9 THEN 630
610 N7=N7-1
620 T2=T1+W5*(N7-1)
630 PRINT "  NO. OF WINDOWS = ";N7
640 PRINT "     AGC END TIME = ";T2
650 F$=STR(T1)
660 P$=P$&F$
670 P$=P$&" TO"
680 F$=STR(T2)
690 P$=P$&F$
700 J2=(T2-T0)/S1+1
710 N2=(T2-T1)/S1+1
720 PRINT "NO. OF AGC VALUES = ";N2
730 REM ** COMPUTE RMS AMPLITUDES FOR EACH WINDOW
740 DIM A1(N7),J3(N7),X(N8),Y(N8)
750 J3(1)=J1-W2/S1
```

```
760 FOR J=2 TO N7
770 J3(J)=J3(J-1)+W6
780 NEXT J
790 FOR J=1 TO N7
800 L=J3(J)-1
810 FOR K=1 TO N8
820 L=L+1
830 X(K)=S(L)
840 NEXT K
850 Y1=SUM(X)
860 Y2=Y1/N8
870 Y=X-Y2
880 Y=Y↑2
890 Y3=SUM(Y)
900 A1(J)=SQR(Y3)
910 NEXT J
920 DELETE L,X,Y
930 N3=N7-1
940 REM ** DETREND FUNCTION
950 G3=A1(N7)-A1(1)
960 G1=G3/N3
970 G2=A1(1)
980 DIM V(N7)
990 V=0
1000 FOR J=2 TO N3
1010 G2=G2+G1
1020 V(J)=A1(J)-G2
1030 NEXT J
1040 REM ** CREATE AND APPEND ODD-FUNCTION
1050 P1=(N2-N7)/(N7-1)
1060 P2=P1+1
1070 P3=PI/N3
1080 N8=2*N7-1
1090 N9=2*N3
1100 DIM L(N8)
1110 FOR I=1 TO N7
1120 L(I)=V(I)
1130 NEXT I
1140 K=0
1150 FOR I=N3 TO 1 STEP -1
1160 K=K+1
1170 L(I+N7)=-V(K)
1180 NEXT I
1190 DELETE V
1200 REM ** GENERATE (SIN X)/X COEFFICIENTS
1210 DELETE C
1220 DIM C(N9,P1)
1230 FOR J=1 TO N9
1240 FOR K=1 TO P1
1250 P=K/P2
1260 M4=J-N7+1
1270 M=PI*(P-M4)
1280 C(J,K)=SIN(M)/(N9*TAN(M/N9))
1290 NEXT K
1300 NEXT J
1310 REM ** COMPUTE INTERPOLATED FUNCTION
1320 N4=N3*(P1+1)+1
1330 DIM V(N4),V1(N3-1)
1340 V=0
1350 K=1
1360 FOR J=1 TO N3
1370 FOR P=1 TO P1
1380 K=K+1
1390 FOR M=1 TO N3-1
1400 K1=M-J+1+N3
1410 K2=-M-J+1+N3
```

```
1420 IF -M-J=>-(N3-1) THEN 1440
1430 K2=K2+2*N3
1440 IF K2<=N9 THEN 1460
1450 K2=K2-N9
1460 V1(M)=L(1+M)*(C(K1,P)-C(K2,P))
1470 NEXT M
1480 V(K)=SUM(V1)
1490 NEXT P
1500 K=K+1
1510 V(K)=L(J+1)
1520 NEXT J
1530 DELETE L
1540 REM ** RESTORE TREND TO INTERPOLATED FUNCTION
1550 DELETE W1
1560 G4=-G3/(N4-1)
1570 G5=-G4
1580 DIM W1(N4)
1590 FOR K=1 TO N4
1600 G5=G5+G4
1610 W1(K)=V(K)-G5
1620 NEXT K
1630 W1=A1(1)+W1
1640 DELETE V
1650 REM ** COMPUTE AGC GAIN FUNCTION
1660 W1=-W1
1670 M3=-W1(1)+1
1680 W1=M3+W1
1690 CALL "MAX",W1,M2,I2
1700 W1=W1/M2
1710 CALL "MIN",W1,M1,I1
1720 PRINT "__DO YOU WANT TO PLOT AGC GAIN FUNCTION? (Y/N) ";
