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Users Manual for

RSEC88

Interactive Computer Program for Plotting Seismic Refraction Record Sections

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Interactive Record Section Plotting Package (VAX/VMS version)

Introduction:

RSEC88 is a record section plotting routine designed for plotting seismic refraction data on the USGS VAX computers. As such, there are a number of features peculiar to the local hardware. In particular, the graphical output to terminals is designed to run on VT100/Retrographics or compatible (GraphOn, Envision) terminals. The program is not designed as an exportable package, although it could probably be adapted to other computers and terminals.

RSEC88 produces plots of seismic data in several time versus distance formats. Input data is assumed to be in either USGS refraction data format or SEGY data format. The distance axis may take the following forms;

1) Time vs. distance from shot to receiver.
2) Time vs. distance from a given shot or receiver position. This format is often used for displaying pseudo-fans.
3) Time vs. azimuth. (True fan)
4) Time vs. trace number.

The time axis may be actual time (relative to shot time), reduced time ($T_R = T_0 - X/V_R$), or normal moveout corrected time ($T_{nmo} = \sqrt{T_0^2 - X^2/V^2}$).

In any of the above formats the traces may be filtered and scaled to either a uniform maximum amplitude (normalized), as a function of distance (true amplitude), or automatically gain controlled (AGC) and scaled to a uniform amplitude.

Optionally, two other types of data may be plotted on the record section. Observed arrival times from an auxiliary file may be plotted as centered symbols. Calculated travel time branches from an auxiliary file created by ray tracing programs can also be plotted.

Arrival time picks or trace amplitude measurements may be made from the screen in any of the above plotting formats.

Data input to RSEC88 consists of USGS seismic refraction data direct access data files or SEGY format direct access data files plus optional auxiliary files containing observed travel time picks and calculated travel time branches to be plotted.

RSEC88 has two operational modes, interactive mode and batch mode. In interactive mode, commands are entered from the keyboard. In batch mode, commands are entered in macro files which are created with a separate editing program (*eg.* EDT) or by using the interactive SAVE command. Commands consist of one or two command words followed by optional variables. A command line beginning with an asterisk (*) is considered to be a comment line and is disregarded. This is useful in command files for legibility. An exclamation point (!) may be placed in a command line and followed by a comment. A command line beginning with @ is considered to be a command macro file actuator. The file whose name follows the @ is opened and commands are read from it. Command macro files may be invoked in either interactive or batch mode. Command files have a default suffix .JMP . Commands eliciting a prompt and response are directed to the terminal. When the last command has been read from the command file, control is returned to the terminal or the next higher command level. Six levels of command file are allowed.

Examples:

* The following commands both read from macro files named PLOT.JMP

@PLOT.JMP

@PLOT

A simple command macro file to plot a basic record section might appear like this:

```
*
*   PLOT.JMP - Basic record section for plotting SP01.DAT
*
SET DISTANCE 0.,100.,0.25,5.0,5,0.0,  ! RMIN,RMAX,RSF,DR,NSR,RBIAS
SET TIME -1.0, 7.0, 1.0, 1.0, 10,     ! TMIN,TMAX TSF,DT,NST
WIDTH = 0.4                           ! Trace width
CLIP = 0.4                            ! Clipping width
SHADE = 0.0                           ! Trace shading
RV = 6.0                              ! Reducing velocity
SET PLOTID SHOT POINT 01              ! Establish plot ID
OPEN DATA SP01.DAT
DISABLE VTONLY                        ! Enable plotting prompts
ENABLE FIT                            ! and scale plot to fit
*                                     ! the VT100 screen.
PLOT
SIZE
```

Single Word Commands:

STOP EXIT QUIT	Terminate processing.
CLEAR	Clear alphanumeric text from the screen. The plot file is not affected.

EDIT — Goes to the data file edit processor which prompts for further action. The following macros may be executed to edit USGS format data files. Further editing and sorting may done using the program TRAN3.

1 Delete a record by record number.
2 Delete a record by location number.
3 Undelete records.
4 Change TMIN.
5 Alter location range.
6 Alter shotpoint-recorder distance.
7 Negate distances.
8 List data file.
9 Change dB settings.
10 Mask a record by record number.
11 Mask a record by location number.
12 Unmask records.

When a record is deleted or masked, it will not be plotted. Both of these functions flag the requested records by modifying the header entry for the instrument ID. Delete resets the instrument ID to -1; Mask resets the instrument ID to its negative. It is easier to unmask records than to undelete records as you don't have to remember the value of the instrument ID.

ERASE — Clear text and graphics from the screen. This command establishes a new frame in the output plot file.

HELP — Prints a listing of the command set on the terminal screen.

@ or JUMP — Invokes a command macro file. Command files have a default suffix of .JMP. You may use up to six levels of command files.

PAUSE — Halt program until RETURN is received from the terminal.

PICK — Begins the picking process. This is also a double word command when used to PICK AMPLITUDES.

PLOT — Begins the plotting process. This is also a double word command when used to PLOT OBS or PLOT CALC.

SAVE — Creates a .JMP command file and saves the current parameter settings.

SIZE Reports the size required for plots to the Versatec plotter. The record section plot as it appears on the terminal screen is always scaled to fit within the screen. The actual size of the plotted image may by larger than the default page size for the Versatec. Use this command to determine if the page size needs to be altered before plotting.

TYPE The remainder of the command line is written to the terminal. This may be used in command files to pass additional information to the user. For example,

TYPE This is a message to the user

will print the text <This is a message to the user> on the terminal screen.

Double Word Commands:

Double word commands are grouped by the first of the two words. Following is a list of the first word of two word commands.

PROMPT	Set parameters.
SELECT	Select traces to be plotted.
SET	Set parameters.
PICK	Make picks from the screen.
PLOT	Initiate plotting.
LIST	List information to the terminal.
PRINT	Print information to an output file.
OPEN	Open files.
CLOSE	Close files.
ENABLE	Enable options.
DISABLE	Disable options.

Taken in order, the following is a complete list of the two word commands:

PROMPT - Set parameters via a prompting sequence.

PROMPT FAN	Initiates prompting sequence for fan plotting.
PROMPT FILTER	Initiates prompting sequence for setting the bandpass filter.
PROMPT MONITOR	Initiates prompting sequence for plotting by record number (Monitor plots).
PROMPT RELATIVE	Initiates prompting sequence for plotting distances relative to a given location.

SELECT - Select traces to be plotted.

SELECT AZIMUTHS	Select maximum and minimum azimuths to be plotted.
SELECT DISTANCES	Select maximum and minimum distances to be plotted.
SELECT LOCATIONS	Select maximum and minimum location numbers to be plotted.
SELECT RECORDS	Select maximum and minimum record numbers to be plotted.

DESELECT - Clear selection variables. All traces will be plotted.

SET - Set parameters. See the section "Variable Changing Commands", p. 16, for a more complete description of parameters.

These commands may be given with or without the values for the variables. If no variable values are given <*i.e.* SET TIME>, you will be prompted for the values. If you want to provide all the information on a single line, as in a macro file, you must give a value for <u>all</u> the variables and separate them by commas <*i.e.* SET TIME -1.0, 7.0, 1.0, 1.0, 10, >.

SET ALL	Initiates a prompting sequence for distance, time, and trace parameters.
SET AZIMUTH	Set azimuth axis variables, AZMIN, AZMAX, AZSF, DAZ, NSAZ, AZBIAS.
SET CM	Scaling factors and symbol sizes will be given in centimeters. See also SET INCHES.
SET DISTANCE	Set distance axis variables, RMIN, RMAX, RSF, DR, NSR, RBIAS.
SET FILTER	Set the filter variables, FLO and FHI.
SET INCHES	Scaling factors and symbol sizes will be given in inches [default]. See also SET CM.
SET PENS	Set the line widths for various parts of the plot.
SET PLOTID	Set the PLOTID.
SET ROSETTE	Set the velocity rosette variables, ROSER, ROSET, and ROSES.
SET SYMBOLS	Set the symbol heights HNR, HBS, HOBS, HLAB, HPIC.
SET TIME	Set time axis variables, TMIN, TMAX, TSF, DT, NST.
SET TRACE	Set trace scaling variables, WIDTH, CLIP, and SHADE.
SET TRUEAMP	Set the variables for gain-corrected trace amplitude plotting, DCROSS, EXP1, EXP2, WCROSS.

RESET - Reset all variables to their default values.

PICK - Make picks from the screen. (See p. 27 for more details on picking.)

PICK	Arrival times will be picked.
PICK AMPLITUDE	Amplitudes will be picked.

PLOT - Initiate plotting.

PLOT	If there are no axes plotted or the axis parameters have been changed since the last plot, new axes are plotted. If a data file is open, data traces are plotted. If an observed travel-time file is open, travel-time picks are overlaid. If a calculated arrival time file is open, the calculated arrival time branches are overlaid.
PLOT SINGLE	A single trace is plotted.
PLOT OBSERVED	If there are no axes plotted or the axis parameters have been changed since the last plot, new axes are plotted. If an observed travel-time file is open, travel-time picks are overlaid.
PLOT CALCULATED	If there are no axes plotted or the axis parameters have been changed since the last plot, new axes are plotted. If a calculated arrival time file is open, the calculated arrival time branches are overlaid.

LIST - Print information on the terminal screen.

LIST DATA	List contents of the seismic data file.
LIST OBSERVED	List contents of the observed data file.
LIST PARAMETERS	List all control parameters.
LIST DISTANCE	List distance axis variables.
LIST AZIMUTH	List azimuth axis variables.
LIST TIME	List time axis variables.
LIST RV	List reducing velocity.
LIST TRACE	List trace variables.
LIST PLOTID	List plot ID.
LIST ROSETTE	List rosette variables.
LIST MODE	List plotting mode.
LIST FILTER	List filter variables.
LIST TRUEAMP	List gain-corrected amplitude variables.
LIST SYMBOLS	List symbol sizes.
LIST PFLG	List plotting flags.
LIST FORMAT	List plotting format.
LIST MISCELLANEOUS	List miscellaneous variables.
LIST FILES	List names of files currently open.
LIST FLAGS	List current flag settings.

PRINT - Print information to an output file named RSEC88.OUT

PRINT DATA	Print contents of the seismic data file.
PRINT OBSERVED	Print contents of the observed data file.
PRINT PARAMETERS	Print all control parameters.
PRINT DISTANCE	Print distance axis variables.
PRINT AZIMUTH	Print azimuth axis variables.
PRINT TIME	Print time axis variables.
PRINT RV	Print reducing velocity.
PRINT TRACE	Print trace variables.
PRINT PLOTID	Print plot ID.
PRINT ROSETTE	Print rosette variables.
PRINT MODE	Print plotting mode.
PRINT FILTER	Print filter variables.
PRINT TRUEAMP	Print gain-corrected amplitude variables.
PRINT SYMBOLS	Print symbol sizes.
PRINT PFLG	Print plotting flags.
PRINT FORMAT	Print plotting format.
PRINT MISCELLANEOUS	Print miscellaneous variables.
PRINT FILES	Print names of files currently open.
PRINT FLAGS	Print current flag settings.

OPEN - Open files. Only one file of each type may be open at a time.

OPEN DATA	Open the seismic data file. File suffix .DAT is assumed.
OPEN SEGY	Open a SEGY seismic data file. File suffix .SGY is assumed.
OPEN OBSERVED	Open an observed travel-time file. See p. 23 for a description of the file format.
OPEN CALCULATED	Open a calculated arrival time file. See p. 26 for more information about calculated arrival time files.
OPEN STATICS	Open a file containing static corrections for the traces.

CLOSE - Close files.

CLOSE DATA	Close the seismic data file. File suffix .DAT is assumed.
CLOSE SEGY	Close a SEGY seismic data file. File suffix .SGY is assumed.
CLOSE OBSERVED	Close the observed travel-time pick file.
CLOSE CALCULATED	Close the calculated arrival time file.
CLOSE STATICS	Close a file containing static corrections for the traces.

ENABLE - Enable options.

ENABLE AGC	Trace amplitudes will be automatically gain controlled. Each point in the trace will be scaled such that the maximum deflection in a window LTHWIN points centered on the point will be WIDTH units. See also ENABLE NORMALIZED and ENABLE TRUEAMP.
ENABLE CMP	Distances labeled on the distance axis reflect common midpoint distances rather than actual distances.
ENABLE DATE	Enables plotting of date/time at the lower left of the plot. [default]
ENABLE DEBUG	Enables printing of debug lines to RSEC88.DBG.
ENABLE DISCO	A small symbol will be plotted 5.0 inches to the right of the record section to force the Versatec plotter on the Marine Branch DISCO computer to advance its paper.
ENABLE FAN	Enables azimuthal plotting of the record section. See also ENABLE RELATIVE.
ENABLE FILL	Enables the fill flag which causes the record section to be scaled such that it fills the terminal screen. When the fill flag is in effect, the scaling values RSF (or AZSF) and TSF are ignored. [default] See also ENABLE FIT.
ENABLE FILTER	All traces will be bandpass filtered between FLO and FHI Hz.
ENABLE FIT	Disables the fill flag. The plot is scaled using the current scale factors RSF (or AZSF) and TSF. The version of the plot which is directed to the terminal screen is then enlarged or reduced to fit within the screen. See also ENABLE FILL.
ENABLE NORMALIZED	Traces will be individually normalized in amplitude such that the maximum deflection = WIDTH. This is the default condition. See also ENABLE TRUEAMP and ENABLE AGC.

ENABLE NMO	A constant velocity normal moveout correction will be applied to each trace.
ENABLE NMOG	A velocity-gradient normal moveout correction will be applied to each trace.
ENABLE NOTE	An annotation box will be plotted to the right of the record section with critical plotting parameters. [default]
ENABLE POWER	Enables raising the amplitudes of traces to a power.
ENABLE RELATIVE	Traces will be plotted as a function of distance from a given location. The reference location is defined in terms of distance and azimuth from the shot point (DREF, AZREF). See also ENABLE FAN.
ENABLE REFLECT	Axis labeling will be inverted so that NMO plots may be viewed as shot gather reflection panels.
ENABLE ROSETTE	A velocity rosette will be plotted. [default]
ENABLE SINGLE	Enables plotting of a single trace.
ENABLE TRUEAMP	Trace amplitudes will be corrected for instrument gain and plotted with amplitude as a function of distance. See also ENABLE NORMALIZED and ENABLE AGC.
ENABLE VTONLY	Sets the flag which directs that the plot will be only to the terminal screen. No prompts will be given to open a BATCH.PLT file for plotting to a Versatec plotter. [default]

DISABLE - Disable options.

