U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MacRay

Interactive Two-Dimensional Seismic Raytracing for the Macintosh™

by

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Open-File Report 92-356

Menlo Park, California
1992

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Introduction

MacRay is an interactive application for calculating travel-time curves from two-dimensional velocity models. The ability to quickly manipulate velocity models and quickly see the resulting travel-times revolutionizes the forward modeling of refraction/wide-angle reflection data sets.

MacRay is based upon RAY84 (Luetgert, 1988) and RAY86, seismic raytracing programs written for the DEC VAX™/VMS environment. Tremendous advantages are obtained by exploiting the Apple Macintosh™ graphical interface for the display and manipulation of velocity models. Typically, the time required to obtain a satisfactory velocity model is vastly reduced by comparison to the earlier routines. As an additional benefit, the screen graphics produced by MacRay may be directly exported to standard Macintosh™ drawing applications for the easy production of publication quality figures.

Velocity models are defined by two or more interfaces extending across the model from left to right. Interfaces may "pinch out" but may not cross. Any pair of successive interfaces describe a layer, within which the velocity may be defined in terms of the velocity at the top and bottom of the layer. Within any layer the velocity may be inhomogeneous, but continuous. First or second order discontinuities in velocity may occur at interfaces. The ray tracing algorithm that is used calculates the propagation of rays within a layer by the stepwise integration of the system of first order differential equations,

$$d/dt\, x(t) = V(x,z)Sin\theta$$

$$d/dt\, z(t) = V(x,z)Cos\theta$$

$$d/dt\, \theta(t) = \frac{dV}{dx}Cos\theta - \frac{dV}{dz}Sin\theta$$

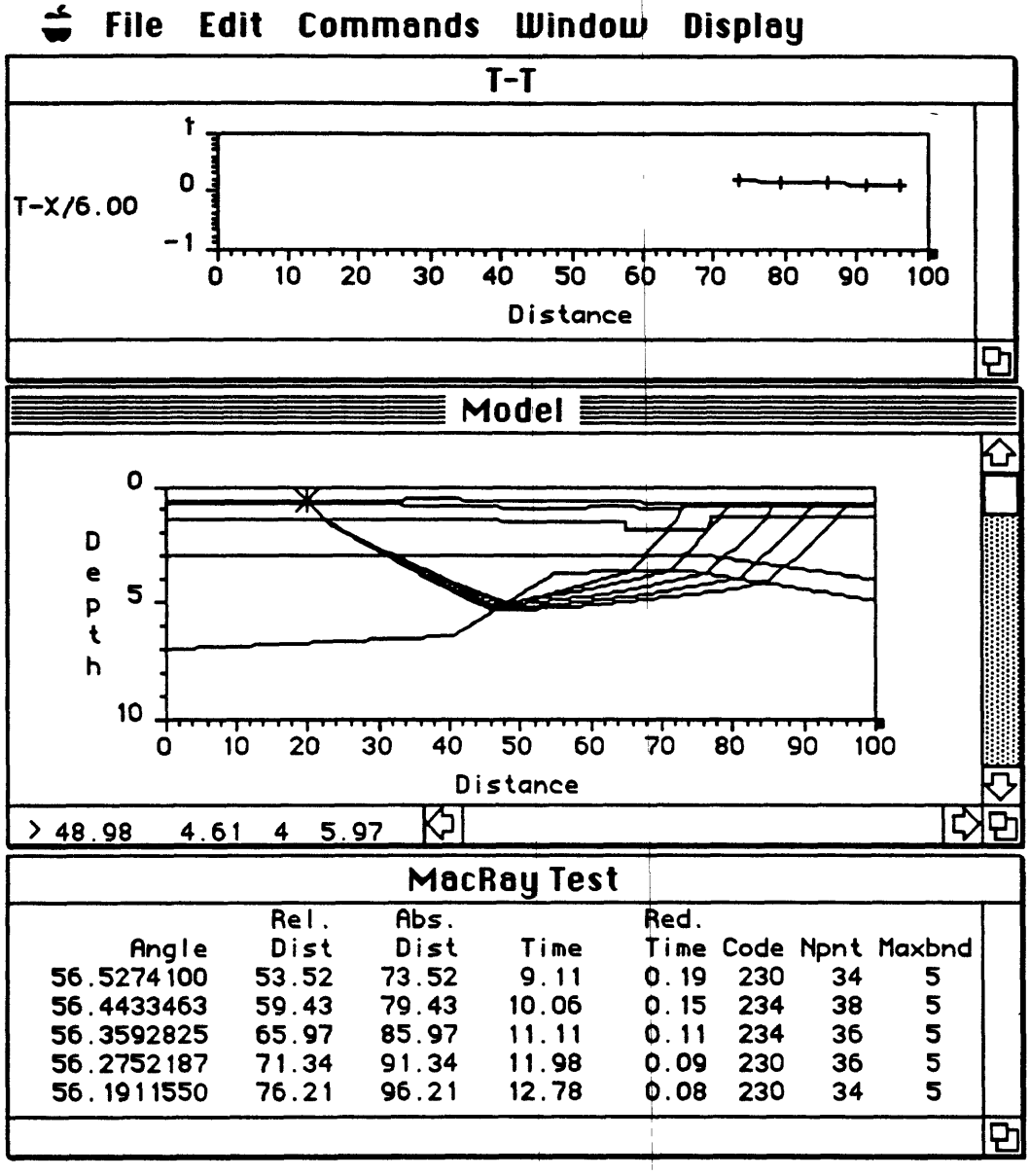
where θ is the ray's angle from the vertical.

By supplying a definition of V(x,z) and initial values for x, z, t, and θ, subsequent values of x, z, t, and θ may be calculated by simultaneously integrating the above three equations over small steps in time. For derivation and details see Cerveny *et al.*, (1977).

Lithologic interfaces are represented in the model as first or second order velocity discontinuities. When an interface is encountered in the calculation of a ray, Snell's law is applied and the calculation is continued.

Windows

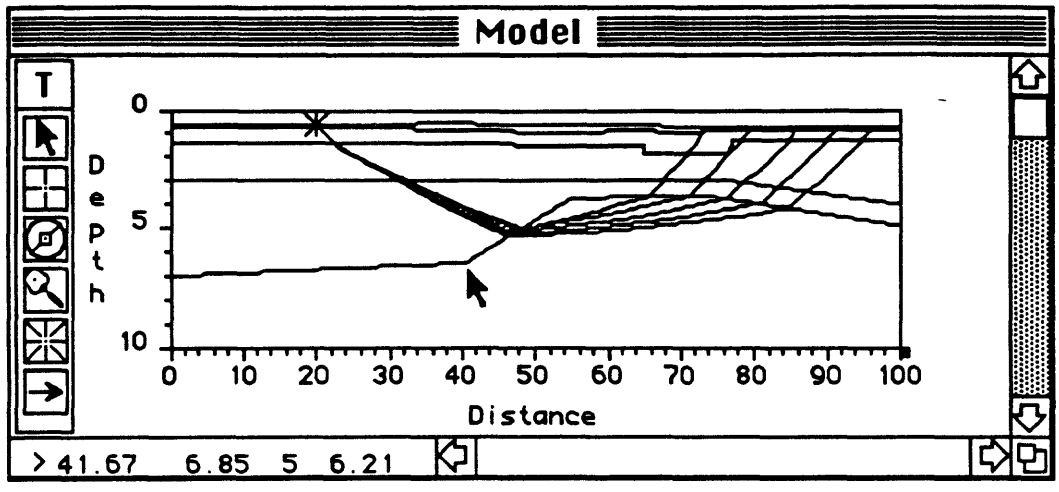
The basic display consists of four windows; a graphics window containing the travel-time curves and [optional] picked arrival times ("Travel Time Window"), a graphics window containing a plot of the two-dimensional model ("Model Window"), a text window containing the ray set results ("Result Window"), and a text window containing a log of rayset parameters ("Rayset Log Window").



Angle	Rel. Dist	Abs. Dist	Time	Red. Time	Code	Npnt	Maxbnd
56.5274100	53.52	73.52	9.11	0.19	230	34	5
56.4433463	59.43	79.43	10.06	0.15	234	38	5
56.3592825	65.97	85.97	11.11	0.11	234	36	5
56.2752187	71.34	91.34	11.98	0.09	230	36	5
56.1911550	76.21	96.21	12.78	0.08	230	34	5

The Model Window

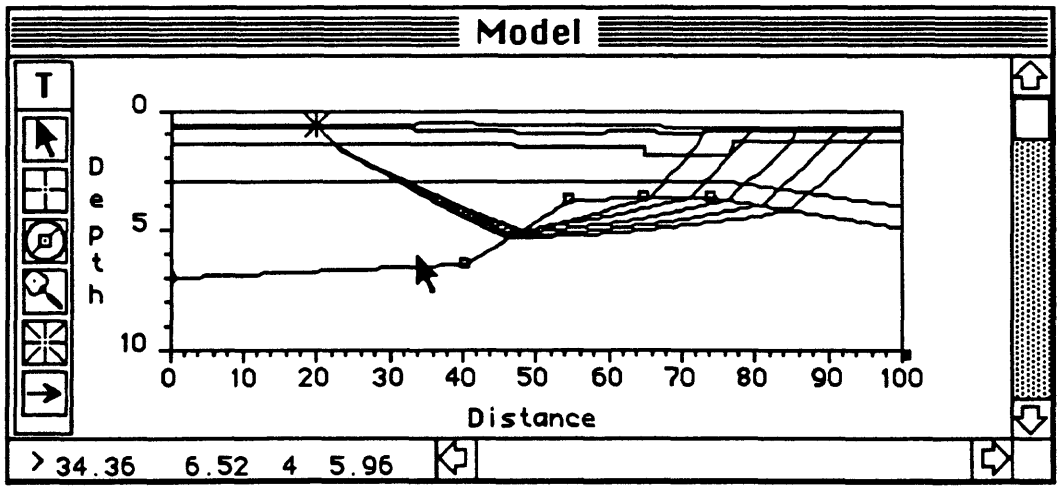
The velocity model is edited graphically in the Model window using the tools displayed at the left side of the window. Select a tool by clicking on it; the appropriate cursor will be displayed when the cursor is within the data area. Note that when the cursor is within the data area, the ray direction, the current position in distance, depth, layer number and velocity are displayed at the bottom of the window.



Editing interfaces:

The model is defined in terms of interfaces (extending from one side of the model to the other), layers (corresponding in number to the upper interface, and velocities at the top and bottom of each layer at several points along the layer. Each interface may be defined at up to 200 points. There may be up to 50 interfaces.

To edit an interface and its corresponding layer, the interface must be selected by double-clicking on it (or by using the **Interface ▸ Select...** command in the Edit Menu). Its defining points (nodes) will then be displayed.



Interface segments and nodes may be moved using the arrow-cursor. Nodes may be added, deleted or interpolated using the respective cursors from the toolbox. Clicking on a node without moving it will select it (it will appear as a filled box instead of an open box). Clicking on a selected node will deselect it. By selecting a series of adjacent nodes, you may define a piece of the interface made up of multiple segments which can then be moved as a unit. The following rules govern how nodes are selected:

a) Only one contiguous group of nodes may be selected at a time.
b) If there is a gap of unselected nodes between the node you are selecting and existing selected nodes, the intervening nodes will also be selected.
c) If you deselect a node from within a string of selected nodes, the smaller fragment will also be deselected.

