UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
MENLO PARK, CALIFORNIA 94025

HYPOELLIPSE/VERSION 2.0*:
A COMPUTER PROGRAM FOR DETERMINING LOCAL EARTHQUAKE HYPOCENTRAL PARAMETERS, MAGNITUDE, AND FIRST MOTION PATTERN

By

John C. Lahr

Open-File Report
89-116

Most recent manual revisions made on January 9, 1989.

Table of Contents

Chapter 1 Introduction to HYPOELLIPSE

1.1 PROGRAM SUMMARY

HYPOELLIPSE is a computer program for determining the hypocenters of local or near regional earthquakes and for each event the ellipsoid that encloses the 68 percent confidence volume. The program was originally developed on the Lawrence Berkeley Laboratory CDC7600 computer and subsequently modified to run on the USGS Honeywell MULTICS, the Stanford Linear Accelerator Center IBM 168, the USGS DEC VAX11/785, and most recently on the PC. Traveltimes are determined from a horizontally layered velocity structure, from a linear increase of velocity with depth, from a linear increase of velocity over a half-space, or from a previously generated travel time table. With the travel-time-table option, gradients are allowed in all layers, but there can be no velocity discontinuities. Arrival times for the first arrival of P waves and S waves, and S minus P interval times can be used in the solutions. Arrival times for refractions such as Pn, even at distances where they do not arrive first, can also be used. Each arrival can be weighted according to the reading clarity, epicentral distance to the station, and the deviation of its residual from the mean. The hypocenter is found using Geiger's method to minimize the root mean square (RMS) of the traveltime residuals. The magnitude of each event is calculated from the maximum amplitude and/or the signal duration. The program includes a station history database, so that magnitudes will always be computed with the correct response function and gain. First motions can be plotted on the printer using an equal area lower focal hemisphere projection. The azimuth and apparent velocity of a plane wave crossing the array from a distant source can also be determined.

1.2 CHANGES FROM PREVIOUS VERSIONS

This report documents the current version of HYPOELLIPSE which is operating on the USGS DEC VAX 11/785 computer in Menlo Park and supersedes the MULTICS version (LAHR, 1980). Many changes have been made since the previous verion was published in 1984 (Lahr, 1984). These changes include the following:

1) The printed horizontal and vertical error limits (now called SEH and SEZ rather than ERH and ERZ) have been rescaled so that they correspond to single variable 68 percent confidence limits. Earlier versions of the program printed 94 percent confidence limits. The 68 percent error ellipsoid axes that are included on the summary record have not been modified from previous versions.

2) The auxiliary program SQUASH (Lahr, 1980) is no longer needed to generate an archive file that contains both the input phase data and information derived from the earthquake solution. Instead, PUNCH OPTION 2 will cause an archive file to be generated in one step.

3) The option of generating HYPO71 style summary records has been removed.

4) More than one summary record may precede the arrival time records for each event.

5) The distance to the closest station, D1, rather than the third closest station, D3, is entered on the summary record.

6) If the closest station has both P and S readings, then the S-P interval is entered on the summary record.

7) The Vp/Vs ratio may be computed for each event. A Wadati printer-plot can also be made. This option is controlled by Test(49).

8) Three velocity models may be specified by travel time tables. This option utilizes routines written by F. W. Klein (1985) for the HYPOINVERSE earthquake location program.

9) The archive phase file now includes the first motion in column 65. If the station has incorrect polarity (according to column 34 of the station parameter record) then the symbol in column 65 of the archive phase record is modified accordingly.

10) The relative weight assigned to readings with different weight codes can now be tailored to individual needs with the WEIGHT OPTION.

11) The first trial hypocenter is now computed from the P-arrival times (up to the first 10 are used) if no other first trial parameters are available (See 2.2.12 for details). A halfspace model with velocity = 6.5 km/s is assumed, and the new subroutines STRTEP and HALFSP are used.

12) The input to HYPOELLIPSE need not be contained in one input file. A JUMP FILENAME record will now cause input to be transferred to the file 'FILENAME'. When the end-of-file is encountered, input resumes from the original input file.

November 1986:
13) The code has been revised in order to be compatible with the standards Fortran 77, and has been compiled on the IBM PC using the IBM Professional Fortran Compiler.

February 1987:
14) The S-phase station delay is no longer computed from the equation
P-Delay*VpVs + S-Delay,
where P-Delay and S-Delay are the delays specified on the station record and VPVS is ;the ratio of P to S velocity. Instead the S-phase delay is simply set equal to the S-Delay specified on the station record.

15) Comment records are now defined as any record with C* in columns 1 and 2. Comments may be included anywhere in the input stream except within the station list.

16) It is often desired to improve the fit of the velocity model to the observed arrival time data by incorporating station delays that are optimum for a given set of data. The final tabulation now includes average station residuals computed in such a way that they will be a better estimate of the modifications that should be made to the station corrections. (See 2.3.10 for the details)

17) The option that plots an epicenter map on the printer has been removed due to the ease of making graphic plots from the summary records.

May 1987:
17) A more complex inversion algorithm may now be used to insure that if there are two or more local minima at different depths, that the global minimum is selected as the final hypocenter. This option has proved useful with Alaskan earthquakes, which can range from the surface to more than 150 km depth. (See 2.2.3.11 for details)

18) In order to check for multiple local minima at different depths, TEST(50) may be used to generate a series of fixed depth solutions. A plot of RMS versus DEPTH can then be made to investigate if there are potential problems with depth.