1730 INPUT G$
1740 IF G$="N" THEN 1890
1750 PRINT "L_NORMALIZED AGC GAIN FUNCTION FROM T=";T1;" TO ";T2
1760 PRINT "NO. OF VALUES=";N4;"  MIN VALUE=";M1
1770 MOVE 5,80
1780 RDRAW 120,0
1790 RDRAW 0,-70
1800 RDRAW -120,0
1810 RDRAW 0,70
1820 VIEWPORT 5,125,10,80
1830 WINDOW 1,N4,M1,1
1840 CALL "DISP",W1
1850 WINDOW 0,130,0,100
1860 VIEWPORT 0,130,0,100
1870 MOVE 0,0
1880 PRINT
1890 REM ** APPLY AGC FUNCTION
1900 FOR J=1 TO J1-1
1910 S(J)=W1(1)*S(J)
1920 NEXT J
1930 M=0
1940 FOR J=J1 TO J2
1950 M=M+1
1960 S(J)=W1(M)*S(J)
1970 NEXT J
1980 RETURN
1990 REM ** SUB: RANGES OF SYNTHETIC
2000 PRINT "__SYNTHETIC STARTS AT ";T7;" AND ENDS AT ";T9;" MSEC"
2010 CALL "MIN",S,M1,I3
2020 CALL "MAX",S,M2,I4
2030 PRINT "AMPLITUDES RANGE FROM ";M1;" TO ";M2
2040 PRINT "SAMPLE INTERVAL FOR SYNTHETIC: ";S1;" MSEC"
2050 N6=(T9-T7)/S1+1
2060 PRINT "TOTAL NUMBER OF VALUES IN SYNTHETIC: ";N6
2070 PRINT "MINIMUM AMPLITUDE ON PLOT = ";
```

```
2080 INPUT M1
2090 PRINT "MAXIMUM AMPLITUDE ON PLOT = ";
2100 INPUT M2
2110 RETURN
2120 REM ** SUB: DRAW BORDER AND PLOT TICKMARKS
2130 WINDOW 0,130,0,100
2140 VIEWPORT 0,130,0,100
2150 M$="PLOT AMPLITUDES RANGE FROM "
2160 Q$=" BETWEEN ORDINAL TICKMARKS"
2170 MOVE 0,95
2180 PRINT "L_SYNTHETIC SEISMOGRAM--";R$
2190 PRINT "    ";L1;" MSEC ";W$;" WITH S.I.=";S1
2200 IF Q2=2 THEN 2240
2210 PRINT "REFL SERIES FROM FILE ";F0;" AND WAVELET'S ";
2220 PRINT "FOURIER COMPONENTS FROM FILE ";F1
2230 GO TO 2170
2240 PRINT "REFLECTIVITY SERIES FROM FILE ";F0;" AND WAVELET'S ";
2250 PRINT "VALUES FROM FILE ";F1
2260 PRINT "AMPLITUDE MODE: ";P$
2270 IMAGE 27A,3D.2D," TO ",3D.2D,26A
2280 PRINT USING 2270:M$,M1,M2,Q$
2290 RESTORE 2300
2300 DATA 1,5,125,10,80
2310 READ B0,C0,C1,D0,D1
2320 C2=C1-C0
2330 C3=C2/50
2340 D2=D1-D0
2350 D3=0.5*D2
2360 MOVE C0,D1
2370 RDRAW C2,0
2380 RDRAW 0,-D2
2390 RDRAW -C2,0
2400 RDRAW 0,D2
2410 REM ** ORDINAL TICKMARKS
2420 D4=4
2430 MOVE C0,D1-D4
2440 RDRAW 1,0
2450 RMOVE C2-2,0
2460 RDRAW 1,0
2470 MOVE C0,D0+D4
2480 RDRAW 1,0
2490 RMOVE C2-2,0
2500 RDRAW 1,0
2510 MOVE C0,D1
2520 GOSUB 2540
2530 GO TO 2660
2540 REM ** SUB: TICKMARKS AND TIME LINES