To select an entire interface, click on one end node, then the other.

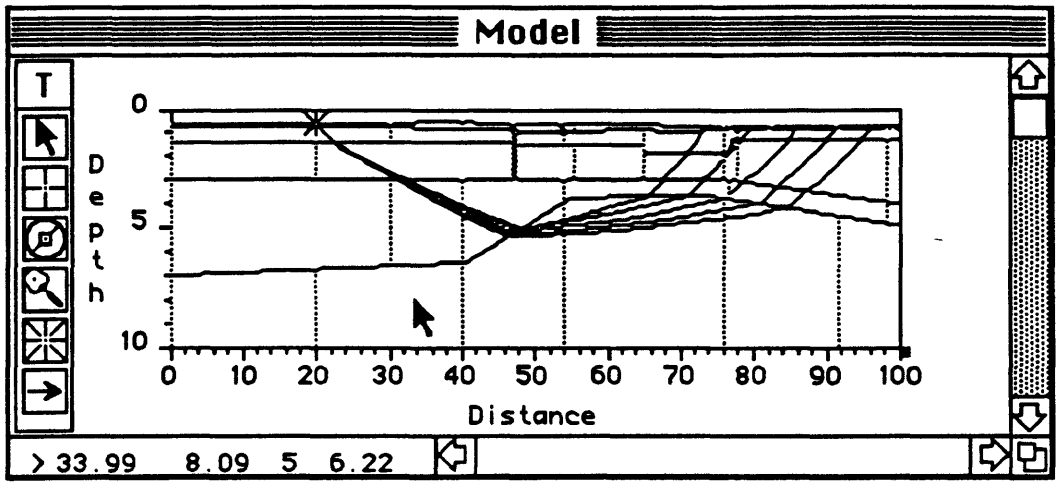
If you have difficulty selecting and moving nodes, their size may be increased by using the **Settings...** dialog in the Edit menu.

When moving nodes and interface segments, the program attempts to prevent you from inadvertently making interfaces cross one another. It will catch 90% of the cases, but it is possible to make interfaces cross if you are not careful. This should be avoided.

For precision editing of the model, save it as a TEXT file and use any standard word processor to fine tune the parameters.

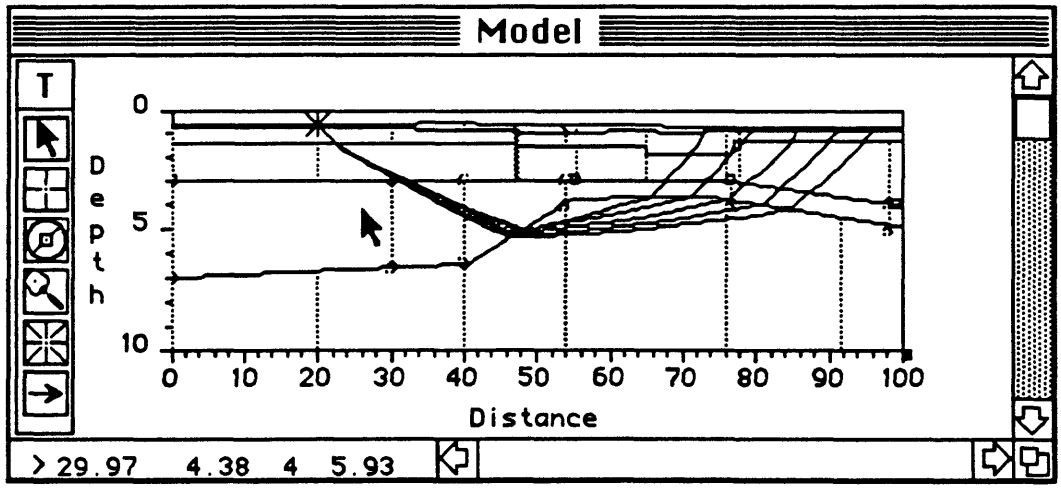
Editing velocities:

To manipulate the velocities - Enable the display of the velocity net using the **Show Net** command from the Display menu.



Vertical gray lines will appear to represent the velocity net. Velocities are defined at the intersections of these net lines and interfaces. At any point in the model the velocity and velocity gradient are defined by bilinear interpolation from the nearest four velocity definition points. Any layer may have up to 85 velocity net lines.

Select a layer for editing by double-clicking on its upper interface (or by using the **Interface ▸ Select...** command in the Edit Menu). The velocity net lines for the **selected layer** will appear with little handles at their tops and bottoms. If the layer is very thin, the velocity net lines will extend below the layer.

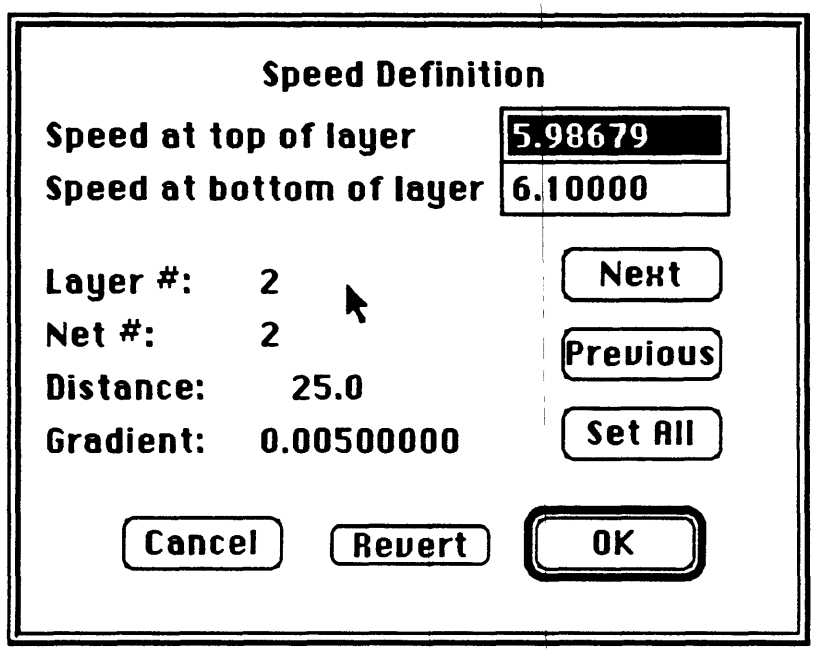


The velocity net lines may be moved laterally by using click-drag with the mouse (careful, they're a little hard to nab). If you have difficulty dragging the velocity net lines, you can change the tolerance for determining if the cursor is on the line by using the **Settings...** dialog in the Edit menu.

To add a new line, hold down the ⌘ key and click on a line. A new net line will appear halfway between this line and the next line to the right.

To remove a velocity net line, hold down both the Option and ⌘ keys and click on the line.

To edit a velocity net line, hold down the Option key and click on the line. You will be presented with the following dialog.



The **Next** and **Previous** buttons may be used to step through the velocity net lines in the layer. The **Set All** button sets all of the velocity net lines in this layer to the values shown. If you hold down the option key while using the **Set All** button, the speeds at the bottom of the layer are modified for each velocity net line. The result is that the current vertical gradient is applied to each.

The Tools.

The tool bar located on the left side of the Model window provides a set of tools for manipulating the model. Click on a tool and the appropriate cursor will appear when you are within the model axes of the Model Window.

Arrow cursor - Node points may be grabbed and moved with the arrow cursor. Segments of the selected interface may also be moved with the arrow cursor. Movement of segments is constrained to the direction of first motion. Movement of nodes and segments is constrained to try to keep the interfaces from crossing. (This is not always successful). The Arrow cursor is also used to change the size of the axes by pulling on the small node at the bottom right of the model or travel-time axes.

Insert cursor - Node points may be added to the currently selected interface using the insert cursor. Place the cursor at the desired location and click to insert a node. Hold down the shift key to temporarily revert to the Arrow cursor.

Delete cursor - Node points may be deleted from the currently selected interface using the delete cursor. Place the cursor over the node to be deleted and click. If multiple nodes are selected, they will all be deleted. Hold down the shift key to temporarily revert to the Arrow cursor.

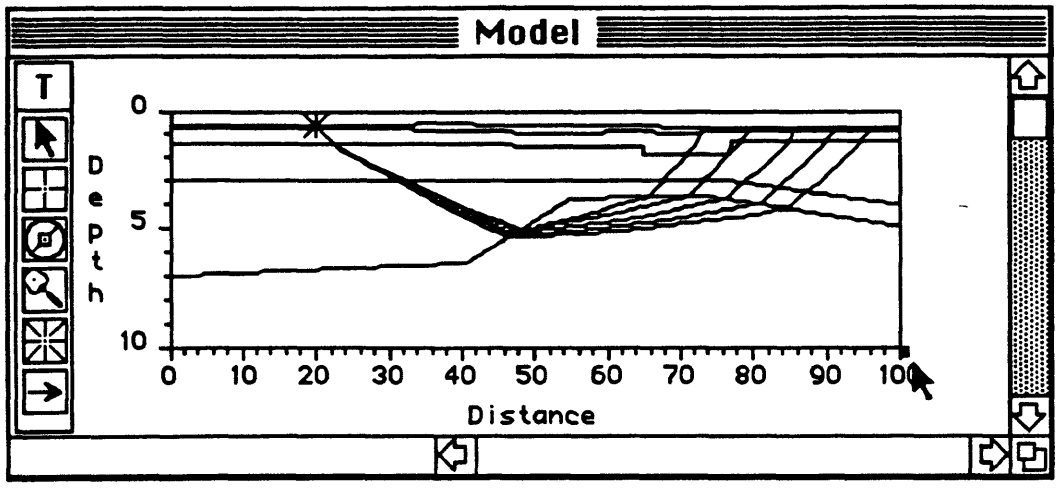
Magnifier cursor - This is used to magnify the display of the model. This is useful for fine-tuning the model. The cursor will appear like this:  . Each time the cursor is clicked, the model will be enlarged by a factor of two about the point clicked. To reverse the zoom, press the shift key. The cursor will change to appear like this:  . If you press both the shift and option keys, model scaling will return directly to 1:1. The Magnifier cursor may be used with either the Model window or the Travel Time window.

Source cursor - This cursor may be used to move the source from its current position to any other point in the model. Place the cursor at the desired point and click. You may also use the dialog initiated by the **Source▸Edit...**command in the Commands Menu.

Interpolate cursor - This cursor may be used to interpolate a new node into the currently selected interface. Hold down the shift key to temporarily revert to the Arrow cursor.