July 1987:
19) The station history file contains information on the telephone delay as a function of time for each station. This delay is due to satellite links which add a round trip delay of 0.27s. At times some stations may be delayed by more than one satellite hop. The number of satellite hops has been added to the archive phase records in column 110. This allows any program reading the arrival times on the archive phase file to unambiguously correct for satellite delays without having to refer to the station history file.

November 1987:
20) To improve the stability of convergence, weights are not recomputed before each iteration. For example, if distance weighting is to be applied on the 5th iteration, distance weights will be computed once based on the location following the 4th iteration and then not recomputed even though the epicenter may continue to move.

21) Rather than print the normalized weight associated with each phase, the standard error of the phase is now given in the output and summary files. The standard error is easier to understand than the weight, which is proportional to the inverse square of the standard error.

22) The input control records are now read with free format rather than the fixed format used previously. Old control records that relied on a blank field being read as a numeric 0.0 must now be modified.

December 1987:
23) In order to allow magnitude to be determined from a given station based on measurements made on more than one output device, the station archive format has been expanded to allow up to four extra response curves and corresponding calibration constants per station. In addition, provision has been made to enter the A1VCO gain range state and the Siemens playback gain state onto the arrival time record.

24) If the number of satellite hops (NHOP) is entered into column 110 of the arrival time record, then the telemetry delay is computed from the formula TDLY = NHOP*0.27 and the telemetry delay in the station archive is ignored. This allows a station to be recorded in two locations, where one has a delay but the other does not.

25) The codes used with the SORT and SELECT DELAY options are now set so that a code of 0 activates the option. These option codes are now consistent with most of the other option codes.

March 1988:
26) Added option to compute XMAG using U. of Alaska style station calibration parameters. (See 2.2.18 for details)

27) Allow nodal first motions, indicated by an 'Z', to be shifted into column 65 of the archive phase record. Z denotes a nodal arrival.

28) Station names with fewer than 4 characters are now right justified within the program. Left justified names are automatically right justified. The station list must still be organized in alphabetical order with all of the 3-letter codes prior to the 4 letter codes.

29) In some cases a station is moved a short distance but the station name is not changed. The station history now allows the station coordinates for a given station code to change with time. (See 2.2.5)

June 1988
30) Added source codes and number of satellite hops to the printed station output.

31) Added number of phases weighted out due the residual being too large to the summary record.

32) Added option to supress printout of station list and program constants (see 2.2.3.20).

December 1988
33) Modified the definition of critical stations so that more S phases would be used (see TEST(44), 2.2.4).

January 1989
34) Changed input keyword for velocity specification (see 2.2.2) from 'CRUSTAL' MODEL to 'VELOCITY' MODEL. 'CRUSTAL' MODEL will still work, however.

1.3 <u>NOTES FOR PROGRAMMERS</u>

If a copy of the HYPOELLIPSE program is desired, the author can copy the program onto a blank magnetic tape or 3 blank 360 K floppy disks provided. The tape format is ANSI-standard label with ASCII characters, fixed-block length, 9-track, and 1600 density. There are some options in the program that require extensions to FORTRAN 77, and these options are noted in the manual. The PC version of the program does not include the extensions. The VAX version, which is supplied on magnetic tape, includes the non-standard subroutines, but the program may be run without them. For an IBM PC or compatible an 8087 coprocessor is required, and with the current array dimensions at least 575 K bytes of free memory must be available.

The maximum number of stations in the station list, NSN, and the maximum number of phases per earthquake, NPA, are set in PARAMETER statements. NSN and NPA are set to 501 and 257, respectively, for the VAX version and to 450 and 200 for the

PC version of the program. In the PC version, the number of calibration records allowed in the University of Alaska magnitude subroutine (MX_REC in UOFAMAG) is set to 1 to save further space. In the VAX version, MX_REC equals 1000.

The function RND generates random numbers with mean zero and standard deviation 1.0. RND uses a DEC VAX/VMS system program RAN that generates a uniform random distribution with values ranging from 0 to 1. Most computer systems have an equivalent subroutine available. Random numbers are used in two optional portions of the program (see sections 2.2.13 and 2.2.14) that could be removed, if desired. RND has not yet been implemented on the PC.

The other DEC VAX/VMS dependent subroutines are:
TIMIT -- times the duration of the program's execution
JDATE -- returns the current date
DUBL -- converts from single to double precision
ERSET -- modifies the default error message levels
GETIST, GETONE, and STOPEN -- used for indexed station list
OPFLS -- prompts for file names opens files
AASK, BELL, LENTRU, IBEGTRU, and TROF are utility programs used in OPFLS

UNIX NOTE: Change \ to \\ in subroutine NPUNCH.

The files used by HYPOELLIPSE are:

FILE NO.	READ	WRITE	CONTENTS	TYPICAL SUFFIX
8	X		Input control parameters and earthquake data (Program prompts for name of this file)	.DAT
4		X	Summary record file optionally generated.	.SUM
6		X	Final summary showing warning messages and the average residual for each station.	.LOG
9		X	Printed output from execution.	.OUT
2	X	X	Station parameter scratch file.	.ST2
3	X	X	Station parameter scratch file.	.ST3
10	X		Indexed file with station data. If the station file contains a long history of station parameter changes, then an indexed station file can be used to speed up processing. This option uses VAX/VMS routines. Contact the author for details.	.IDX
11		X	Archive-phase file optionally generated.	.ARC
12		X	Alternate input file used with JUMP option.	

13		X	Final station corrections when automatic revision has been used. (See 2.2.3.17)	.STC
14	X	X	Scratch file for summary and input records.	.SSS
15	X	X	Scratch file for archive records.	.AAA
16	X	X	Scratch file for temporary message storage.	.TMP
21	X		Travel time tables for velocity model 11.	.C11
22	X		Travel time tables for velocity model 12.	.C12
23	X		Travel time tables for velocity model 13.	.C13
24	x		University of Alaska calibration data file.	