DISABLE AGC	Trace amplitudes will not be automatically gain controlled. [default] See also DISABLE TRUEAMP and ENABLE NORMALIZED.
DISABLE CMP	Disables common midpoint distances plotted on the distance axis. [default]
DISABLE DATE	Disables plotting of date/time at the lower left of the plot.
DISABLE DEBUG	Disables printing of debug lines to RSEC88.DBG.
DISABLE DISCO	A small symbol will not be plotted 5.0 inches to the right of the record section to force the Versatec plotter on the Marine Branch DISCO plotter to advance its paper. [default]
DISABLE FAN	Disables azimuthal plotting of the record section. [default] See also DISABLE RELATIVE.
DISABLE FILL	Disables the fill flag. The plot is scaled using the current scale factors RSF (or AZSF) and TSF. The version of the plot which is directed to the terminal screen is then enlarged or reduced to fit with in the screen. See also DISABLE FIT.
DISABLE FILTER	The filter will be disabled. [default]
DISABLE FIT	Enables the fill flag which causes the record section to be scaled such that it fills the terminal screen. When the fill flag is in effect, the scaling values RSF (or AZSF) and TSF are ignored. See also DISABLE FILL.
DISABLE NMO	A normal moveout correction will not be applied to each trace. [default]
DISABLE NMOG	A velocity-gradient normal moveout correction will not be applied to each trace.
DISABLE NOTE	Disables annotation box plotted to the right of the record section.
DISABLE POWER	Disables raising the amplitudes of traces to a power. [default]

DISABLE RELATIVE	Traces will not be plotted as a function of distance to a given location. They may be plotted as a function of actual distance from the shot point or as a function of azimuth. [default] See also DISABLE FAN.
DISABLE REFLECT	Axis labeling will not be inverted so that NMO plots may be viewed as shot gather reflection panels. [default]
DISABLE ROSETTE	A velocity rosette will not be plotted.
DISABLE SINGLE	Disables plotting of a single trace.
DISABLE TRUEAMP	Gain-corrected amplitudes will be disabled. [default] See also DISABLE AGC and ENABLE NORMALIZED.
DISABLE VTONLY	Disables the flag which directs that the plot will be only to the terminal screen. Normal plotting prompts will be given to open a BATCH.PLT file for plotting to a Versatec plotter.

Variable Changing Commands:

Variables within the program may be changed by giving a command containing the variable name and '='. If a valid value for the variable follows the '=' sign, the variable will be reset to that value, otherwise you will be prompted for a new value. Following the prompt, if you enter a carriage return, the variable will be unchanged. The following list of changeable variables is grouped by function and default values are given.

Distance axis variables:

Range = 0.0, 60.0	Specify the minimum and maximum range in kilometers for the distance axis.
Rmin = 0.0	Specify the minimum range in kilometers for the distance axis.
Rmax = 60.0	Specify the maximum range in kilometers for the distance axis.
Rsf = 0.25	Specify the range scale factor in plot units/km.
Dr = 5.0	Specify the distance between labeled tics on the distance axis in km.
Nsr = 5	Specify the number of intervals between labeled tics on the distance axis.
Rbias = 0.0	Specify the distance axis labeling offset in km. The minimum distance on the axis will be RMIN + RBIAS.
Rlth = 15.0	Specify the length of the distance axis. This re-calculates the value of RSF.

Time axis variables:

Time = -2.0, 8.0	Specify the minimum and maximum time in seconds for the time axis.
Tmin = -2.0	Specify the minimum time in seconds for the time axis.
Tmax = 8.0	Specify the maximum time in seconds for the time axis.
Tsf = 1.0	Specify the time scale factor in plot units/second.
Dt = 1.0	Specify the distance between labeled tics on the time axis in seconds.
Nst = 10	Specify the number of intervals between labeled tics on the time axis.
Tlth = 10.0	Specify the length of the time axis. This re-calculates the value of TSF.

Time transformation:

RV = 6.0	Reducing velocity for reduced time plots. Set to 0.0 for unreduced plots.
VNMO = 6.0	NMO velocity for constant velocity NMO correction.
V0 = 5.9	Surface velocity for velocity gradient NMO correction.
V1 = 6.74	Velocity at depth ZMAX for velocity gradient NMO correction.
VGRAD = .028	Velocity gradient for velocity gradient NMO correction.
ZMAX = 30.	Bottom depth for velocity gradient NMO correction.

Azimuth axis variables: (Measured East from North)

Azimuth = 0., 360.	Specify the minimum and maximum azimuth in degrees for the azimuth axis.
Azmin = 0.0	Specify the minimum azimuth in degrees for the azimuth axis. $-360 \leq AZMIN \leq +360$
Azmax = 360.0	Specify the maximum azimuth in degrees for the azimuth axis. $-360 \leq AZMAX \leq +360$
Azsf = 0.1	Specify the azimuth scale factor in plot units/degree.
Daz = 10.0	Specify the distance between labeled tics on the azimuth axis in degrees.
Nsaz = 5	Specify the number of intervals between labeled tics on the azimuth axis.
Azbias = 0.0	Specify the azimuth axis labeling offset in degrees. The minimum azimuth on the axis will be AZMIN+AZBIAS. Note: if AZMIN > AZMAX, the axis is reversed and the leftmost tic label is AZMAX+AZBIAS.
Azlth = 36.0	Specify the length of the azimuth axis. This re-calculates the value of AZSF.

Trace variables:

Width = 0.4	Specify the maximum width of the trace.
Clip = 0.4	Specify the clipping width of the trace.
Shade = 0.0	A number between 0.0 and 1.0 indicating the fraction of the trace to shade. Make SHADE negative to shade the opposite side of the trace.
Power = 1.0	The amplitudes of the traces will be raised to this power before plotting.
Lthwin = 200	Length of AGC window in data points.
Agclth = 1.0	Length of AGC window in seconds.
Tshift = 0.0	Time shift in seconds to be applied to all the traces.
Dfudge = 1.0	Distance scaling factor for the traces. To reverse the plot, set DFUDGE = -1.0.
Istep = 2	Decimation level for plotting data. Every ISTEP point of the data trace time series is plotted.
Hlab = 0.1	Trace label height. Set to 0.0 for no trace labels.
Islab = 0	Trace label information flag. - 1 - Attenuation only. 0 - Attenuation and location number. + 1 - Location number only.

Range scaled amplitude variables:

Dcross = 50.0	Crossover distance in km.
Exp1 = 1.0	Exponent for distances less than DCROSS.
Exp2 = 1.0	Exponent for distances greater than DCROSS.
W300 = 0.1	Scale factor at crossover distance.

Symbols for axes:

Hnr = 0.15 — Size of tics and labels on the axes.

Hbs = 0.15 — Size of plot ID and axis labels. To eliminate axis labels, set HBS to a small positive number (0.00001).

Plotid = <string> — Plot ID to be plotted with the record section. Default is no plot id.

Note = <string> — An annotation line to be plotted in the annotation box to the right of the record section. Default is no annotation line.

Hlbl = 0.1 — Height of characters in the annotation box.

Observed data display:

Hobs = 0.1 — Observed data symbol height.

Isobs = 3 — Observed travel-time data default symbol (0-31). See p.25 for symbol table. Set ISOBS = -1 to use QUAL from the travel-time file to define symbol.

I1form = 0 — Observed data file format. See "Plotting Observed Travel Time Data", p.23, for a description of formats.

- 0 - Standard format.
- 1 - TEKSEC standard format.
- 2 - Old standard format.
- 3 - Amplitude file.
- 4 - RT11 format.

Calculated data display:

Itform = 0 Calculated data file format.

0 - Standard format.
1 - TEKSEC standard format.
2 - Old standard format.
3 - amplitude file.
4 - RT11 format.

Icline = 0 Calculated branch line type.

0 - Solid.	5 - 1/16" dash.
1 - 50 dots/inch.	6 - 1/8" dash.
2 - 25 dots/inch.	7 - 1/4" dash.
3 - 10 dots/inch.	8 - 1/2" dash.
4 - 5 dots/inch.	9 - 1" dash.

Filter: The program uses a 4-pole Butterworth filter.

Filter = 1.0, 20.0 Set the filter bounds in Hz.
Flo = 1.0 Lower frequency bound for the filter in Hz.
Fhi = 20.0 Upper frequency bound for the filter in Hz.

Velocity rosette variables:

Roser = 0.0 Distance for center of velocity rosette in km.
Roset = 7.0 Time for center of velocity rosette in seconds.
Roses = 1.0 Size of arms of velocity rosette. Set ROSES to 0.0 or DISABLE ROSETTE for no rosette.
Rosign = 0.0 Direction of velocity rosette. 0.0 will plot the rosette both to the right and the left. 1.0 will plot to the right only. -1.0 will plot to the left only.

Data picking:

Hpic = 0.5	Picking symbol height.
Ispic = 3	Picking symbol (0-14).
I2form = 0	Pick output file format. 0 - ID, Range, Time, Azimuth, Code. 1 - ID, Range, Time, Code.
Ipick = 0	0 - Travel time pick will be taken at the trace nearest the cursor. 1 - Travel time pick will be taken at the position of the cursor.
Jpick = 0	0 - Amplitude picks will be taken using the values indicated by the cursor. 1 - Amplitude picks will be taken using the values of the data at the locations selected by the cursor. 2 - Amplitude picks will be taken using the maximum and minimum values of the data between the locations selected by the cursor.
Kpick = 0	0 - Gain-corrected amplitude values will be reported. 1 - Raw amplitude values will be reported. 2 - Both raw and gain-corrected values will be reported.

Reference point for plotting relative to a point:

Azref = 0.0	Azimuth of reference point.
Dref = 0.0	Distance of reference point.

Pen Widths:

Newpen = 1	Sets pen width (1-6) for all lines in plot.
Pen = 1,1	Sets pen width (1-6) for individual parts of the plot (1-7). Syntax is Pen = 1,3 where the first entry is the plot characteristic and the second is the pen width.

Plot characteristics:
1 - Axes.
2 - Timing lines.
3 - Velocity rosette.
4 - Traces.
5 - Trace shading.
6 - Observed points.
7 - Calculated branch lines.

Shtrng = 0.0	The distance of the shot from an arbitrary profile end point. This is used only when plotting data in common midpoint format to provide registration of the distance axes from shot to shot.

Timing line variables:

Tminl = -20.	Minimum time for timing lines.
Tmaxl = 20.	Maximum time for timing lines.
Dtline = 1.0	Time between timing lines. Set to 0.0 for no timing lines.
Isline = 2	Line type for timing lines.

0 - Solid.	5 - 1/16" dash.
1 - 50 dots/inch.	6 - 1/8" dash.
2 - 25 dots/inch.	7 - 1/4" dash.
3 - 10 dots/inch.	8 - 1/2" dash.
4 - 5 dots/inch.	9 - 1" dash.

Plotting Observed Travel Time Data

Observed travel time data are found in ASCII files (pick files) under one of five recognized formats. The appropriate format is selected by the variable I1FORM which has a default value of 0. Under any of the formats, a line with an asterisk (*) in the first column is considered to be a comment line and is ignored. The formats are:

0 Default standard format

The first line is a global parameter line, FORMAT (3F10.0), containing RNG, VR, and TADD. RNG is ignored by this program. To shift the travel time origin with respect to the axes, use SHTRNG. VR is the reducing velocity which has been applied to the subsequent tabulated pick times. TADD is an additive constant to be applied to all times.

Travel time data lines, FORMAT (A4, 3F10.0, I3), contain ID, DELT, TIME, AZIM, and QUAL.

ID is a four character identification, usually the location number. It is ignored by this program. DELT is the distance from the shot to the receiver. TIME is the travel time reduced by VR. AZIM is the azimuth of the receiver from the shot in degrees clockwise from north. QUAL is a number which may be used to identify an arrival as a member of a class of arrivals, *i.e.* quality of a pick or branch number. QUAL may be used to select the plotting character; see ISOBS below.

Control lines; NEW, END, CHAR

If a line is read with NEW in the first three columns, the program expects that the next data line will contain global parameters. This allows you to change global parameters within a file. This is useful for combining pick files which have been picked with different reducing velocities.

If a line is read with END in the first three columns, that line is treated as an end-of-file and no further data are read.

The plotting character may be changed by a line containing CHA in the first three columns followed by a blank and a numeric value. *i.e.* CHA 3 or CHARACTER 4.

1 TEKSEC format

This format contains only travel time data. Global parameters are assumed. VR is assumed to be the same as the reducing velocity being used for the record section plot. TADD is assumed zero. Travel time data lines are the same as for Format 0 above. Control lines, as defined in Format 0, are recognized although they are non-standard for TEKSEC format.

2 Old standard format

This format is identical to Format 0 except that there is no azimuth entry in the travel time data lines. The travel time data lines, FORMAT (A4, 2F10.0, I3), contain ID, DELT, TIME, and QUAL.

3 Amplitude file format

This format is that produced by the 2-dimensional ray trace program RAY88. There is no azimuth entry in the travel time data lines. The travel time data lines, FORMAT (2F10.0, 20X, I3), contain DELT, TIME, and QUAL.

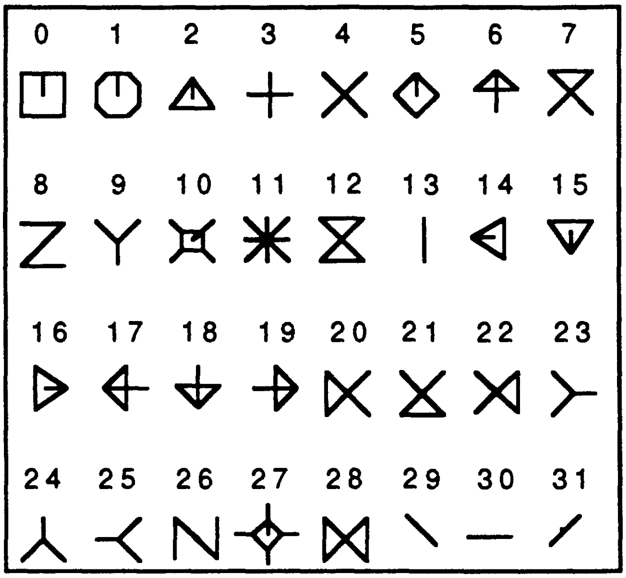
4 RT11 format

This is the pick file format produced by the digitizing computer. Like TEKSEC format, global parameters are assumed.

Travel time data lines, FORMAT (4X, 2I4, 7X, F7.0, 2F8.0), contain ID, QUAL, TIME, DELT, and AZIM.

Specifying the symbol to be used for plotting.

The size of the plotted symbol is given by HOBS. [default value = .15] The plotted symbol is determined by ISOBS. [default value = 3 (+)] For ISOBS = 0-31, use the appropriate index symbol from the table below.



For ISOBS < 0, use the value of QUAL from each travel time data line to determine the symbol.

If I1FORM = 0,1, or 2, the symbol may be changed by a CHAR control line.

If I1FORM = 3 (amplitude file) and ISOBS = 99, refracted arrivals are plotted as X; reflected arrivals as +.

Plotting Calculated Arrival Branches.

Arrival time branches calculated and placed in summary files by programs such as R1D or RAY88 may be overlaid on the record section plot. The arrival time information must be in a travel time file under one of the standard formats described above for observed pick data. The format of the calculated data file is specified by the variable ITFORM.