2550 FOR J=1 TO 10
2560 FOR K=1 TO 4
2570 RMOVE C3,0
2580 RDRAW 0,-B0
2590 RDRAW 0,B0
2600 NEXT K
2610 RMOVE C3,0
2620 RDRAW 0,-D3
2630 RDRAW 0,D3
2640 NEXT J
2650 RETURN
2660 MOVE C0,D0
2670 D3=-D3
2680 B0=-B0
2690 GOSUB 2540
2700 REM ** LABEL TIME LINES
2710 IMAGE 3D
2720 B4=(T9-T7)/10
2730 MOVE C0-4.1,D1+1
```

```
2740 PRINT USING 2710:T7
2750 FOR K=1 TO 10
2760 RMOVE C2/10,0
2770 PRINT USING 2710:T7+K*B4
2780 NEXT K
2790 RETURN
2800 REM ** SUB: PLOT SYNTHETIC SEISMOGRAM
2810 WINDOW 1,N6,M1,M2
2820 VIEWPORT C0,C1,D0+D4,D1-D4
2830 MOVE 0,0
2840 RDRAW N6,0
2850 MOVE 0,0
2860 CALL "DISP",S
2870 WINDOW 0,130,0,100
2880 VIEWPORT 0,130,0,100
2890 MOVE 0,0
2900 PRINT
2910 RETURN
2920 REM ** SUB: REPLOT SYNTHETIC SEIS WITH DIFFERENT SCALE
2930 PRINT "DO YOU WANT TO REPLOT WITH DIFFERENT SCALE? (Y/N) ";
2940 INPUT G$
2950 IF G$="N" THEN 2970
2960 GOSUB 1990
2970 RETURN
2980 REM ** SUB: STORE SYN SEIS WITH AGC APPLIED
2990 PRINT "__DO YOU WANT TO STORE AGC'D SYNTHETIC? (Y/N) ";
3000 INPUT G$
3010 IF G$="N" THEN 3040
3020 S$="AGC'D "&S$
3030 GOSUB 3110
3040 RETURN
3050 REM ** SUB: READY TO PROCEED
3060 MOVE 0,6
3070 PRINT "ARE YOU READY TO PROCEED? (Y/N) ";
3080 INPUT G$
3090 IF G$="N" THEN 3070
3100 RETURN
3110 REM ** SUB: STORE SYNTHETIC ON TAPE
3120 PRINT "G_G_G_INSERT MDT IN 4924     FILE NO. = ";
3130 INPUT F2
3140 L2=200+10*(N2+N5+L1)
3150 L2=INT(L2/256+1)*256
3160 PRINT "LENGTH OF FILE REQUIRED = ";L2
3170 PRINT "IS FILE LENGTH SUFFICIENT? (Y OR N) ";
3180 INPUT G$
3190 IF G$="Y" THEN 3230
3200 PRINT "G_G_G_INSERT SSDT IN 4051"
3210 GOSUB 3070
3220 FIND F2
3230 MARK 1,L2
3240 PRINT "G_G_G_RETURN SSDT TO 4924"
3250 GOSUB 3070
3260 FIND @2:F2
3270 WRITE @2:N2,N5,R$,S$,W$,F0,F1,L1,Q2,S1,T0,T9,W1,S
3280 PRINT @2,2:
3290 REM ** VERIFY TAPE WRITE
3300 DELETE N2,N5,R$,S$,W$,F0,F1,L1,Q2,S1,T0,T9,W1,S
3310 DIM R$(50),S$(41),W$(50)
3320 FIND @2:F2
3330 READ @2:N2,N5
3340 DIM S(N5),W1(N2)
3350 READ @2:R$,S$,W$,F0,F1,L1,Q2,S1,T0,T9,W1,S
3360 T7=T0
3370 IF Q1=2 THEN 3390
3380 PRINT "DATA ARE STORED AND RETRIEVABLE FROM FILE ";F2
3390 RETURN
```

LISTING OF PROGRAM TO GENERATE FORWARD-MODEL DATA

```