Chapter 2 HYPOELLIPSE Users Guide

2.1 INTRODUCTION

HYPOELLIPSE has been developed to meet some of the research needs of the USGS and is in a constant state of modification and revision to meet new needs and implement new ideas. There are many subtle uses of the various options available, and a complete description of these would expand the current work to book length. This program and manual are not error-free, and the author would greatly appreciate feedback on any errors or problems encountered.

The number of "options" available in this program is very large, and hence a new user may have trouble deciding where to begin and which to use. The easiest course is to start out by specifying only the minimum amount of information necessary to run the program, including station locations, velocity model, and a few sets of earthquake arrival times. Then review section 2.2 for modifications to the default conditions or additional calculations which your data set require. After the run, refer to section 2.3 to interpret the printed output.

The choice of which velocity model and variable layer thickness options to use will depend upon how much information one has about the region of study. Some of the possible choices are described below.

1. Very little is known about velocity structure.

   In this case a single simple model consistent with any information available could be used. The linear increase with depth over a half-space model might be desirable in that few assumptions need be made.

2. Detailed information is available about upper sediment layer thickness.

   In this case a single simple model could be used with the thickness of the upper layer varying from station to station. VMOD of section 2.2.3.5 would be set equal to 0.0. On the station list records (section 2.2.5) layer thickness for variable layer model 1 would be filled out for each station, and the preferred layer thickness model for each station would be set equal to 1.

3. The region covered by the network includes two or more distinct velocity structures which are well known.

   In this case the multiple velocity structure option could be used. Each station would be assigned to one of the velocity models, and that model will always be used to calculate traveltimes to that station. Note that ray tracing is not done so that a shallow earthquake whose waves pass through a number of different velocity structures in the earth will be poorly modeled. However, events deeper than the velocity variations will be modeled relatively well.

HYPOELLIPSE allows up to five different sets of P and S delays to be assigned to each station. In the case of Alaskan data, three sets of delays are specified for each station. For events in the west, each station uses P delay(1) and S delay(1), central events use P delay(2) and S delay(2), while eastern events use P delay(3) and S delay(3). This option, which is described below in section 2.2.3.6, when combined with assignment of one of three velocity structures to each station, allows all of the events from a very large area to be run in chronological order. Otherwise, pre-sorting by source area would be required.

4. Fault zone time delays

Work in California indicates that there is a low velocity zone along the San Andreas fault. To model this situation, each station is assigned two delays, one termed delay model 1 and the other termed delay model 2. In addition, stations on the east side of the fault are assigned the delay model preference number 1, while those on the west side are assigned number 2. The delay model used (1 or 2) in locating a particular earthquake is determined by the delay model preference number of the closest station to the event. For example, station XYZ is on the west side of the fault, so delay model 2 will be used for earthquakes near XYZ. Delay model 2 has fault zone delays added to the delays of stations on the east side of the fault.

5. Poisson ratio variation between velocity models and with depth

If desired, the ratio of P-velocity to S-velocity may be specified independently for each layer. A simple use of this option would be to specify a different Vp/Vs ratio for each velocity model, but constant within each model. A more complex use would be to specify a Vp/Vs ratio which varies within each model.

2.2 SPECIFICATIONS FOR DATA INPUT RECORDS

The input records for this program provide three types of information:

1. Parameters specific to each user and required for program operation such as the four-letter code and location of each station and the velocity model(s) to be used in traveltime calculations;

2. Parameters that control the iterative location procedure or that specify which of the available output options are to be used;

3. Arrival time data to be used in the location of each earthquake.

Except where otherwise noted, items 1 and 2 above have the following format: Columns 1 through 18 contain a keyword which is scanned to determine the number and type of free format variables on the remainder of the record. The directions for each input item indicate how many variables are required and whether they are real, integer, or character. For example,

```
Format:VELOCITY              real, real, real
```

indicated that the keyword is VELOCITY and that three real variables must be specified. All columns beginning with an ! mark are ignored, so comments may be placed on any input parameter record. Records starting with C* are processed

as comments, and the contents are written to the output file.
Note that the number of variables on each record must agree with the instructions, so leaving columns 19 and above blank is not equivalent to specifying a value of 0.0, but instead will generate an error message. If two records with the same keyword in columns 1 through 18 are found, the second one encountered will update the value(s) specified by the first.

Each of the input items is described below. In many cases parameters have default values, which are enclosed in brackets []. If the default is desired, then the record does not need to be included in the input file. The order of sections 2.2.1 through 2.2.5 makes no difference <u>except</u> that the Reset Test records (2.2.4) must precede the Station records (2.2.5).

2.2.1 <u>Jump record</u> - Format:JUMP character

If a record of the form JUMP FILENAME is encountered, where JUMP begins in column 1 and filename is in columns 6-55, then input is switched to file 'FILENAME'. Input resumes from the original input file after an end-of-file is reached. The jump file may not include any additional JUMP records. A JUMP record may not be imbedded within the station list records or within an earthquake's phase records. A JUMP record after the ARRIVAL TIMES NEXT record or between earthquakes may optionally contain in columns 56-65 the contents of the start of the next record to be processed. For example, if columns 56-65 contain the character string '7901' followed by 6 blanks, then all records will be skipped until one beginning with '7901' is found. All records encountered prior to that one will be skipped.

2.2.2 <u>Velocity models</u> - Format:VELOCITY real, real, real

Either the velocity model may be specified, or a travel time table may be used.

a) <u>Velocity model specifications (Models 1-10)</u>
The velocity models are specified by up to 48 records. There are three types of model that may be specified and up to 10 models may be defined. Models are placed in order starting with model 1.