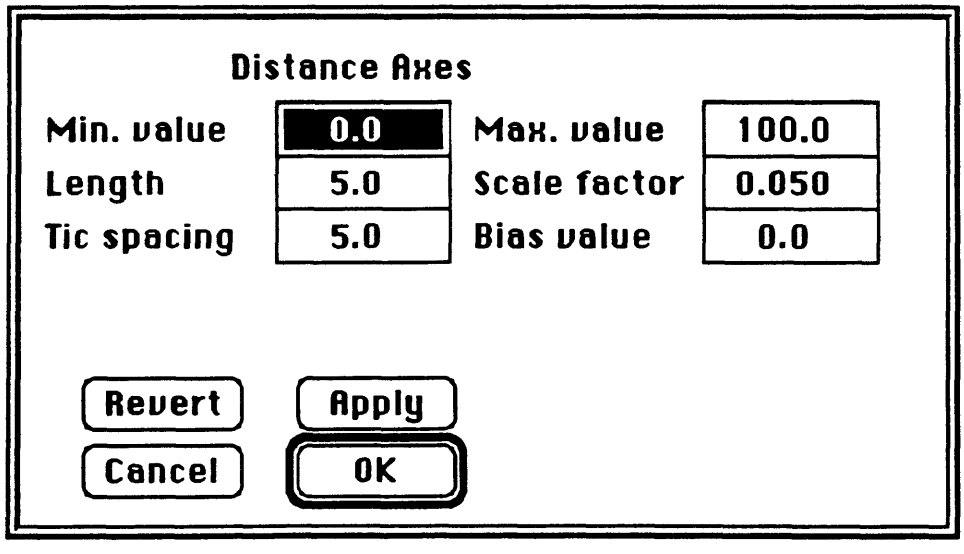
Changing the axes

The overall size of the axes may be easily changed by dragging the small box at the lower right corner of the axes.



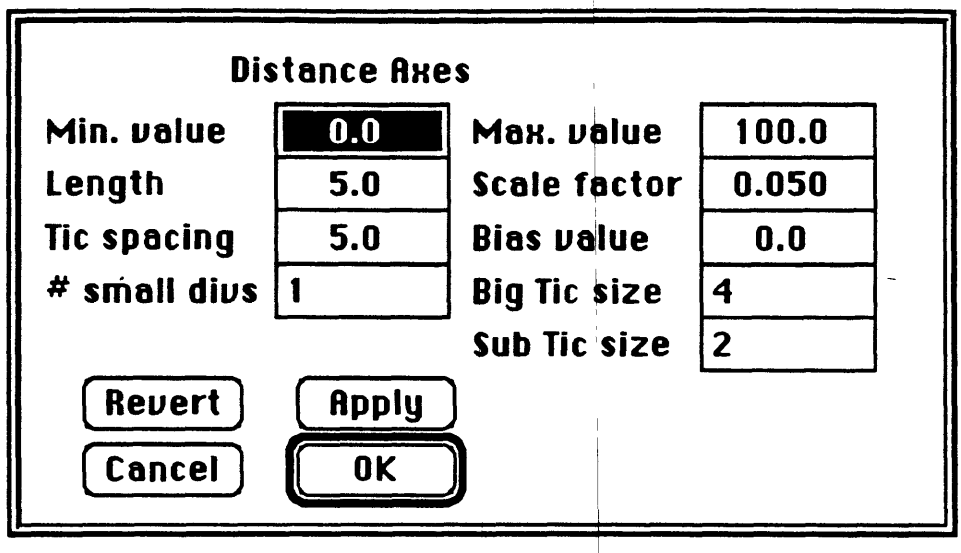
The axis bounds, length, etc. may be changed via a dialog activated by double-clicking on axis numbers.

You will be presented with a dialog identifying the axis and allowing you to change values using normal editing procedures. Double-click on a number to select it, tab to advance to the next value. The **Apply** button causes the appropriate axis to be re-drawn with the currently displayed values. The **Revert** button returns the values and the graph to their original values. The **Cancel** button does a **Revert** and exits the dialog. The **OK** button does an **Apply** and exits the dialog.



When setting the distance axes for either the Model or Travel Time window, holding down the Option key while clicking OK will set the same values for both windows.

If you hold the shift key while double-clicking on an axis, you will get the expanded dialog.

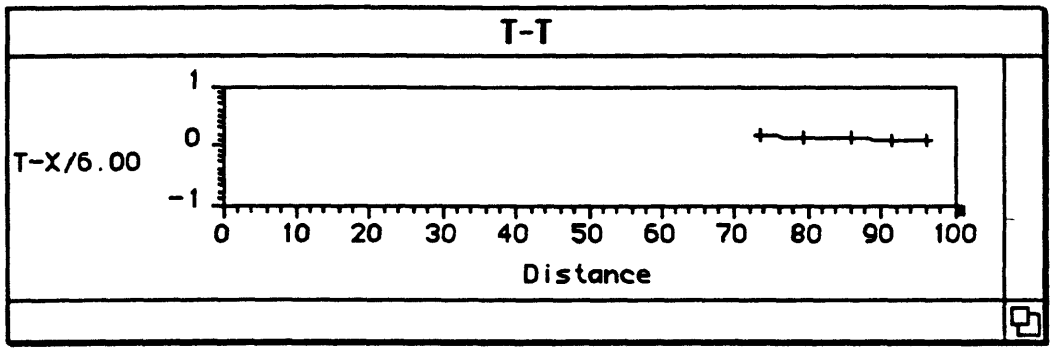


This lets you alter the sizes of the tic marks on the axis and change the number of small divisions between labeled tics. Sizes are given in pixels.

The entry for Tic spacing is also used as the spacing for grid lines if they are being plotted (see **Show Grid** in the Display menu). If the Tic spacing requested forces the tic labels to overlap, a larger spacing will be used. The grid will still be plotted at the requested spacing, however.

The Travel Time Window:

The Travel Time Window displays travel time picks and calculated travel times in a time vs. distance format.



The axes parameters may be changed by double-clicking on the axis labels. To change the time transformation, see **Time Transform...** in the Display menu.

The Result Window:

The Result Window displays information about the rays which have been traced.

MacRay Test

Angle	Rel. Dist	Abs. Dist	Time	Red. Time	Code	Npnt	Maxbnd
56.5274100	53.52	73.52	9.11	0.19	230	34	5
56.4433463	59.43	79.43	10.06	0.15	234	38	5
56.3592825	65.97	85.97	11.11	0.11	234	36	5
56.2752187	71.34	91.34	11.98	0.09	230	36	5
56.1911550	76.21	96.21	12.78	0.08	230	34	5

For each ray, the following information is given:

1) The starting angle in degrees from vertical.

2) The relative lateral distance of the endpoint from the source.

3) The absolute lateral distance of the endpoint in model coordinates.

4) The absolute travel time.

5) The reduced travel time.

6) The result code. This number tells how the ray terminated.

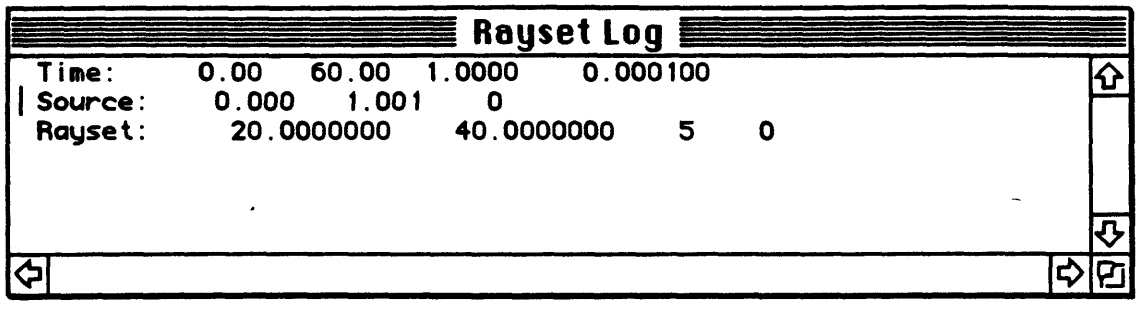
Code	Meaning	Notes
0	The time limit has been exceeded.	Increase the Time Limit in the Rayset dialog.
125	The raycode has been violated.	This ray is unable to follow the layer sequence specified by the raycode.
126->131	Failure to correctly calculate the intersection of a ray with an interface within the model.	This rarely occurs as the result of round-off errors. Try changing the Time Step in the Rayset dialog.
150	Critical angle failure.	The raycode is attempting to calculate a transmitted ray at an angle beyond critical. Change your starting angles.
175	Ray requires more than 400 points.	Increase the Time Step in the Rayset dialog.
180	Ray oscillates about an interface.	Check for peculiarities, e.g. waveguides in the velocity model. Try changing the Time Step in the Rayset dialog.
201	Ray left model at left edge.	
202	Ray left model at right edge.	
204	Ray left model at top.	
208	Ray left model at bottom.	
230->234	Ray ends at a requested interface.	
300	Successful ray guided by Raycode.	

7) The number of points in the ray.

8) The maximum interface or layer encountered. If this is a positive number, it is the number of the deepest layer encountered as a turning ray. If this is a negative number, it is the number of the deepest interface for a reflected ray.

The Rayset Log Window:

The Rayset Log Window is used to store rayset parameters. It is essentially a scratchpad that can be used to keep track of rayset parameters which work.

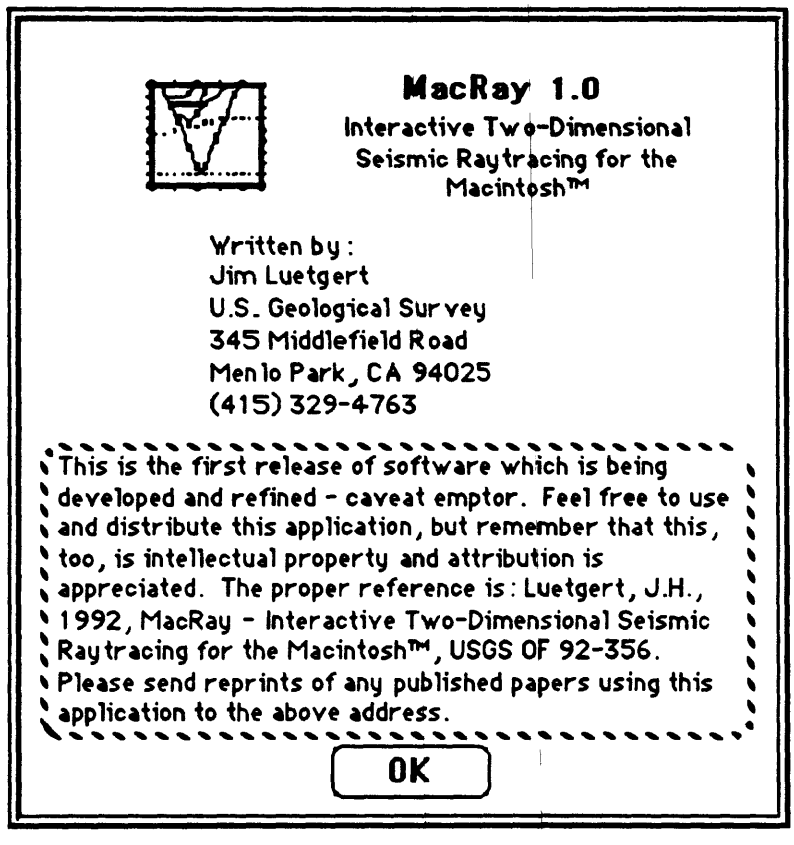


Using the menu commands in the File menu, you can save the parameters for the most recently run rayset. The contents of the window may be edited using standard editing techniques. The contents of the window may be saved to a file or loaded from a file. You may run the entire contents of the window or, by selecting them, only a few lines. A quick way to fine-tune a rayset is to save it in the log window, edit the line using copy-and-paste from the result window, select the line and run.