The program will draw branch lines between successive data entries having the same value of QUAL. The style of the line is controlled by ICLINE. If you have selected one of the dashed line styles and the distance between data points is less than the dash length, you will get a solid line. Start with a short dash length (ICLINE=5) and work up.

Note that you may have to edit summary files created by RAY88 so that arrivals from separate ray groups having the same QUAL value are not connected to one another.

Picking.

This program supports two types of interactive data picking. Arrival times may be picked and trace amplitudes may be picked.

Picking arrival times.

To pick arrival times, first plot the portion of the record section containing the arrivals you wish to pick. Set the pick output file format you want using I2FORM. Enter the command PICK. You will be prompted for the name of the pick output file to receive the data. Following the successful opening of the pick file, cross-hairs will be displayed on the terminal. Move the cross-hairs using the arrow keys above the alphanumeric keyboard. When the Y-cursor is positioned at the time you wish to pick and the X-cursor is nearest the trace you wish to pick, make the pick by striking one of the alphanumeric keys followed by Enter. The value of the key will appear in the pick file as QUAL. It is common practice to use only numeric values for QUAL. If you strike Q, the program will stop picking and return to the command level. After a value has been picked, a symbol is plotted at the picked location and the value picked is printed on the screen. You may modify the appearance of the plotted symbol using the variables HPIC and ISPIC. When doing successive picks down a record section, it is useful to see any previous picks each time you plot a new section of the record for picking. To do this, simply open the pick file you are writing to as an observed data file.

Picking amplitudes.

Arrival amplitudes may be picked by plotting a portion of the record section and using the cursor to select the trace and section of trace to measure. There are three methods of measuring amplitudes, selected by the variable JPICK. If JPICK = 0, the amplitude is measured based upon the actual location of the cursor and the plot scaling factor for the trace being measured. This is the old way of measuring amplitudes and suffers from inaccuracies due to screen granularity. This option is retained for consistency with old files. If JPICK = 1, the amplitude is measured based upon the actual values of the data at the times picked with the cursor. If JPICK = 2, the amplitude is measured based upon the maximum and minimum values of the data between the times picked with the cursor. The information written to your amplitude pick file is controlled by the variable KPICK. If KPICK = 0, the measured values of amplitude are corrected for the attenuation setting of the recording instrument. This means that amplitudes may be directly compared from trace to trace although they may have been recorded with different gains. If KPICK = 1, the raw measured values of amplitude are reported. If KPICK = 2, both raw and gain-corrected values are reported. You may start the amplitude picking process by plotting a portion of the record section and giving the command PICK AMPLITUDE. You will be prompted for the name of a file to receive the amplitude data. Following the successful opening of this file, the picking loop will begin.

First, the cross-hairs will appear to allow you to select the trace you wish to operate on. Move the cursor to the trace you wish to pick, strike a numeric key and strike Enter. A picking symbol will be plotted and information about the trace printed to the terminal screen. If you had entered Q, the program would return to the command level. The numeric value entered will appear with the amplitude in the output file.

Next, you will be prompted to pick the minimum. Move the cursor to a minimum value on the trace and make the pick by striking a numeric key and Enter. Strike X to return to the trace-selection picking operation. If you are picking with JPICK = 0, the X-cursor should intersect the minimum you are picking; the Y-cursor is not used. If you are picking with JPICK = 1, the Y-cursor should be placed at the time of the minimum you are picking; the X-cursor is not used. If you are picking with JPICK = 2, the Y-cursor should be placed at or before the time of the minimum you are picking; the X-cursor is not used.

Finally, you will be prompted to pick the maximum. Move the cursor to a maximum value on the trace and make the pick by striking a numeric key and Enter. Strike X to return to the trace-selection picking operation. Strike R to return to the trace-minimum picking operation. If you are picking with JPICK = 0, the X-cursor should intersect the maximum you are picking; the Y-cursor is not used. If you are picking with JPICK = 1, the Y-cursor should be placed at the time of the maximum you are picking; the X-cursor is not used. If you are picking with JPICK = 2, the Y-cursor should be placed at or after the time of the maximum you are picking; the X-cursor is not used.

Statics.

This program provides the ability to apply static corrections to the start times of individual traces. The static corrections must be written to an ASCII file. Each line of the statics file contains the instrument location number, ILOC, and the static correction under the format (I4, 6X, F10.3) . To apply static corrections, simply open the statics file before plotting.

OPEN STATICS

For each trace, the statics file will be searched for an entry whose location number matches the trace and the static correction will be subtracted from the start time of the trace. If no static correction is found, no action is taken. To incorporate the shot point static correction, use the command TSHIFT to shift all the traces by a constant time.

Setting up a Command Macro File.

Setting up a command sequence to produce a record section consists of the following tasks.

Task 1) Set up the axes.

1.1 The distance axis.

The X-axis for the record section plot may be either in terms of distance (from the shot point or relative to a reference point) or azimuth. If you are plotting in terms of distance (the default), set the needed variables with the command,

```
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
```

The arguments are RMIN, RMAX, RSF, DR, NSR, and RBIAS. If no arguments are given,

```
SET DISTANCE
```

the program will prompt you for values. Alternatively, you may set the variables individually,

```
RMIN = 0.   }
RMAX = 100  } or  RANGE = 0.0, 100.0,
RSF = 0.25
DR = 5.0
NSR = 5
RBIAS = 0.0
```

1.2 The azimuth axis.

If you are plotting in terms of azimuth, you must set the azimuth axis variables and enable azimuthal plotting.

```
SET AZIMUTH 90. 180. 0.2, 5.0, 5, 0.0,
ENABLE FAN
```

The arguments are AZMIN, AZMAX, AZSF, DAZ, NSAZ, and AZBIAS.

If no arguments are given,

```
SET AZIMUTH
```

the program will prompt you for values. Alternatively, you may set the variables individually,

```
AZMIN = 90.    }
AZMAX = 180.   } or  AZIM = 90., 180.0,
AZSF = 0.2
DAZ = 5.0
NSAZ = 5
AZBIAS = 0.0
ENABLE FAN
```

If you want to reverse the axis, enter AZMIN > AZMAX.

1.3 The time axis.

The Y-axis for the record section plot may be set by the command,

SET TIME -1.0, 7.0, 1.0, 1.0, 10,

The arguments are TMIN, TMAX, TSF, DT, and NST. If no arguments are given,

SET TIME

the program will prompt you for values. Alternatively, you may set variables individually,

TMIN = -1.0 } or TIME = -1.0, 7.0,
TMAX = 7.0 }
TSF = 1.0
DT = 1.0
NST = 10

The Y-axis label will depend upon the time format selected.

A) Actual time (RV=0.0, DISABLE NMO) Axis label is TIME
B) Reduced time (RV=6.0, DISABLE NMO) Axis label is T-X/6.0
C) NMO-corrected time (RV=6.4, ENABLE NMO) Axis label is TIME(NMO=6.4) If you are plotting NMO data, you may want to invert the axis labeling (ENABLE REFLECTION).

Additionally, when plotting NMO data, you may want to label the distance axis in terms of common midpoint distance instead of actual distance. To do this, enter

ENABLE CMP

To provide the proper alignment of distance axis labeling for multiple shot gathers, you must give the actual range of each shot along the profile,

SHTRNG =

1.4 Timing lines.

Horizontal timing lines may be plotted across the record section. They will begin at time TMINL and end at time TMAXL. The lines will be separated by DTLINE seconds. Set DTLINE to 0.0 to eliminate the plotting of timing lines. The timing lines may be dotted, dashed or solid as determined by ISLINE. The pen number used for plotting timing lines is PEN 2. A typical command sequence might be,

```
TMINL = -2
TMAXL = 15
DTLINE = 1.0
ISLINE = 2
PEN 2, 2
```

1.5 Miscellaneous axis variables.

You may specify a plot ID to be plotted with the record section and specify its size,

```
SET PLOTID   TEST PLOT
HBS = 0.2
```

You may reset the size of the axis tics and labels,

```
HNR = 0.2
```

You may enable the plotting of an annotation box to the right of the record section containing plotting variables and specify the size of characters to be used.

```
ENABLE NOTE
HLBL = 0.1
```

You may enter a line of additional text for the annotation box.

```
NOTE = This is an example.
```

Task 2) Set up the trace scaling, etc.

Traces may be scaled in one of three ways prior to plotting.

A) Normalized scaling. Each trace is scaled so that the maximum deflection displayed is equal to a common width.

WIDTH = 0.4
CLIP = 0.4
SHADE = 0.0

B) Range-corrected scaling. (sometimes referred to as "true-amplitude") Traces are corrected for instrument gain and plotted with amplitude proportional to an exponential function of distance.
The scheme used in this program allows you to specify two different exponential scalings. You must specify a crossover distance (the point at which the two exponentials meet), exponentials for distances less than and greater than the crossover distance, and an amplitude at the crossover distance.

SET TRUEAMP 50., 1.0, 1.0, 0.1,
ENABLE TRUEAMP

C) Automatic Gain Controlled scaling. Traces are scaled to the maximum deflection within a time window surrounding each data point.

WIDTH = 0.4
CLIP = 0.4
SHADE = 0.0
LTHWIN = 400 ! or AGCLTH = 2.0
ENABLE AGC

D) Additional trace variables.

If traces are to be filtered prior to plotting, you must specify,

```
FLO = 1.0
FHI = 20.0
ENABLE FILTER
```

Traces are normally labeled with their location number and attenuation setting. You may delete one or the other of these by setting ISLAB,

```
ISLAB =  - 1  !Attenuation only.
ISLAB =    0  !Location and attenuation.
ISLAB =  +1   !Location only.
```

To delete plotting of both, set the label height to 0.0,

```
HLAB = 0.0
```

All the traces may be time-shifted with respect to the axes by setting TSHIFT,

```
TSHIFT = 0.5
```

Traces may be reversed in range with respect to the axes by setting the distance fudge factor to -1.0,

```
DFUDGE = -1.0
```

Task 3) Set up the plotting mode.

Determine whether the plot is to be directed to the terminal only, or whether the normal system plotting prompts allowing you to select a plot file for later plotting to the Versatec will be given and whether the plot axes will be scaled to fit the terminal screen or to fill the terminal screen.

ENABLE VTONLY
DISABLE VTONLY
ENABLE FIT
ENABLE FILL

Task 4) Set up the data files.

Additional data files are opened to provide seismic data in USGS refraction format or SEGY format; observed travel time picks; calculated arrival time branches; and/or static corrections. Only one file of each type may be open at the same time.

To open a USGS cassette recorder seismic data file, for example MYFILE.DAT, use,

OPEN DATA MYFILE.DAT

If you don't give a file name, you will be prompted for a file name. Respond with a file name or NONE if you don't wish to open a file.

To open a SEGY format seismic data file, for example MYFILE.SGY, use,

OPEN SEGY MYFILE.SGY

To open a pick file, for example MYFILE.OBS, use,

OPEN OBSERVED MYFILE.OBS

If you don't give a file name, you will be prompted for a file name. Respond with a file name or NONE if you don't wish to open a file.

To open a file with calculated arrival branches, for example MYFILE.CLC, use,

OPEN CALCULATED MYFILE.CLC

If you don't give a file name, you will be prompted for a file name. Respond with a file name or NONE if you don't wish to open a file.

To open a file with static corrections, for example MYFILE.STA, use,

OPEN STATICS MYFILE.STA

If you don't give a file name, you will be prompted for a file name. Respond with a file name or NONE if you don't wish to open a file.

Examples

Perhaps the best way to learn the use of this program is through the use of examples. The following are several examples of control files for producing different types of record section plots.

1) A command file to plot a simple record section:

```
*
* PLOT.JMP - Basic record section for plotting SP01.DAT
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
*
PLOT
SIZE
```

2) A command file to plot a simple record section consisting of data from three data files, the last of which is a SEGY format data file:

```
*
* PLOT.JMP - Basic record section for plotting
*               SP01.DAT, SP02.DAT & SP03.SGY
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
PLOT
CLOSE DATA
*
OPEN DATA SP02.DAT
OPEN SEGY SP03.SGY
PLOT
SIZE
```

3) A command file to plot a record section consisting of selected filtered data from a data file:

```
*
* PLOT.JMP - Basic record section for plotting selected records
*                   from SP01.DAT with filtered data.
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
FLO = 5.0
FHI = 15.0
ENABLE FILTER
*
SELECT RECORDS 21,60
*
PLOT
SIZE
```

4) A command file to plot a record section consisting of distance corrected amplitude data from a data file:

```
*
* PLOT.JMP - Record section for plotting records from SP01.DAT
*                    with distance corrected amplitudes.
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
*
SET TRUEAMP 50.0, 1.0, 1.0, 0.08,
ENABLE TRUEAMP
PLOT
SIZE
```

5) A command file to plot an azimuthal fan record section:

```
*
* PLOT.JMP - Basic record section for plotting SP01.DAT
*                   as a function of azimuth.
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
*
SET AZIMUTH 30.0, 120., 0.25, 5.0, 5, 0.0,
ENABLE FAN
PLOT
SIZE
```

6) A command file to plot a pseudo-fan record section. Traces are plotted relative to a given point:

```
*
* PLOT.JMP - Record section for plotting records from SP01.DAT
*                   as a function of distance from a reference point.
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
*
DREF = 90.0,
AZREF = 125.2,
ENABLE RELATIVE
PLOT
SIZE
```

7) A command file to plot a normal moveout corrected record section:

```
*
* PLOT.JMP - Basic record section for plotting records from SP01.DAT
*            as an NMO plot with AGC.
*
SET DISTANCE 0., 100., 0.25, 5.0, 5, 0.0,
SET TIME -1.0, 7.0, 1.0, 1.0, 10,
WIDTH = 0.6
CLIP = 0.4
SHADE = 1.0
RV = 6.0
ENABLE FIT
DISABLE VTONLY
SET PLOTID SHOT POINT 01
*
OPEN DATA SP01.DAT
*
RV = 6.4,
ENABLE NMO
ENABLE REFLECT
LTHWIN = 400
ENABLE AGC
PLOT
SIZE
```

Appendix A - **The Reduced Time Transformation:**

Though the reduced time transformation is widely used in refraction seismology its properties are usually taken for granted. It can be shown that, in addition to the non-linear rotation of travel-time plots for easier viewing and interpretation, the reduced time transformation can provide an improvement in the angular resolution of apparent velocity branches. On a time-distance plot, a given velocity is represented by a line with slope equal to the inverse of the velocity. Our ability to resolve arrival branches of different apparent velocity is linked to our ability to resolve different slopes or angles from the horizontal. We may define angular resolution, $d\theta/dV$, as the rate of change in angle from the horizontal of an arrival branch as a function of change in velocity. The degree of improvement in angular resolution achieved by using a reduced time transformation is a function of the distance and time scaling used for the plot. For combinations of distance and time scaling most commonly used, it can be shown that although the maximum angular resolution, $d\theta/dV$, always occurs for velocities less than the reducing velocity, the maximum improvement in angular resolution over the unreduced case occurs for velocities equal to the reducing velocity. For some combinations of distance and time scaling factors, an unreduced plot will provide greater angular resolution than a reduced plot.