Constant velocity in each layer.

The three real variables to be specified are P-phase velocity (km/sec), depth to top of layer (km), and Vp/Vs ratio. The first record of each model must have a depth of 0.0 km specified. Each model may consist of from 1 to 11 layers over a half space.

Any or all of the velocity models may consist of layers of constant velocity, and embedded low velocity zones are allowed.

Linear increase in velocity.

Any or all of the velocity models may be specified as a linear increase of velocity with depth of the form V(Z) = Vo + KZ, where Z is depth and Vo and K are constants. To call this option into play, the first VELOCITY record has velocity = K and depth = 0.0, the second has velocity = Vo and depth = 1.0, and the third has velocity = 100. and depth = 3.0. Vp/Vs must be specified on each record and remain constant.

Linear increase over a half space.

Any or all of the velocity models may be specified as a linear increase of velocity with depth over a half space.

$$0 \le Z \le D \quad V(Z) = Vo + KZ$$

$$Z > D \quad V(Z) = VH$$

To use this option, the first VELOCITY record has velocity = Vo and depth = 0.0, the second has velocity = K and depth = 1.0, the third has velocity = D and depth = 2.0, the fourth has velocity = VH and depth = 3.0, and the fifth has velocity = 200, and depth = 4.0. If this model is used in conjunction with TEST(2) = 0.0 (See section 2.2.4), then the elevation correction is made assuming that the velocity continues to decrease between the datum level and the station. In other words, the velocity between the top of the model and the station would vary linearly from Vo to Vo - (K)(Elevation). Vp/Vs must remain constant in a linear-increase-over-half-space model. For example, to specify three models, the first model with 20 km of 6.0 km/sec over a half space of 7.5 km/sec, the second model with a linear increase with depth starting at 3.0 km/sec at the surface and increasing 0.1 km/sec per km of depth, and the third model with a linear increase with depth starting at 4.0 km/sec at the surface, increasing 0.11 km/sec per km of depth down to 30 km, overlying a half space with a velocity of 8.1 km/sec, the following records would be used:

```
VELOCITY            6.0     0.0     0.0
VELOCITY            7.5    20.0     0.0

VELOCITY            0.1     0.0     0.0
VELOCITY            3.0     1.0     0.0
VELOCITY          100.0     2.0     0.0

VELOCITY            4.0     0.0     0.0
VELOCITY            0.11    1.0     0.0
VELOCITY           30.0     2.0     0.0
VELOCITY            8.1     3.0     0.0
VELOCITY          200.0     4.0     0.0
```

(A blank record between models is optional)

Ratio of P-phase velocity to S-phase velocity
The Vp/Vs ratio must be specified for each velocity layer. If specified as 0.0 then the current value of TEST(1) will be used. Use of this feature will be described by considering various cases:

All models used have the same Vp/Vs ratio
In this case set TEST(1) to the desired value before the VELOCITY model is input and set the Vp/Vs ratio to zero on the VELOCITY records.

Variation in Vp/Vs ratio between models
Specify Vp/Vs ratio on each VELOCITY model record. Do not vary Vp/Vs within a given model.

Variation in Vp/Vs ratio within a given model
This feature is allowed only for models with constant velocity layers (not the linear-increase models). If the Vp/Vs ratio changes within a given model, then a separate S-velocity model is defined and used for S-phase traveltimes. The S-phase model is assigned a number one higher then the corresponding P-phase model. For example, if two models are specified in the input stream, and the first model has variable Vp/Vs ratio, then three models will be defined and used as
follows:

	P-Phase Travel Times	S-Phase Travel Times
Stations Using Model 1	Model 1	Model 2
Stations Using Model 3	Model 3	Model 3

In this example, no primary station parameter record should assign a station to velocity model 2. (See section 2.2.5)

One limitation of this feature is that S-P interval times (See section 2.2.9) do not use the S model, but instead assume the constant Vp/Vs ratio defined by TEST(1). Another limitation is that each variable Vp/Vs ratio model uses up two models, so that a maximum of five models with variable Vp/Vs may be specified.

b) Travel-time table specification (Models 11 - 13)
In addition to the 10 models previously described, up to three velocity models may be specified by travel-time tables. The first, which will be model number 11, is read from file number 21. The second and third are model numbers 12 and 13 and are read from file numbers 22 and 23, respectively. The program prompts for the names of the travel-time tables. See Chapter 6 for the operation of the program TTGEN that may be used to generate a travel time table. This option used portions of the code written by Klein (1985) for HYPOINVERSE.

2.2.3 Option records

This set of records is optional. Include only those required.

2.2.3.1) Printer option record - Format:PRINTER OPTION   Integer

Code	Printed output
-2	Only warning messages.
-1	Date and time of each earthquake and warning messages.
0	Final solution for each event showing residuals at each station.
[1]	Above plus one line per iteration
2	Above plus residuals at each station each iteration
3, 4, or 5	Above plus details from many subroutines. Used for debug purposes only.

2.2.3.2) Summary option record - Format:SUMMARY OPTION   Integer

See section 2.4.1 for summary record format and 2.2.15 for archive format.

Code	Summary record output
0	No summary records
[1]	Summary records on FILE4
2	Summary records on FILE4 and ARCHIVE-PHASE FILE on FILE11.
3	ARCHIVE-PHASE FILE on FILE11
4	Not used
5	Phase records in input format with "fake" arrival times on FILE4. See section 2.2.14 for example of use.