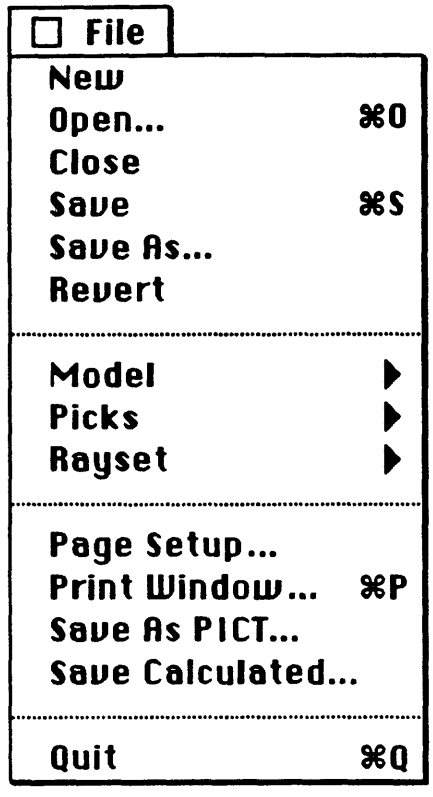
Menus:

The Apple Menu

The first entry in the Apple Menu is **About MacRay...** . Selecting this will display the following message.



The File Menu



The first group of menu commands pertain to MacRay Project files. MacRay project files contain information about the velocity model, source locations, and picks. In addition, MacRay project files contain information about the placement and size of the graphics windows. They appear on the desktop like this,

SRP1

New

Open a new untitled model.

Open... ⌘O

Open a MacRay project file. Standard file dialogs are used. The MacRay project file contains information about the velocity model, source locations, and picks. In addition, the MacRay project file contains information about the placement and size of the graphics windows. Hold the option key down while opening the file to ignore this information and use the current windows.

Close

Close the current MacRay project file. If changes have been made to the current file, appropriate dialogs are presented.

Save ⌘S

Save the current MacRay project file.

Save As...

Save the current MacRay project file under a new name.

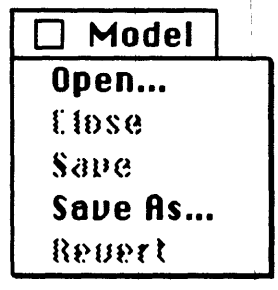
Revert

Revert to the last saved version of the current MacRay project file.

The next menu command pertains to MacRay Model files. A MacRay Model file is a TEXT file describing the interfaces and velocities in the model. It may be edited by any standard word processor. A description of the format is at the end of this document.

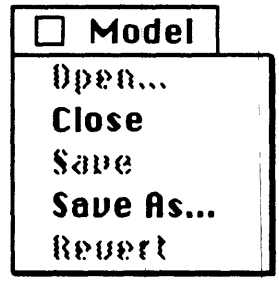
Model ▶

Hierarchical menu for opening the velocity model.

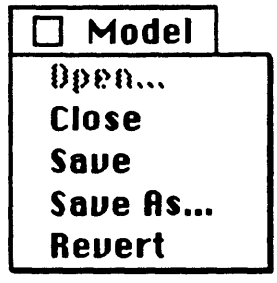


Open...

Open a MacRay model file. Standard file dialogs are used. After a model file is opened, the menu will look like this:



Once the model has been modified, the menu will look like this:



Close

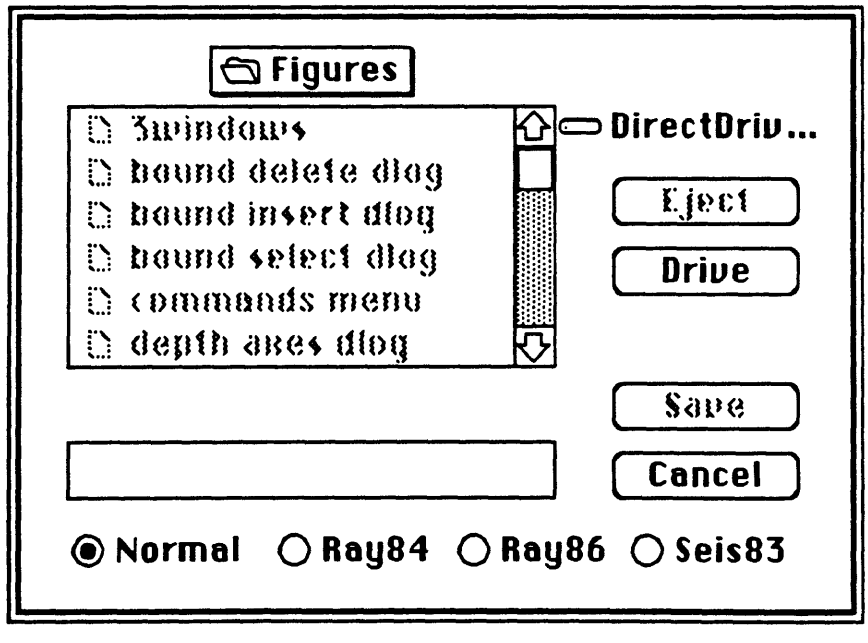
Close the current MacRay model file. Standard file dialogs are used.

Save

Save the current MacRay model in a TEXT model file.

Save As...

Save the current MacRay model file under a different name or in a different format. The following file dialog is used. **Normal** saves the file in MacRay TEXT format. These files may be opened and edited from within any word processing application. **Ray84** will save the file in Ray84 TEXT format suitable for export to Ray84 on any other machine. **Ray86** saves the file in Ray86 TEXT format suitable for export to Ray86 on any other machine. **Seis83**, when implemented, will save the file in Seis83 TEXT format suitable for export to Seis83 on any other machine.



Revert

Revert to the last saved version of the current MacRay model file.

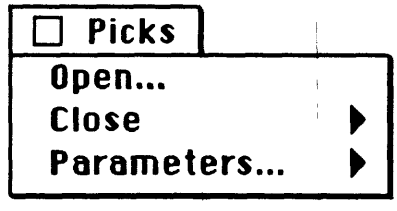
The next menu command pertains to MacRay Pick files. Pick files, containing picked arrival times, are assumed to be in TEXT format and are read in free-format. The first line must contain a SHOT_RANGE and a REDUCING_VELOCITY. Additional first line variables are TIME_OFFSET to be applied to all times and DISTANCE_MULTIPLIER to be applied to all distances. Following the first line are data lines containing a TRACE_ID (usually an integer location number or ASCII location name), DISTANCE, TIME, [AZIMUTH], and PICK_CODE. DISTANCE is the offset distance, usually km. TIME is the picked arrival time. This may be a reduced time, in which case it is changed to unreduced time using REDUCING_VELOCITY from the first line. A REDUCING_VELOCITY of 0.0 implies that the times are not reduced. AZIMUTH is optional and is not used by this application. PICK_CODE is a character code usually used for pick-confidence weighting or branch identification. It is not presently used by this application. Any line beginning with * is taken as a comment line.

This is an example of a pick file:

```
   121.73        8.0         0.0         1.0
214   100.0000    4.1750   126.8000   1
215   110.0000    4.5500   126.8000   1
216   120.0000    4.9250   126.8000   1
217   130.0000    5.3000   126.8000   1
218   140.0000    5.7500   126.8000   1
219   150.0000    6.1250   126.8000   1
220   120.0000    7.2500   126.8000   1
221   130.0000    7.2500   126.8000   1
222   143.0000    7.1000   126.8000   1
223   167.0000    7.5500   126.8000   1
224   180.0000    7.7000   126.8000   1
```

Picks ▶

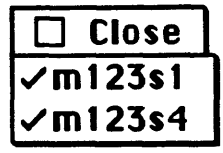
Hierarchical menu for opening and manipulating files containing travel time picks.



Open...

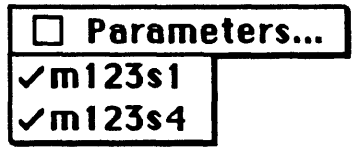
Open a TEXT pick file. Standard file dialogs are used. When a pick file has been opened, its name will appear in the sub-menus for **Close** ▶ and **Parameters...** ▶. Up to 10 pick files may be open at once.

Close ▶

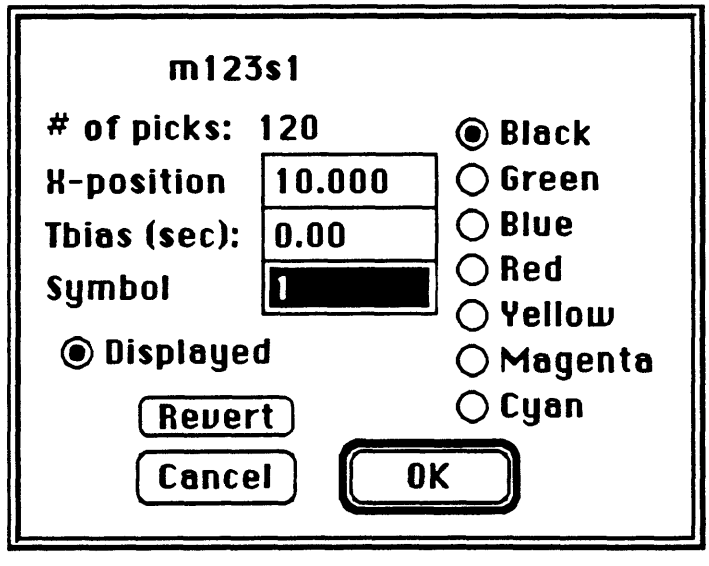


Close the selected pick file.

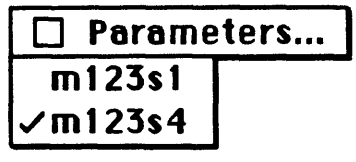
Parameters... ▶



Change the display parameters of the selected pick file. The following dialog allows you to change the X-position of the picks, bias all the times by a constant, change the symbol used for the picks, and change the color used for the picks (on color machines). You may also turn the display of this pick file on and off.



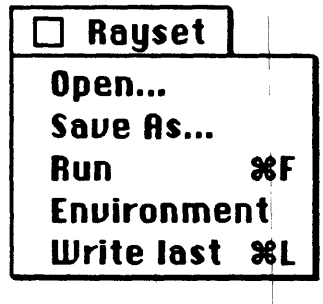
Displayed pick files show a check mark in the **Close** ▶ and **Parameters...** ▶ sub-menus.



The next menu command pertains to MacRay Rayset files. The Rayset Log can be used as a scratch pad to create and save scripts of raysets.

Rayset ▶

This sub-menu provides a means of maintaining, editing and running a script of raysets.



Open...

Load a previously saved script of raysets into the Rayset Log.

Save As...

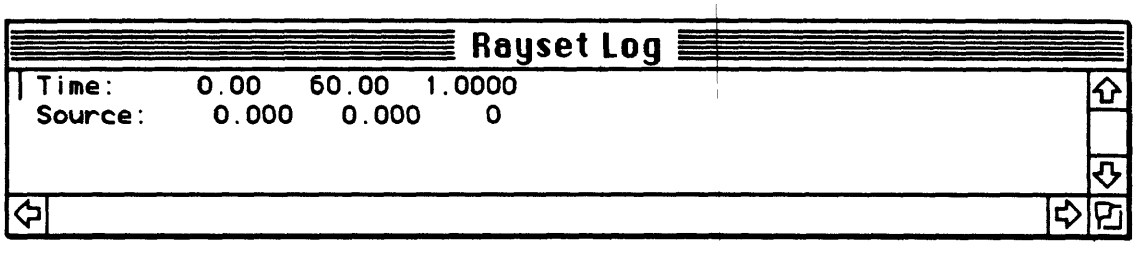
Save the current contents of the Rayset Log to a script file.

