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CWELL: 2.5-Dimensional Crosswell Modeling Program

by

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Contents

1 Introduction

This document describes the crosswell modeling program CWELL. In the crosswell geometry, shots are set off inside a source well and data is recorded at a distant receiver well. CWELL uses ray theory to calculate the response at the receivers. Like the earlier CSHOT programs, CWELL is designed for layered, acoustic media. Amplitudes of the synthetic data are computed by assuming a two-and-one-half dimensional medium (for the spreading calculation), and by taking into account transmission and reflection effects. In addition to direct waves and primary reflections, CWELL can be directed to generate multiple reflections, head waves, and multiply reflected head waves. Curved source and receiver wells may also be specified.

The program uses the shooting method of ray tracing. With this approach, rays leaving the source do not, in general, terminate at precise receiver locations, and interpolation is used to determine the required quantities at the receivers. Details of the shooting+interpolation approach are given in the next section. Also discussed are modifications necessary for the calculation of head waves. This is followed, in Section 3, by a brief overview of the input parameter files read by CWELL and the types of output that can be generated. A set of example runs, detailed in Section 4, illustrate the capabilities and limitations of the program. Finally, some instructions are provided on how to produce model plots and ray diagrams.

2 Program Description—Shooting+Interpolation

As mentioned above, CWELL traces rays by the shooting method: rays leave the source at specified takeoff angles and are refracted, or reflected, according to Snell's law by interfaces in the model. A ray is terminated at its point of intersection with the receiver well or, if it misses the well, at the boundary of the model. Since rays that hit the well rarely do so at the exact locations of the receivers, the program interpolates to obtain traveltimes and amplitudes at receiver positions.

To ensure that the interpolation produces accurate results, it is necessary to hit the receiver well with a dense set of rays. To illustrate how the program has been designed to achieve this goal, consider the problem of finding the direct wave between source and receivers. The user provides the following input parameters:

starting takeoff angle β_i,
ending takeoff angle β_f,
coarse takeoff angle increment $\Delta\beta$,
fine takeoff angle increment $\delta\beta$,
and ray density ρ,

where $\delta\beta$ is smaller in magnitude than $\Delta\beta$, and ρ is defined as the number of rays intersecting the well in a distance equal to the receiver spacing. Starting at takeoff angle β_i, and with takeoff angle increment $\Delta\beta$, rays are set off from the source in a coarse search for the receiver well. (See Figure 1. In this case, the takeoff angles are being measured from the horizontal.) The search ends as soon as a ray is found that intersects the well or, if no well intersections are found, at the final takeoff angle β_f. In Figure 1, the ray labeled with takeoff angle β_1 is the first ray to hit the well.

At this point, the program backs up to takeoff angle $\beta_1^- = \beta_1 - \Delta\beta + \delta\beta$, and approaches the well more carefully using the takeoff angle increment $\delta\beta$. The idea here is to find a ray that intersects near to the top of the well. This set of rays is plotted in Figure 2.

When the well is located for the second time (by the ray labeled β_2 in Figure 2), the program starts to monitor the change in end point of rays that intersect the well. This is where the ray density takes over. The program now tries to adjust the change in takeoff angle to satisfy the ray density parameter, that is, it tries to find ρ rays between each pair of receivers in the well. The program continues with this procedure until a breakdown occurs. These rays are shown in Figure 3. Breakdown occurs for the ray labeled β_3, which strikes the second interface at an incident angle greater than critical and, therefore, is not transmitted into the next layer.

Whenever a breakdown occurs, the procedure described above is repeated: starting at the current takeoff angle, a search for more ray solutions is begun using coarse increment $\Delta\beta$. If an additional ray-well intersection is found, the program backs up and approaches more carefully (using increment $\delta\beta$.) Ray density takes over when the well is intersected a second time. Figure 4 shows all of the rays associated with this restart procedure. In fact, Figure 4 contains rays traced after a second breakdown, which occured at the bottom of the model (rays are terminated at the deepest interface, that is, at the edge of the model). This search was ended when the final takeoff angle, β_f, was reached.

The approach described above for direct waves is also used to find reflection events. Head waves, however, require a modification to the procedure. In the case of head waves, the program first searches between takeoff angles β_i and β_f for the ray that intersects the refractor at the critical angle, θ_c. Generally, there are two such rays, and the program chooses the one headed in the direction of the receivers. (The program calculates this ray very accurately, using a Newton procedure to converge on the solution.) Note that this part of the raypath is the same for all head rays traveling towards the receiver well.

Next, the program introduces a secondary source located right on the refracting interface. Starting at the point of intersection of the critical ray, the secondary source is moved along the refractor in the direction of the receivers. Rays are emitted from the secondary source at takeoff angle θ_c in search of the receiver well. (For these rays the takeoff angle is measured from the normal to the refractor.) If a well intersection is detected, the program backs up to the previous secondary source location and approaches more carefully. Once again, ray density takes over when the well is intersected for a second time. As above, breakdowns are followed by a further search. All searching ends when the secondary source reaches the edge of the model. Figure 5 illustrates the head wave procedure.

The head wave logic is, thus, a modification of that described above for direct waves and reflections, in which coarse and fine takeoff angle increments are replaced by coarse and fine secondary source movements along the refractor. Note, however, that the secondary source movements are not read as input parameters. Instead, the program uses the receiver spacing as the coarse secondary source moveup and one tenth of this value for the fine moveup. These values have proved satisfactory in testing but if necessary could easily be changed in the source code.

For each ray that intersects the well, the program calculates the traveltime along the ray, the ray theoretical amplitude and also any phase shifts associated with post-critical reflections and caustics. These quantities are then linearly interpolated to construct the wavefield at the receiver locations. In carrying out the interpolation, the program views the ray field for a given event as a series of separate branches and interpolates independently for each branch. Within a branch, the quantities to be interpolated are assumed to vary smoothly. Thus, interfaces in the model mark boundaries where one branch ends and another begins, since there is often a discontinuity in amplitude, and sometimes—for direct waves—in traveltime, across an interface. Turning points associated with caustics also bound branches, as do locations where breakdowns occur in the ray tracing procedure.

3 Input and Output

Program CWELL reads parameters from five separate input files:

1. file PARAM1
2. a model file
3. a receiver well file
4. a source well file (downhole shooting mode) OR
   a source coordinates file (general shooting mode)
5. a colors file

The main parameter file input to CWELL, which must have the name PARAM1, controls the shooting mode (either downhole—sources inside source well, or general—sources arbitrarily located), describes the events to be generated (head waves, reflections, etc.), specifies the velocities, determines the output produced, and defines some ray search angles. Also contained in PARAM1 are the names of the other parameter files input to CWELL. The model file is a list of (x, z) coordinates describing the interfaces and the upper surface. The interfaces should extend all the way across the model and should not be too curvy. The receiver well file defines the receiver locations. Source locations are similarly described in the source well file or, if sources are not confined within a well, their coordinates are listed in the source coordinates file. Finally, when plotting to the screen, CWELL allows the user to specify the colors of various elements of the plot by way of entries in the colors file.

CWELL can generate the following output:

1. ray and models plots
2. a listing file of traveltimes and ray coordinates
3. a shot record data file

The shot record data file output by CWELL contains the necessary information for constructing wiggle traces. To actually produce wiggle traces we must run the program CSHOT2 on the shot data generated by CWELL. CSHOT2 reads from a parameter file named PARAM2 which defines the trace length, sample rate, and so on. See the CSHOT documentation for a description of CSHOT2 and for a justification of this two-step approach. Example PARAM2 files will be listed in the section below.

4 Examples

The precise format of the input parameter files is developed and explained by means of the examples in this section. The input parameter files and the output generated for each example can be found at the end of this section.

4.1 Plot the model

In this example, CWELL is used to make a plot of the model. Three input files are required: PARAM1, the model file, and the colors file. (See the listings of these files under the heading *Example 1* at the end of the section.) PARAM1 contains only four records for this run. Record 1 of PARAM1 gives the name of the file describing the model. Here the model file is called *syncline*. The number of interfaces in the model is entered in Record 2 of PARAM1. There are four interfaces in model *syncline* (not including the upper surface). Next comes the name of a file describing the colors of various elements of the plot. Finally, Record 4 is a plot descriptor. To get a plot of the model, enter m. To quit immediately after plotting the model, enter mq.

File *syncline* contains the (x, z) coordinates of four interfaces and the upper surface (z is measured positive downwards). The upper surface, which may be curved, is described first in the file and is viewed by the program as Interface 0. The program fits a cubic spline through the points defining each interface. To terminate the description of an interface, a large negative z-coordinate is used; specifically, $z < -9999$ does the job.

The colors file has the name *plotcolors* here. You can specify the colors in which the interfaces, rays, wells, etc., will be drawn on a color screen. A key is given at the end of the file.

4.2 Plot the model and the receiver well

The model, the receiver well and the receiver locations are plotted in this run. Two records have been added to PARAM1: Record 5, naming the receiver well file, and Record 6, another plot descriptor. File *rwell* contains a list of (x, z) coordinates describing the receiver well which will be splined by the program. The z-coordinate of the top of the well (i.e., its elevation at the upper surface) is not given but instead is calculated by the program. This is because the precise value of this coordinate may not be known if the upper surface is curved. The receiver well should not be excessively curved and in any case should be single valued in z. A value $z < -9999$ ends the well definition.

Next in the receiver well file is the depth (arc length) down the well to the first receiver location. This is followed by the number of receivers and the receiver spacing. To plot the receiver well, enter *w* for the plot descriptor in Record 6. To plot the receivers, enter *g* (for geophones). To plot both well and receivers, enter *wg*. You can also quit at this point by tagging on a *q* in Record 6. (Notice how Record 4 has been changed to *m*—plot the model, do not quit after plotting the model.)

Important Note

To aid in its bookkeeping the program assumes the following:

- The well intersects ALL interfaces in the model. Make sure you define the receiver well so that it cuts through the deepest interface in the model.
- No receivers are located below the deepest interface.

4.3 Plot the model, the receiver well, and the source well

Here we go a little bit further and plot the source well also. First of all, in Record 7 of PARAM1, we must specify the shooting mode, either downhole (d) or general (g). In downhole mode, the sources are located inside a source well. In general mode, the sources can be anywhere in the model and their locations are simply listed in a source coordinates file (see Example 6). Choosing downhole mode, we give the name of the file describing the source well in Record 8 of PARAM1. The format of the source well file is identical to that of the receiver well file. If only one source is specified, as is the case here, then the source spacing is not used.

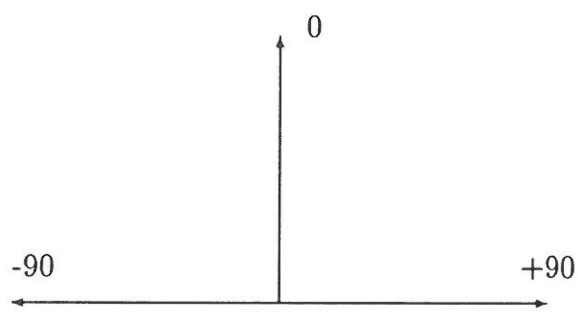
Record 9 of PARAM1 (the name of the source coordinates file) is not used in downhole mode. Record 10 is a source plot descriptor. Enter *w* here to plot the source well, *s* to plot the source points, *ws* for both, and *q* to quit after the plot.

4.4 Ray plot — direct wave. Takeoff angle definition.

This example calculates the direct rays from source to receivers and discusses how the takeoff angles are measured. There are a lot more entries in PARAM1 for this run. First, Record 10 has been changed to *ws* (plot the source well, plot the source locations, do not quit). Record 11 is the job descriptor. To get a ray plot, enter *r* in Record 11. To get a listing of some ray information, enter *l*. To produce shot record data, enter *t*. To get all three at once, enter *rlt*, and so on. See Section 4.7 for an example of generating a listing. The first shot data is produced in Section 4.8.

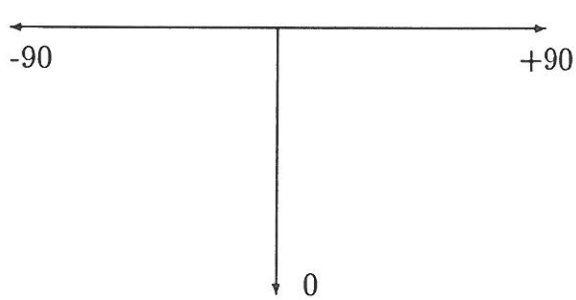
When generating a listing or shot data, the program creates output files. The first part of the name given to these files comes from Record 12. Appended to this are .listing, for the listing file, and .shot for the shot data file. No output files are generated when making ray plots only, so Record 12 is not used here.