2.2.3.3) <u>Magnitude option record</u> - Format:MAGNITUDE OPTION Integer

Local magnitude (XMAG) and coda magnitude (FMAG) are computed from formulas given in Chapter IV.

Code	Preferred magnitude used on summary record and in final line output (See sections 2.2.17, 2.3.5 and 2.4.1)
[0]	XMAG (Amplitude magnitude)
1	FMAG (coda length magnitude)
2	(XMAG + FMAG)/2
3	Prefer FMAG but use XMAG if FMAG not calculated.

MAGTYP on summary record is set to X, F, or A, (corresponding to XMAG, FMAG, and average) to denote which type of magnitude was used. If no location can be obtained, then the magnitude is left blank and MAGTYP is set to K.

If code is negative, the calculation will be based on F minus S (F - S) rather than F minus P (F - P) time. F - P is still entered on arrival time records as coda length, but the S-P interval is subtracted. If S has not been read, the S residual is greater than (F - P)/10., or the computed S weight is zero, then the calculated rather than observed S-P interval is subtracted.

2.2.3.4) <u>Quality option record</u> - Format:QUALITY OPTION Integer

The tabulation at the very end of each run gives statistics such as average residual for each station.

Code	Events included in final tabulation
0	No tabulation
±1	Tabulation for A quality only
[+2]	Tabulation for A and B quality
-2	Tabulation for A and B quality
±3	Tabulation for A, B, and C quality
±4	Tabulation for A, B, C, and D quality

Positive for quality based on error ellipsoid.
Negative for quality defined in HYPO71 (Lee and Lahr, 1972).
See section 2.3.4 for definition of A, B, C, and D.

2.2.3.5) <u>Variable layer option record</u> -

Format:VARIABLE LAYER Integer Integer Integer

NLAY VMOD LOWV

This record is required for the variable layer thickness option. NLAY is the number of the layer to be varied, VMOD determines how the layer thickness model is chosen, and LOWV is set to 1 if an equal and opposite change in the thickness of the layer below the variable layer is to be made.

For each station two thickness are specified for the variable layer, a model 1 thickness and a model 2 thickness. In the calculation of each travel-time two stations are considered, the closest station to the epicenter and the receiving station. VMOD is used to specify which of three options is desired:

VMOD

+1.0 The thickness specified for the receiving station's preferred model (1 or 2) is used. For example, station STA has the layer thickness for variable-layer model 1 equal to 3 km, and model 1 is its preferred layer-thickness model. Then all traveltimes to station STA will use 3 km as the variable layer thickness. With this option only one thickness need be specified for each station.

0.0 The depth to the lower boundary of the variable layer is calculated for the receiving and closest station. If the hypocentral depth is below the average of the two lower boundary depths, then the receiving station's variable layer thickness is used. For shallower depths, the lower boundary depth is set to the average of the receiving and closest station's lower boundary depths.

-1.0 The thickness model (1 or 2) preferred by the closest station to the epicenter is used to determine the variable layer thickness used at each station.

Example of variable-layer-model velocity in the case where the first layer thickness is variable and LOWV equals 1:

```
CRUSTAL MODEL AS SPECIFIED ON          CRUSTAL STRUCTURE WHEN VARIABLE
  CRUSTAL STRUCTURE RECORDS              LAYER THICKNESS EQUALS 5KM

 Z                                      Z
 0-------------------------             0----------------------------
         5 km/sec                                 5 km/sec
                                        5----------------------------

10-------------------------
         6 km/sec                                 6 km/sec
15-------------------------            15----------------------------
         7 km/sec                                 7 km/sec
```

Note that in this example no station should be given a variable layer thickness greater than 15 km.

2.2.3.6) <u>Crustal delay, velocity model, and starting depth option record</u> -
Format:SELECT DELAY Integer

By default, the velocity delay model used (1-5) is the one preferred by the closest station. An alternate mode can be set up in which a more complicated algorithm is used to select the delay model to be used. If code equals 0, then the subroutine USEDLY, which must be set up by the user, is used to control the following items:

Velocity Model
: The velocity model may be selected and updated each iteration on the basis of the current trial earthquake location.

Delay Model
: The delay model may be selected and updated each iteration on the basis of the current trial earthquake location.

First Trial Depth
: The first trial depth can be selected on the basis of the first trial location. (See section 2.2.12)

2.2.3.7) Missing stations option record - Format:MISSING STATIONS Integer

Code	Effect
0	The station list will be searched after each event for stations that would probably improve the earthquake solution quality. Those stations which are closer than the third closest station used or that would reduce the GAP by 303 or more are listed.
[1]	A search for "missing" stations is not conducted.

Searching for missing stations requires that the entire station list be initialized, so this option can not be used with a negative code on the BEGIN STATION LIST record. (See 2.2.5)

2.2.3.8) Sort option record - Format:SORT Integer

Code	Effect
[0]	Stations are listed in the output in order of increasing epicentral distance.
1	Stations are listed in the same order as the input arrival time records.

2.2.3.9) Compress option record - Format:COMPRESS Integer

Code	Effect
0	Printout is compressed by not skipping to the top of a new page for each solution.
[1]	Printout for each earthquake starts on a new page.

2.2.3.10) Debug option record - Format:DEBUG Integer

Code	Effect
[0]	This option is not called into play and no additional record is needed.
1	This option is used and the next record must be included:

Debug limits record - the following format must be used:

```
(      10X,F5.2,  5X,F5.2,  5X,F5.2,  5X,  I5,  5X,  I5,  5X,  I5)
```

For example:

```
MAX     RMS 0.65 PRES 1.00 SRES 1.00NWOUT    2 NMAX    8 SEMX   25
```

The words are typed only for your convenience and the order of the variables is fixed. The value of any variable not specified will be read as zero. This setup would give a detailed printout of traveltime, residuals, etc., for each station only for "Debug events" defined by:

RMS > 0.65 sec, or
Largest P-Resid. with computed weight greater than 0.2 > 1.0 sec, or
Largest S-Resid. with computed weight greater than 0.2 > 1.0 sec, or
The combined number of P and S readings weighted out by the program (does not include readings assigned weight code 4) > 2, or
Total number of iterations > 8, or
The maximum error estimate > 25 km.