Run ⌘F

Play back the contents of the Rayset Log. You may either play the entire log or, by using the cursor to select a subset of lines, play back a subset of raysets.

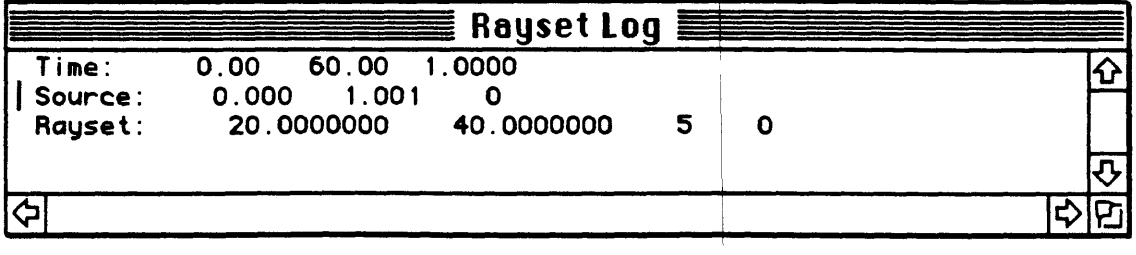
Environment

Clicking on this item writes the current raytrace environment to the end of the Rayset Log.



Write last ⌘L

The specifications for the last set of rays to be traced are written into the Rayset Log.



The Rayset Log window contains text which may be edited using standard Macintosh techniques. In particular, you may want to insert comment lines to help remember the sequence of operations. Any line beginning with * is considered a comment and ignored. This also provides a means for temporarily removing raysets from a script driven run.

Valid scripting lines contain a keyword and a sequence of variables separated by spaces, commas, or tabs (free format). All information must be on a single line. There are presently five recognized keywords.

Scripting line	Notes
Time: T0 TLimit TStep	
Source: Xposition Zposition Color	Color is an integer between 0 & 7
Rayset: Angle1 Angle2 NRays Ray_direction	
Raycode: entry1 entry2 entry3 ... entryN	The raycode may be entered in compressed form. To turn off the raycode, give no entries.
Clear:	Erases rays.

Page Setup...

Standard Page setup dialog.

Print Window... ⌘P

If the model or travel time window is currently active, it will be plotted. If the result window or Rayset Log window is currently active, it will be printed.

Save As PICT... or Save As TEXT...

If the model or travel time window is currently active, it will be saved in PICT format to a file.

If the result or Rayset Log window is currently active, it will be saved in TEXT format to a file.

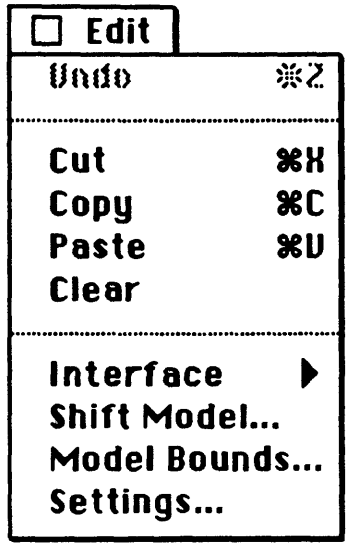
Save Calculated...

If rays have been calculated, their times and distances may be saved to a TEXT file in pick file format.

Quit ⌘Q

Application will quit after you are given the option of saving your model.

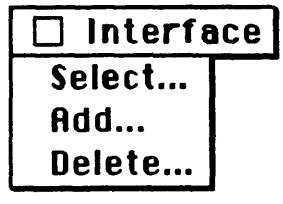
The Edit Menu



Standard Edit menu items are included for compatibility. These items work when editing the raysets in the Rayset Log window. Copy and Paste are also quite useful when you are refining the starting and ending angles for a rayset. Copy appropriate angles from the result window of your previous run and Paste them into the Rays... dialog.

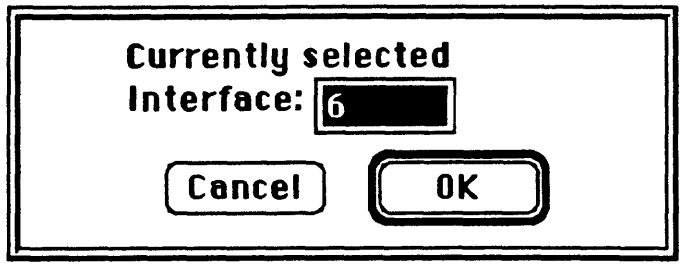
In addition, there are a series of commands which initiate dialog boxes for editing the model.

Interface ▸



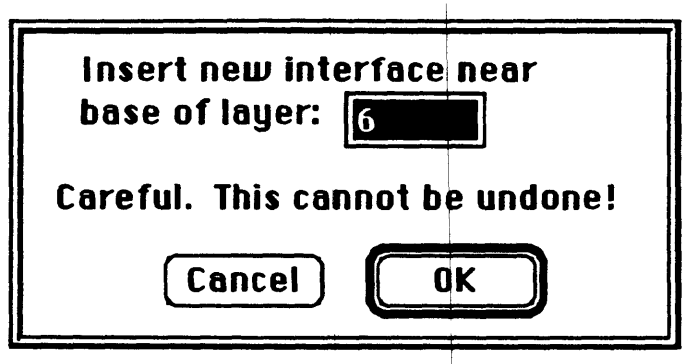
Select...

A dialog box is presented allowing you to select an interface.



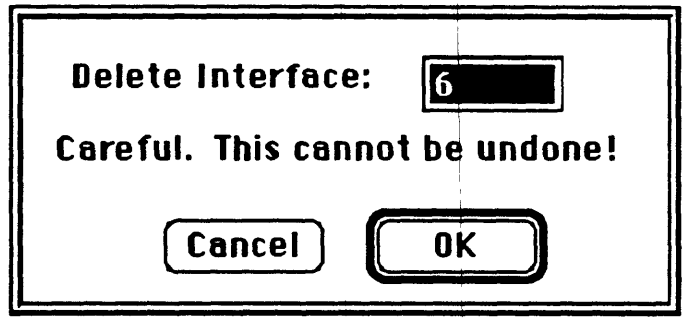
Add...

A dialog box is presented allowing you to add an interface to the model.



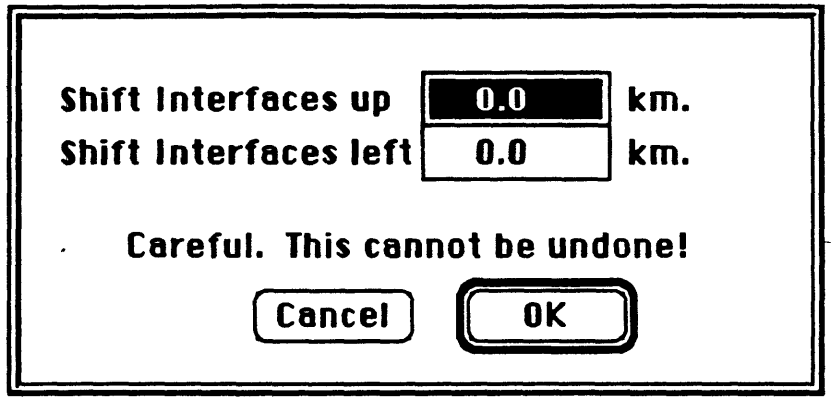
Delete...

A dialog box is presented allowing you to delete an interface from the model.



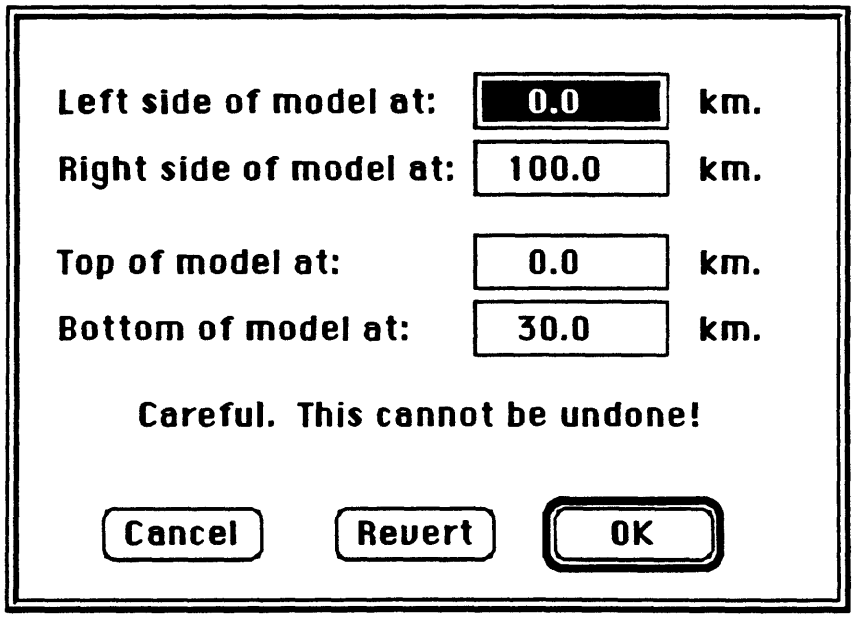
Shift Model...

A dialog box is presented allowing you to shift the whole model horizontally or vertically.



Model Bounds...

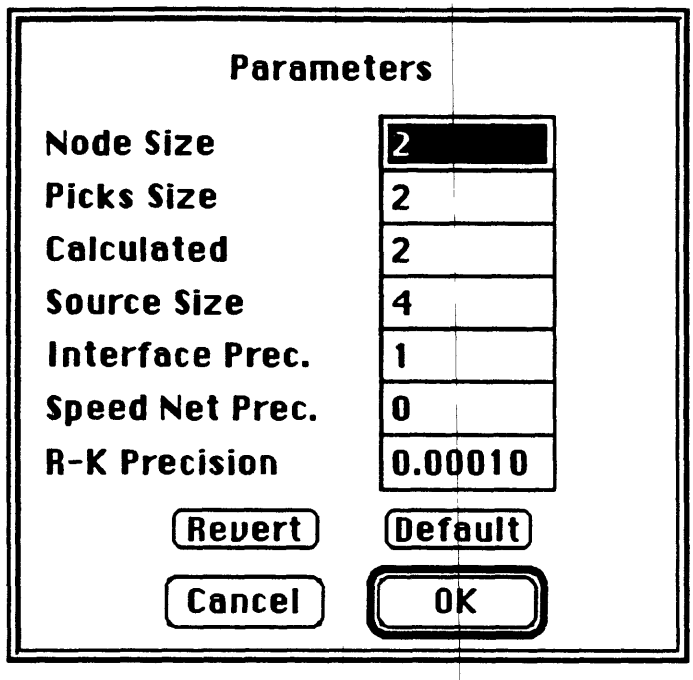
Dialog box is presented allowing you to redefine the limiting bounds of the model.



The limiting bounds for the left and right sides of the model must fall within the defined interfaces. Resetting these values to points beyond the lateral extent of the defined interfaces will cause the interfaces to be extended horizontally to the new model bounds.

Settings...

A dialog box is presented allowing you to redefine several miscellaneous variables.