Record 13 contains the starting and ending takeoff angles used in the shooting procedure. The program rotates the range of angles you specify in Record 13 depending on the direction of the target. For upgoing rays, aimed at a target reflector or refractor above the source location, the angles are measured from the upward pointing vertical as follows:

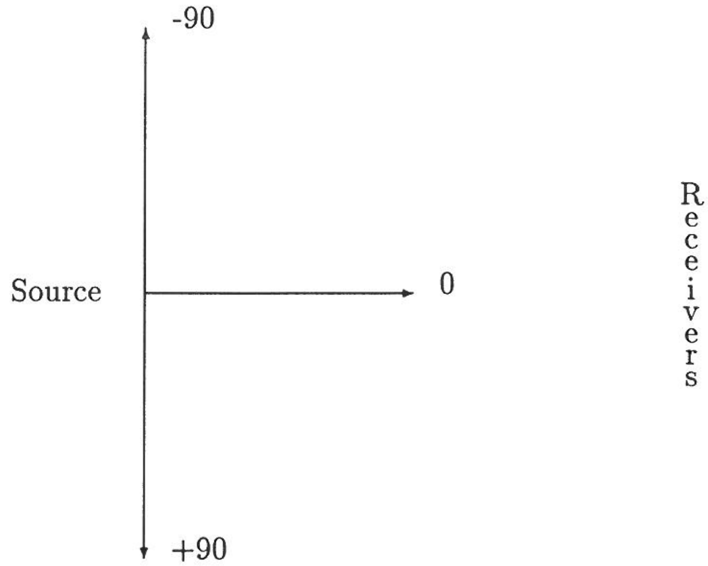


Although not indicated, the range of angles may extend beyond ±90 degrees. A range ±180 degrees covers all possible takeoff angles.

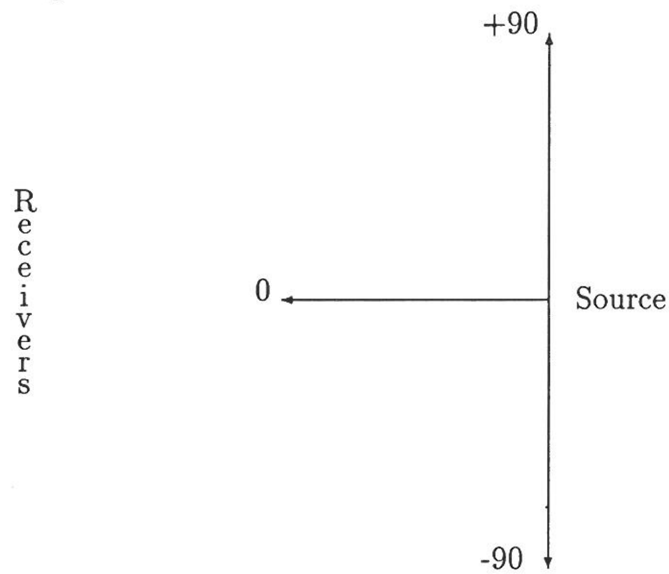
Downgoing rays are similarly measured from the downward pointing vertical



In the case of direct waves, takeoff angle values depend on the location of the source relative to the receiver well. For a source to the left of the receivers, the angles are measured as



and for a source to the right of the receivers as



Using this system we find, in most cases, that a range of -90 to +90 is wide enough to encompass all types of events.

Record 14 of PARAM1 contains the coarse and fine changes in takeoff angle and the ray density. These parameters were discussed in Section 2. Typically, we use a value of 1 degree for the coarse increment, .1 for the fine increment and 3 rays per receiver spacing for the density.

The layer velocities (shallowest first) are given in Record 15 of PARAM1. The program expects to find one more velocity than the number of interfaces specified in

Record 2. The event specifiers follow Record 15. To generate a direct wave, enter y in Record 16, as we have done here; otherwise, enter n. To generate a primary reflection from each interface in the model, enter y in Record 17; otherwise, enter n. To generate head waves from all interfaces, enter y in Record 18; otherwise, enter n.

The ray plot for this example indicates a wide gap in the ray field before rays enter the second layer. Rays traced inside the gap strike the first interface at angles greater than critical and are not transmitted (these rays would contribute to reflection energy from Interface 1). Notice also from the plot that the program has difficulty finding a ray near to the receiver at the top of Layer 2. Small changes in takeoff angle in the neighborhood of the critical ray often result in large changes in ray end point at the well. Since the program is restricted in its ability to hit all parts of the well by the magnitude of the fine takeoff angle increment, inevitably there will be cases where parts of the well receive no rays. The program will try to extrapolate traveltime and amplitude information to receivers outside the ray field (to the receiver at the top of Layer 2, for example); however, this may not give acceptable results and portions of events may be missing from the shot record, if one is produced. (Note that the program does not extrapolate across interfaces. Thus, in the extreme case where a layer receives no rays, there will be no event recorded at the corresponding receivers.)

4.5 Ray plot — primary reflections.

This time the program has been instructed to seek a primary reflection from each interface (Record 17 = y). The direct wave has been turned off. Notice the three branches of ray solutions in the reflection from the syncline.

4.6 Ray plot — multiples.

Here we have switched to general shooting mode (Record 7 = g) and specified two source locations in file *sources* (Record 9). The source well plot (Record 10) has been turned off and a multiple has been described in Record 19. The letter r in the first column of Record 19 specifies a reflection event. (The only other choice is h for head wave. See Section 4.11 for an example of this option.) The integers that follow are the interface numbers where reflections occur; thus, Record 19 specifies bounces from Interface 0 (the upper surface), Interface 2, and then Interface 1. To request more events, simply include additional records at the end of PARAM1. Each record must begin with the letter r or h and be followed by a list of integers describing the reflecting interfaces. (For the case of head waves, the last integer in the list defines the refractor.)

4.7 Ray plot and listing.

For this example we have returned to downhole mode with two sources specified in file *swell2*. A ray plot and listing (Record 11) have been requested for a single event—a reflection from Interface 2 (Record 19). The first part of the file name given to the listing comes from Record 12 of PARAM1. Appended to this is .listing, so that the file will be named *demo7.listing* here. The listing file begins with the layer velocities and the shot and receiver locations. This is followed, for each ray, by the (x, z) coordinates defining the raypath and the traveltime along the ray. Note that these values are for all rays that reach the well—not interpolated values at the receiver locations. Note also how the ray density in Record 14 was reduced to avoid a lengthy listing.

4.8 Ray plot and shot record.

To generate a shot record we must run both CWELL and the program CSHOT2. When instructed to generate shot data, CWELL writes time, amplitude and phase information, interpolated onto the receiver locations, to a shot data file. CSHOT2 reads the shot file created by CWELL and outputs wiggle traces. CSHOT2 also reads from an input parameter file called PARAM2 which is described briefly below and in detail in the CSHOT documentation (CWP-U08R).

First, for CWELL, we include a t (generate time data) in Record 11 of PARAM1. The shot data file will be called *demo8.shot*, the first part of its name being given by Record 12 of PARAM1. Data for a direct wave (Record 16) and all primary reflections (Record 17) will be calculated.

In file PARAM2 we have asked CSHOT2 to build one shot (Records 1 and 2 of PARAM2) of 20 traces (Record 3). The number of traces specified here should equal, or at least not exceed, the number of receivers in the receiver well (see file *rwell*). Next in PARAM2 are the wavelet description, sample rate and trace length. Finally, PARAM2 contains the name of the shot data file created by CWELL and the name of the file to which the wiggle traces will be output.

The shot record for this run has been plotted with automatic gain control (agc) applied. Data from the shallowest receiver is plotted as Trace 1. The direct wave is the first arrival on all traces. The time of arrival of a given reflection decreases with depth and reflections eventually meet the direct wave where the well cuts through the corresponding interface. The behavior is not unlike that of vertical seismic profiling (VSP), since in this case the shot is located near to the upper surface.

4.9 Multi-shot data. No model plots.

In this example, data is generated for 10 shots in a well (see file *swell3*). Ray and model plots are turned off. This is accomplished by leaving blank Records 4, 6 and

10, and by removing r (plot rays) from Record 11. Data is calculated for a direct wave and primaries.

All 200 traces for this run have been plotted, again with agc. The first 20 traces correspond to the shallowest shot in the well and have the characteristic appearance of VSP data. For this shot, the direct wave slopes to the right (increasing time with increasing depth), since this is a downgoing wave. Reflections, which are upgoing for this shot, slope to the left. As the shot is moved deeper, interfaces above the shot reflect waves downwards while the direct wave becomes increasingly upgoing.

4.10 Head waves.

Here we have used a simpler model that is described in file *smoothmodel*, adjusted the velocities, and requested head waves from all interfaces (Record 18).

We recommend calculating head waves from fairly flat interfaces only. This is because the program assumes that head waves travel along an interface regardless of its curvature: effects due to short cuts taken by head waves are not accounted for. Also, where head waves go through caustics, the required ninety-degree phase shift is not applied. This is really a shortcoming of the program CSHOT2 which does not compute the necessary wavelet for these (hopefully rare) events.

4.11 Multiple bounce head waves.

Records 19 and 20 of PARAM1 describe multiple bounce head wave events. The entry h in the first column defines these events as head waves. The integers that follow are the interfaces where reflections occur and the interface where the head wave is initiated. Thus, Record 19 describes a wave that reflects from Interface 2, then reflects from Interface 1, and then becomes a head wave traveling along Interface 2. Record 20 describes a wave that reflects from Interface 4 before becoming a head wave at Interface 3. Notice how the velocities have been adjusted to make these events valid. (Note: If many bounces are specified then you might observe no arrivals at all at the receiver well. Typically, this is because the rays do not go critical at the refractor until after they have passed beyond the receiver well. Remember, head wave events do not exist at all source-receiver offsets.)

File PARAM1

```
syncline                  :model file
4                         :#interfaces in model
plotcolors                :model colors file
mq                        :model plot descriptor (mq)
```

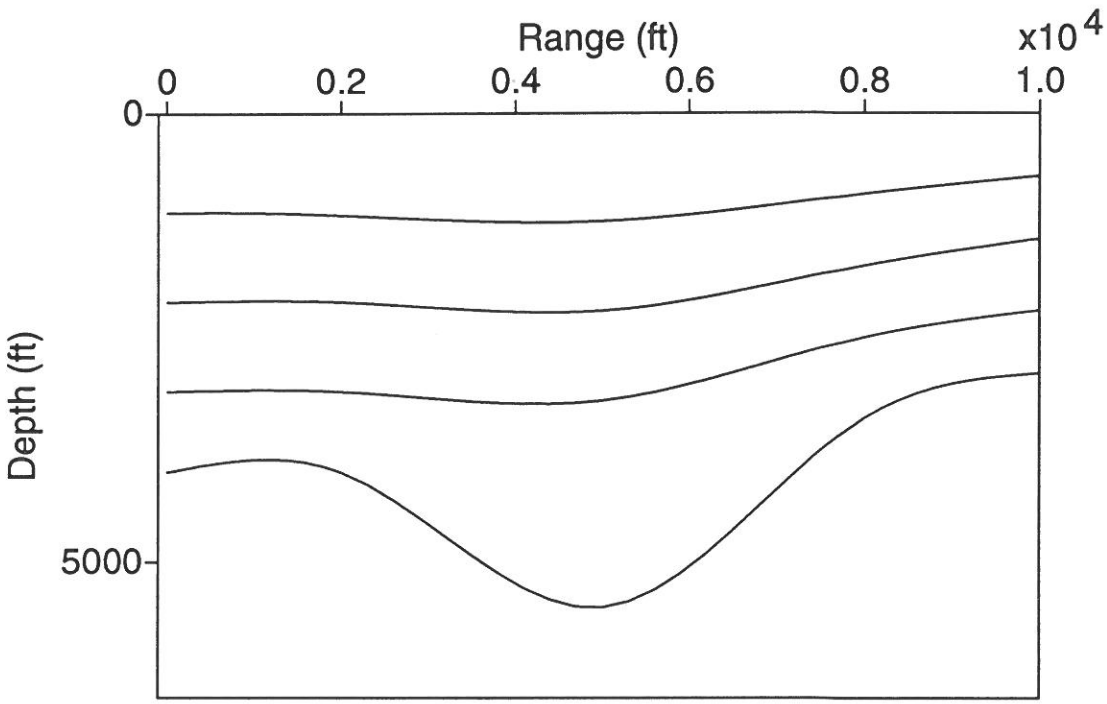
File *syncline*

```
0.        0.              :start of upper surface
10000.    0.
1.    -99999.             :end of upper surface
0.      1100.             :start of interface 1
1000.   1100.
5000.   1200.
8000.    900.
10000.   700.
1.    -99999.             :end of interface 1
0.      2100.             :start of interface 2
2000.   2100.
5000.   2200.
8000.   1700.
10000.  1400.
1.    -99999.             :end of interface 2
0.      3100.             :start of interface 3
2000.   3100.
5000.   3200.
8000.   2500.
10000.  2200.
1.    -99999.             :end of interface 3
0.      4000.             :start of interface 4
2000.   4000.
5000.   5500.
8000.   3400.
10000.  2900.
1.    -99999.             :end of interface 4
```