The debug option can be used with the Compress Option so that each event will not start on a new page.

TABLE OF DEBUG OPTIONS

CODE	EVENT PRINTOUT	SUMMARY RECORD
[0]	Controlled by print option.	Controlled by summary option
+1	Summary line for good events. Detailed for debug events.	For both good and debug events
-1	Same as +1.	Only for good events
+2	No print for good events. Detailed for debug events.	For both good and debug events
-2	Same as +2.	Only for good events
±3	Detailed for all events. To rerun debug events with only critical stations set TEST(44) = 1.0.	For both good and debug events

2.2.3.11) Find global minimum in depth - Format:GLOBAL Integer

This option is now set up to find the best solution in regions where depths vary from the surface to 100 km or more.

Code	Effect
[1]	Global option is turned off.
0	Global search option is turned on. The "global" search begins by solving fixed depth solutions with z = 0 and z = 75 km. Then a free depth solution starting at z = 75 km is found. If the latter solution has z < 20 km and significantly lower RMS than at z = 0, then it is taken as the final solution. If z = 0 has significantly lower RMS, then a free depth solution starting at z = 0 is used as the final solution. If neither has significantly lower RMS, both solutions are reported to the output and that with the lower RMS is considered the best. This option can not be used if the hypocenter is fixed on a plane, so TEST(47) must be set to 0.0.

If the solution starting at 75 km depth has z greater than or equal 20 km then a solution with z fixed at 9 km is computed. Of the 0 and 9 km fixed depth solutions, the one with lower RMS is used as a starting location for free depth solution. If the latter solution is within 5 km of the free solution that started at 75 km, then the solution with the lower RMS is reported as final. If the solutions are more than 5 km apart, then the one with significantly lower RMS is reported as final. If neither has significantly lower RMS, both are reported to the output, and the one with the lower RMS is taken as the final solution.

Error limits reported to the output and to the summary record are the greatest deviations of depth with RMS less than RMSLIM (See Chapter 3 for the definition of RMSLIM), even if there are intervening peaks in the RMS. This limit is approximately equivalent to one standard deviation in depth.

For different networks and regions, the values of 75., 20., and 9. km may need to be adjusted for best results. Comments in the subroutine GLOBAL describe the variables that would need to be modified.

2.2.3.12) Residual option record - Format:RESIDUAL OPTION Integer

After the initial location of an earthquake the printed output can be checked for large residuals. When the original seismograms are reviewed to correct errors, inexperienced processors can be influenced in their revisions by the printed computer residual. This is very hazardous and not recommended because in many cases the true error, if any, is not reflected by the individual residuals.

To prevent this ill-advised feedback, the "preliminary option" may be used.

Code	Effect
0	Print output in residual form as described below.
[1]	Print output in normal form.

Residual output form consists of the following:

1) P and S residuals less than 2.25 seconds are shown only in absolute value and are rounded to the nearest 0.5 second. The printed residual (Rp) is related to the absolute value of the calculated residual (R) as follows:

$0 < R \leq .25$ Rp = 0
$.25 < R \leq .75$ Rp = 0.5
$.75 < R \leq 1.25$ Rp = 1.0
$1.25 < R \leq 1.75$ Rp = 1.5
$1.75 < R \leq 2.25$ Rp = 2.0

2) Flag large residuals: For residuals that have not been weighted out automatically by the program, an * is placed after the residual if it

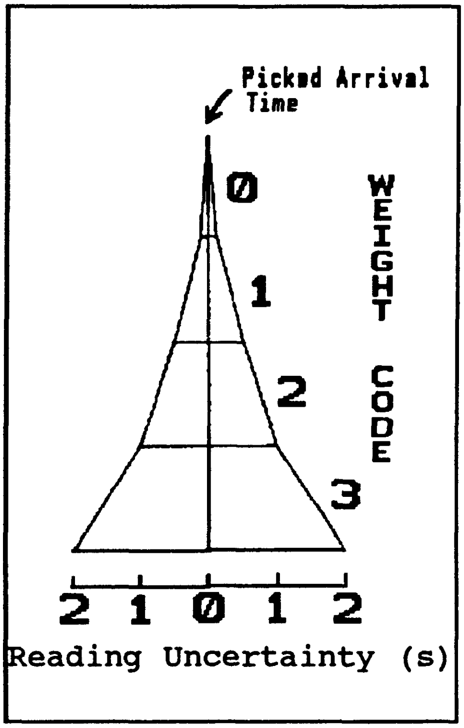
meets one of the following criteria:

P Residuals
R > .6 for one of closest five stations
R > .9 for distance less than 150 km
R > 1.5 for distance less than 350 km

S Residuals
R > .9 for one of closest five stations
R > 1.5 for distance less than 150 km
R > 2.0 for distance less than 350 km

2.2.3.13) Weight assignment option -
Format:WEIGHT OPTION Real Real Real

The relative weight assigned to each reading is dependent upon an integer weight-code, which can range from 0 for the most impulsive to 4 for readings that are too uncertain to be used in the hypocentral solution. Weights should be assigned so that they are proportional to the inverse square of the reading standard deviations. Zero weight code readings are always given a weight of 1.0, so if, for example, the standard error of zero weight code readings is .1, then readings with a standard error of .2 should be given a weight of 0.25. For processing Alaskan seismic data, the most accurate readings have standard errors of approximately 0.05 to 0.10 seconds, and the graph below is used to assign weight codes according to the estimated accuracy of the arrival times.