Seismic refraction data are usually displayed using the reduced time format wherein range is plotted on the x-axis and reduced time, T-Range/V_r, on the y-axis. This is a fundamental of seismic refraction data display, yet little has been written about its use and the potentials for abuse. There are a number of reasons for using this format rather than the simple format of time versus range. The most obvious reason, that which is most frequently given in explanation, is that the first-arrival branches for most travel time plots can be entirely contained within a rectangular space which is a small subset of the total space required for a time versus range plot. By rotating this rectangular area by using a reduced time plot, a more efficient figure is displayed (Figure 1). If Figure 1 were a record section instead of a first-arrival plot, it would be obvious that about half of the unreduced time-distance plot was devoted to pre-arrival background noise.

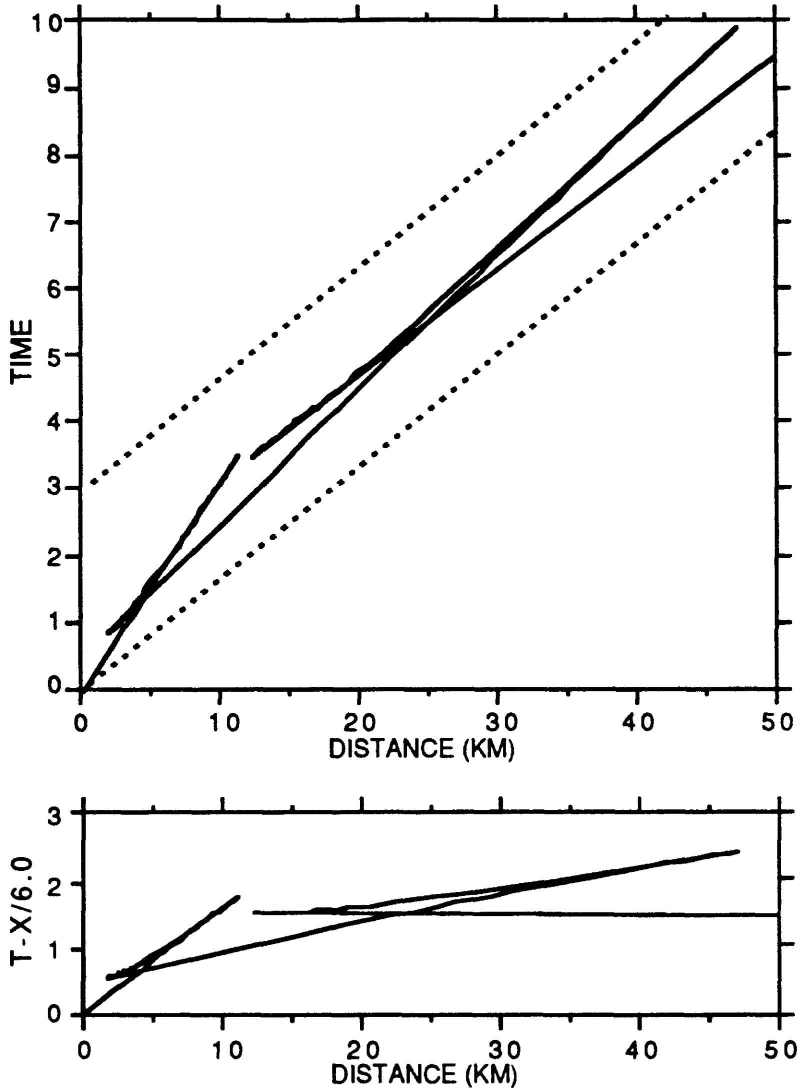


Figure 1. A typical set of travel time curves plotted unreduced and reduced with a reducing velocity of 6.0 km/sec. These plots are made with the same time and distance scales to demonstrate the more efficient use of space made by the reduced time format.

Plotting efficiency, however, is not the only reason for using reduced time plots for interpretation. The visual identification of arrival branches on time series data traces, especially secondary arrivals, is most easily accomplished when the arrivals are aligned in time. This may be accomplished by plotting them at a reduced time equal to or near their phase velocity.

Yet another reason for using the reduced time format is the fact that, under certain circumstances, the angular spread between apparent velocities is enhanced, permitting easier discrimination of arrival branches having apparent velocities which differ by only a small amount. Herein lie many of the subtleties of the reduced time plot.

We will here examine in some detail the reduced time transformation and provide criteria for choosing scaling factors for the display of seismic refraction data which maximize the benefits of using the reduced time format. In addition, a simple analog model of the reduced time transformation is described (Appendix A.1) and a Fortran subroutine is given for plotting apparent velocity rosettes for use with reduced time plots (Appendix A.2).

Basic Definitions:

Travel times or seismic record sections are plotted with time as some function of distance. The simplest case plots actual time versus distance as in the top of Figure 1 . Reduced travel time plots are produced by transforming all times by the linear relation $T_r = T - X/V_r$ before plotting.

Analytically, the velocity at any point (x,t) of a travel time curve is dx/dt, the inverse of the local slope. Since we are examining physical display characteristics, we must be concerned with the actual slope resulting from scaling factors applied to the two axes of the plot. If, for example, data were plotted on a set of axes in which 1 sec = 1 cm on the time axis and 1 km = 1 cm on the distance axis, the inverse slope measured directly from the plot would be equal to the velocity in km/sec. If, however, the time axis were compressed by plotting 1 sec = 0.5 cm while retaining 1 km = 1 cm on the distance axis, the inverse slope measured directly from the plot would be equal to twice the velocity in km/sec.

We define the plot scaling factor S = XSF/TSF = cm/km / cm/sec = sec/km. This may be thought of as an aspect ratio or exaggeration factor. We will refer to a plot in which the axes are defined to produce an actual slope equal to the analytical slope, S=1.0, as unscaled.

The Unscaled Reduced Time Transformation:

Figure 2 shows a set of lines of constant velocity plotted in unreduced format and with a reducing velocity of 6.0 km/s. These plots are unscaled; that is, the range scale in cm/km is equal to the time scale in cm/sec.

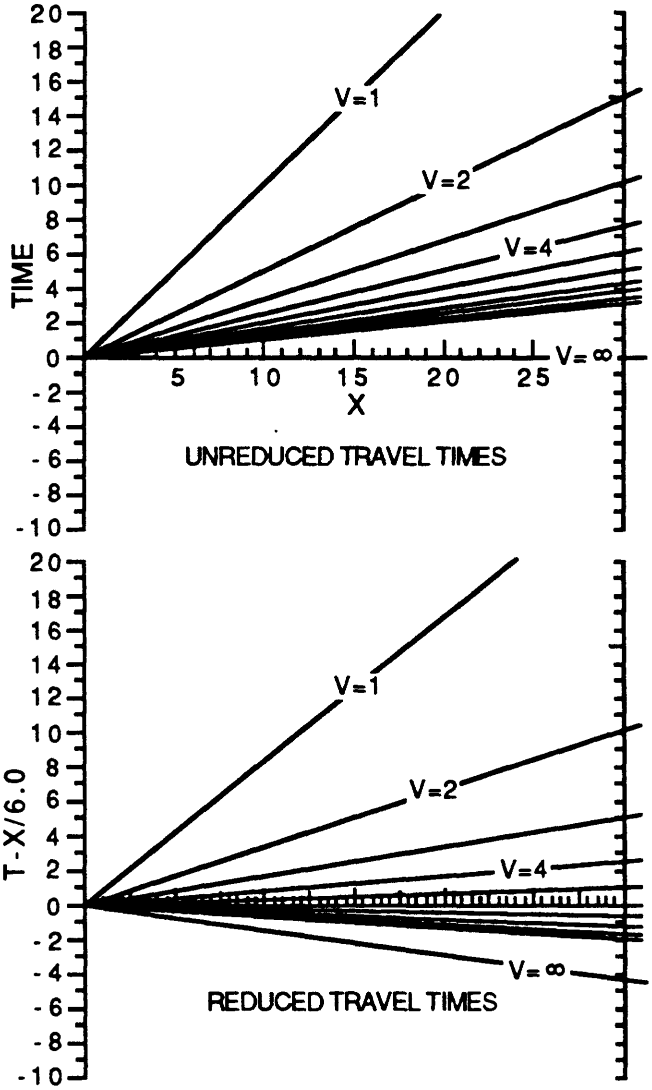


Figure 2. Lines of constant velocity plotted in unreduced format and with a reduction velocity of 6.0 km/s. In addition to velocities 1.0 through 10.0, the infinite velocity line (vertical incidence) is plotted in both cases.

If we define θ as the angle between the time axis and an apparent velocity line (V), we can express,

$$\theta = Tan^{-1}(X/T) = Tan^{-1}(V)$$

for the unreduced case. For a reduced plot, in which $T_r = T - X/V_r$, where V_r is the reducing velocity,

$$\theta_r = Tan^{-1}(X/(T-X/V_r)) = Tan^{-1}(VV_r/(V_r - V)).$$

In figure 3, we see θ_r plotted as a function of V for several values of reducing velocity, V_r. Each curve intersects θ=90° at its reducing velocity (i.e. a horizontal line on the travel time plot corresponds to the reducing velocity). The curves appear quite similar implying that, especially for higher velocities, the travel time plot is rotated but not distorted under different reducing velocities.

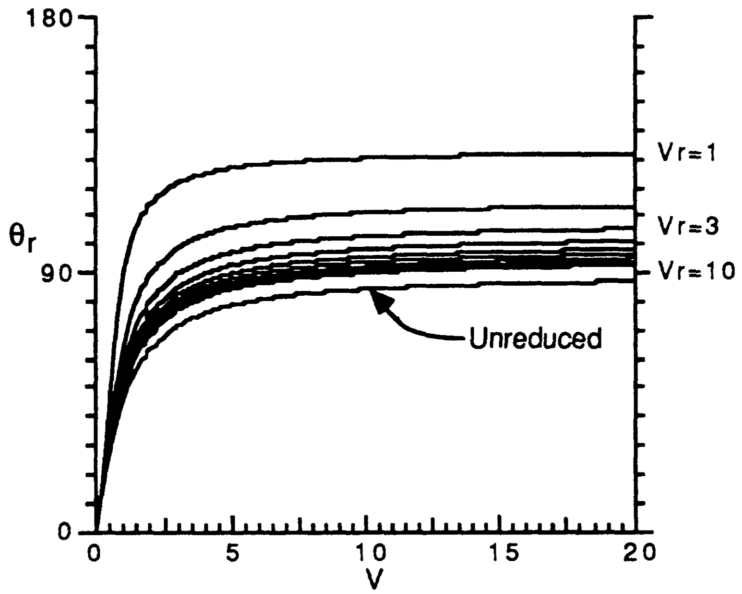


Figure 3. θ_r, the angle of a line of constant velocity from the vertical, plotted as a function of velocity for reducing velocities ranging from 1.0 through 10.0 . The unreduced case (reducing velocity infinite) is also plotted.

A measure of their similarity may be made by calculating and plotting the change in θ with velocity.

$$\frac{d\theta_r}{dV} = \frac{d}{dV}\left\{\mathrm{Tan}^{-1}\left(\frac{V V_r}{V_r - V}\right)\right\} = \frac{1}{V^2\left(1+1/V_r^2\right)-2V/V_r+1}$$

Figure 4 shows $d\theta_r/dV$ as a function of V for several values of reducing velocity, V_r. For values of V and V_r greater than 2 km/s, the curves are essentially identical. Thus, for unscaled reduced time plots, for velocities and reducing velocities commonly of interest to refraction seismologists, the reduced time transformation has the effect of rotating the plot about the origin with very little distortion of relative angular relationships. Significant differences in $d\theta/dV$ occur only for low values of V_r and V. This fulfills the two reasons most frequently given for using the reduced time transformation; efficient figures and ease of observation of horizontal branches.

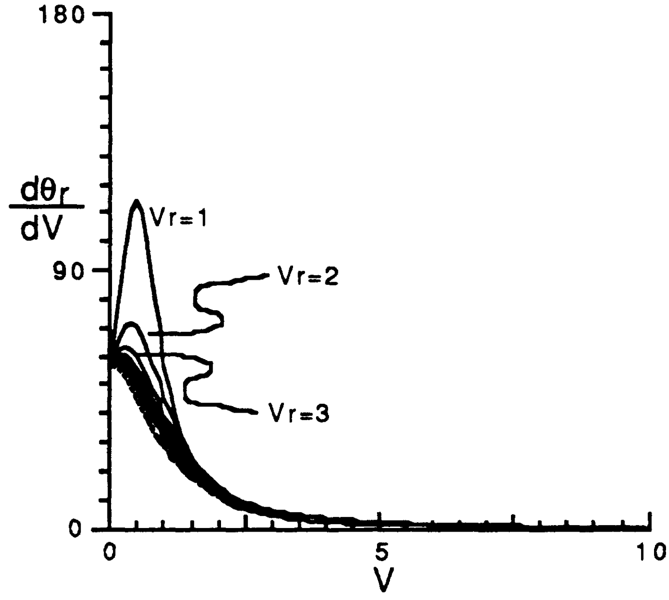


Figure 4. $d\theta_r/dV$ plotted as a function of velocity for reducing velocities ranging from 1.0 through 10.0 for an unscaled travel time plot. Although the unreduced travel time plot has a maximum change in θ for V=0, reduced plots have a maximum $d\theta_r/dV$ at small positive velocities. In an unscaled plot, however, the maxima occur at velocities which are too low to be of interest.

The Effect Of Scaling On Reduced Time Plots:

For reasons of data trace density and frequency content of the traces, record section plots are seldom plotted with a scaling factor of 1.0. Defining the scaling factor S = XSF/TSF, where XSF is in units of cm/km and TSF is in units of cm/sec, the above relations for θ, θ_r, and $d\theta_r/dV$ may be rewritten,

$$\theta = \mathrm{Tan}^{-1}(SV)$$

$$\theta_r = \mathrm{Tan}^{-1}\left(\frac{S\,V\,V_r}{V_r - V}\right)$$

$$\frac{d\theta_r}{dV} = \frac{S}{V^2\left(S^2 + 1/V_r^2\right) - 2V/V_r + 1}$$

In figures 5a and 5b, θ unreduced and θ_r with a reducing velocity of 6 km/s are plotted as a function of V for several different scaling factors between 0.1 and 1.0 . In figure 5c, θ_r is plotted as a function of V for several different reducing velocities with a scaling factor of 0.1. Compare this with figure 3 where the scaling factor is 1.0. Notice the strikingly different forms the curves take for small values of S.