File *plotcolors*

```
5                         :receivers
3                         :sources
4                         :well color
3                         :not used
2                         :rays
1                         :interfaces
```

```
Color Key: CWP graphics

0       black
1       white
2       red
3       green
4       dark blue
5       light blue
6       violet
7       yellow
```



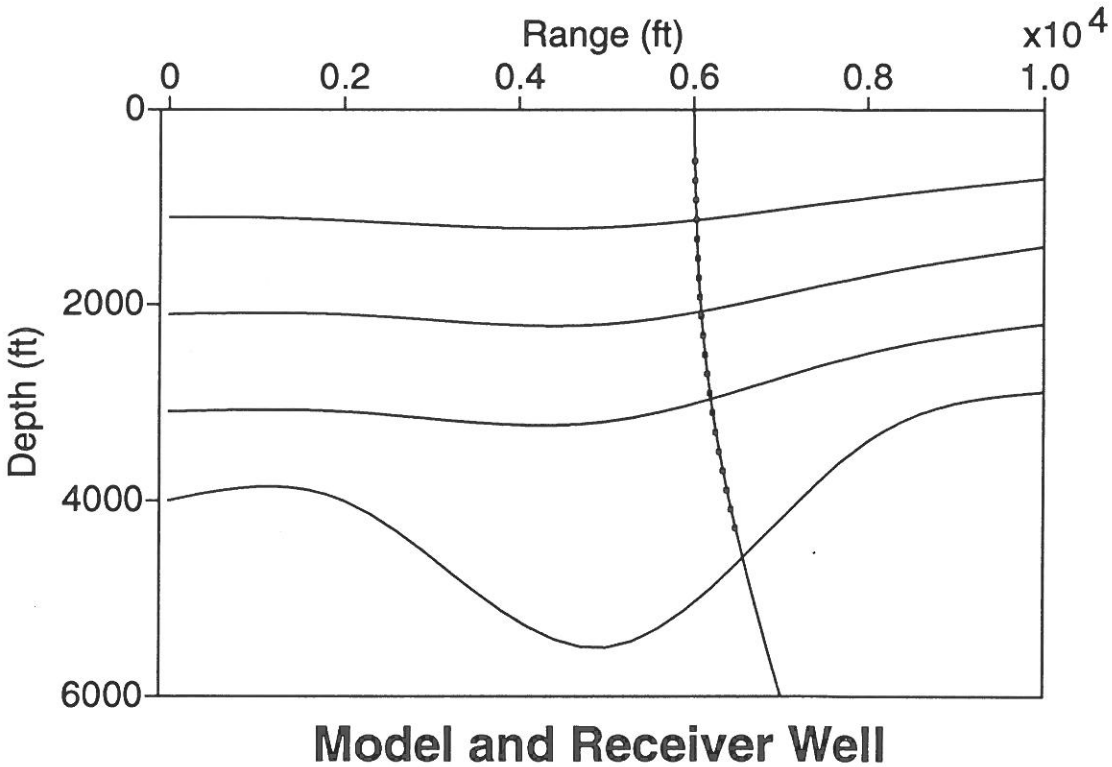
Model for demo1

File PARAM1

```
syncline                            :model file
4                                   :#interfaces in model
plotcolors                          :model colors file
m                                   :model plot descriptor (mq)
rwell                               :receiver well coordinates
wgq                                 :receiver plot descriptor (wgq)
```

File *rwell*

```
6000.                               :x-coord. of top of receiver well
6200.    3000.
7000.    6000.
1.      -99999.                     :end of receiver well definition
500.                                :depth to first receiver
20        200.                      :#receivers, receiver spacing
```

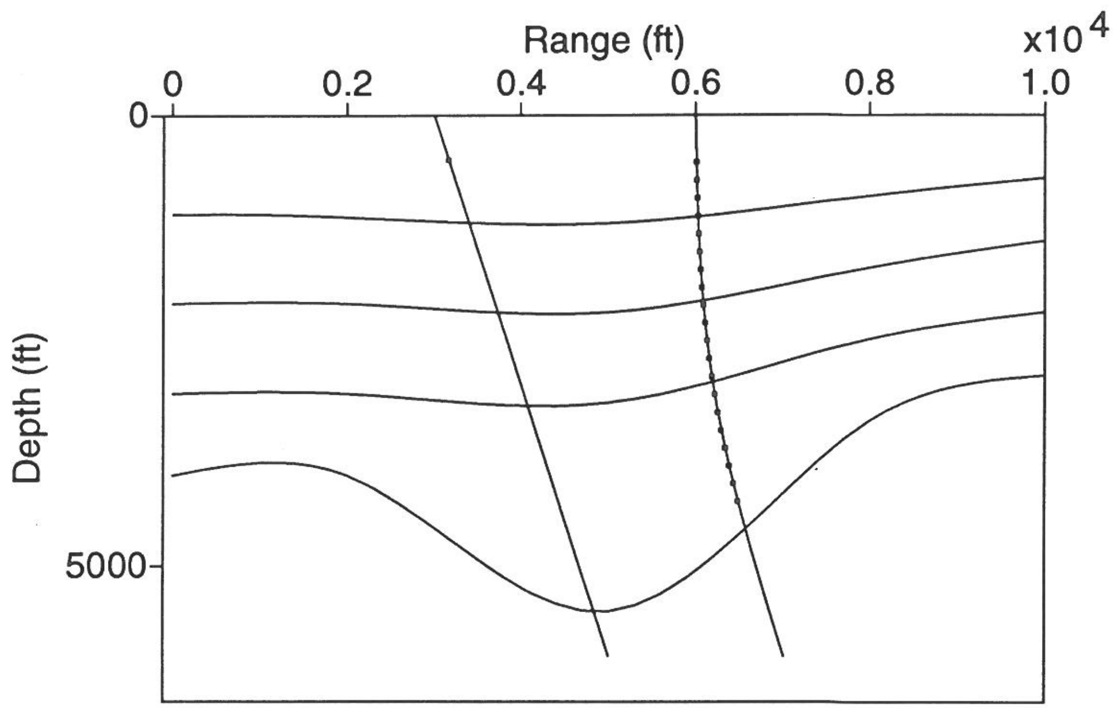


File PARAM1

```
syncline                    :model file
4                           :#interfaces in model
plotcolors                  :model colors file
m                           :model plot descriptor (mq)
rwell                       :receiver well coordinates
wg                          :receiver plot descriptor (wgq)
d                           :shooting mode (dg)
swell1                      :source well coordinates
don't care                  :arbitrary source coordinates
wsq                         :source plot descriptor (wsq)
```

File *swell1*

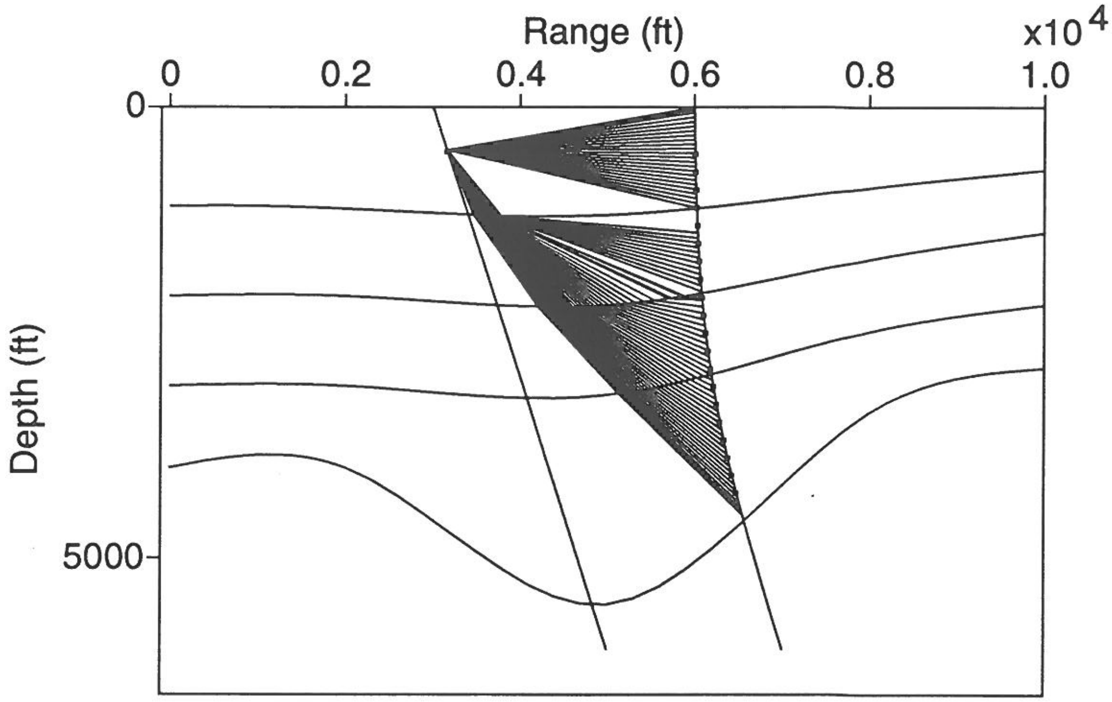
```
3000.                       :x-coord. of top of source well
5000.    6000.
1.     -99999.              :end of source well definition
500.                        :depth to first source
1          500.             :#sources, source spacing
```



Model, Source Well and Receiver Well

File PARAM1

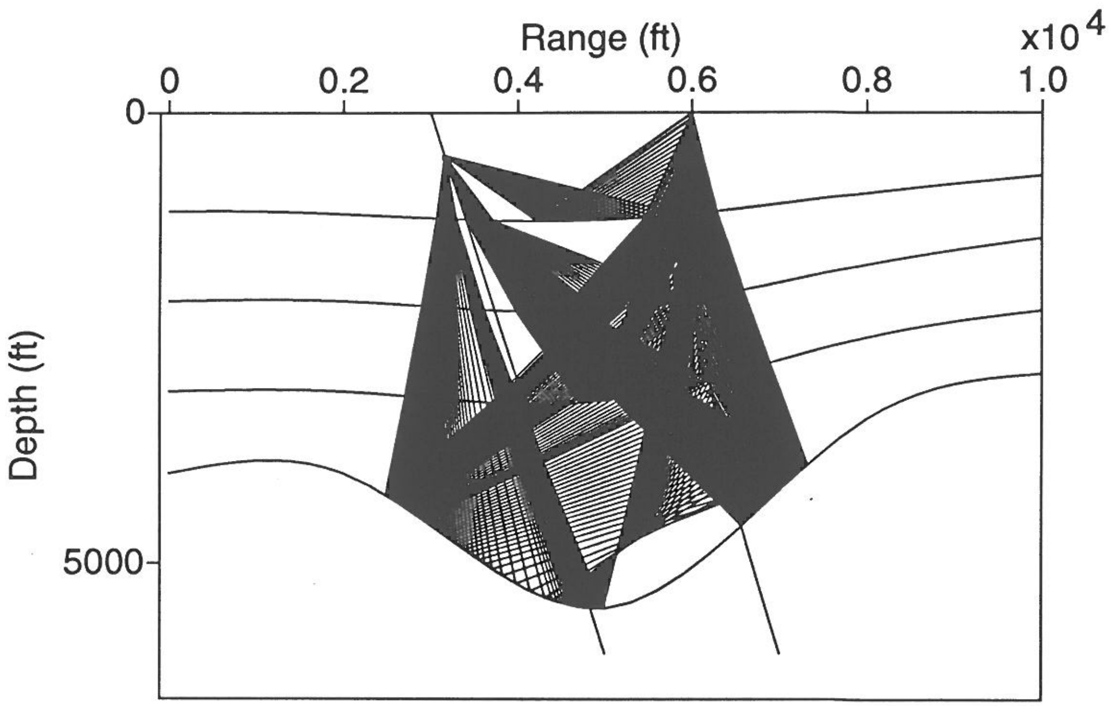
```
syncline                            :model file
4                                   :#interfaces in model
plotcolors                          :model colors file
m                                   :model plot descriptor (mq)
rwell                               :receiver well coordinates
wg                                  :receiver plot descriptor (wgq)
d                                   :shooting mode (dg)
swell1                              :source well coordinates
don't care                          :arbitrary source coordinates
ws                                  :source plot descriptor (wsq)
r                                   :job descriptor (rlt)
don't care                          :output file name
-90.    90.                         :range of takeoff angles
1.       .1        3.               :coarse, fine angle increment; ray density
4000. 6000. 7000. 7500. 12000.      :velocities
y                                   :direct wave? (y or n)
n                                   :primaries?   (y or n)
n                                   :head waves?  (y or n)
```