Node Size is the size in pixels of the nodes used to manipulate the interfaces. It is sometimes easier to do these manipulations if the node size is modestly increased.

Picks Size is the size in pixels of the symbols used to represent picked arrival times.

Calculated is the size in pixels of the symbols used to represent calculated arrival times.

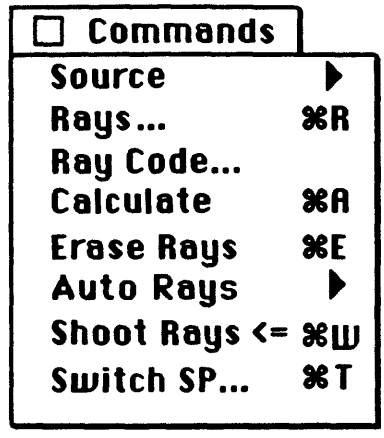
Source Size is the size in pixels of the symbol used to represent the source.

Interface Prec. is the precision in pixels used to determine whether you have touched an interface with the cursor.

Speed Net Prec. is the precision in pixels used to determine whether you have touched a speed net line with the cursor.

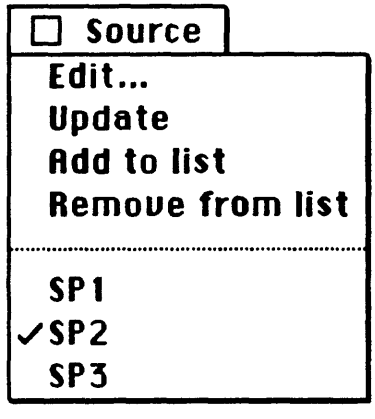
R-K Precision is the precision variable used by the Runge-Kutta integration routine. This is here principally for debugging and should not be changed.

The Commands Menu



Source ▶

This menu allows you to specify the source and produce a list of sources. The latter is particularly convenient when you are modeling multiple overlapping shot gathers. Once a source list is defined, it may be saved in the MacRay project file document along with the model, axis parameters and observed data picks.

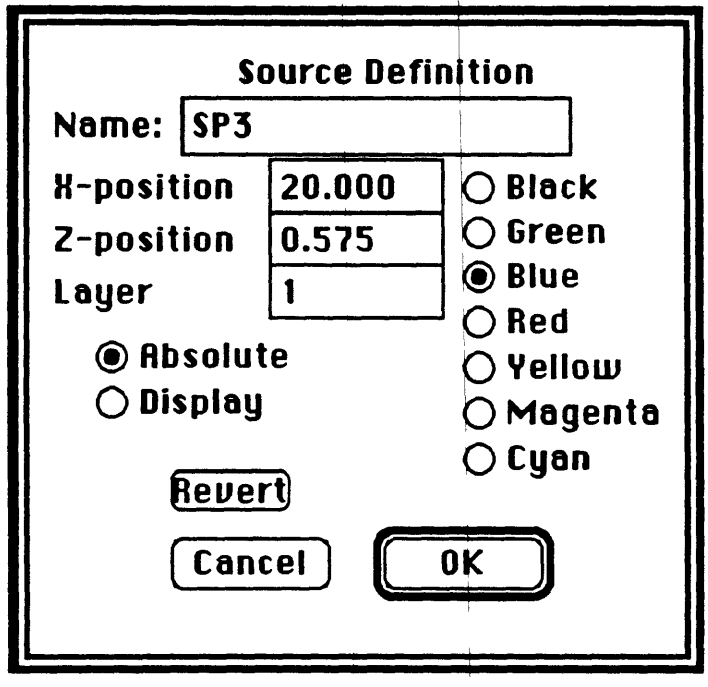


After a source list has been defined, you may change sources by selecting the appropriate source from the menu. Think of this list as a scratchpad. If you select a listed source and proceed to **Edit...** the source definition, you must **Update** to save the new information in the scratchpad.

Edit...

A dialog box is presented allowing you to redefine the source position and name. If you enter a Z-position which is above the model, the source will be placed 1 meter within the model when you tab to the following field. Note that you have the option of specifying the source position in Absolute or Display coordinates. Display coordinates are only different from Absolute coordinates if you have assigned a Bias value in the Depth or Distance Axis dialogs.

If you are going to save the source in the source list, give it a unique name. On machines with color monitors, you may specify different colors for each source. The source, rays and calculated times will be plotted in this color.



Update

If a listed source is selected, you may update it to the current source specifications using this command.

Add to list

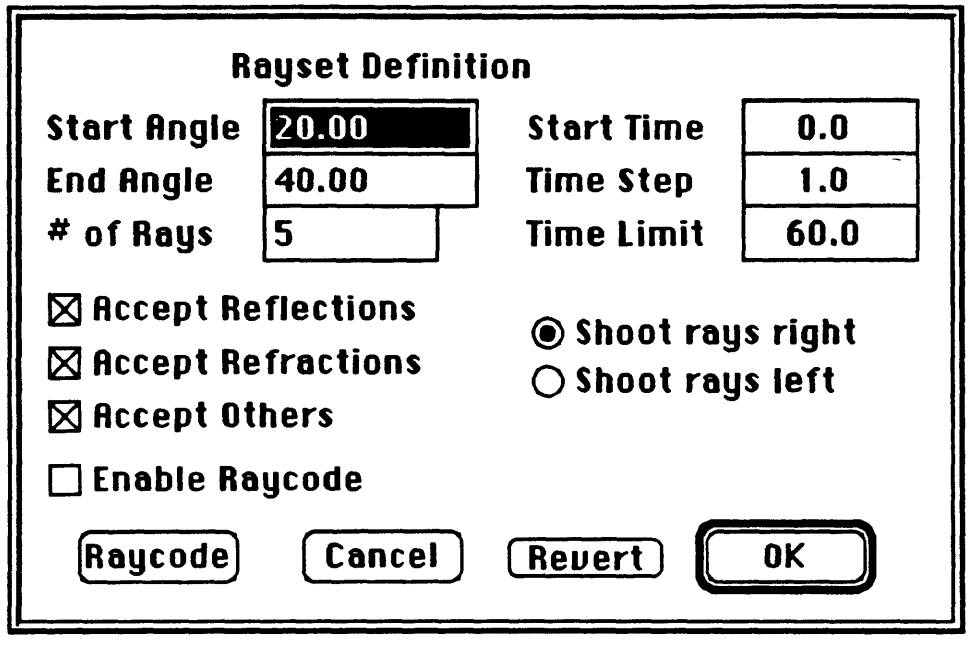
The current source specifications are added to the source list. The source list may contain up to 10 entries.

Remove from list

If a listed source is selected, you may delete it from the list.

Rays... ⌘R

A dialog box is presented allowing you to define the current rayset. Angles are defined in degrees from the vertical. The number of rays defined here is also used by all of the automatic ray-shooting routines defined below.



Start Time is almost always set to 0.0 seconds. The Time Step is initially set to 1.0 second. This provides a reasonably speedy calculation which is also fairly accurate in the absence of tricky velocity gradients. For increased accuracy (at the expense of compute time), reduce this value. Making it less than 0.01 is probably meaningless for crustal refraction. The Time Limit allows you to place an upper bound in seconds on how long the calculation will continue. Rays which terminate within the model are usually running up against this limit or the model bounds may be set to lie within the defined model.

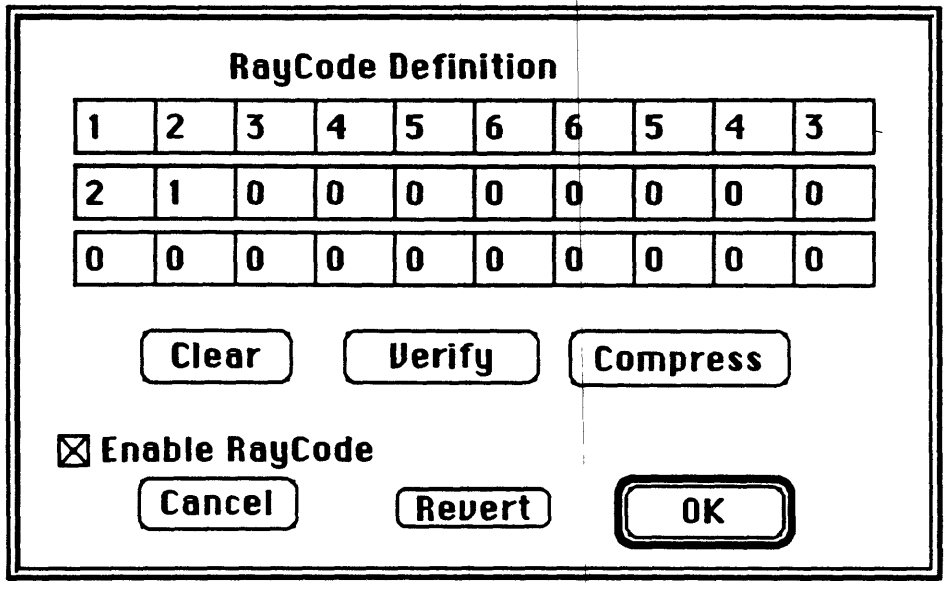
Radio buttons allow you to specify if the rays are to be shot to the right or the left. The direction of rays is displayed in the lower left corner of the Model window. The ray direction may also be toggled using the **Shoot Rays** <= command in the Command menu.

Check boxes specify which of the calculated rays will be plotted.

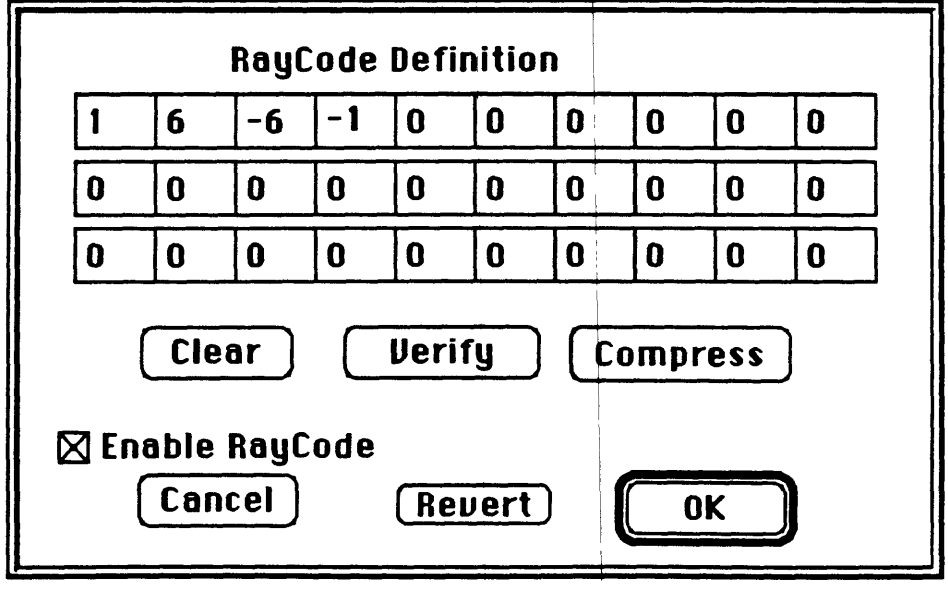
A button allows you to go directly to the Raycode dialog and a check box allows you to enable or disable the Raycode.

Ray Code...