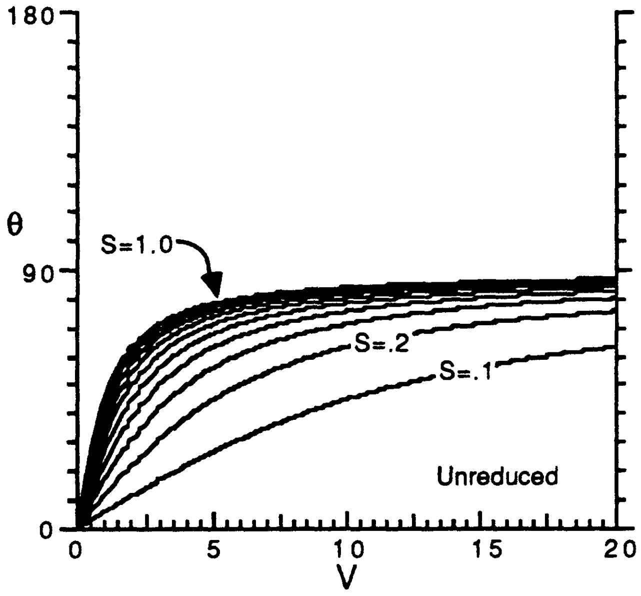


Figure 5. a) The effect of scaling on the unreduced travel time plot. θ, the angle in degrees from the time axis, is plotted as a function of V for a set of scaling factors ranging from 1.0 to 0.1

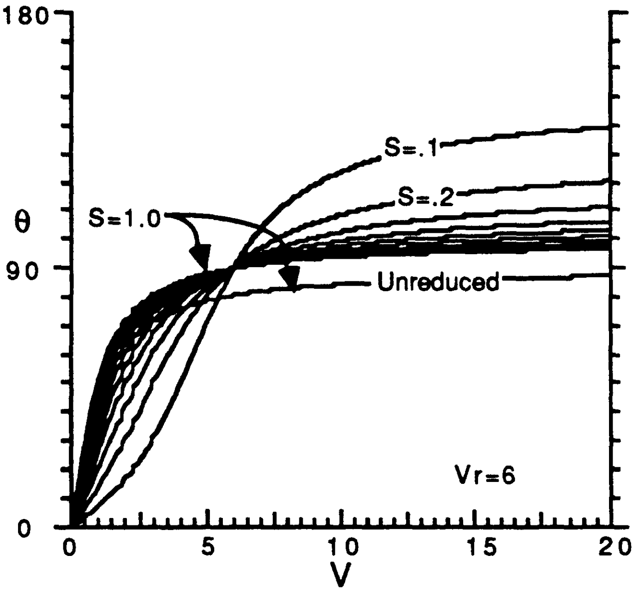


Figure 5. b) The effect of scaling on the reduced travel time plot for a reducing velocity of 6.0 km/s. The unreduced curve with scale factor 1.0 is plotted for reference.

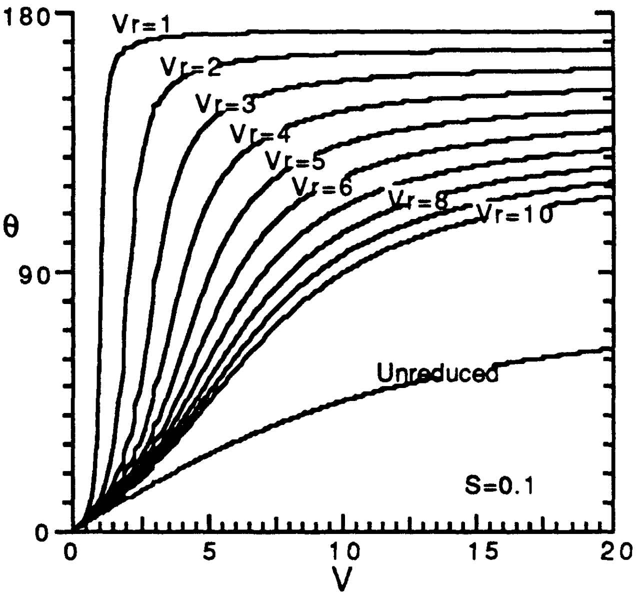


Figure 5. c) The effect of using different reducing velocities for a scaling factor of 0.1 . Compare this figure with figure 3 which plots the same curves for a scaling factor of 1.0 .

Most important to the display of data, what is the effect of different values of S upon $d\theta_r/dV$? Figure 6 shows a series of curves representing $d\theta_r/dV$ as a function of V for a reducing velocity of 6 km/s. These curves are for a series of different scaling factors. Figure 6a shows S = 0.1 to 1.0; figure 6b shows S = 1.0 to 10.0. We notice that for any scaling factor less than 1.0, the value of $d\theta_r/dV$ is greater than for the unscaled case for velocities near the reducing velocity. Thus, there is an improvement in our angular resolution of apparent velocities to be attained by using scale factors less than 1.0. The maximum $d\theta_r/dV$ is displaced to higher velocities as the scaling factor is reduced. For scaling factors greater than 1.0, the value of $d\theta_r/dV$ is less than for the unscaled case except for very low velocities.

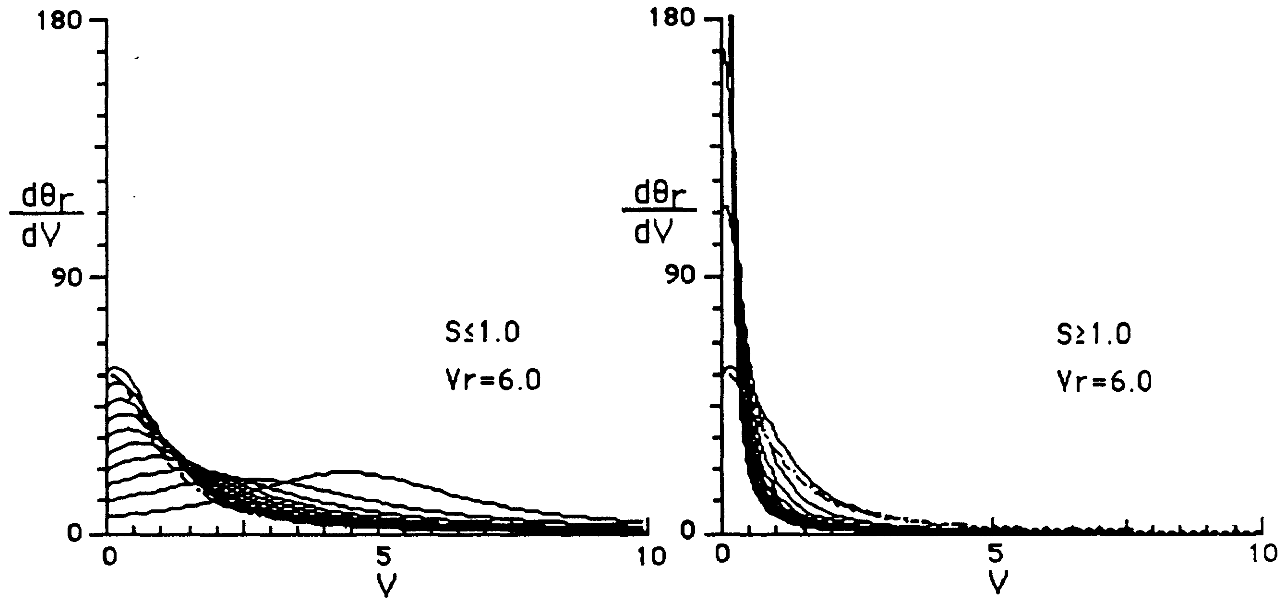


Figure 6. The effect of scaling on $d\theta_r/dV$ as a function of V for a reducing velocity of 6.0 km/sec . The unscaled, unreduced curve is plotted (dashed) in each case for reference. The scaling factor in 6a varies from 0.1 through 1.0 . The scaling factor in 6b varies from 1.0 through 10.0 .

Can we find a scaling factor for which the maximum $d\theta_r/dV$ occurs at the reducing velocity? We may differentiate our previous expression for $d\theta_r/dV$ with respect to V to obtain,

$$\frac{d^2\theta_r}{dV^2} = \frac{2S\left(1/V_r - V\left(S^2 + 1/V_r^2\right)\right)}{V^2\left(S^2 + 1/V_r^2\right) - 2V/V_r + 1}$$

The maximum occurs when $d^2\theta_r/dV^2 = 0$, which occurs when,

$$V = \frac{V_r}{\left(V_r^2 S^2 + 1\right)} .$$

As V approaches V_r, S approaches 0. Thus, it is impossible to scale a plot such that the maximum angular separation occurs at the reducing velocity. Many published reports of crustal refraction profiles with lengths of 200-500 km use scaling factors of approximately 0.1. For a reducing velocity of 8 km/s, the maximum $d\theta/dV$ occurs at V=4.88 km/s.

More important to the actual display of data, we would like to know the improvement in angular resolution to be had for a given reducing velocity and scaling ratio at each apparent velocity. We can write a general expression for improvement in angular resolution,

$$IMP(V,S) = \frac{\left(\frac{d\theta}{dV}\right)_{S=S}}{\left(\frac{d\theta}{dV}\right)_{S=1}}$$

$$IMP(V,S) = \frac{S\left(V^2 + \frac{V^2}{V_r^2} - \frac{2V}{V_r} + 1\right)}{V^2S^2 + \frac{V^2}{V_r^2} - \frac{2V}{V_r} + 1}$$

Note that the improvement for $V=V_r$ is always equal to 1/S, providing another demonstration of the need to keep S less than 1.0 if we are seeking an improvement in angular resolution. For the velocity at which the angular resolution is a maximum,

$$IMP(V_m,S) = \frac{\left(V_r^2 S^4 + 1\right)}{S\left(V_r^2 S^2 + 1\right)}$$

which is always less than 1/S for S less than 1.0. Figure 7 shows a graphical display of angular resolution improvement versus S for several velocities for a reducing velocity of 6.0 km/s. Although the maximum $d\theta/dV$ never occurs at the reducing velocity, the maximum improvement always occurs at V_r for S less than 1.0.

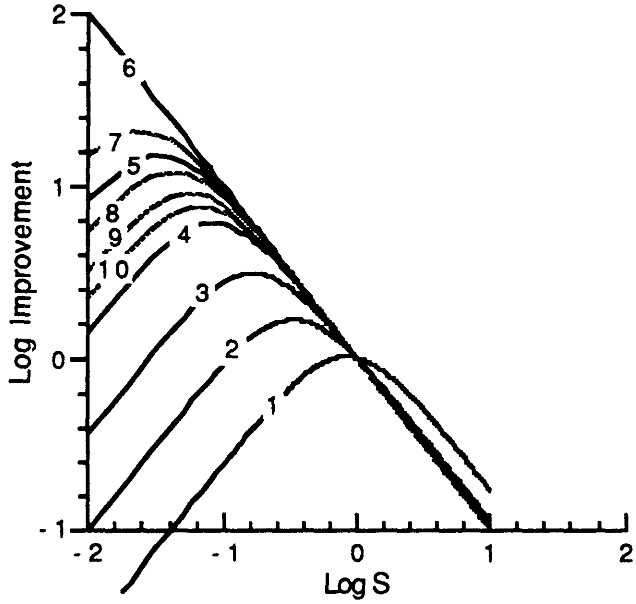


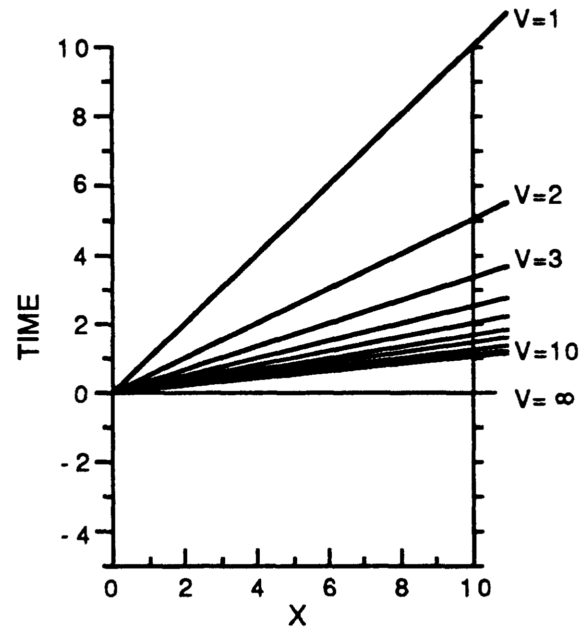
Figure 7. Improvement in angular resolution versus scaling factor S for several velocities at reducing velocity of 6 km/sec.

The reduced time transformation applied to seismic refraction data provides both more efficient display of travel times through its properties of rotation and more easily interpreted record sections through its ability to align consecutive traces at or near the phase velocity of their arrivals. We have seen, however, that the rotation is non-linear and that the non-linearity is dependent upon the scaling factor or exaggeration used. Lithospheric refraction data has traditionally been recorded with station spacings ranging from 0.5 km to several km in the US and Western Europe. This has made it convenient to use scaling factors between 0.6 and 0.08; a range of values that takes advantage of all the good features of the reduced time transformation. As we proceed to more densely recorded data, however, it is tempting to use larger scaling factors in order to adequately display each trace without overlap. We must remain cognizant of the price to be paid in reduced capability to resolve velocity differences as we do so.

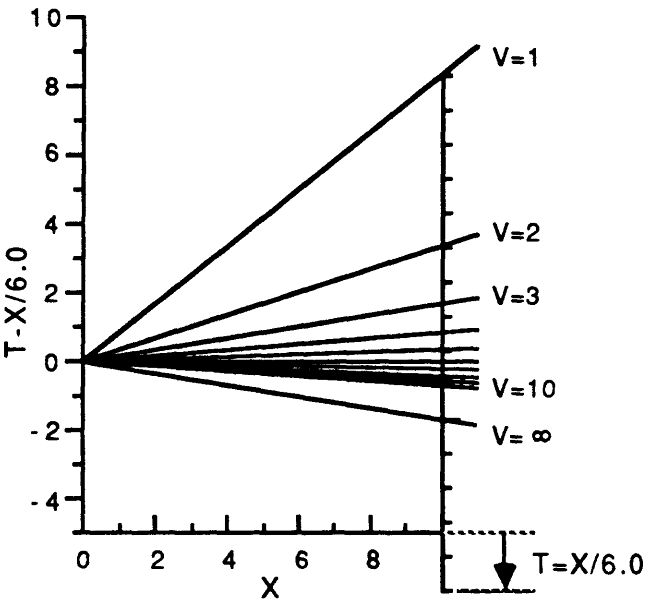
Appendix A.1 - A rubber-band model of the reduced time transformation:

As an aid to the visualization of the properties of the reduced time transformation, a simple model may be constructed which is a complete analog of the transformation.