Direct Rays

File PARAM1

```
syncline                          :model file
4                                 :#interfaces in model
plotcolors                        :model colors file
m                                 :model plot descriptor (mq)
rwell                             :receiver well coordinates
wg                                :receiver plot descriptor (wgq)
d                                 :shooting mode (dg)
swell1                            :source well coordinates
don't care                        :arbitrary source coordinates
ws                                :source plot descriptor (wsq)
r                                 :job descriptor (rlt)
don't care                        :output file name
-90.    90.                       :range of takeoff angles
1.       .1        3.             :coarse, fine angle increment; ray density
4000. 6000. 7000. 7500. 12000.    :velocities
n                                 :direct wave? (y or n)
y                                 :primaries?   (y or n)
n                                 :head waves?  (y or n)
```



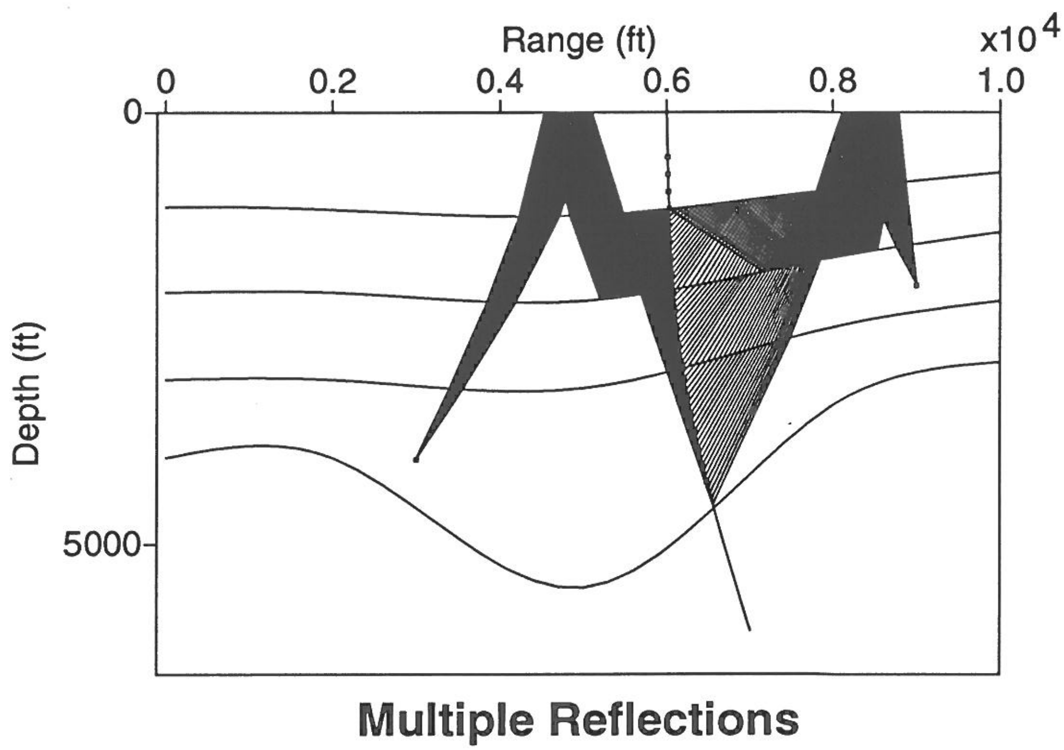
Primaries

File PARAM1

```
syncline                              :model file
4                                     :#interfaces in model
plotcolors                            :model colors file
m                                     :model plot descriptor (mq)
rwell                                 :receiver well coordinates
wg                                    :receiver plot descriptor (wgq)
g                                     :shooting mode (dg)
don't care                            :source well coordinates
sources                               :arbitrary source coordinates
 s                                    :source plot descriptor (wsq)
r                                     :job descriptor (rlt)
don't care                            :output file name
-90.    90.                           :range of takeoff angles
1.        .1          3.              :coarse, fine angle increment; ray density
4000. 6000. 7000. 7500. 12000.        :velocities
n                                     :direct wave? (y or n)
n                                     :primaries?   (y or n)
n                                     :head waves?  (y or n)
r 0 2 1                               :multiple reflection event
```

File *sources*

```
3000.    4000.                        :(x,z) coordinates of source 1
9000.    2000.                        :(x,z) coordinates of source 2
```

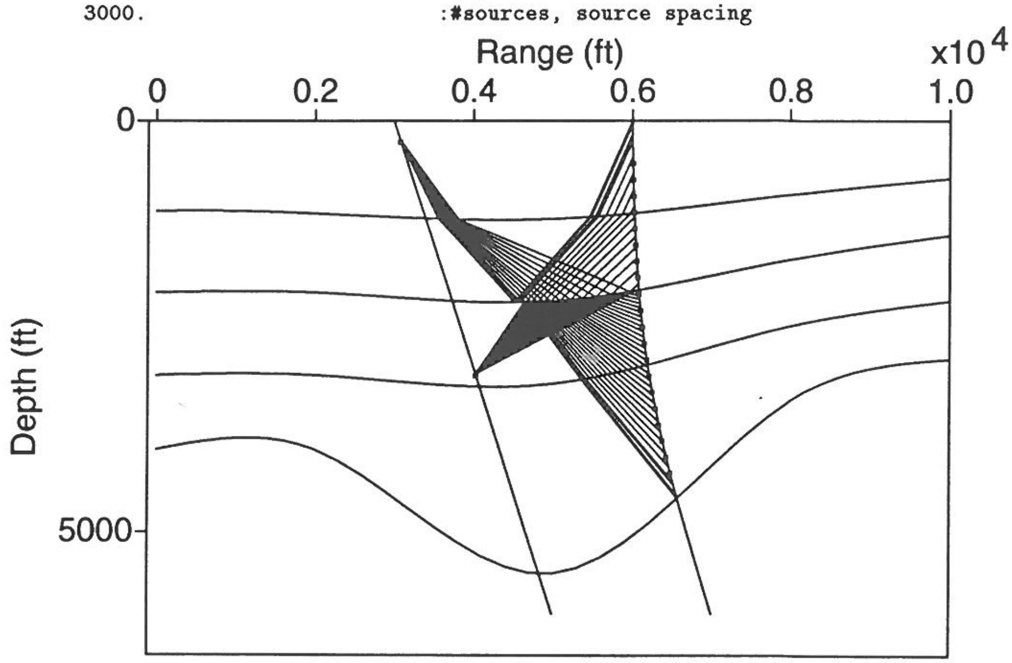


File PARAM1

```
syncline                          :model file
4                                 :#interfaces in model
plotcolors                        :model colors file
m                                 :model plot descriptor (mq)
rwell                             :receiver well coordinates
wg                                :receiver plot descriptor (wgq)
d                                 :shooting mode (dg)
swell2                            :source well coordinates
don't care                        :arbitrary source coordinates
ws                                :source plot descriptor (wsq)
rl                                :job descriptor (rlt)
demo7                             :output file name
-90.    90.                       :range of takeoff angles
1.      .1      1.                :coarse, fine angle increment; ray density
4000. 6000. 7000. 7500. 12000.    :velocities
n                                 :direct wave? (y or n)
n                                 :primaries?   (y or n)
n                                 :head waves?  (y or n)
r 2                               :reflection from Interface 2
```

File *swell2*

```
3000.                             :x-coord. of top of source well
5000.   6000.
1.      -99999.                   :end of source well definition
250.                              :depth to first source
2       3000.                     :#sources, source spacing
```



2 Shots, Reflection from Interface 2

```
                CWELL Listing File


Velocities:
layer  1   4000.0
layer  2   6000.0
layer  3   7000.0
layer  4   7500.0
layer  5  12000.0

Top of receiver well is at coordinates  6000.00,      .00
Top of source well is at coordinates  3000.00,      .00


Number of shots =     2
Number of events per shot =     1

shot            x-z coordinates          layer number
  1          3079.06     237.17               1
  2          4027.77    3083.31               3

receiver        x-z coordinates          layer number
  1          6009.03     499.92               1
  2          6013.57     699.87               1
  3          6019.04     899.79               1
  4          6025.72    1099.68               1
  5          6033.85    1299.51               2
  6          6043.71    1499.27               2
  7          6055.56    1698.92               2
  8          6069.65    1898.42               2
  9          6086.25    2097.73               3
 10          6105.59    2296.79               3
 11          6127.93    2495.54               3
 12          6153.51    2693.90               3
 13          6182.54    2891.78               3
 14          6215.24    3089.08               4
 15          6251.58    3285.75               4
 16          6291.28    3481.77               4
 17          6334.06    3677.15               4
 18          6379.64    3871.88               4
 19          6427.76    4066.01               4
 20          6478.15    4259.56               4


Shot     1       event     1

This is a reflection.

 3079.06     237.17
 3558.53    1198.85
 4526.71    2217.29
 5475.40    1173.51
 6000.85      35.89
 t =    1.051203

 3079.06     237.17
```

```
3575.39   1199.38
4592.88   2216.33
5571.11   1166.55
6004.06    238.98
t =   1.005492

3079.06    237.17
3592.23   1199.91
4661.21   2214.88
5668.06   1159.01
6007.76    437.83
t =    .960877

3079.06    237.17
3609.43   1200.43
4733.47   2212.80
5768.24   1150.70
6012.06    637.21
t =    .916277

3079.06    237.17
3626.95   1200.96
4809.93   2209.96
5871.37   1141.66
6017.20    836.59
t =    .871826

3079.06    237.17
3644.81   1201.49
4891.15   2206.24
5977.31   1131.89
6023.44   1035.91
t =    .827569

3079.06    237.17
3686.70   1202.69
5097.00   2193.14
6033.66   1295.20
6766.02        .00
t =    .788687

3079.06    237.17
3710.93   1203.35
5228.16   2182.18
6039.48   1418.05
6917.80        .00
t =    .775294

3079.06    237.17
3735.73   1204.01
5374.54   2167.58
6046.36   1547.19
7086.09        .00
t =    .761447

3079.06    237.17
3761.15   1204.67
```

```
 5540.96   2148.26
 6054.63   1684.51
 7276.36       .00
 t =     .747026

 3079.06    237.17
 3787.22   1205.31
 5735.13   2122.48
 6064.75   1832.77
 7497.48       .00
 t =     .731853

 3079.06    237.17
 3813.98   1205.95
 5970.37   2087.01
 6077.45   1996.04
 7765.13       .00
 t =     .715657


End of Event


End of Shot




Shot     2       event    1

This is a reflection.

 4027.77   3083.31
 4642.34   2215.34
 5369.64   3148.92
 6560.55   4559.85
 t =     .567174

 4027.77   3083.31
 4663.99   2214.81
 5416.76   3140.89
 6510.75   4380.50
 t =     .544732

 4027.77   3083.31
 4687.92   2214.18
 5468.57   3131.69
 6464.15   4206.71
 t =     .523375

 4027.77   3083.31
 4712.73   2213.46
 5522.06   3121.84
 6423.31   4048.57
 t =     .504330
```

```
4027.77   3083.31
4738.33   2212.64
5577.01   3111.39
6387.55   3904.66
t =     .487374

4027.77   3083.31
4764.79   2211.73
5633.55   3100.24
6356.04   3772.71
t =     .472186

4027.77   3083.31
4792.18   2210.70
5691.81   3088.25
6328.10   3650.87
t =     .458508

4027.77   3083.31
4820.57   2209.56
5751.98   3075.61
6303.31   3538.25
t =     .446200

4027.77   3083.31
4850.05   2208.25
5814.23   3062.02
6281.13   3433.27
t =     .435053

4027.77   3083.31
4880.71   2206.78
5878.79   3047.49
6261.25   3335.14
t =     .424952

4027.77   3083.31
4912.67   2205.13
5945.92   3032.08
6243.43   3243.33
t =     .415811

4027.77   3083.31
4946.05   2203.28
6015.90   3015.56
6227.37   3156.96
t =     .407512

4027.77   3083.31
4980.98   2201.21
6089.10   2997.82
6212.87   3075.52
t =     .399981

4027.77   3083.31
5017.62   2198.89
6165.88   2978.76
```

```
6199.78    2998.67
t =     .393164

4027.77    3083.31
5096.80    2193.21
6175.03    2842.94
7676.92    3620.73
t =     .378563

4027.77    3083.31
5139.77    2189.82
6164.11    2769.09
7774.52    3549.34
t =     .371896

4027.77    3083.31
5185.35    2186.02
6154.15    2698.56
7879.79    3477.00
t =     .365807

4027.77    3083.31
5233.83    2181.73
6145.04    2631.06
7995.34    3402.82
t =     .360252

4027.77    3083.31
5285.61    2176.76
6136.67    2566.33
8124.96    3328.51
t =     .355211

4027.77    3083.31
5341.11    2171.14
6128.98    2504.20
8274.43    3253.63
t =     .350630

4027.77    3083.31
5400.86    2164.80
6121.90    2444.52
8452.81    3176.04
t =     .346482

4027.77    3083.31
5465.50    2157.45
6115.35    2387.11
8676.71    3098.88
t =     .342757

4027.77    3083.31
5535.81    2148.96
6109.30    2331.76
8986.56    3019.97
t =     .339422
```