100 PRINT "L_SYNTHETIC SEISMOGRAM: GENERATE SAMPLE PROBLEM DATA"
110 INIT
120 DIM A$(49),B$(10),C$(10),D$(6),E$(10),G$(1),I$(16),S$(14),V$(5)
130 K1=1000
140 F1=0
150 P=51
160 PRINT "__DO YOU WANT TO WORK IN THE METRIC SYSTEM? (Y OR N) ";
170 INPUT G$
180 IF G$="Y" THEN 250
190 D$="ft"
200 I$="ftxgm/(ms*ft↑3)"
210 S$="ft,ft/ms,gm/cc"
220 V$="ft/ms"
230 PRINT "__NOTE: ENTER DIST.=INTEGER FT; VEL.=FT/MS ; DEN.=GM/CC"
240 GO TO 300
250 PRINT "__NOTE: ENTER DIST.=INTEGER M; VEL.=M/MS ; DEN.=GM/CC"
260 D$="m"
270 I$="kg/m↑2sx10↑6"
280 S$="m,m/ms,gm/cc"
290 V$="m/mS"
300 PRINT "__NUMBER OF LAYERS IN THE MODEL = ";
310 INPUT N1
320 A$="SYN SEIS -- SAMPLE PROB DATA FROM MODEL SECTION"
330 DIM A(N1),D(N1),R(N1),T(N1),T1(N1),V(N1),V1(N1),Z(N1),Z1(N1)
340 REM ** ENTER MODEL PARAMETERS
350 PRINT "__LAYER NO.   LAYER THICKNESS   LAYER DENSITY   LAYER VELOCITY"
360 FOR J=1 TO N1
370 PRINT "    ";J;"              ";
380 INPUT Z(J)
390 PRINT "K_                                   ";
400 INPUT D(J)
410 PRINT "K_                                             ";
420 INPUT V(J)
430 NEXT J
440 REM ** COMPUTE IMP., REFL TIME, REFL COEFF, DEPTH, & TRANS TIME/FT
450 IF D$="ft" THEN 470
460 K1=304.8
470 A(1)=D(1)*V(1)
480 A(2)=D(2)*V(2)
490 T(1)=Z(1)/V(1)
500 T1(1)=K1/V(1)
510 Z1(1)=Z(1)
520 FOR J=2 TO N1
530 A(J)=D(J)*V(J)
540 R(J-1)=(A(J)-A(J-1))/(A(J)+A(J-1))
550 T(J)=T(J-1)+Z(J)/V(J)
560 T1(J)=K1/V(J)
570 Z1(J)=Z1(J-1)+Z(J)
580 NEXT J
590 R(N1)=0
600 T=2*T
610 N2=Z1(N1)
620 GOSUB 1400
630 PRINT "DO YOU WANT TO STORE RESULTS ON MDT? (Y OR N) ";
640 INPUT G$
650 IF G$="N" THEN 930
660 REM ** STORE RESULTS ON MDT
670 PRINT "G_G_G___INSERT MDT IN 4924     NUMBER OF SELECTED FILE = ";
680 INPUT F1
690 N3=85+10*(8*N1+2*N2)
700 N3=INT(N3/256+1)*256
710 PRINT "LENGTH OF FILE REQUIRED = ";N3
720 PRINT "DOES FILE HAVE SUFFICIENT LENGTH? (Y OR N) ";
730 INPUT G$
740 IF G$="Y" THEN 830
```

```
750 PRINT "NUMBER OF FILE TO BE MARKED = ";
760 INPUT F1
770 PRINT "G_G_G___INSERT MDT IN 4051"
780 GOSUB 1680
790 FIND F1
800 MARK 1,N3
810 PRINT "G_G_G___INSERT MDT IN 4924"
820 GOSUB 1680
830 FIND @2:F1