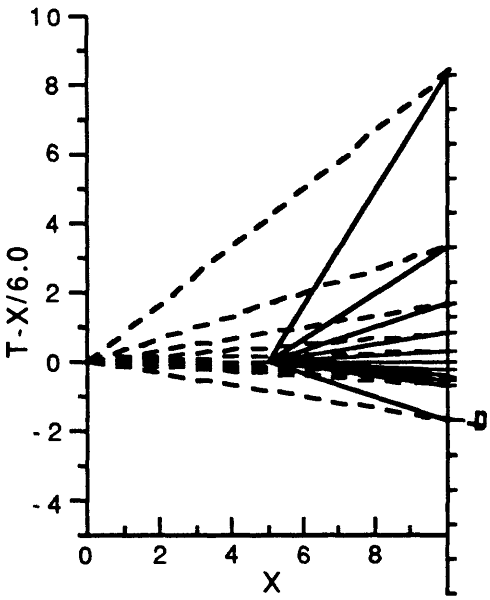
A basic set of travel time lines are constructed by affixing rubber bands to a time axis at appropriate arrival times. The other ends of the rubber bands are gathered at the origin. If, for example, we use X=10cm, T_1 will be at X/V_1=10cm on the time axis, where V_1 is the lowest velocity. Considering a set of velocities V_1, V_2, ... V_n, we produce an unscaled, unreduced set of travel time curves.



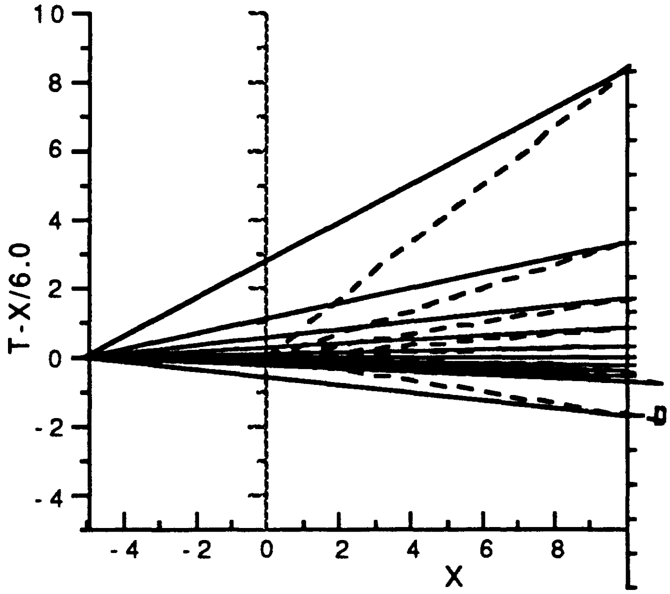
The relative arrival times at any range X are, of course, invariant under transformation. The effect of applying different reducing velocities may be modeled by sliding the right hand time axis down $T=X/V_r$.



The effects of scaling are modeled by sliding the gather point parallel to the X-axis. To illustrate two examples of scaling, move the gather point 5 cm to the right of the origin to model a scaling factor of 0.5 .



Alternatively, we may move the gather point 5 cm left of the origin to model a scaling factor of 1.5 .



Appendix A.2 - A FORTRAN subroutine for producing reduced travel time velocity rosettes.

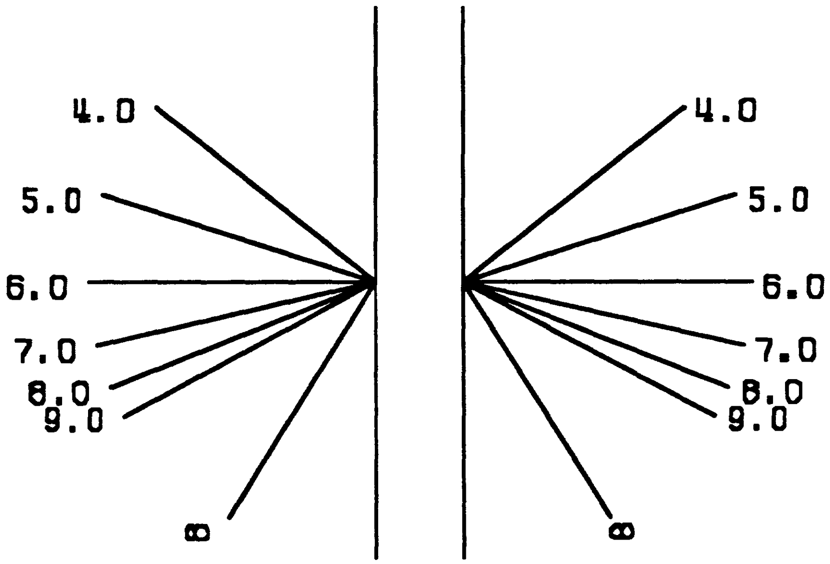
The following subroutine is based on an algorithm written by J.G. Kosalos a number of years ago. S.ROSETE may be used with any program which plots data in reduced time format to produce a set of reference lines of apparent velocity. This is particularly helpful during the initial visual interpretation of refraction data. In addition to the set of finite apparent velocities, the line representing infinite apparent velocity (vertical incidence) is plotted. This represents a practical limit to post-critical apparent velocity for most refraction data and provides a guideline for initial interpretation.

Since the scaling factor used in most published plots of refraction data is usually guided by esthetic considerations of data density and frequency content, there can be no accepted standard scaling factor. In fact, a quick and incomplete survey of the literature shows variation in scaling factors used from 0.6 to 0.08 . The best guide to help a reader understand the interpretation of a record section is the accompanying plot of a velocity rosette.

```
      SUBROUTINE ROSETE (X, Y, SIZE, RDV, TSF, RSF, SIGN)
C..........................................................................
C
C     This routine draws a velocity rosette for use with reduced
C     travel time plots.
C     X,Y   = Coordinates of the geometric center of the rosette.
C     SIZE = Rosette radius in inches.
C     RDV   = Reducing velocity.
C     TSF   = Time scale factor (inches/sec).
C     RSF   = Distance scale factor (inches/km).
C     Rotation of rosette is with time axis = Y-axis.
C     SIGN  = +/- 1.0 Indicating a right-hand or a left-hand rosette.
C     Make sure this is a real variable in the calling program!
C
C..........................................................................
C
C
      If (RDV .lt. 0.1)   Return
      Call PLOT (X, Y+SIZE, 3)
      Call PLOT (X, Y-SIZE, 2)
      ISIZE = SIZE*1.5
      If (ISIZE .lt. 1)   ISIZE = 1
C--MAKE NUMBER SIZE MULTIPLE OF 0.05
      SIZNUM = 0.05*ISIZE
      OSIZE  = 0.07*ISIZE
```

```
      TMD = 1.0/RDV
      YLAST = Y+SIZE
      VELINC = 0.5
C
C--USE VELOCITY OF 60 DEGREE LINE AS STARTING POINT
C
      DELVEL = RDV - 1.0/(1.0/RDV+4.0*RSF/TSF)
C
      If (IFIX(DELVEL*10.0) .gt. 10) Then
C--DETERMINE INCREMENT TO HAVE NINE LINES MAX
         LINES = DELVEL*2.0 + 1.0
C--LINES SHOULD BE AN ODD NUMBER
         LINES = 2*(LINES/2) + 1
C
 1       If (LINES .lt. 9) Go To 2
            VELINC = VELINC*2.0
            LINES  = LINES/2 + 1
            Go To 1
 2       Continue
C
      Else
         LINES = 3
      End If
C
      IRDV = RDV
C--COMPUTE VELOCITY OF FIRST LINE
      VEL = IRDV - VELINC*(LINES-1)/2.0
C--NOW LOOP FOR THE VELOCITY LINES
      NLINES = LINES + 1
C
      Do 3 I=1,NLINES
         TINC = (1.0/VEL-TMD)*TSF
         DINC = RSF
         FACTOR = SIZE/SQRT(DINC*DINC+TINC*TINC)
         DINC = DINC*FACTOR
         TINC = TINC*FACTOR
C
         Call PLOT (X, Y, 3)
         Call PLOT (X+DINC*SIGN, Y+TINC, 2)
         DINC = DINC + OSIZE/2.0
         TINC = TINC - OSIZE/2.0
C
C--PLOT THE VELOCITY
C--SKIP NUMBER IF IT WILL OVERLAP THE LAST ONE
C
         If (IFIX(OSIZE*10.+OSIZE) .le. IFIX(10.0*(YLAST-Y-TINC))) Then
            IVEL = VEL
            Call PLOT (X+DINC*SIGN, Y+TINC, 3)
            If (IVEL .lt. 10) Then
               XP = X + (DINC+1.5*SIZNUM)*SIGN - 1.5*SIZNUM
C
               Call NUMBER (XP, Y+TINC, SIZNUM, VEL, 0.0, 1)
            Else
```

```
               XP = X + (DINC+2.0*SIZNUM)*SIGN - 2.0*SIZNUM
C
               Call NUMBER (XP, Y+TINC, SIZNUM, VEL, 0.0, 1)
            End If
C
C--SAVE COORDS OF LAST NUM PLOTTED AND INCREMENT THE VELOCITY
C
            YLAST = Y + TINC
         End If
         VEL = VEL + VELINC
 3    Continue
C
C--NOW PLOT THE INFINITE VELOCITY LINE
C
      TINC = -TMD*TSF
      DINC = RSF
      FACTOR = SIZE/SQRT(DINC*DINC+TINC*TINC)
      TINC = TINC*FACTOR
      DINC = DINC*FACTOR
      Call PLOT (X, Y, 3)
      Call PLOT (X+DINC*SIGN, Y+TINC, 2)
      XP = X + (DINC+SIZNUM)*SIGN
C
      Call NUMBER (XP, Y+TINC-SIZNUM, SIZNUM, 8, 90.0, -1)
C
      Return
      End
```



Appendix B - Normal Moveout in Wide-angle Reflections

Wide-angle reflections observed in seismic refraction experiments may be used to infer vertical two-way travel time (TWTT) and, hence, thickness if an appropriate normal moveout correction can be determined. A number of analysis routines have been developed for the interpretation of wide-angle reflections which rely on various conversions of wide-angle travel time to equivalent vertical TWTT and depth. The following derivations provide key equations for use in analysis programs.

There are several levels of complexity which can be used to determine normal moveout. These are based on the complexity of the velocity function used. The simplest approach to this problem is to assume that the earth has a uniform mean velocity and make a hyperbolic normal moveout correction. The simple hyperbolic normal moveout correction assumes reflections from within a constant velocity half space.

D = Shot-receiver distance.
T_0 = Travel time.
V_m = Assumed mean velocity.
Z = Reflector depth.

The vertical two-way travel time is expressed,

$$T^* = \frac{2Z}{V_m} \qquad (1)$$

The equivalent vertical two-way travel time is expressed,

$$T^* = \sqrt{T_0^2 - \frac{D^2}{V_m^2}} \qquad (1a)$$

Equation (1a) also allows us to calculate the actual arrival time, T_0, which yields the normal moveout time T^*.

$$T_0 = \sqrt{T^{*2} + \frac{D^2}{V_m^2}} \qquad (1b)$$

The normal moveout correction may be expressed,

$$T_{corr} = T^* - T_0 = \sqrt{T_0^2 - \frac{D^2}{V_m^2}} - T_0 \qquad (1c)$$

From (1), we can calculate the depth, Z.

$$Z = \frac{V_m T^*}{2} = \frac{V_m}{2}\sqrt{T_0^2 - \frac{D^2}{V_m^2}} \qquad (2)$$

Alternatively, if we are given D, T_0, Z, we can calculate the mean velocity. From (1b),

$$T_0 = \sqrt{T^{*2} + \frac{D^2}{V_m^2}}$$

$$= \sqrt{\left(\frac{2Z}{V_m}\right)^2 + \frac{D^2}{V_m^2}}$$

$$= \frac{\sqrt{(4Z^2 + D^2)}}{V_m}$$

$$V_m = \frac{\sqrt{(4Z^2 + D^2)}}{T_0} \qquad (3)$$

Examination of equation (1a) shows that there is a minimum arrival time, corresponding to the direct arrival, for which we can calculate a normal moveout.

$$T_{min} = D / V_m \qquad (4)$$

The above equations provide solutions which are only as good as the assumption that the earth has a constant mean velocity. For any offset distance, D, a mean velocity V_m, may be determined which correctly describes the moveout. In the case of non-uniform velocity, however, V_m is a function of offset distance and reflection depth, making these equations inexact.

The constant velocity normal moveout correction often fails to calculate correct times in cases where there is a large variation in offset distances and the velocity is not constant with depth. A better approximation may be obtained by assuming that the velocity function is a linear gradient rather than a constant.

Assume a linear velocity gradient, $V = V_0+kZ$. For a given observation, we know D, the shot-receiver distance, and T_0, the overall travel time. Assume a one-dimensional model and calculate the depth, Z, of the reflection point (which occurs at distance $X=D/2$; time $T=T_0/2$).

The wavefront emanating from the source is described by,

$$X^2 + \left(Z - \frac{V_0}{k}(\mathrm{Cosh}\,(kT) - 1)\right)^2 = \left(\frac{V_0}{k}\,\mathrm{Sinh}\,(kT)\right)^2$$

Solving for Z as a function of X, T, and the velocity function,

$$Z = \sqrt{\left(\frac{V_0}{k}\,\mathrm{Sinh}\,(kT)\right)^2 - X^2} + \frac{V_0}{k}(\mathrm{Cosh}\,(kT) - 1) \qquad (5)$$

Next, calculate the vertical TWTT, T*.

$$T^* = 2\int_0^z \frac{dz}{V(z)} = 2\int_0^z \frac{dz}{V_0+kz}$$

$$T^* = \frac{2}{k}\ln\left(\frac{V_0+kz}{V_0}\right) \qquad (6)$$

To verify (6), calculate (5) at zero offset.

$$Z = \sqrt{\left(\frac{V_0}{k}\,\mathrm{Sinh}\,(kT)\right)^2 - X^2} + \frac{V_0}{k}\left(\mathrm{Cosh}\,(kT) - 1\right)$$

$$Z = \frac{V_0}{k}\,\mathrm{Sinh}\,(kT) + \frac{V_0}{k}\left(\mathrm{Cosh}\,(kT) - 1\right)$$

$$Z = \frac{V_0}{k}\left(\mathrm{Sinh}\,(kT) + \mathrm{Cosh}\,(kT) - 1\right)$$

$$Z = \frac{V_0}{k}\left(e^{kT} - 1\right)$$

And solve for T.

$$\frac{kZ}{V_0} + 1 = e^{kT} = \frac{V_0 + kZ}{V_0}$$

$$kT = \ln\left(\frac{V_0 + kZ}{V_0}\right)$$

$$T^* = 2T = \frac{2}{k}\ln\left(\frac{V_0 + kZ}{V_0}\right)$$

Given a velocity gradient, $V = V_0 + kZ$, there is a minimum time, corresponding to the circular raypath from source to receiver, for which we can calculate Z.