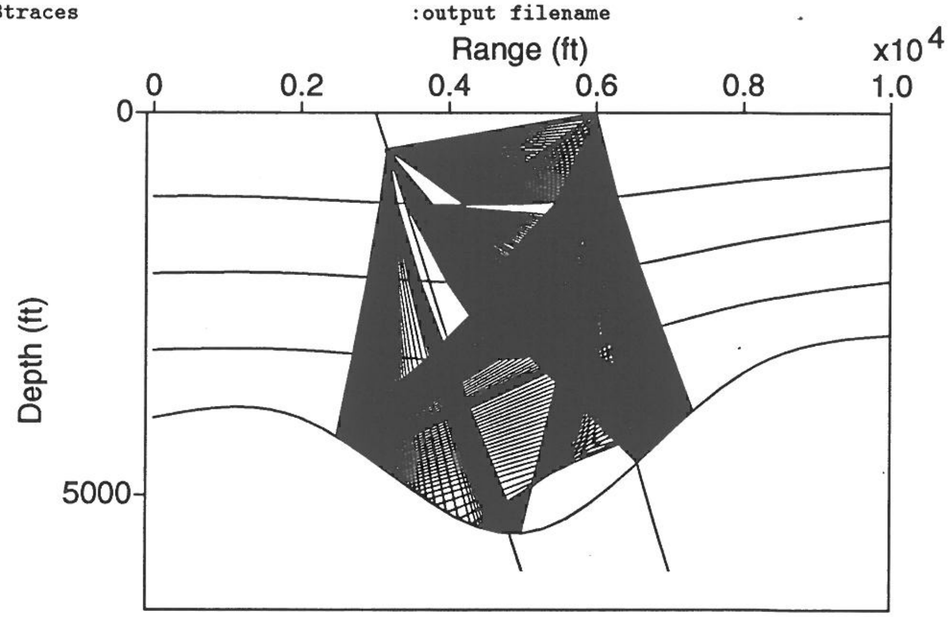
```
 4027.77    3083.31
 5612.73    2139.26
 6103.74    2278.98
 9487.83    2943.17
 t =     .336473

 4027.77    3083.31
 5697.47    2127.78
 6098.59    2228.09
10000.00    2815.16
 t =     .333893

 4027.77    3083.31
 5791.56    2114.45
 6093.85    2179.62
10000.00    2602.58
 t =     .331659

 4027.77    3083.31
 5896.96    2098.58
 6089.50    2133.39
10000.00    2335.43
 t =     .329768

 4027.77    3083.31
 6016.26    2079.78
 6086.30    2090.00
10000.00    2335.43
 t =     .328307


End of Event


End of Shot
```

File PARAM1

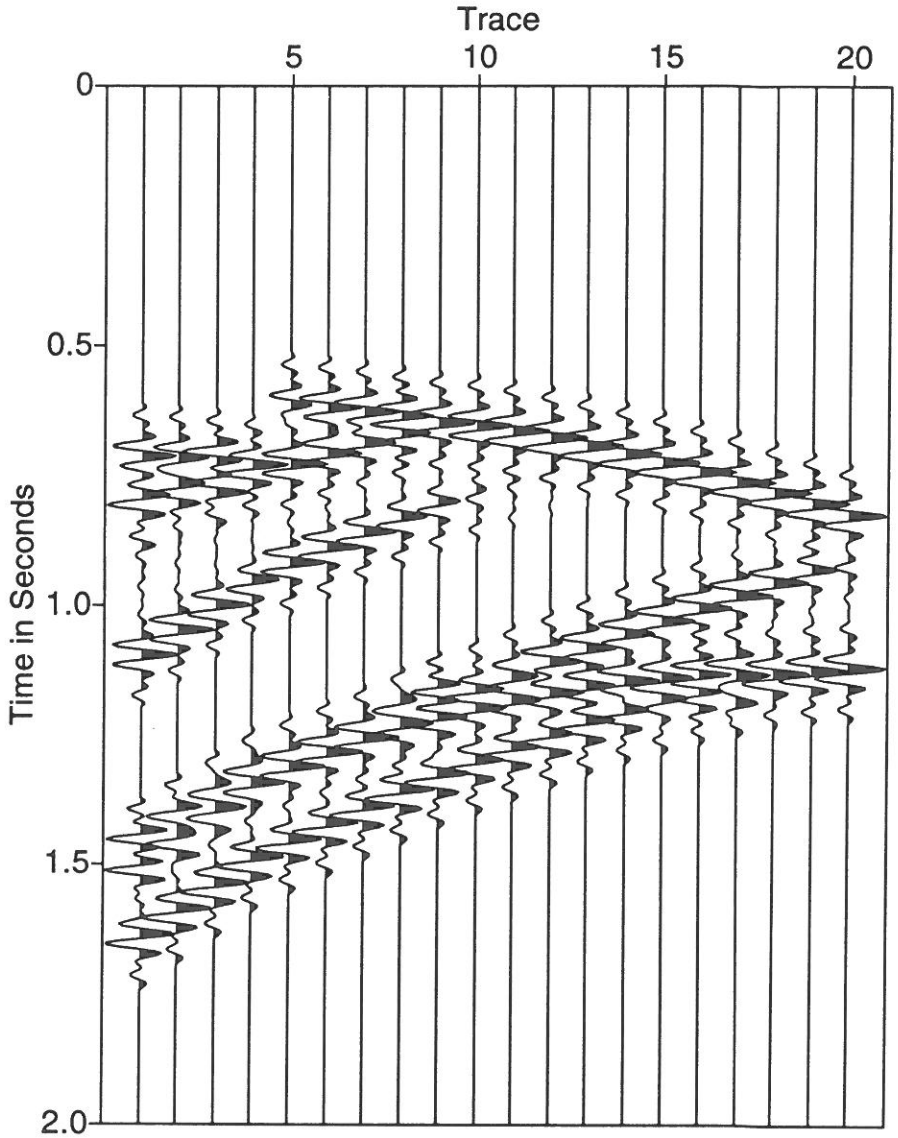
```
syncline                          :model file
4                                 :#interfaces in model
plotcolors                        :model colors file
m                                 :model plot descriptor (mq)
rwell                             :receiver well coordinates
wg                                :receiver plot descriptor (wgq)
d                                 :shooting mode (dg)
swell1                            :source well coordinates
don't care                        :arbitrary source coordinates
ws                                :source plot descriptor (wsq)
rt                                :job descriptor (rlt)
demo8                             :output file name
-90.    90.                       :range of takeoff angles
1.        .1        3.            :coarse, fine angle increment; ray density
4000. 6000. 7000. 7500. 12000.    :velocities
y                                 :direct wave? (y or n)
y                                 :primaries?   (y or n)
n                                 :head waves?  (y or n)
```

File PARAM2

```
s                                 :sort option (s,r)
1  1                              :first, last shot for sort
1  20                             :first, last trace; OR first, last receiver
10.  25.   35.  50.               :frequency spectrum of wavelet
.150                              :wavelet length (secs)
.004                              :sample rate (secs)
2.                                :trace length (secs)
demo8shot                         :input filename
demo8traces                       :output filename
```



Direct + Primaries



Crosswell Data (agc)

File PARAM1

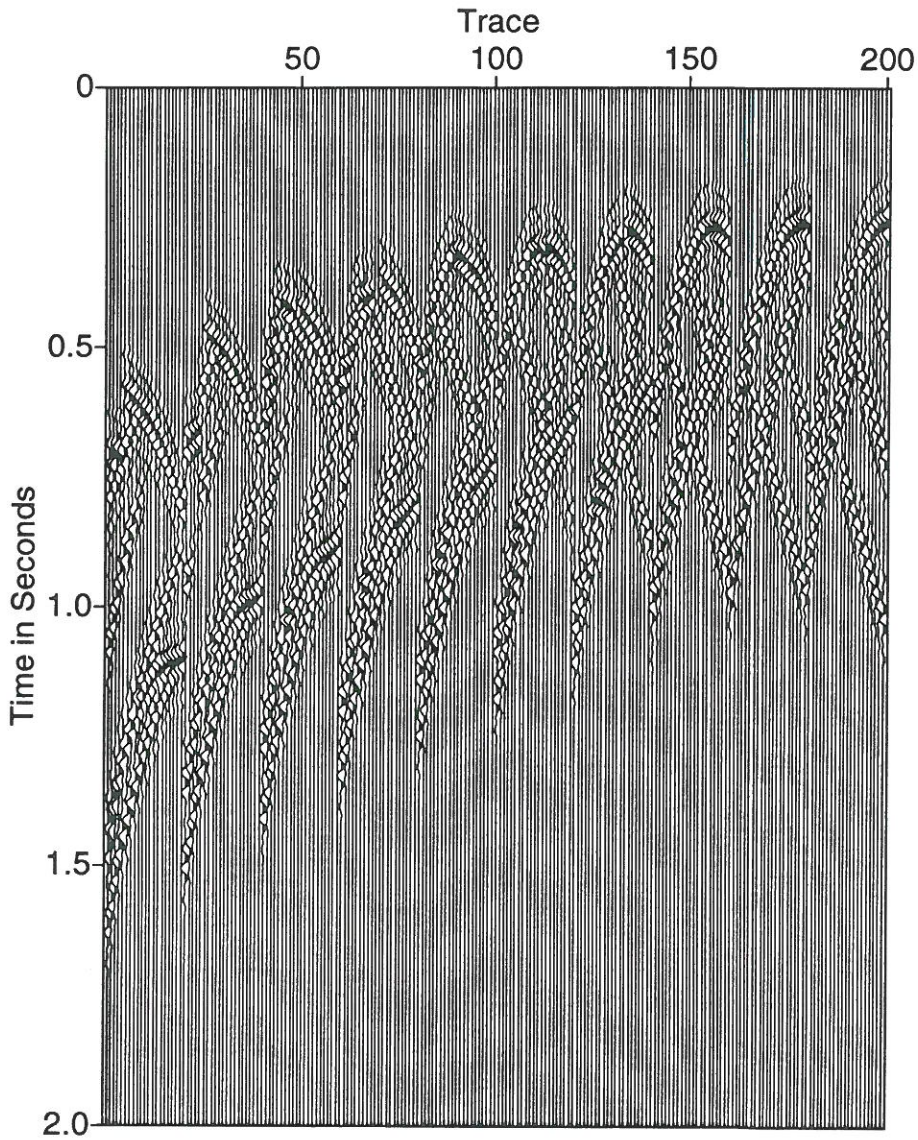
```
syncline                                 :model file
4                                        :#interfaces in model
plotcolors                               :model colors file
                                         :model plot descriptor (mq)
rwell                                    :receiver well coordinates
                                         :receiver plot descriptor (wgq)
d                                        :shooting mode (dg)
swell3                                   :source well coordinates
don't care                               :arbitrary source coordinates
                                         :source plot descriptor (wsq)
 t                                       :job descriptor (rlt)
demo9                                    :output file name
-90.    90.                              :range of takeoff angles
1.        .1        3.                   :coarse, fine angle increment; ray density
4000. 6000. 7000. 7500. 12000.           :velocities
y                                        :direct wave? (y or n)
y                                        :primaries?   (y or n)
n                                        :head waves?  (y or n)
```