840 WRITE @2:A$,S$,N1,N2,A,D,D2,R,T,T1,T2,V,Z,Z1
850 PRINT @2,2:
860 REM ** CHECK ON READABILITY OF STORED DATA
870 DELETE A$,S$,N1,N2,A,D,D2,R,T,T1,T2,V,Z,Z1
880 FIND @2:F1
890 READ @2:A$,S$,N1,N2
900 DIM A(N1),D(N1),D2(N2),R(N1),T(N1),T1(N1),T2(N2),V(N1),Z(N1),Z1(N1)
910 READ @2:A,D,D2,R,T,T1,T2,V,Z,Z1
920 PRINT "DATA STORED IN AND RETRIEVABLE FROM FILE ";F1
930 REM ** QUICK PRINT OF MODEL AND SAMPLE  PROBLEM DATA
940 PRI "__DO YOU WANT TO SEE MODEL AND SAMPLE PROBLEM DATA? (Y OR N) ";
950 INPUT G$
960 IF G$="N" THEN 1260
970 PRINT "DO YOU WANT TO PRINT ON 4642? (Y OR N) ";
980 INPUT G$
990 IF G$="Y" THEN 1010
1000 P=32
1010 PRINT @P:"L_QUICK PRINT OF MODEL AND SAMPLE  PROBLEM DATA"
1020 PRINT @P:A$;"    NO. OF LAYERS = ";N1
1030 PRINT @P:"LAYER THICKNESS IN ";D$;":"
1040 PRINT @P:Z
1050 PRINT @P:"LAYER DENSITY IN gm/cc:"
1060 PRINT @P:D
1070 PRINT @P:"LAYER VELOCITY IN ";V$;":"
1080 PRINT @P:V
1090 PRINT @P:"LAYER ACOUSTIC IMPEDANCE IN ";I$;":"
1100 PRINT @P:A
1110 PRINT @P:"REFLECTION TIME TO BASE OF LAYER IN msec:"
1120 PRINT @P:T
1130 PRINT @P:"REFLECTION COEFFICIENT:"
1140 PRINT @P:R
1150 PRINT @P:"DEPTH TO BASE OF LAYER IN ";D$;":"
1160 PRINT @P:Z1
1170 PRINT @P:"INTRA-LAYER SONIC-LOG TRANSIT TIME IN microsec/ft"
1180 PRINT @P:T1
1190 PRINT @P:"TRANSIT TIME/";D$;" FOR EACH ";D$;" OF DEPTH"
1200 PRINT @P:T2
1210 PRINT @P:"__DATA STORED IN FILE ";F1
1220 PRINT "__DO YOU WANT TO TABULATE LOG DATA? (Y OR N) ";
1230 INPUT G$
1240 IF G$="N" THEN 1260
1250 GOSUB 1600
1260 PRINT "__DO YOU WANT TO PLOT SIMULATED LOG DATA? (Y OR N) ";
1270 INPUT G$
1280 IF G$="N" THEN 1370
1290 GOSUB 1730
1300 GOSUB 1790
1310 GOSUB 2050
1320 GOSUB 2360
1330 GOSUB 2650
1340 GOSUB 2880
1350 GOSUB 3100
1360 GOSUB 3200
1370 WINDOW 0,130,0,100
1380 VIEWPORT 0,130,0,100
```

```
1390 MOVE 0,4
1400 PRI "DO YOU WANT TO REPLOT WITH DIFFERENT PLOT LIMITS? (Y OR N) ";
1410 INPUT G$
1420 IF G$="N" THEN 1450
1430 T2=T0-T2
1440 GO TO 1300
1450 CALL "TIME",C$
1460 PRINT "G_G_G_PROGRAM COMPLETED: ";C$
1470 END
1480 REM ** SUB: COMPUTE TRANSIT TIME/UNIT DEPTH FOR EACH UNIT OF DEPTH
1490 DIM D2(N2),T2(N2),V2(N2)
1500 L=0
1510 FOR J=1 TO N1