From Equation (5),

$$\left(\frac{V_0}{k}\,\mathrm{Sinh}\,(kT)\right)^2 - X^2 = 0$$

$$\mathrm{Sinh}\,(kT) = \frac{kX}{V_0}$$

$$kT = \mathrm{Sinh}^{-1}\left(\frac{kX}{V_0}\right)$$

$$T = \frac{1}{k} \ln \left\{ \frac{kX}{V_0} + \sqrt{\left(\frac{kX}{V_0}\right)^2 + 1} \right\}$$

$$T_{min} = \frac{2}{k} \ln \left\{ \frac{kX}{V_0} + \sqrt{\left(\frac{kX}{V_0}\right)^2 + 1} \right\} \qquad (7)$$

We can combine equations (5) and (6) to give the equivalent vertical TWTT for a linear gradient.

$$T^* = \frac{2}{k} \ln \left\{ \frac{V_0 + kZ}{V_0} \right\}$$

$$= \frac{2}{k} \ln \left\{ 1 + \frac{k}{V_0} Z \right\}$$

$$T^* = \frac{2}{k} \ln \left\{ 1 + \frac{k}{V_0} \left(\sqrt{\left(\frac{V_0}{k} \text{Sinh}(kT)\right)^2 - X^2} + \frac{V_0}{k} (\text{Cosh}(kT) - 1) \right) \right\}$$

$$T^* = \frac{2}{k} \ln \left\{ 1 + \sqrt{\text{Sinh}^2(kT) - \left(\frac{kX}{V_0}\right)^2} + \text{Cosh}(kT) - 1 \right\}$$

$$T^* = \frac{2}{k} \ln \left\{ \sqrt{\text{Sinh}^2\left(\frac{kT_0}{2}\right) - \left(\frac{kD}{2V_0}\right)^2} + \text{Cosh}\left(\frac{kT_0}{2}\right) \right\} \qquad (8)$$

For a given distance, D, what is the actual time, T_0, which maps to the gradient normal moveout time, T^* ?

Starting with equation (8),

$$T^* = \frac{2}{k} \ln\left\{\sqrt{\operatorname{Sinh}^2\left(\frac{kT_0}{2}\right) - \left(\frac{kD}{2V_0}\right)^2} + \operatorname{Cosh}\left(\frac{kT_0}{2}\right)\right\}$$

For brevity, let $A = \frac{k}{2}$; $B = \frac{kD}{2V_0}^2$

$$AT^* = \ln\left\{\sqrt{\operatorname{Sinh}^2(AT_0) - B} + \operatorname{Cosh}(AT_0)\right\}$$

$$e^{AT^*} = \sqrt{\operatorname{Sinh}^2(AT_0) - B} + \operatorname{Cosh}(AT_0)$$

$$\sqrt{\operatorname{Sinh}^2(AT_0) - B} = \operatorname{Cosh}(AT_0) - e^{AT^*}$$

$$\operatorname{Sinh}^2(AT_0) - B = \operatorname{Cosh}^2(AT_0) - 2e^{AT^*}\operatorname{Cosh}(AT_0) + e^{2AT^*}$$

$$B = 2e^{AT^*}\operatorname{Cosh}(AT_0) - \operatorname{Cosh}^2(AT_0) - e^{2AT^*} + \operatorname{Sinh}^2(AT_0)$$

$$B = 2e^{AT^*}\operatorname{Cosh}(AT_0) - e^{2AT^*} - 1$$

$$2e^{AT^*}\operatorname{Cosh}(AT_0) = B + e^{2AT^*} + 1$$

$$\operatorname{Cosh}(AT_0) = \frac{1}{2}\left(Be^{-AT^*} + e^{AT^*} + e^{-AT^*}\right)$$

$$\operatorname{Cosh}(AT_0) = \frac{1}{2}\left(Be^{-AT^*}\right) + \operatorname{Cosh}\left(AT^*\right) = C$$

$$AT_0 = \operatorname{Cosh}^{-1}(C) = \ln\left(C + \sqrt{C^2 - 1}\right)$$

$$T_0 = \frac{1}{A} \ln \left(C + \sqrt{C^2 - 1} \right)$$

$$T_0 = \left(\frac{2}{k}\right) \ln \left\{ \cosh\left(\frac{kT^*}{2}\right) + \frac{1}{2}\left(\frac{kD}{2V_0}\right)^2 e^{\frac{-kT^*}{2}} + \sqrt{\left(\cosh\left(\frac{kT^*}{2}\right) + \frac{1}{2}\left(\frac{kD}{2V_0}\right)^2 e^{\frac{-kT^*}{2}}\right)^2 - 1} \right\}$$

(9)

Appendix C - USGS Refraction Data Format

USGS seismic refraction data files are organized as direct access files with 512 byte blocks. Data traces are usually records consisting of 4001 integer*2 words. The data is laid into the file in a sequential manner, so record boundaries do not fall at direct access block boundaries. The first record in the file, trace 0, is used to store the file header information. There may be up to 150 data traces in a file.

File header information is stored sequentially in the first five 512 byte blocks.

MSAMP	Integer*2	Data record length
MREC	Integer*2	Number of data records in the file.
MAXR	Integer*2	Maximum number of records (150).
IHEAD(1,150)	Integer*2	Instrument ID number.
IHEAD(2,150)	Integer*2	Location number.
IHEAD(3,150)	Integer*2	TMIN (reduced) in whole seconds.
RRDIST(150)	Real*4	Range in km.
TITLE(20)	Integer*4	Data file title.
NSRATE	Integer*2	Sample rate in milliseconds.
RVD	Real*4	Reducing velocity used in digitizing.
ICHANL(150)	Integer*2	Attenuation setting in dB.
AZ(150)	Real*4	Azimuth to the shot point.