File *swell3*

```
3000.                                    :x-coord. of top of source well
5000.    6000.
1.      -99999.                          :end of source well definition
600.                                     :depth to first source
10         500.                          :#sources, source spacing
```

File PARAM2

```
s                                        :sort option (s,r)
1  10                                    :first, last shot for sort
1  20                                    :first, last trace; OR first, last receiver
10.  25.   35.  50.                      :frequency spectrum of wavelet
.150                                     :wavelet length (secs)
.004                                     :sample rate (secs)
2.                                       :trace length (secs)
demo9shot                                :input filename
demo9traces                              :output filename
```



Multi-Shot Data (agc)

File PARAM1

```
smoothmodel                              :model file
4                                        :#interfaces in model
plotcolors                               :model colors file
m                                        :model plot descriptor (mq)
rwell                                    :receiver well coordinates
wg                                       :receiver plot descriptor (wgq)
d                                        :shooting mode (dg)
swell4                                   :source well coordinates
don't care                               :arbitrary source coordinates
ws                                       :source plot descriptor (wsq)
rt                                       :job descriptor (rlt)
demo10                                   :output file name
  0.    90.                              :range of takeoff angles
1.        .1          2.                 :coarse, fine angle increment; ray density
4000. 6000. 8000. 10000. 15000.          :velocities
n                                        :direct wave? (y or n)
n                                        :primaries?   (y or n)
y                                        :head waves?  (y or n)
```

File *smoothmodel*

```
0.          0.                           :start of upper surface
10000.      0.
1.      -99999.                          :end of upper surface
0.       1100.                           :start of interface 1
1000.    1100.
5000.    1200.
8000.     900.
10000.    700.
1.      -99999.                          :end of interface 1
0.       2100.                           :start of interface 2
2000.    2100.
5000.    2200.
8000.    1700.
10000.   1400.
1.      -99999.                          :end of interface 2
0.       3100.                           :start of interface 3
2000.    3100.
5000.    3200.
8000.    2500.
10000.   2200.
1.      -99999.                          :end of interface 3
0.       4500.                           :start of interface 4
2000.    4500.
5000.    4700.
8000.    4000.
10000.   3700.
1.      -99999.                          :end of interface 4
```

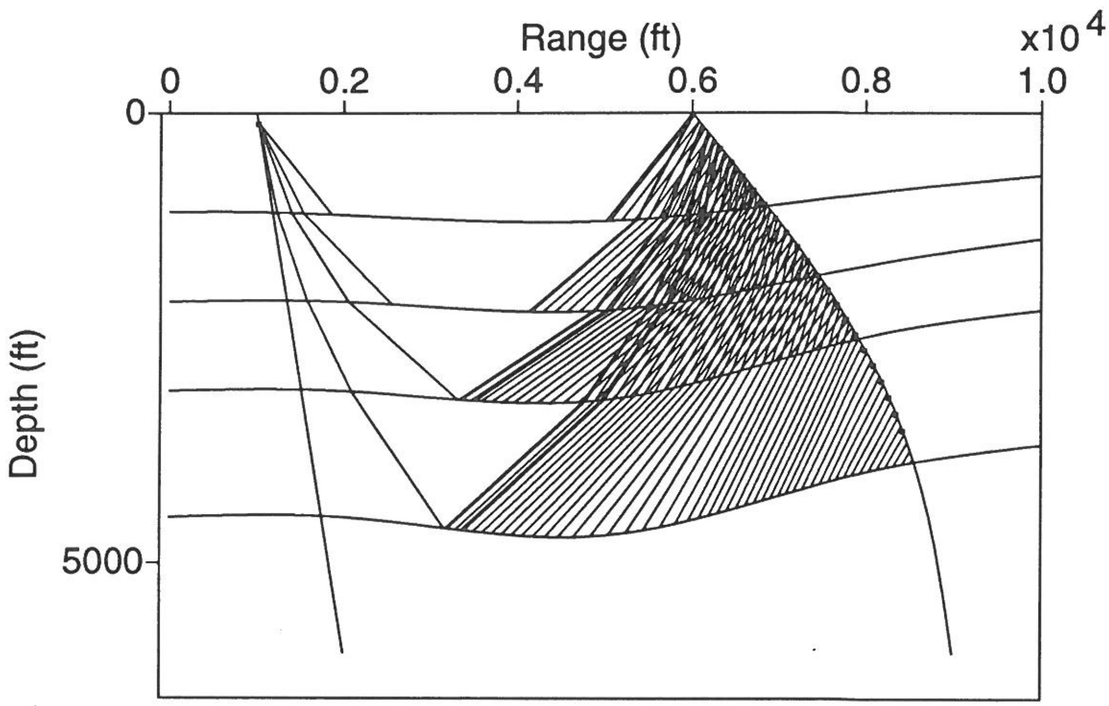
File *swell4*

```
1000.                                    :x-coord. of top of source well
2000.     6000.
```

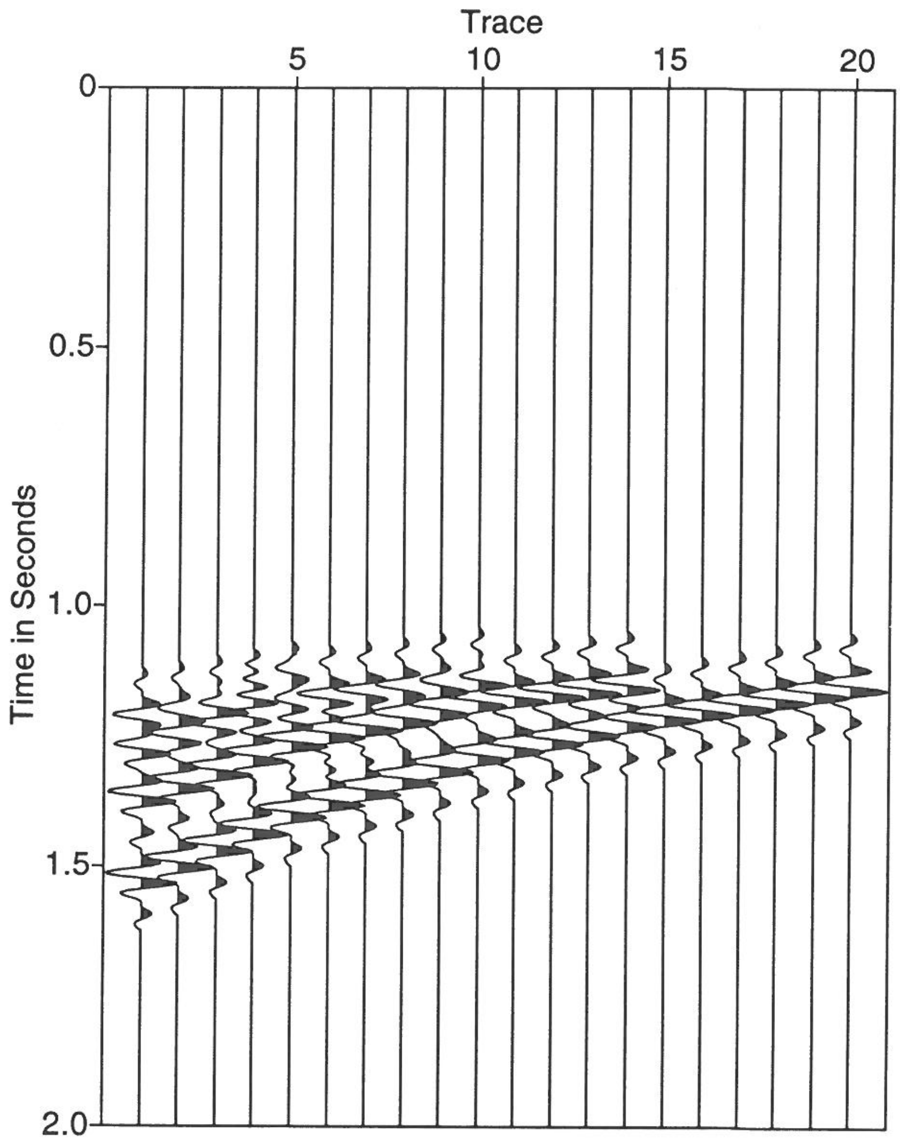
```
1.      -99999.                     :end of source well definition
100.                                :depth to first source
1          500.                     :#sources, source spacing
```

File PARAM2

```
s                                   :sort option (s,r)
1  1                                :first, last shot for sort
1  20                               :first, last trace; OR first, last receiver
10.  25.   35.  50.                 :frequency spectrum of wavelet
.150                                :wavelet length (secs)
.004                                :sample rate (secs)
2.                                  :trace length (secs)
demo10shot                          :input filename
demo10traces                        :output filename
```



Head Waves



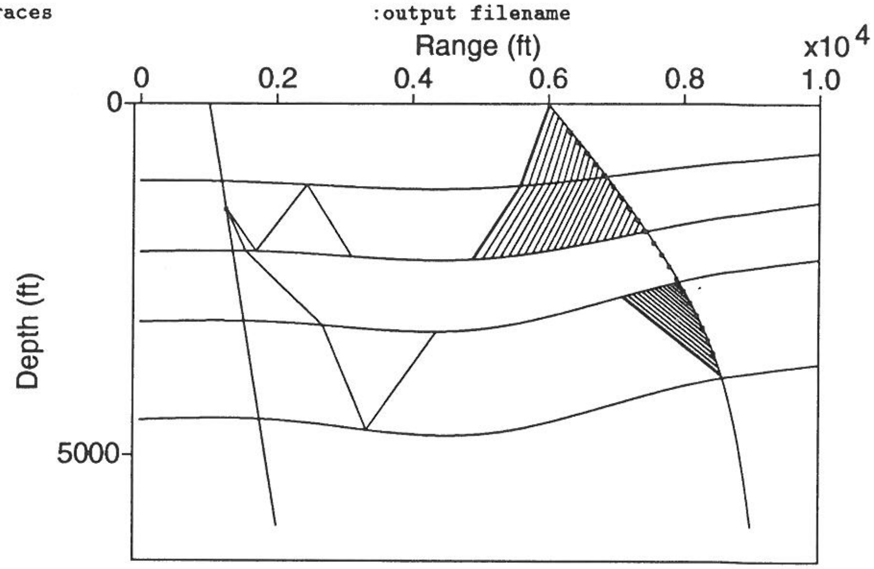
Head Wave Data (agc)