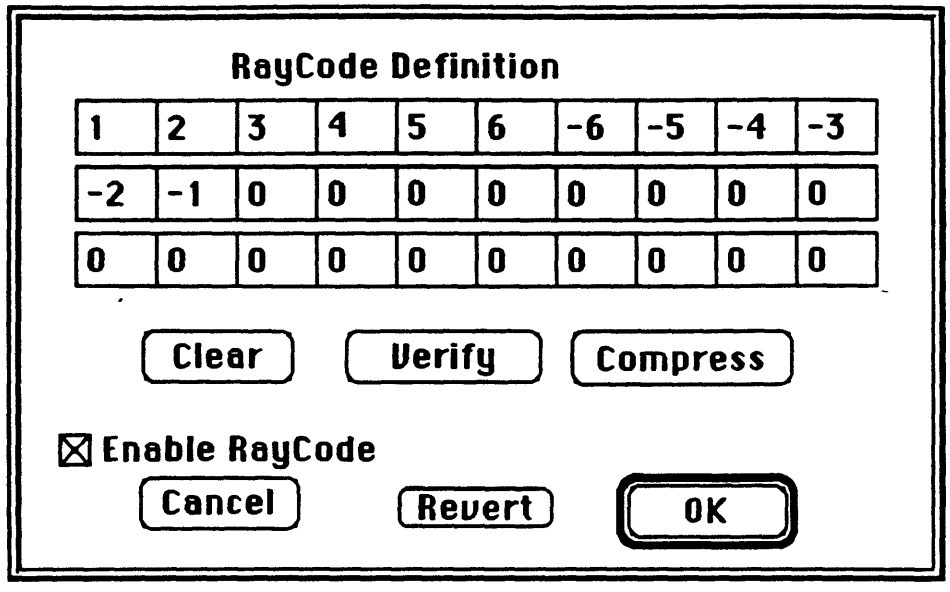
If a ray code is defined and enabled, rays will follow the defined sequence of layers. In this case, the source is in layer 1. Rays traverse layers 1 through 6; are reflected at the base of layer 6 and return to the surface. It is a good idea, after entering a ray code, to hit the "Verify RayCode" button to assure that you have a valid RayCode.



Verifying the RayCode checks that the ray starts in the same layer as the source and makes sure that the layers are all in sequential order. The latter provides a useful shortcut for entering RayCodes. In the following example, we want to again reflect rays from the bottom of layer 6 (this time with a P-S conversion upon reflection). We can skip the tedium of entering all the intervening layers and let the verifier fill them in.



This is the RayCode after verification.



Calculate ⌘A

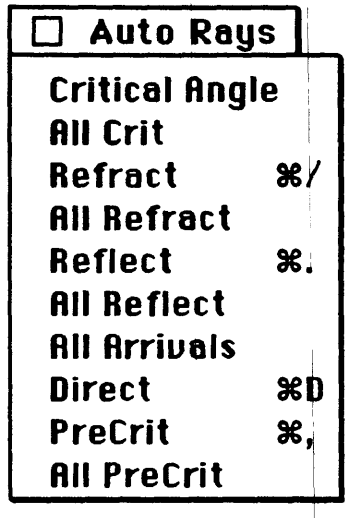
Rays are calculated and plotted using the current rayset settings. Starting and ending angles and number of rays are those set in the **Rays...** dialog. If the RayCode is enabled, the RayCode is used. If you need to terminate calculation of a rayset, hold the mouse button down.

Erase Rays ⌘E

All the currently plotted rays and travel-times are erased.

Auto Rays ▸

This menu allows you to specify the automatic ray functions. Note that some of these require that an interface in the model be selected. The number of rays shot and the direction from the source are defined in the **Rays...** dialog above. Each of these functions requires that the application find the critical angle for the interface of interest. This is accomplished by an iterative search using the starting and ending angles from the **Rays...** dialog as initial values. Sometimes when this search fails, changing the starting and ending values to closely bracket the expected critical angle will help. There are, of course, some cases where a critical angle cannot be found, e.g. low velocity zones, pathologic structures.



Critical Angle

The critical angle for the selected interface is found via an iterative search using the starting and ending angles from the **Rays...** dialog as initial values.

All Crit

The critical angles for all interfaces are found.

Refract ⌘/

Rays are calculated and plotted which refract through the layer beneath the selected interface.

All Refract

All refracted rays are calculated and plotted.

Reflect ⌘.

Rays are calculated and plotted which reflect post-critically from the selected interface.

All Reflect

Rays are calculated and plotted which reflect post-critically from all interfaces.

All Arrivals

A combination of **All Refract** and **All Reflect** .

Direct ⌘D

Rays are calculated and plotted for direct arrivals.

PreCrit ⌘,

Rays are calculated and plotted which reflect pre-critically from the **selected interface**.

All PreCrit

Rays are calculated and plotted which reflect pre-critically from all interfaces.

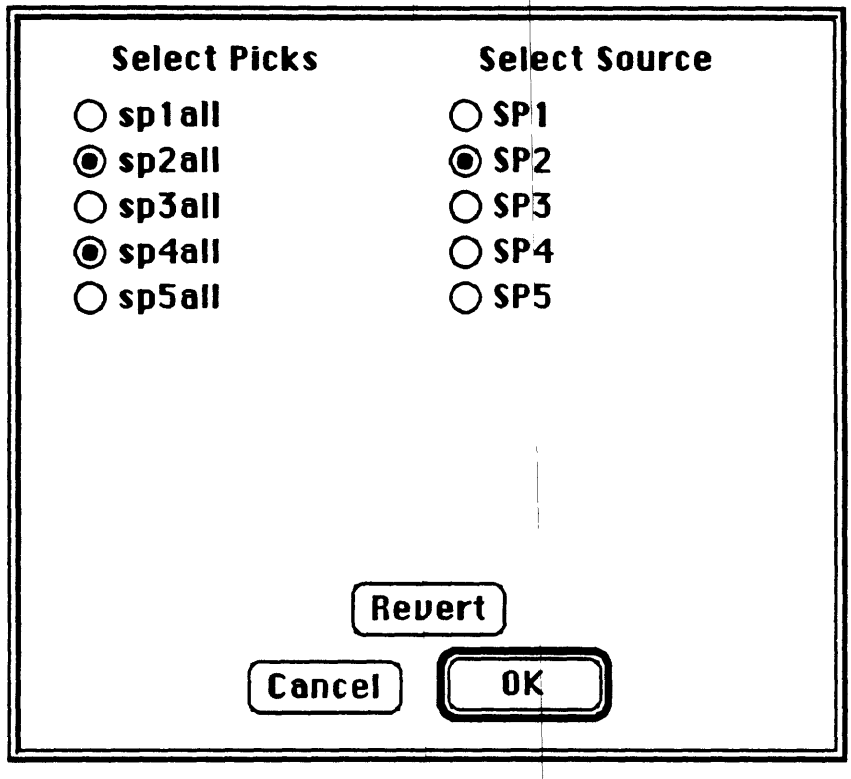
If you need to terminate an automatic ray calculation before it is completed, hold the mouse button down.

Shoot Rays <= ⌘W

This menu item allows you to switch the direction in which rays are being shot without having to go to the **Rays...** dialog. The current ray direction is displayed in the lower left side of the Model window.

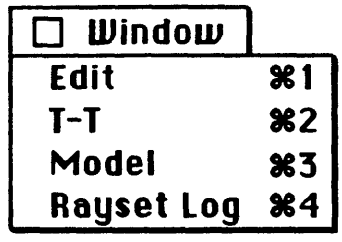
Switch SP... ⌘T

This menu item allows you to specify the source and observed data picks to be displayed via a single dialog. This is redundant to other menu controls, but should save motions when switching back and forth between sources.

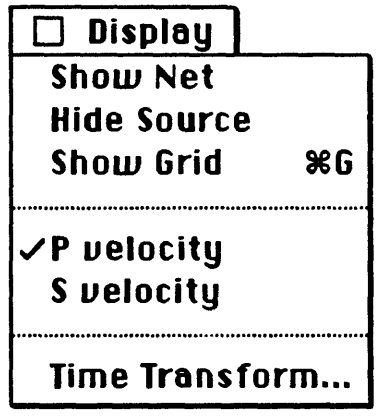


The Window Menu

The Window Menu allows you to quickly switch between windows. This is particularly useful when the window you want is totally obscured.



The Display Menu



Show Net

Click here if you wish to display the velocity net lines on the model. This menu item will be replaced by **Hide Net** when in effect.

Hide Source

Click here to remove the source from the model plot. This menu item will toggle with **Show Source**.

Show Grid ⌘G

Click here if you wish to plot a grid overlaid on the plots. Grid lines are plotted at the Tic Spacing interval specified in the axes dialogs. This menu item will toggle with **Hide Grid**.

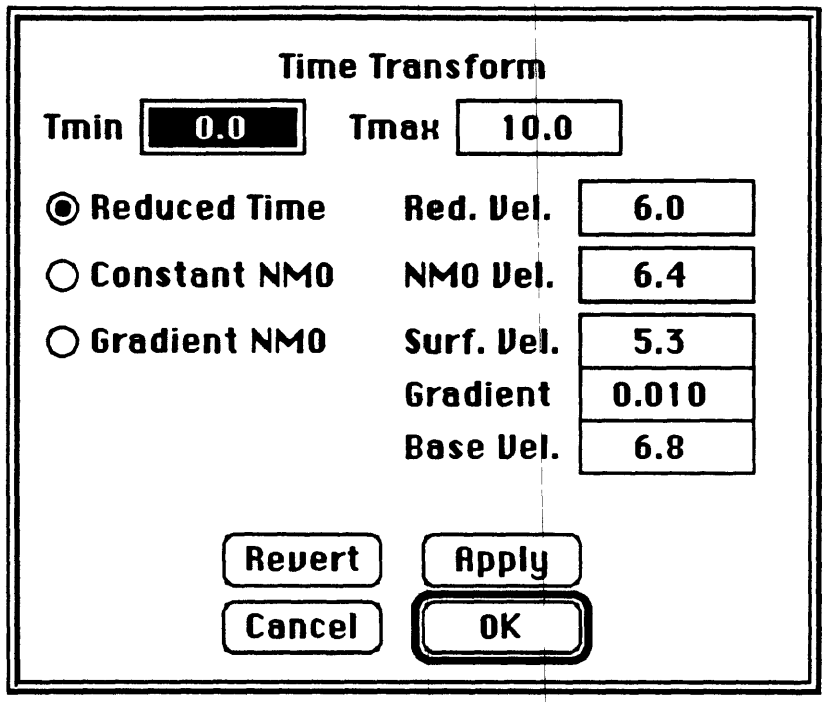
4P velocity

S velocity

Click on the velocity function to be used to calculate the travel time plot. The appropriate menu item will be checked when in effect.

Time Transform...

Click here to open the Time Transform dialog.



You may plot absolute time by specifying **Reduced Time** with a Reducing Velocity of 0.0. If **Red. Vel.** is greater than 0.0, T_{red} = TIME-OFFSET/**Red.Vel.**

Files and Icons:

This is the application Icon. Click it to run MacRay.

This is a saved MacRay project document. It contains all the model data, picks, sources and window sizing and placement information. Click it to run MacRay.