The default weight and corresponding relative standard error corresponding to each weight code is given in the table below:

WEIGHT CODE	WEIGHT	STANDARD ERROR RELATIVE TO READINGS WITH WEIGHT CODE ZERO
0	1.0	1.0
1	1/9	3.0
2	1/56	7.5
3	1/225	15.0
4	0.0	INFINITE

To change the default weight assignments, include a record with WEIGHT OPTION starting in Column 1 followed by the relative standard errors for weight codes of 1, 2, and 3. For example, the default weights that used to be set in older versions of HYPOELLIPSE could be reset with:

```
WEIGHT OPTION       1.33     2.        4.
```

2.2.3.14) Ignore summary records - Format:IGNORE SUMMARY REC Integer

Code	Effect
[1]	Starting location parameters (latitude, longitude, depth, and origin time) may be taken from the summary record. (See section 2.2.12)
0	The summary record will be ignored in determining the starting location parameters.

2.2.3.15) Header content record - Format:HEADER Any heading.

Used to write a heading of up to 50 characters above each earthquake in the output.

2.2.3.16) Comment records - Format:C* Any Comment

Any record with C* in columns 1-2 will be printed out during program execution but is otherwise ignored. Comments may not be imbedded within the station list.

2.2.3.17) Relocate after revising delays - Format:RELOCATE Integer

This will cause the input file to be rewound and rerun N = Code times. Prior to each rerun, the station delays for delay model 1 will be revised by adding the event-weighted average station residual. At the end of the job a file is generated on Unit 13 with one record for each station used. These records are in the format of the primary station records. (See section 2.2.5) The P- and S-delay field for delay model 1 will contain the revised stations delays. The field for delay models 2 through 5 will be blank. The default is Code = 0.

2.2.3.18) Uofacal option - Format:UOFACAL Filename

Used to specify the name of the file that contains calibration data in the format used by the U. of Alaska. (See section 2.2.18). Type UOFACAL beginning in column 1 and filename in columns 19-68.

2.2.3.19) <u>Reset all control parameters to the initial default values</u> - Format:STANDARD TEST

2.2.3.20) <u>Constants printout option</u> - Format:CONSTANTS PRINT integer

Controls whether the station list, user specified constants, and control options will written to the output file.

Code	Effect
0	Do not write out these items.
[1]	Write out these items.

2.2.4 <u>Reset test records</u> - Format:RESET TEST Integer Real

These records have RESET TEST typed starting in column 1 and beginning in column 19 the test number and the new value for the test variable. All of these records are optional and need be included only if a non-default value is required.

Test Number	Default Test Value	Description
1	1.78	--- Ratio of P-wave to S-wave velocity
2	5.0	--- P-wave velocity for elevation (correction) (km/sec). If negative, make no elevation corrections. If zero, use first layer velocity for elevation corrections. If greater than zero, use this for elevation corrections. In the latter case, value must be less than first layer P-phase velocity.
		--- Trial Location
3	0.0	First trial latitude (degrees). North positive. If TEST(3) or (4) .eq. 0, then ignore. See 2.2.12 for use.
4	0.0	First trial longitude (degrees). West positive. If TEST(3) or (4) .eq. 0, the ignore. See 2.2.12 for use.
5	-1.0	Used for first trial depth (km) unless negative. See 2.2.12 for use.
6	0.0	--- RMS calculation at additional points. Radius of sphere for auxiliary RMS values (km). If zero, no auxiliary RMS values are calculated. If negative, continue iteration once starting at most negative point.

Test Number	Default Test Value	Description
7	10.0	--- Focal Mechanism Plot Minimum number of first motions for a first motion plot to be made. If negative, make a second plot showing station names.
8	0.0	--- Not used.
9	0.0	--- Not used.
		--- Distance Weighting
10	50.0	Apply distance weighting on this iteration. See also TEST(11) and (12).
11	50.0	XNEAR = Greatest distance with weight of 1.0 (km)
12	100.0	XFAR = Least distance with weight of 0.0 (km). See also TEST(46).
13	50.0	--- Azimuthal Weighting Apply azimuthal weighting on this iteration. Warning: this option has not been tested.
		--- Truncation Weighting
14	50.0	If there are 6 or more phases, then weight out large residuals on this iteration. See also TEST(15).
15	10.0	Give zero weight to residuals greater than this (sec).
		--- Boxcar Weighting
16	50.0	If there are 6 or more phases, then apply boxcar weighting on this iteration. See also TEST(17), (34) and (35).
17	2.0	Give zero weight to residuals greater than this times the standard deviation (sec).
		--- Jeffrey's Weighting
18	50.0	Begin Jeffrey's weighting on this iteration. (See also TEST(34) and (35)).
19	0.05	Use Jeffrey's weighting only if RMS is greater than this (sec).
20	0.05	Mu of Jeffrey's weighting function
21	9.0	--- Maximum number of iterations