File PARAM1

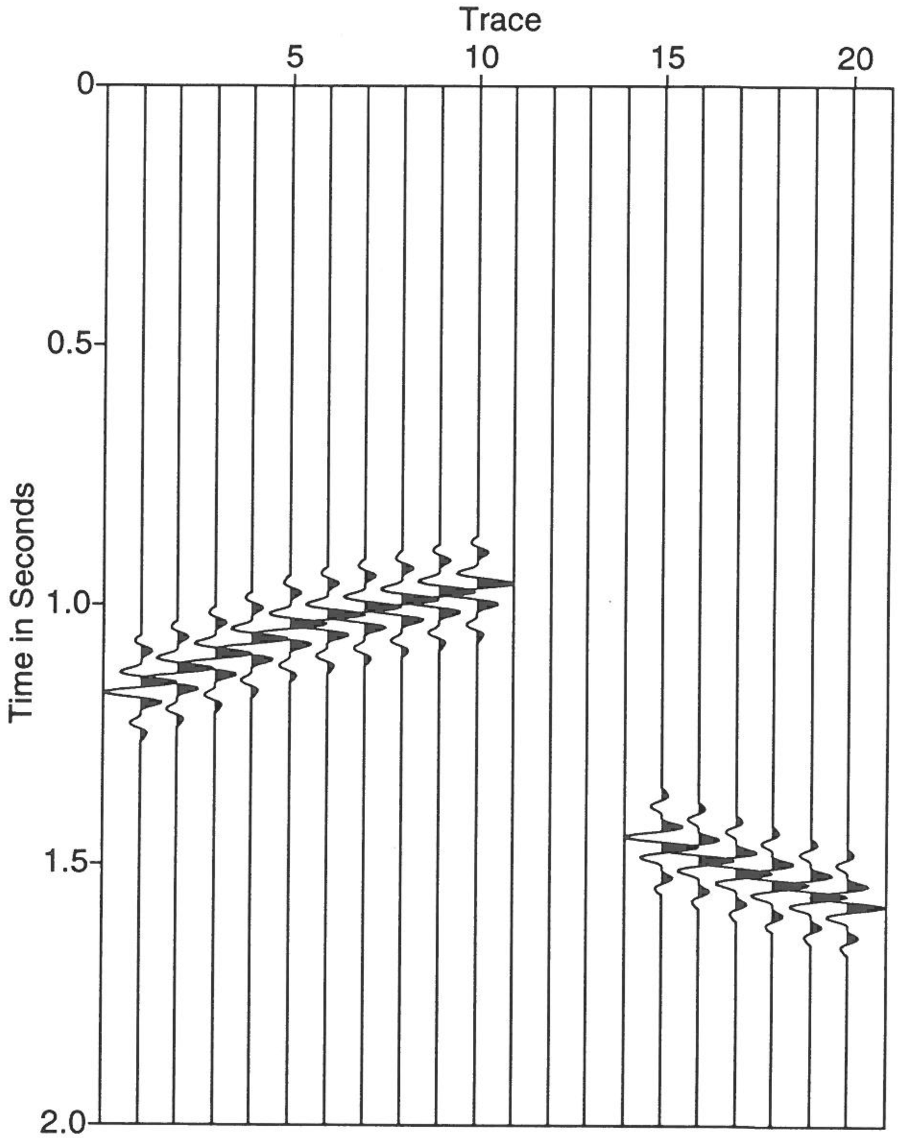
```
smoothmodel                        :model file
4                                  :#interfaces in model
plotcolors                         :model colors file
m                                  :model plot descriptor (mq)
rwell                              :receiver well coordinates
wg                                 :receiver plot descriptor (wgq)
d                                  :shooting mode (dg)
swell4                             :source well coordinates
don't care                         :arbitrary source coordinates
ws                                 :source plot descriptor (wsq)
rt                                 :job descriptor (rlt)
demo11                             :output file name
  0.    90.                        :range of takeoff angles
1.        .1         2.            :coarse, fine angle increment; ray density
4000. 6000. 10000. 6000. 20000.    :velocities
n                                  :direct wave? (y or n)
n                                  :primaries?   (y or n)
n                                  :head waves?  (y or n)
h 2 1 2                            :multiple bounce head wave
h 4 3                              :multiple bounce head wave
```

File PARAM2

```
s                                  :sort option (s,r)
1  1                               :first, last shot for sort
1  20                              :first, last trace; OR first, last receiver
10.  25.   35.  50.                :frequency spectrum of wavelet
.150                               :wavelet length (secs)
.004                               :sample rate (secs)
2.                                 :trace length (secs)
demo11shot                         :input filename
demo11traces                       :output filename
```



Multiple Bounce Head Waves



Multiple Bounce Head Wave Data (agc)

5 Graphics

CWELL issues no graphics commands. Instead, it sends lists of (x, z) coordinates to standard output. You must provide software to capture these lists, perform any necessary scaling, and then join the coordinate pairs within each list using straight line segments. In this way the ray pictures shown in this document can be reproduced. Note that the program CSHOT1 handles graphics in exactly the same way.

The format of the lists is as follows:

np1 icolor1	:#pairs in List 1 and color
x(1) z(1)	:first pair in List 1
x(2) z(2)	
...	
x(np1) z(np1)	:last pair in List 1
np2 icolor2	:#pairs in List 2 and color
x(1) z(1)	:first pair in List 2
x(2) z(2)	
...	
x(np2) z(np2)	:last pair in List 2
...	
...	
...	
npn icolorn	:#pairs in List n and color
x(1) z(1)	:first pair in List n
x(2) z(2)	
...	
x(npn) z(npn)	:last pair in List n

The first record in each list contains two integers: the number of coordinate pairs that follow in the list, and the color in which the line segments joining the coordinates should be drawn on a color screen. The colors are those specified in the colors file (see Section 3). The coordinates in any given list may describe a portion of an interface, a portion of a well, a raypath, or possibly a symbol at the location of a source or receiver. The total number of lists is not given and must be counted if required.