This is a saved model file. It contains all the model data in TEXT format and may be edited using any standard word processor. The data in this file is read unformatted, so the placement of fields is unimportant. The program recognizes spaces, commas or tabs as field delimiters. Click it to run MacRay.

This is a saved model file. It contains all the model data in TEXT format and may be edited using any standard word processor. The data in this file is read unformatted, so the placement of fields is unimportant. The program recognizes spaces, commas or tabs as field delimiters.

This is a saved rayset script. It contains all the rayset data in TEXT format and may be edited using any standard word processor. The data in this file is read unformatted, so the placement of fields is unimportant. The program recognizes spaces, commas or tabs as field delimiters.

This is a saved graphics file. It contains an image of one of the display windows in PICT format and may be edited using any standard draw program.

This is a temporary file used to hold ray graphics information. You may find it in your folder if MacRay quits in a non-normal fashion.

Model File format:

MacRay will read TEXT model files in either RAY84 (Luetgert, 1988) or RAY86 formats. RAY86 format is preferred and the native output format for MacRay is a superset of the RAY86 format. (Velocities are formated 10f8.3 rather than 10f7.2) For reference, the following is a specification of the RAY86 format:

The model is specified in two steps. First, interfaces are defined. Then velocities at the interfaces are defined.

Interfaces

The model is defined in terms of NBND interfaces each of which must extend from the left edge of the model to the right edge. The interfaces define NLAY = NBND-1 layers whose velocities are defined in the second part of the model section. The first interface is commonly used to represent surface topography. Interfaces may merge but not cross. That is, a layer, defined by two adjacent interfaces, may be made to "pinch out". Care must be used in the choice of velocities, however, when pinching out layers. It is best to only pinch out layers in regions of constant velocity.

Line 1 - NBND, (NPNT(I), I=1,NBND) (14I5)

NBND = Number of interfaces (50 or fewer).

NPNT(I) = Number of (X,Z) points used to define the I^{th} interface (200 or fewer).

Line 2-N - Interface lines; each interface reads as an ascending sequence of X values, possibly requiring multiple lines, followed on a new line by a sequence of corresponding Z values under format (10F7.0). Z is defined as positive downward. Although the program will work with sea level defined as Z=0 and elevations above sea level defined as negative numbers, it is ultimately less confusing to define an artificially elevated datum such that all interfaces are defined with positive values of Z. For final plots of the model, the Z-axis may be properly labeled with respect to sea level by using the variable ZBIAS. Interfaces must extend across the entire model. All interfaces should have the same X values at the beginning and end of the model.

Groups of interface lines may be separated by comment lines containing an asterisk (*) in the first column to make the input file easier to read.

Note: Concerning the interface lines, if Z_i is entered as 999.0, Z_i will be linearly interpolated between the nearest defined points.

Specification of the Velocities

The velocities are specified along vertical grid lines in the model. Where these lines intersect the layers, the velocity is specified at the top and bottom interfaces.

This subdivides the model space into a number of polygonal areas each of which has a velocity defined at four points. For each of these areas a polynomial "velocity surface" is calculated which passes through the defined points. This is a numerically neat way of dealing with specifying velocities at any point in the model, but it is the source of many problems and frustrations for the user if not properly used.

Remember that the velocity at an interface is explicitly defined only at the intersection point with a velocity net line. At all other points along the interface the velocity is the intersection of the interface with the velocity surface. In regions of the model in which there are large structural or velocity variations, the resultant surface may have substantial curvature which leads to unexpected velocities.

The solution to the large curvature problem is to break up the surface into smaller surfaces each having smaller curvature through the use of more velocity net lines. There is, however, a trade-off here in that the model becomes cumbersome to edit if you use more grid lines than you need.

Start off with grid lines at the left and right sides of the model and at those ranges where they are needed to define lateral velocity changes. Put additional grid lines in any large gaps. If you see rays which do not behave as expected, consider inserting additional grid lines.

There are two formats available for specifying velocities. In RAY84 format, the vertical grid lines are at the same horizontal distances for each layer of the model. This is adequate for simple models. As models become more complex, however, it is frequently the case that some layers require many more velocity definition points than others. At this point it is useful to use RAY86 format, in which each layer has its own vertical grid lines. Format selection is based on the sign of the first variable, NXSPD, in line 1.

Line 1 - NXSPD, NZSPD, VFACTR, GMAX (2I5, 2F10.0)

NXSPD = Number of vertical grid lines (85 or fewer). If this number is positive, RAY84 format is used. If this number is negative, RAY86 format is used.

NZSPD = Number of horizontal grid lines (Always use NZSPD=2). This variable is ignored by the program.

VFACTR = A multiplicative factor used for determining S-velocities in the model. This is used internally to calculate S-velocities from the P-velocity model. If VFACTR = 0.0, it is set to 1.732 . Ray paths with mixed S and P paths must be generated with the ray code.

GMAX = Maximum vertical velocity gradient in km/sec/km. If your model specifies velocities having gradients greater than GMAX, the velocity gradient is set to GMAX. If GMAX = 0.0, it is set to 2.0 by the program.

Line 2 - Model Bounds - DMIN, DMAX, ZMIN, ZMAX (4F7.2)

The Model Bounds specify the region in which the model is defined. Normally, DMIN and DMAX are equal to the minimum and maximum distances at which interfaces are specified. ZMIN should be less than any value of the first interface and ZMAX should be greater than or equal to the deepest point of the last interface.

Line 3-N - Velocities

A block of lines for each layer containing velocity data for intersections of the vertical grid lines with the interfaces.
The first line (I5) specifies the number of velocity net lines for the next layer, NXSPD .
The next line(s) specify the X-coordinates of the velocity net lines.
Velocities at the top and bottom of each layer are read in along interfaces from left to right (or in the order specified in the previous set of X-coordinates). First, NXSPD velocities at the top of the layer are read. Then, starting on a new line, NXSPD velocities at the bottom of the layer are read. For any layer there are 2*NXSPD values. Layers are taken from top to bottom. All X-coordinates and velocities are read under format (10F7.2).

Note: If a 0.0 is entered for VEL(I), VEL(I) will be set to VEL(I-1), the previous velocity. If a negative number is entered, VEL(I) will be linearly interpolated between the nearest defined velocities.

Example Model file:

The following is an example model file using the native MacRay format.

```
    9   14   12   11    8    9    4    5    5    2
*   Interface     1
   0.000  20.000  30.000  36.810  47.100  64.500  70.000  76.750  88.960  90.002
 101.670 120.000 121.730 140.000
   0.574   0.574   0.566   0.491   0.635   0.667   0.704   0.751   0.750   0.750
   0.750   0.864   0.875   0.875
*   Interface     2
   0.000  20.000  47.000  47.500  53.500  54.000  65.000  68.000  76.500 101.672
 121.730 140.000
   0.725   0.725   0.850   1.000   1.000   0.900   0.800   0.900   0.850   0.850
   1.070   1.100
*   Interface     3
   0.000  20.000  47.000  47.500  64.750  65.000  76.500  76.932 101.449 121.730
 140.000
   1.400   1.400   1.400   1.500   1.500   1.890   1.890   1.279   1.279   1.600
   1.600
*   Interface     4
   0.000  55.500  76.500  99.195 107.000 116.667 122.866 139.775
   3.000   3.000   3.000   4.020   4.000   4.386   5.154   5.848
*   Interface     5
   0.000  40.500  54.500  64.750  74.000 101.670 106.000 118.700 140.000
   7.000   6.500   3.800   3.600   3.600   5.000   5.300   6.610   8.502
*   Interface     6
   0.000  77.000 120.000 140.000
  10.000  10.000  11.000  11.000
*   Interface     7
   0.000  20.556  88.889 120.000 140.000
  25.000  25.000  12.963  13.000  13.000
*   Interface     8
   0.000  50.000  95.000 120.000 140.000
  38.000  38.000  38.000  35.000  35.000
*   Interface     9
   0.000 140.000
  45.000  45.000
*
*  Speed Network
  -32    2     1.732     3.000
*  Model Bounds
     0.000   140.000     0.000    50.000
*
*   Layer     1
   32
   0.000  20.000  30.000  40.000  47.000  47.500  53.500  54.000  55.500  55.502
  64.750  65.000  76.000  76.500  77.000  77.700  82.000  82.500  91.200  91.702
  98.200  98.700 101.670 106.000 107.000 113.200 113.700 118.200 118.700 121.730
 122.200 140.000
*
   5.000   5.000   5.000   5.000   5.000   4.500   4.500   5.000   5.000   5.002
   5.000   5.800   5.800   4.500   4.500   4.500   4.500   5.000   5.000   4.502
   4.500   5.000   5.000   5.000   5.000   5.000   4.500   4.500   5.000   5.002
   5.000   5.000
   5.050   5.050   5.050   5.050   5.050   4.520   4.520   5.050   5.050   5.050
   5.050   5.850   5.850   4.550   4.550   4.550   4.550   5.050   5.050   4.510
   4.510   5.050   5.050   5.050   5.050   5.050   4.510   4.510   5.050   5.050
   5.050   5.050
*
```

```
*   Layer     2
   15
   0.000  30.000  47.000  47.500  54.000  64.750  65.000  76.000  77.700 101.670
 106.000 107.000 118.700 121.730 140.000
*
   5.700   5.700   5.700   5.700   5.700   5.400   5.400   5.700   5.700   5.701
   5.700   6.250   6.250   5.400   5.400
   5.710   5.710   5.710   5.710   5.710   5.410   5.410   5.710   5.710   5.710
   5.710   6.255   6.255   5.410   5.410
*
*   Layer     3
   14
   0.000  20.000  47.000  47.500  55.500  55.502  64.750  76.000  77.700  98.200
 107.000 113.200 122.200 140.000
*
   5.900   5.900   5.900   5.900   5.900   5.900   5.900   5.900   5.900   5.900
   5.900   6.255   6.255   6.000
   5.917   5.917   5.917   5.917   5.917   5.917   5.917   5.917   5.917   5.911
   5.910   6.255   6.255   6.000
*
*   Layer     4
    9
   0.000  30.000  40.000  54.000  76.500  98.200 106.000 118.200 140.000
*
   5.917   5.917   5.917   5.917   5.917   5.917   5.917   5.917   5.917
   5.960   5.957   5.955   5.954   5.940   5.925   5.925   5.920   5.920
*
*   Layer     5
    9
   0.000  20.000  40.000  54.000  76.000  91.702 106.000 121.730 140.000
*
   6.200   6.200   6.200   6.200   6.200   6.200   6.200   6.200   6.200
   6.250   6.250   6.250   6.250   6.250   6.250   6.250   6.250   6.250
*
*   Layer     6
    9
   0.000  20.000  54.000  76.000  91.702 101.670 107.000 121.730 140.000
*
   6.250   6.250   6.250   6.250   6.250   6.250   6.250   6.250   6.250
   6.360   6.360   6.360   6.360   6.300   6.300   6.300   6.300   6.300
*
*   Layer     7
    7
   0.000  20.000  47.000  65.000  90.000 118.700 140.000
*
   6.800   6.800   6.800   6.800   6.800   6.800   6.500
   7.000   7.000   7.000   7.000   7.000   7.000   6.600
*
*   Layer     8
    5
   0.000  50.000  90.000 120.000 140.000
*
   8.000   8.000   8.000   8.000   8.000
   8.100   8.100   8.100   8.100   8.100
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