1520 FOR K=1 TO Z(J)
1530 L=L+1
1540 T2(L)=K1/V(J)
1550 D2(L)=D(J)
1560 V2(L)=V(J)
1570 NEXT K
1580 NEXT J
1590 RETURN
1600 REM ** SUB: TABULATE LOG DATA
1610 IMAGE 2X,4D,9X,D.2D,11X,4D,8X,2D.D
1620 PRINT @P:"L_DATA AS IF A LOG HAD BEEN RUN"
1630 PRINT @P:"DEPTH (";D$;") DENSITY(gm/cc)  TT(usec/ft)  VEL(";V$;")"
1640 FOR J=1 TO N2
1650 PRINT @P: USING 1610:J,D2(J),T2(J),V2(J)
1660 NEXT J
1670 RETURN
1680 REM ** SUB: READY TO PROCEED
1690 PRINT "ARE YOU READY TO PROCEED? (Y OR N) ";
1700 INPUT G$
1710 IF G$="N" THEN 1690
1720 RETURN
1730 REM ** SUB: COMPUTE RANGES
1740 CALL "MIN",D2,D7,I1
1750 CALL "MAX",D2,D8,I2
1760 CALL "MIN",T2,T7,I1
1770 CALL "MAX",T2,T8,I2
1780 RETURN
1790 REM ** SUB: ENTER PLOT LIMITS
1800 MOVE 0,0
1810 PRINT
1820 PRINT "ENTER PLOT LIMITS"
1830 PRINT "__Depths range from 0 to ";Z1(N1)
1840 PRINT "            Min. depth on plot = ";
1850 INPUT Z9
1860 PRINT "            Max. depth on plot = ";
1870 INPUT Z0
1880 PRINT "     Depth tickmark interval = ";
1890 INPUT M1
1900 PRINT "__Densities range from ";D7;" to ";D8
1910 PRINT "          Min. density on plot = ";
1920 INPUT D9
1930 PRINT "          Max. density on plot = ";
1940 INPUT D0
1950 PRINT "   Density tickmark interval = ";
1960 INPUT M2
1970 PRINT "__Transit times range from ";T7;" to ";T8
1980 PRINT "Min. transit time on plot = ";
1990 INPUT T9
2000 PRINT "Max. transit time on plot = ";
2010 INPUT T0
2020 PRINT "Transit time tickmark int = ";
```

```
2030 INPUT M3
2040 RETURN
2050 REM ** SUB: PRINT HEADING, PLOT BORDERS, AND LABEL AXES
2060 WINDOW 0,130,0,100
2070 VIEWPORT 0,130,0,100
2080 PRINT "L_";A$;"          DATA IN FILE ";F1
2090 RESTORE 2100
2100 DATA 10,68,70,128,10,90,1.0,2.0
2110 READ B1,B2,B4,B5,C1,C2,K5,K6
2120 N$="DEPTH IN METERS"
2130 B3=B2-B1
2140 B6=B5-B4
2150 C3=C2-C1
2160 MOVE B1,C2
2170 RDRAW B3,0
2180 RDRAW 0,-C3
2190 RDRAW -B3,0
2200 RDRAW 0,C3
2210 MOVE B4,C2
2220 RDRAW B6,0
2230 RDRAW 0,-C3
2240 RDRAW -B6,0
2250 RDRAW 0,C3
2260 MOVE 0.5*(B1+B2)-13*K5,C2+K6
2270 PRINT " LOGGED  DENSITY IN gm/cc"
2280 MOVE 0.5*(B4+B5)-11*K5,C2+K6
2290 PRINT " TRANSIT TIME IN usec "
2300 MOVE 0,0.5*(C1+C2)+6.5*K6