6 Figures

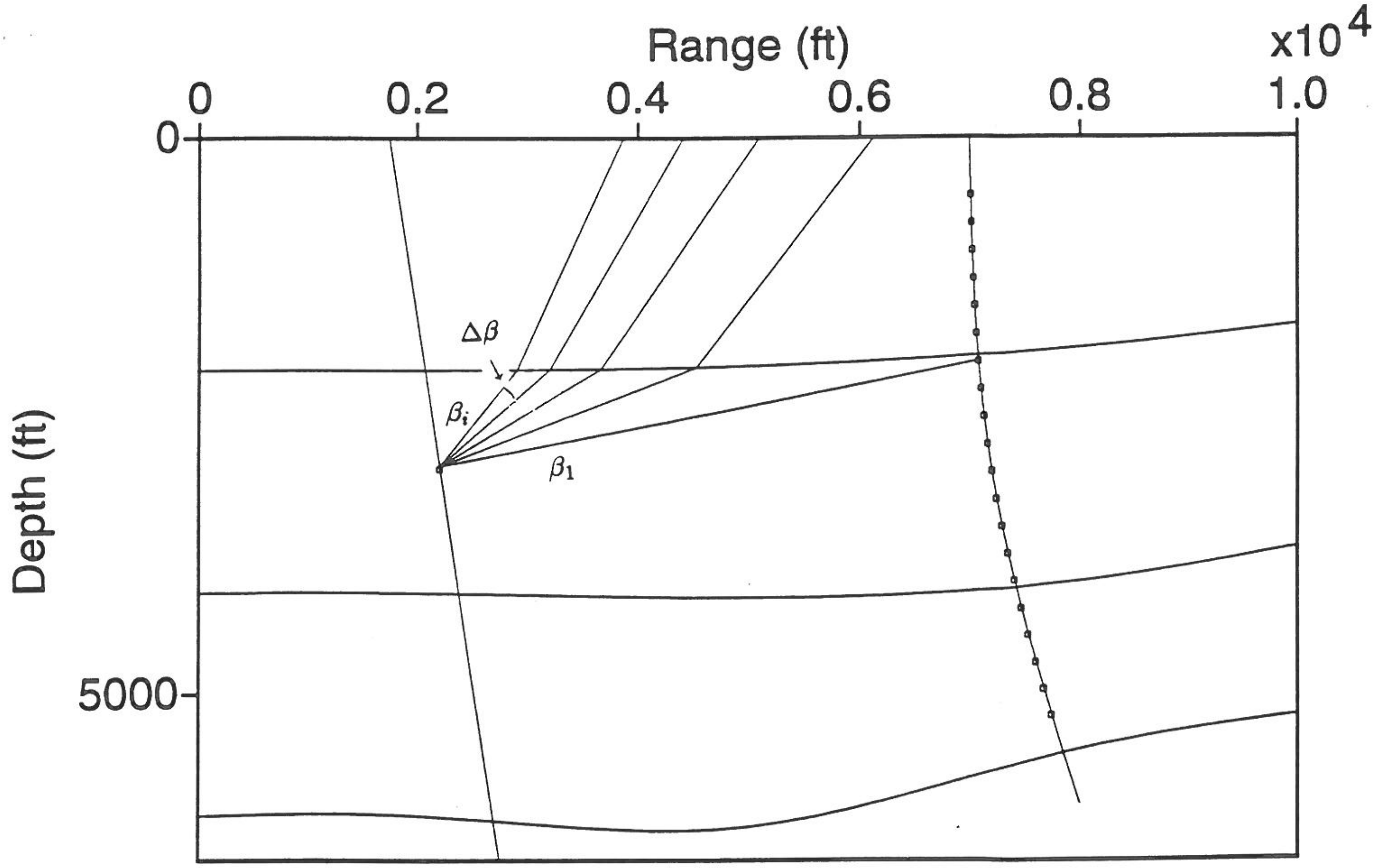


Figure 1

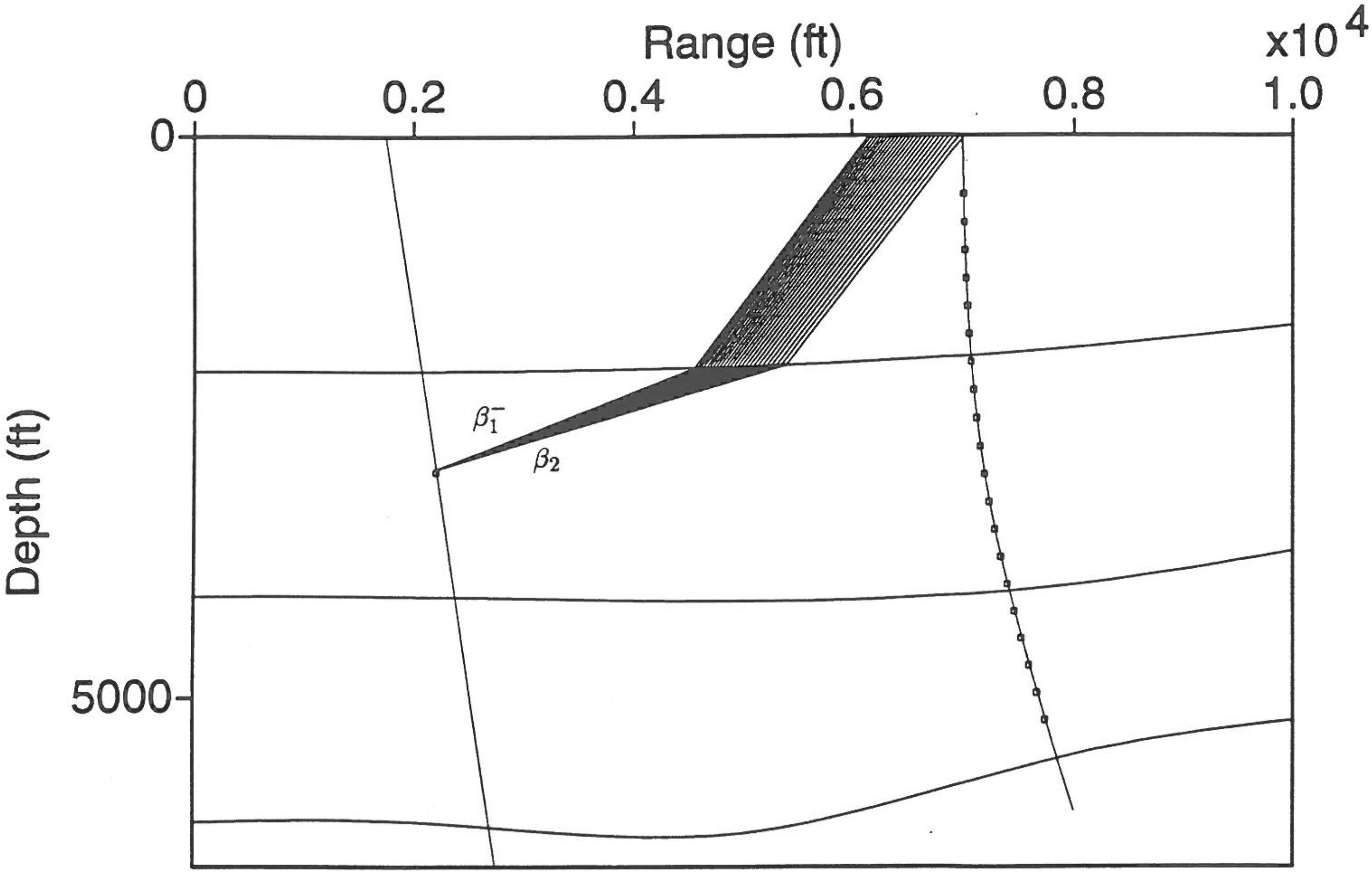


Figure 2

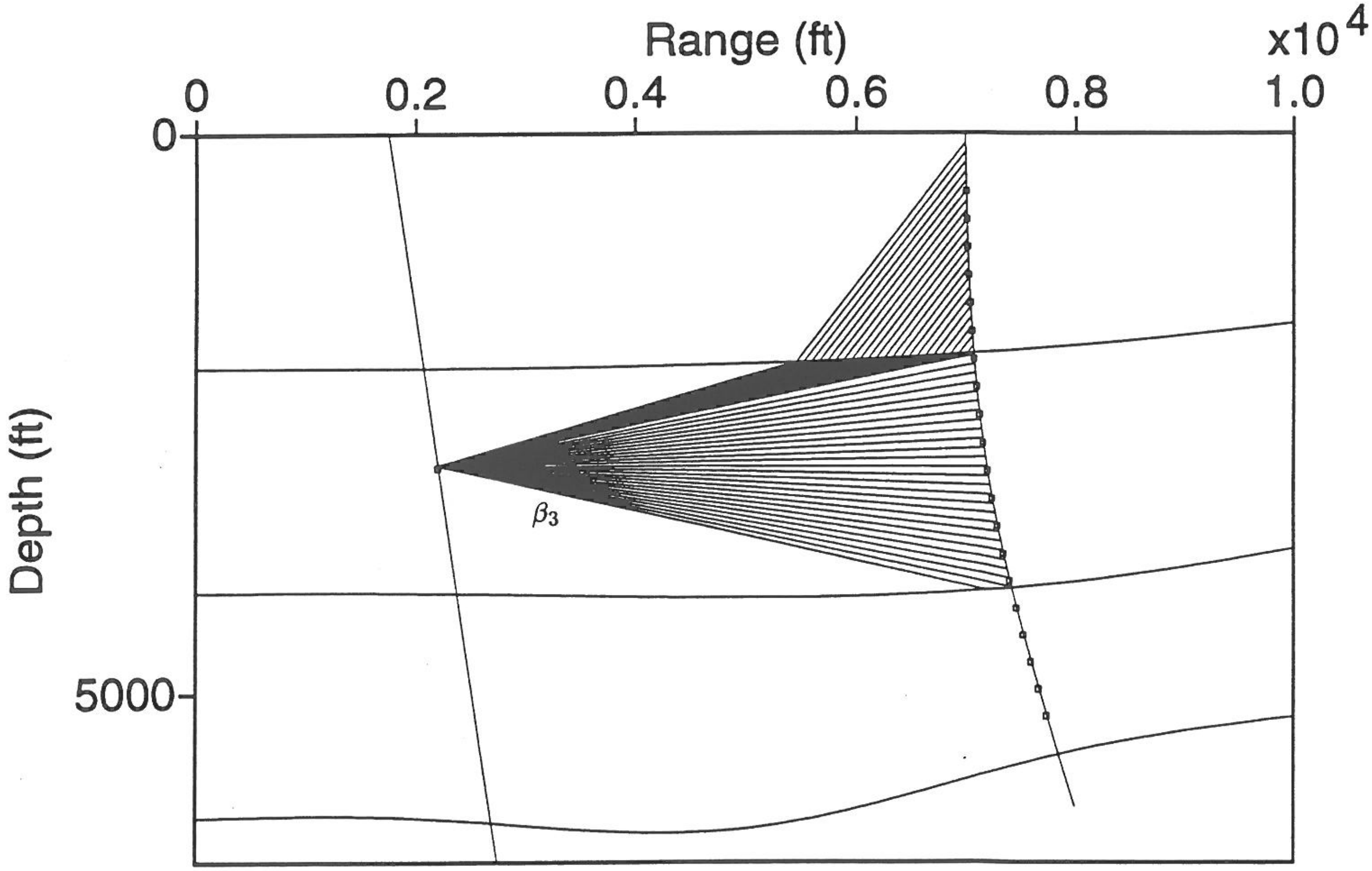


Figure 3

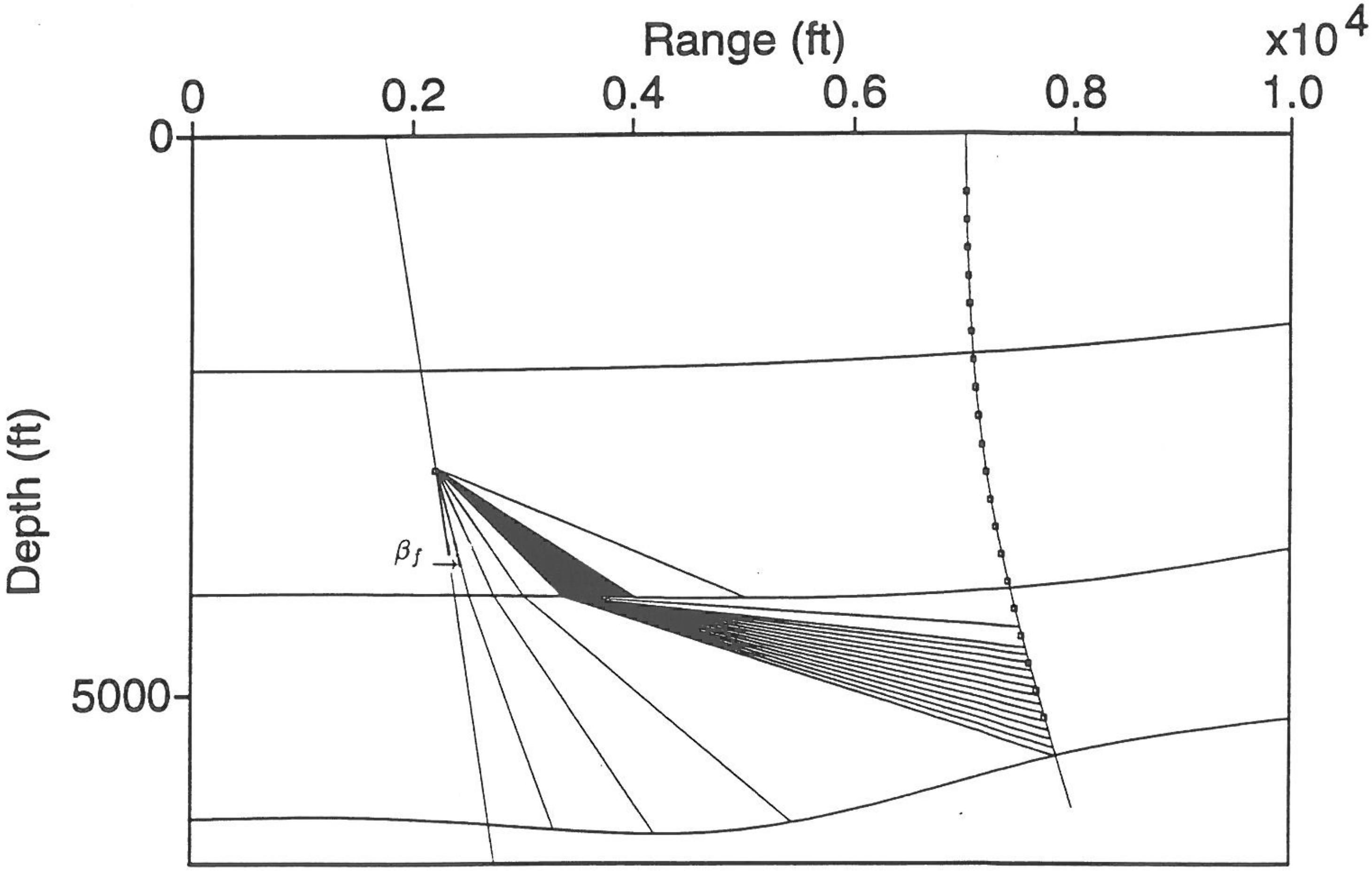


Figure 4

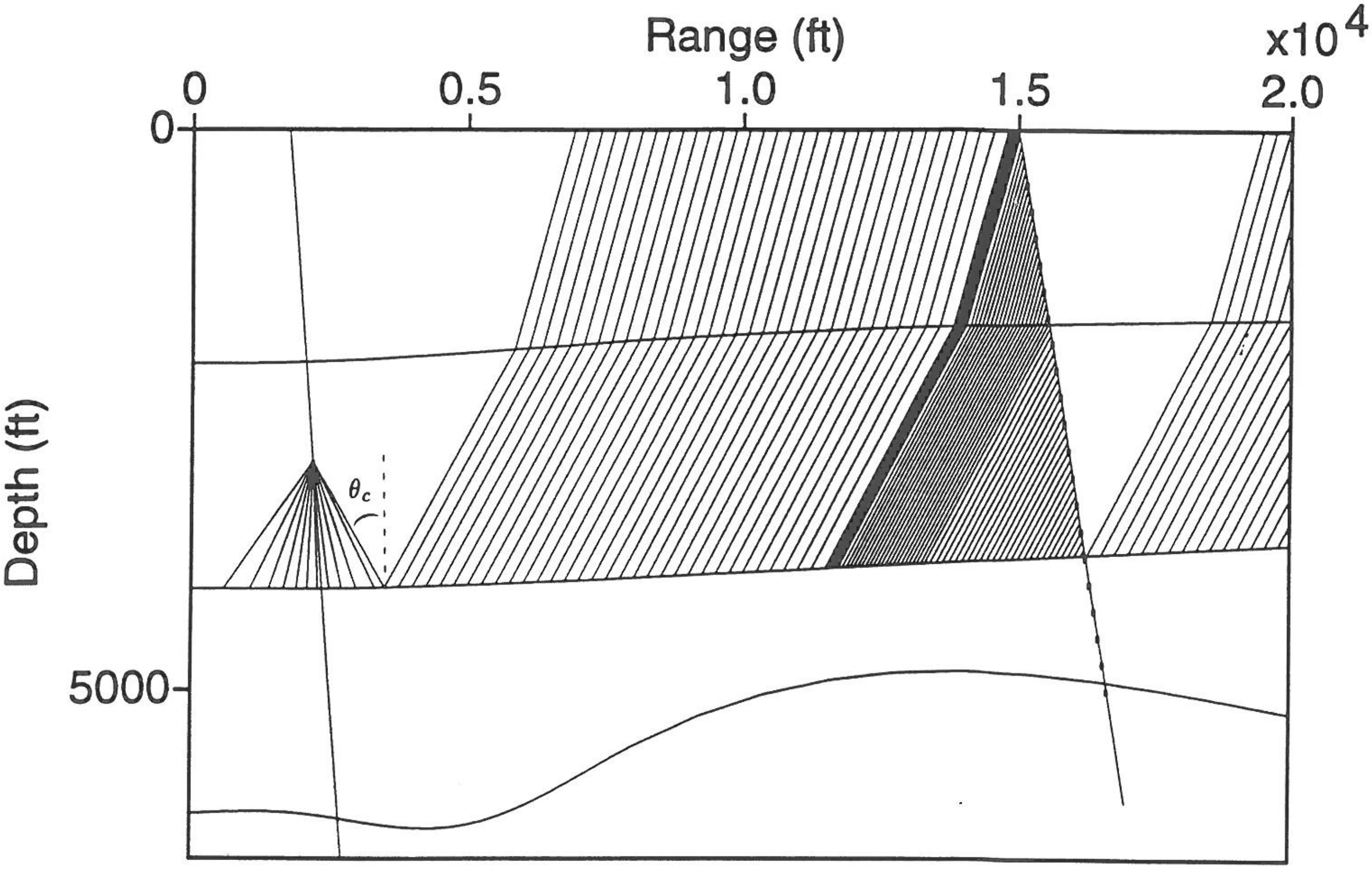


Figure 5