Appendix D - SEGY Data File Format

```
c
c     INCLUDE FILE FOR FORTRAN PROGRAMS TO READ SEGY DATA FILES
c
c This file is an implicit definition of SEGY format with additions
c for refraction work.  It is the SEGY standard of Barry et al
c Geophysics (1975) with extensions labelled LDS USE and USGS use
c for refraction work.  When used as an include file for a FORTRAN
c program, all variables will be set after reading arrays SEGY1A,
c SEGY1B, and SEGYDB.
c
c Character code is EBCDIC unless IEEE data format (see variable icode)
c If IEEE, then the character code is ASCII.
c
c Written by Carl Spencer and Isa Asudeh  4/2/86 original specification
c This version is compatible with the final Lithoprobe version dated
c       5-DEC-1987.
c
c
c Maximum number of bytes allowed in a trace (system dependent)
c MAXLEN = ((max trace length) * (sample rate) * (bytes per sample))
c                                                      + 240
      parameter (MAXLEN=16620)
c
c
c SEGY REEL IDENTIFICATION HEADER PART 1
      byte  segy1a(3200)
c SEGY REEL IDENTIFICATION HEADER PART 2
      byte  segy1b(400)
c SEGY TRACE DATA BLOCK
      byte  segydb(MAXLEN)
      common/segycom/iiopen,segy1a,segy1b,segydb
c
c EBCDIC CARDS
      character*80  cards(40)
      equivalence  (segy1a(1),cards(1))
c
```

```
c TRACE IDENTIFICATION HEADER
      byte   thead(240)
      equivalence  (segydb(1),thead(1))
c
c DATA WORDS
      integer*2    iidata((MAXLEN-240)/2)
      integer*4    jdata((MAXLEN-240)/4)
      real*4       rdata((MAXLEN-240)/4)
      equivalence  (segydb(241),iidata(1),jdata(1),rdata(1))
c
c
c---------------------------------------------------------------
c Binary area of file (or reel) Identification Header starts here
c---------------------------------------------------------------
c
c
c
c Job Identification number                          SEGY STANDARD
      integer*4 jobid
      equivalence  (segy1b(1),jobid)
c
c Line number                                        SEGY STANDARD
      integer*4 lineno
      equivalence  (segy1b(5),lineno)
c
c Reel number                                        SEGY STANDARD
      integer*4 reelno
      equivalence  (segy1b(9),reelno)
c
c Number of data traces per record                   SEGY STANDARD
      integer*2 ntrace
      equivalence  (segy1b(13),ntrace)
c
c Number of auxiliary traces per record              SEGY STANDARD
      integer*2 nauxt
      equivalence  (segy1b(15),nauxt)
c
c Sample interval in microseconds - this data        SEGY STANDARD
      integer*2 sint
      equivalence  (segy1b(17),sint)
c
```

```
c Sample interval in microseconds (in field)          SEGY STANDARD
      integer*2  sint2
      equivalence  (segy1b(19),sint2)
c
c No of samples per trace - this data                 SEGY STANDARD
      integer*2  nsam
      equivalence  (segy1b(21),nsam)
c
c No of samples per trace (in field)                  SEGY STANDARD
      integer*2  nsam2
      equivalence  (segy1b(23),nsam2)
c
c Data sample format code                             SEGY STANDARD
c  icode=0001 (1)     IBM FLOATING POINT              SEGY STANDARD
c  icode=0002 (2)     FIXED POINT (4 bytes)           SEGY STANDARD
c  icode=0003 (3)     FIXED POINT (2 bytes)           SEGY STANDARD
c  icode=0004 (4)     FIXED POINT WITH GAIN           SEGY STANDARD
c  icode=0100 (256)   FLOATING POINT - IEEE           VERITAS STANDARD
c  icode=0200 (512)   FIXED POINT (4 bytes) - IEEE
c  icode=0300 (768)   FIXED POINT (2 bytes) - IEEE
c  icode=0500 (1280)  LUNCHBOX FORMAT                 LDS USE
c  icode=0600 (1536)  VAX R*4 FORMAT                  LDS USE
      integer*2  icode
      equivalence  (segy1b(25),icode)
c
c Number of traces in CDP ensemble                    SEGY STANDARD
      integer*2  ncdp
      equivalence  (segy1b(27),ncdp)
c
c Trace sorting code                                  SEGY STANDARD
c  itsort=1  as recorded                              SEGY STANDARD
c  itsort=2  CDP ensemble                             SEGY STANDARD
c  itsort=3  Single fold continuous                   SEGY STANDARD
c  itsort=4  Horizontal stack                         SEGY STANDARD
c  No LDS or USGS use.
      integer*2  itsort
      equivalence  (segy1b(29),itsort)
c
```

```
c Vertical sum code                                 SEGY STANDARD
c   vcode=n sum on n traces
      integer*2  vcode
      equivalence  (segy1b(31),vcode)
c
c Start sweep frequency (hz)                        SEGY STANDARD
      integer*2  ssweep
      equivalence  (segy1b(33),ssweep)
c
c End sweep frequency (hz)                          SEGY STANDARD
      integer*2  esweep
      equivalence  (segy1b(35),esweep)
c
c Sweep length in milliseconds                      SEGY STANDARD
      integer*2  sleng
      equivalence  (segy1b(37),sleng)
c
c Sweep type                                        SEGY STANDARD
c  stype=1  Linear                                  SEGY STANDARD
c  stype=2  Parabolic                               SEGY STANDARD
c  stype=3  Exponential                             SEGY STANDARD
c  stype=4  Other                                   SEGY STANDARD
c  stype=5  Borehole  source                        LDS USE
c  stype=6  Water  explosive  source                LDS USE
c  stype=7  Airgun  source                          LDS USE
      integer*2  stype
      equivalence  (segy1b(39),stype)
c
c Trace number of sweep channel                     SEGY STANDARD
      integer*2  nts
      equivalence  (segy1b(41),nts)
c
c Sweep trace taper in milliseconds at start        SEGY STANDARD
      integer*2  stts
      equivalence  (segy1b(43),stts)
c
c Sweep trace taper in milliseconds at end          SEGY STANDARD
      integer*2  stte
      equivalence  (segy1b(45),stte)
c
```

```
c Taper type                                          SEGY STANDARD
c  ttype=1  Linear                                    SEGY STANDARD
c  ttype=2  cos**2                                    SEGY STANDARD
c  ttype=3  Other                                     SEGY STANDARD
      integer*2  ttype
      equivalence  (segy1b(47),ttype)
c
c Correlated data traces                              SEGY STANDARD
c   cort=1 no  2 yes
      integer*2  cort
      equivalence  (segy1b(49),cort)
c
c Binary gain recovered                               SEGY STANDARD
c    bgr=1  Yes. For USGS data, the data has also been demeaned.
c    bgr=2  No
      integer*2  bgr
      equivalence  (segy1b(51),bgr)
c
c Amplitude recovery methods                          SEGY STANDARD
c   arm=1 none  2 spherical  3 AGC  4 other
      integer*2  arm
      equivalence  (segy1b(53),arm)
c
c Measurement system                                  SEGY STANDARD
c   isys=1 meters  2 feet
      integer*2  isys
      equivalence  (segy1b(55),isys)
c
c Polarity                                            SEGY STANDARD
c   ipol=1 Upward movement gives neg. number          SEGY STANDARD
c   ipol=2 Upward movement gives pos. number          SEGY STANDARD
      integer*2  ipol
      equivalence  (segy1b(57),ipol)
c
c Vibrator polarity code                              SEGY STANDARD
      integer*2  vpc
      equivalence  (segy1b(59),vpc)
c
```

```
c Number of traces in the file                      LDS USE
c   Used for disk files.
      integer*2  notif
      equivalence  (segy1b(61),notif)
c
c  Attribute  information                            LDS USE
c  attri=0  velocity/displacement  data
c  attri=1  instantaneous  amplitude
c  attri=2  instantaneous  frequency
c  attri=3  instantaneous  phase
c  attri=4  slowness  (m/ms)
c  attri=5  semblance  (0-1000)
      integer*2  attri
      equivalence  (segy1b(63),attri)
c
c Mean amplitude of all samples                      LDS USE
c    in all traces in file     Used for disk files.
      real*4  meanas
      equivalence  (segy1b(65),meanas)
c
c Domain of data                                     LDS USE
c    domain=0 Time - distance domain
c     domain=1 Frequency - wavenumber domain
c     domain=2 Intercept time - slowness domain
      integer*2  domain
      equivalence  (segy1b(69),domain)
c
c      Bytes 71, 72 unused to align four byte boundaries.
c
c Reduction velocity meters/sec if data is reduced  LDS USE
      integer*4  vred
      equivalence  (segy1b(73),vred)
c
c Minimum of all samples in file.                    LDS USE
      real*4  minass
      equivalence  (segy1b(77),minass)
c
c Maximum of all samples in file.                    LDS USE
      real*4  maxass
      equivalence  (segy1b(81),maxass)
c
```

```
c Recording instrument type                              USGS USE
c  iinstr=1   EDA lunchbox recorder
c  iinstr=2   USGS seismic cassette recorder
c  iinstr=3   GEOS
c  iinstr=99 Mixed
      integer*2  iinstr
      equivalence  (segy1b(85),iinstr)
c
c File creation date - Last two digits of year           USGS USE
      integer*2  cryear
      equivalence  (segy1b(87),cryear)
c
c File creation date - Month of year                     USGS USE
      integer*2  crmnth
      equivalence  (segy1b(89),crmnth)
c
c File creation date - Day of month                      USGS USE
      integer*2  crday
      equivalence  (segy1b(91),crday)
c
c   Bytes 93-398 of the binary File Identification Header are not used
c
c  Format version number (x100)
c  Version 0.99    "Discussion version", October 1986.
c  Version 1.00    "Final version", December 5, 1987
      integer*2  fvn
      equivalence  (segy1b(399),fvn)
c
```

```
c--------------------------------------------------------------
c Trace Identification Header (total of 240 bytes) starts here
c--------------------------------------------------------------
c
c Trace sequence number within line                 SEGY STANDARD
      integer*4 tsnl
      equivalence (thead(1),tsnl)
c
c Trace sequence number within file                 SEGY STANDARD
      integer*4 tsnt
      equivalence (thead(5),tsnt)
c
c Original field record number                      SEGY STANDARD
c For LDS use this will be sequential shot number   LDS USE
      integer*4 ofrn
      equivalence (thead(9),ofrn)
c
c Trace number within original field record         SEGY STANDARD
      integer*4 tnofr
      equivalence (thead(13),tnofr)
c
c Energy source point number                        SEGY STANDARD
      integer*4 espn
      equivalence (thead(17),espn)
c
c CDP number                                        SEGY STANDARD
      integer*4 cdp
      equivalence (thead(21),cdp)
c
c Trace number within CDP                           SEGY STANDARD
      integer*4 tncdp
      equivalence (thead(25),tncdp)
c
c Trace identification code                         SEGY STANDARD
c  1 = Seismic data, 2 = Dead,    3 = Dummy         SEGY STANDARD
c  4 = Time break,   5 = Uphole, 6 = Sweep          SEGY STANDARD
c  7 = Timing,       8 = Water break                SEGY STANDARD
c  9 = Deleted trace                                USGS USE
c  10 = Long Period data (see thead(117),isi)       USGS USE
      integer*2 tic
      equivalence (thead(29),tic)
c
```

```
c Number of vertically summed traces
c       yielding this trace                    SEGY STANDARD
      integer*2  nvs
      equivalence  (thead(31),nvs)
c
c Number of horizontally stacked traces
c       yielding this trace                    SEGY STANDARD
      integer*2  nhs
      equivalence  (thead(33),nhs)
c
c Data use (1=production 2=test)               SEGY STANDARD
      integer*2  duse
      equivalence  (thead(35),duse)
c
c Distance from source to receiver             SEGY STANDARD
      integer*4  idist
      equivalence  (thead(37),idist)
c
c Receiver group elevation                     SEGY STANDARD
      integer*4  irel
      equivalence  (thead(41),irel)
c
c Surface elevation of source                  SEGY STANDARD
      integer*4  ishe
      equivalence  (thead(45),ishe)
c
c Shot depth                                   SEGY STANDARD
      integer*4  ishd
      equivalence  (thead(49),ishd)
c
c Datum elevation at receiver                  SEGY STANDARD
      integer*4  delr
      equivalence  (thead(53),delr)
c
c Datum elevation at source                    SEGY STANDARD
      integer*4  dels
      equivalence  (thead(57),dels)
c
c Water depth at source                        SEGY STANDARD
      integer*4  wds
      equivalence  (thead(61),wds)
c
```

```
c Water depth at receiver                            SEGY STANDARD
      integer*4  wdr
      equivalence  (thead(65),wdr)
c
c Scalar multiplier/divisor for bytes 41-68          SEGY STANDARD
      integer*2  smul1
      equivalence  (thead(69),smul1)
c
c Scalar multiplier/divisor for bytes 73-88          SEGY STANDARD
      integer*2  smul2
      equivalence  (thead(71),smul2)
c
c Source coordinate X or longitude (East positive)   SEGY STANDARD
      integer*4  ishlo
      equivalence  (thead(73),ishlo)
c
c Source coordinate Y or latitude (North positive)   SEGY STANDARD
      integer*4  ishla
      equivalence  (thead(77),ishla)
c
c Group coordinate X or longitude (East positive)    SEGY STANDARD
      integer*4  irlo
      equivalence  (thead(81),irlo)
c
c Group coordinate Y or latitude (North positive)    SEGY STANDARD
      integer*4  irla
      equivalence  (thead(85),irla)
c
c Coordinate units                                   SEGY STANDARD
c  1:  meters/feet
c  2:  seconds of arc (smul2 holds multiplier)
c  N:  mod 100 = TX zone
c      div 100 = RX zone
      integer*2  cunits
      equivalence  (thead(89),cunits)
c
c Weathering velocity (m/s?)                         SEGY STANDARD
      integer*2  wvel
      equivalence  (thead(91),wvel)
c
```

```
c Subweathering velocity (m/s?)                              SEGY STANDARD
      integer*2 swvel
      equivalence (thead(93),swvel)
c
c Uphole time at source                                      SEGY STANDARD
      integer*2 utimes
      equivalence (thead(95),utimes)
c
c Uphole time at group                                       SEGY STANDARD
      integer*2 utimeg
      equivalence (thead(97),utimeg)
c
c Source static correction (ms?)                             SEGY STANDARD
      integer*2 sstati
      equivalence (thead(99),sstati)
c
c Group static                                               SEGY STANDARD
      integer*2 gstati
      equivalence (thead(101),gstati)
c
c Total static                                               SEGY STANDARD
      integer*2 tstati
      equivalence (thead(103),tstati)
c
c Lag time A                                                 SEGY STANDARD
      integer*2 istime
      equivalence (thead(105),istime)
c
c Lag time B                                                 SEGY STANDARD
      integer*2 ibtime
      equivalence (thead(107),ibtime)
c
c Delay recording time (reduced start time) (msec)           SEGY STANDARD
      integer*2 ictime
      equivalence (thead(109),ictime)
c
c Mute start time                                            SEGY STANDARD
      integer*2 mtimes
      equivalence (thead(111),mtimes)
c
```

```
c Mute end time                                   SEGY STANDARD
      integer*2  mtimee
      equivalence  (thead(113),mtimee)
c
c No of samples in this trace                     SEGY STANDARD
      integer*2  length
      equivalence  (thead(115),length)
c
c Sampling interval in microseconds               SEGY STANDARD
c If (thead(29),itic) = 10, in milliseconds       USGS STANDARD
      integer*2  isi
      equivalence  (thead(117),isi)
c
c Gain type (1=fixed 2=binary 3=floating)         SEGY STANDARD
      integer*2  gaint
      equivalence  (thead(119),gaint)
c
c Gain constant                                   SEGY STANDARD
      integer*2  gc
      equivalence  (thead(121),gc)
c
c Instrument or initial gain in DB                SEGY STANDARD
      integer*2  gidb
      equivalence  (thead(123),gidb)
c
c Correlated 1=no 2=yes                           SEGY STANDARD
      integer*2  tcorr
      equivalence  (thead(125),tcorr)
c
c Start sweep frequency (hz)                      SEGY STANDARD
      integer*2  tsswee
      equivalence  (thead(127),tsswee)
c
c End sweep frequency (hz)                        SEGY STANDARD
      integer*2  teswee
      equivalence  (thead(129),teswee)
c
c Sweep length in milliseconds                    SEGY STANDARD
      integer*2  tsleng
      equivalence  (thead(131),tsleng)
c
```

```
c Sweep type                                       SEGY STANDARD
c  stype=1 Linear                                  SEGY STANDARD
c  stype=2 Parabolic                               SEGY STANDARD
c  stype=3 Exponential                             SEGY STANDARD
c  stype=4 Other                                   SEGY STANDARD
c  stype=5 Borehole source                         LDS USE
c  stype=6 Water explosive source                  LDS USE
c  stype=7 Airgun source                           LDS USE
      integer*2 tstype
      equivalence (thead(133),tstype)
c
c Sweep trace taper in milliseconds at start       SEGY STANDARD
      integer*2 tstts
      equivalence (thead(135),tstts)
c
c Sweep trace taper in milliseconds at end         SEGY STANDARD
      integer*2 tstte
      equivalence (thead(137),tstte)
c
c Taper type                                       SEGY STANDARD
c  ttype=1 Linear                                  SEGY STANDARD
c  ttype=2 Cos**2                                  SEGY STANDARD
c  ttype=3 Other                                   SEGY STANDARD
      integer*2 tttype
      equivalence (thead(139),tttype)
c
c Antialias filter frequency                       SEGY STANDARD
      integer*2 aif
      equivalence (thead(141),aif)
c
c Alias filter slope                               SEGY STANDARD
      integer*2 ais
      equivalence (thead(143),ais)
c
c Notch filter frequency                           SEGY STANDARD
      integer*2 nif
      equivalence (thead(145),nif)
c
c Notch filter slope                               SEGY STANDARD
      integer*2 nis
      equivalence (thead(147),nis)
c
```

```
c Low cut frequency                              SEGY STANDARD
      integer*2 flc
      equivalence (thead(149),flc)
c
c High cut frequency                             SEGY STANDARD
      integer*2 fhc
      equivalence (thead(151),fhc)
c
c Low cut slope                                  SEGY STANDARD
      integer*2 slc
      equivalence (thead(153),slc)
c
c High cut slope                                 SEGY STANDARD
      integer*2 shc
      equivalence (thead(155),shc)
c
c Year of start of trace                         SEGY STANDARD
      integer*2 tyear
      equivalence (thead(157),tyear)
c
c Day of start of trace                          SEGY STANDARD
      integer*2 tday
      equivalence (thead(159),tday)
c
c Hour of start of trace                         SEGY STANDARD
      integer*2 thour
      equivalence (thead(161),thour)
c
c Minute of start of trace                       SEGY STANDARD
      integer*2 tmin
      equivalence (thead(163),tmin)
c
c Second of start of trace                       SEGY STANDARD
      integer*2 tsec
      equivalence (thead(165),tsec)
c
c Time basis code  1=local 2=GMT                 SEGY STANDARD
      integer*2 tbcode
      equivalence (thead(167),tbcode)
c
```

```
c Trace weighting factor                               SEGY STANDARD
      integer*2  twf
      equivalence  (thead(169),twf)
c
c Geophone group no. on roll switch first position     SEGY STANDARD
      integer*2  ggrp1
      equivalence  (thead(171),ggrp1)
c
c Geophone group no. trace position 1                  SEGY STANDARD
c    on field record
      integer*2  ggtp
      equivalence  (thead(173),ggtp)
c
c Time code translator error light                     USGS USE
c    1=No error  2=Error
      integer*2  errlt
      equivalence  (thead(175),errlt)
c
c Distance-azimuth calculation algorithm               USGS USE
c    1 = Sodano algorithm.  The program utilizes the Sodano and Robinson
c         (1963) direct solution of geodesics (Army Map Service, Tech Rep
c        #7, Section IV).
      integer*2  daca
      equivalence  (thead(177),daca)
c
c Earth dimension code                                 USGS USE
c  1 = Fischer spheroid (1960),
c           OMEGA & NASA datums                        6378166.    298.30
c  2 = Clark ellipsoid (1866),
c           N. American datum 1927                     6378206.4   294.98
c  3 = Ref ellipsoid (1967), S. American datum         6378160     298.25
c  4 = Hayford International Ellipsoid (1910)          6378388.    297.00
c  5 = World Geodetic Survey Ellipsoid (1972)          6378135.    298.26
c  6 = Bessel (1841), Tokyo datum                      6377397.    299.15
c  7 = Everest (1830), India datum                     6377276.    300.80
c  8 = Airy (1936),
c           Ordnance survey of Great Britain           6377563.    299.32
c  9 = Hough (1960), Wake-Eniwetok                     6378270.    297.00
c 10 = Fischer (1968), Modified Mercury                6378150.    298.30
c 11 = Clarke (1880)                                   6378249.    293.47
      integer*2  edc
      equivalence  (thead(179),edc)
```

```
c
c Microseconds of trace start time                          LDS USE
      integer*4  mst
      equivalence  (thead(181),mst)
c
c Millisecond of timing correction                           LDS USE
      integer*2  cor
      equivalence  (thead(185),cor)
c
c Charge size in kg                                          LDS USE
      integer*2  charge
      equivalence  (thead(187),charge)
c
c Shot time - Year                                           LDS USE
      integer*2  syear
      equivalence  (thead(189),syear)
c
c Shot time - Day                                            LDS USE
      integer*2  sday
      equivalence  (thead(191),sday)
c
c Shot time - Hour                                           LDS USE
      integer*2  shour
      equivalence  (thead(193),shour)
c
c Shot time - Minute                                         LDS USE
      integer*2  shmin
      equivalence  (thead(195),shmin)
c
c Shot time - Second                                         LDS USE
      integer*2  sseco
      equivalence  (thead(197),sseco)
c
c Shot time - Microsecond                                    LDS USE
      integer*4  ssmic
      equivalence  (thead(199),ssmic)
c
c Azimuth of receiver from shot (minutes of arc)             LDS USE
      integer*2  azimut
      equivalence  (thead(203),azimut)
c
```

```
c Azimuth of geophone orientation axis with
c respect to true north in minutes of arc            LDS USE
      integer*2 geoazi
      equivalence (thead(205),geoazi)
c
c Angle between geophone orientation axis and
c vertical in minutes of arc                          LDS USE
      integer*2 geover
      equivalence (thead(207),geover)
c
c Time to be added to recorded trace time to get
c actual trace start time. To be used when data
c has been reduced but start time is not updated
c so that the actual time can be recovered even if
c distance and shot time have changed
c (microseconds)                                      LDS USE
      integer*4 ttrace
      equivalence (thead(209),ttrace)
c
c Recording instrument number                         LDS USE
      character*4 scrs
      equivalence (thead(213),scrs)
c
c Deployment name                                     LDS USE
      character*4 deploy
      equivalence (thead(217),deploy)
c
c Shotpoint name (shotpoint number)                   LDS USE
      character*4 spname
      equivalence (thead(221),spname)
c
c Receiver site name (station number)                 LDS USE
      character*4 rstnam
      equivalence (thead(225),rstnam)
c
c Shot name (shot number)                             LDS USE
      character*4 shotid
      equivalence (thead(229),shotid)
c
```

```
c Line name                                          LDS USE
      character*4  lineid
      equivalence  (thead(233),lineid)
c
c Geophone orientation eg R40,Z                      LDS USE
      character*4  geoor
      equivalence  (thead(237),geoor)
c
c   End of Trace Identification Header
```

Appendix E - Operational Notes

When plotting record sections interactively, a plot is occasionally initiated with the wrong plot parameters. Rather than aborting the program or waiting until the entire plot is finished, you may interrupt the current plot and return to the command level by the following procedure.

a) Enter CNTRL/Y to suspend the program.

b) Enter SPAWN PUB1:[REFRACT.LUETGERT.RAY83]RAYSTOP

This program will open a one-line ASCII file named STOP.DAT in your directory and write STOP in it. RSEC88 looks for STOP after each trace is plotted. You may wish to abbreviate this command with an entry in your LOGIN.COM file. I use,

Q :== SPAWN PUB1:[REFRACT.LUETGERT.RAY83]RAYSTOP

c) Enter CONTINUE to return to RSEC88.