2310 FOR I=1 TO LEN(N$)
2320 F$=SEG(N$,I,1)
2330 PRINT F$
2340 NEXT I
2350 RETURN
2360 REM ** SUB: PLOT AND LABEL DEPTH TICKMARKS
2370 C4=C3/(Z0-Z9)
2380 H1=M1*(INT(Z9/M1)+1)
2390 G1=(H1-Z9)*C4
2400 MOVE B1,C2
2410 RMOVE -5.4,-0.5*K6
2420 PRINT USING "3D":Z9
2430 RMOVE 5.4,0.5*K6
2440 RMOVE 0,-G1
2450 GOSUB 2530
2460 FOR I=1 TO INT((Z0-Z9)/M1)
2470 RMOVE 0,-M1*C4
2480 H1=H1+M1
2490 IF H1>Z0 THEN 2520
2500 GOSUB 2530
2510 NEXT I
2520 RETURN
2530 REM ** SUB: TICKMARK PLOTTING
2540 RDRAW 0.2,0
2550 RMOVE B3-0.4,0
2560 RDRAW 0.2,0
2570 RMOVE 2,0
2580 RDRAW 0.2,0
2590 RMOVE B6-0.4,0
2600 RDRAW 0.2,0
2610 RMOVE B1-B5-5.4,-0.5*K6
2620 PRINT USING "3D":H1
2630 RMOVE 5.4,0.5*K6
2640 RETURN
2650 REM ** SUB: PLOT AND LABEL DENSITY TICKMARKS
2660 C4=B3/(D0-D9)
```

```
2670 H1=M2*(INT(D9/M2)+1)
2680 G1=(H1-D9)*C4
2690 MOVE B1,C1
2700 RMOVE G1,0
2710 GOSUB 2730
2720 GO TO 2810
2730 REM ** SUB: PLOT DENSITY TICKMARKS
2740 RDRAW 0,0.2
2750 RMOVE 0,C3-0.4
2760 RDRAW 0,0.2
2770 RMOVE -1.2*K5,0
2780 PRINT USING "D.D":H1
2790 RMOVE 1.2*K5,0
2800 RETURN
2810 FOR I=1 TO INT((D0-D9)/M2)
2820 H1=H1+M2
2830 IF H1=>D0 THEN 2870
2840 RMOVE M2*C4,-C3
2850 GOSUB 2730
2860 NEXT I
2870 RETURN
2880 REM ** SUB: PLOT AND LABEL TRANSIT TIME TICKMARKS
2890 C4=B6/(T0-T9)
2900 H1=M3*(INT(T9/M3)+1)
2910 G1=(H1-T9)*C4
2920 MOVE B5,C1
2930 RMOVE -G1,0
2940 GOSUB 3020
2950 FOR I=1 TO INT((T0-T9)/M3)
2960 H1=H1+M3
2970 IF H1=>T0 THEN 3010
2980 RMOVE -M3*C4,-C3
2990 GOSUB 3020
3000 NEXT I
3010 RETURN
3020 REM ** SUB: PLOT TRANSIT TIME TICKMARKS
3030 RDRAW 0,0.2
3040 RMOVE 0,C3-0.4
3050 RDRAW 0,0.2
3060 RMOVE -4.2*K5,0
3070 PRINT USING "5D":H1
3080 RMOVE 4.2*K5,0
3090 RETURN
3100 REM ** SUB: PLOT DENSITY VS. DEPTH
3110 WINDOW D9,D0,Z9,Z0
3120 VIEWPORT B1,B2,C1,C2
3130 MOVE D2(1),Z0+Z9
3140 RDRAW 0,-1
3150 FOR J=2 TO N2
3160 RDRAW D2(J)-D2(J-1),0
3170 RDRAW 0,-1
3180 NEXT J
3190 RETURN
3200 REM ** SUB: PLOT TRANSIT TIME VS. DEPTH
3210 WINDOW T9,T0,Z9,Z0
3220 VIEWPORT B4,B5,C1,C2
3230 T2=T0-T2
3240 MOVE T2(1)+T9,Z0+Z9
3250 RDRAW 0,-1
3260 FOR J=2 TO N2
3270 RDRAW T2(J)-T2(J-1),0
3280 RDRAW 0,-1
3290 NEXT J
3300 RETURN
```