Test Number	Default Test Value	Description
22	35.0	--- Limit change in focal depth to approximately this amount (km).
23	0.7	--- If move would take earthquake above surface, move this proportion of the way to the surface.
24	35.0	--- Limit change in epicenter to approximately this amount (km).
25	40.0	--- Fix depth if epicentral change is greater than this (km).
26	0.0025	--- Stop iterations if adjustment squared is less than this (km).
27	0.0	--- Not used.
28	0.0	--- To fix the hypocenter on a plane, set absolute value of this equal to azimuth of plunge line of plane (03 to 3603 measured clockwise from North). If negative, then a free solution will be determined starting at the best location on the plane. (See also TEST(30) and TEST(47).
29	-0.16	--- If TEST(29) is positive, the standard error of zero weight-code readings is set equal to the RMS residual, unless there are zero degrees of freedom or the estimated reading standard error falls below TEST(29). In that case TEST(29) is used for the standard error of the readings. If TEST(29) is negative, the standard error of the zero weight-code readings is always set equal to minus TEST(29). (Also see 2.2.3.13)
30	0.0	--- Dip of plunge vector for hypocenter fixed on plane. See also TEST(28) and TEST(47).
		--- Duration Magnitude (See also TEST(40) and (43)).
31	-1.15	C1, constant
32	2.0	C2, *log((F-P) * FMGC)
33	0.0	C3, *DELTA
34	0.0	--- Not used
35	0.0	--- Not used

Test Number	Default Test Value	Description
36	100.0	--- Maximum first trial depth, if computed from P-arrival times.
37	3.0	--- If termination occurs before this iteration, set iteration number to this and continue. Prevents iteration from stopping before all forms of weighting have been applied.
38	0.0	--- If 0, use of S depends upon S data indicator on instruction record. If 1, run all with & without S. If 2, run all with S. If 3, run all without S. If negative, use S readings only to fix origin time.
39	1.0	--- Multiply the S and S-P weight-code weights by this factor.
40	0.007	--- Duration magnitude C4, *DEPTH (see also TEST(31)-(33), (43))
41	0.0	--- If equal 1, print option greater than or equal 1, and summary option equals plus or minus 1, then write a new summary record after each iteration.
42	0.0	--- Not used.
43	0.0	--- Duration magnitude (see also TEST(31)-(33), (40)) C5, *(log ((F-P) *FMGC)**2)
44	0.0	--- If 1, rerun "debug events" again (See 2.2.3.10) with critical stations; if 2, make a second run for all events with critical stations See note below for definition of critical stations.
45	0.1379	--- X scale factor for focal mechanism plots. Adjust for printer in use. (See 2.3.9)
46	0.0	--- If TEST(46) not equal 0.0, distance weighting constant XFAR (see TEST(12)) will be set to a minimum of 10 km beyond the distance of the TEST(46)th station. If TEST(46) is negative then any station beyond XFAR that would reduce a gap greater than 90 degrees by 45 degrees or more is given a distance weight of 0.5.

Test Number	Default Test Value	Description
47	0.0	--- Constraint equation weight for hypocenter fixed on plane. A large value, such as 1000, will prevent out-of-plane movement. If equal 0, option is not used. See also TEST(28) and (30). This option may not be used with the Global option (see 2.2.3.11).
48	0.0	--- Not used.
49	0.0	--- If abs value equal 1 compute Vp/Vs and origin time; if equal 2, also make printer plot of S-P vs P. If negative, use this origin time for earthquake location.
50	0.0	--- Compute this number of fixed depth solutions, starting with Z(1) = 0.0 and continuing with Z(i+1) = 1.2*Z(i) + 1.0. The maximum this value can be is 22., which produces a maximum depth of 225 km.

Note on TEST(44) - critical stations

In an effort to speed up the identification of reading errors during preliminary runs of data, the option to rerun each event, using only the most important arrivals, was developed. In some cases reading errors can be identified by comparing the solution using only critical stations with the normal solution. In the printed output for critical station reruns, readings that are not used are marked with an 'X' between the residual and the weight. Critical stations are defined to be:

a) The closest four stations with P-phase readings;

b) Additional stations with P- or S-phase readings are considered one at a time and added only if they reduce a gap of greater than 723 by 53 or more;

c) S-arrivals are used when available at "critical" stations. If there is no S-arrival at any critical station, then S is used from the closest non-critical station.

2.2.5 Station list

The station list is set up so that a complex history of station changes can be maintained, such as starting and closing dates and changes in gain and polarity. (See discussion in 2.2.7) However in situations where this information is not needed, the station list may consist of just two entries for each station, with many fields left blank. For the southern Alaska seismic network, a complex history beginning in 1971 has been developed. To speed up the earthquake processing the Alaskan station list is kept in an indexed file which has a VAX computer dependent format. More information on the indexed station list is available from the author.

2.2.5.1) Begin station list - Format:BEGIN STATION LIST Integer Integer

The first record has BEGIN STATION LIST typed in columns 1-18, followed by Code and date of the first event to be run in free format. The date includes year, month, and day (for example: 821028). If the station list contains many stations that expired before the time of the first event, specifying the correct starting date will eliminate the expired stations from the initial printed station list. The date may be set to 0, but information for stations expired prior to first event will be printed depending on Code.

If the CODE is:		
	0 or 1	Station records follow BEGIN STATION LIST record. Print station list updated to date specified.
	-1	Same as one but do not print station list or print new station parameters when a station is updated during run.
	2	Station list is indexed file. A record with JUMP FILENAME follows the BEGIN STATION LIST record, where FILENAME is the name of the indexed station file. No END record is used in this case (See 2.2.5.4). Stations will be updated to the date specified on the BEGIN STATION LIST record and a station list will be printed.
	-2	Station list is indexed, as for 2, except station parameters are only determined as required as each earthquake is processed. No station parameters are printed. This option allows quick location of a few events without initializing the parameters of all of the stations on the station list.

2.2.5.2) Primary station parameters - Formatted as indicated below.

For each station there is one entry with PRIMARY STATION PARAMETERS, such as latitude and longitude, and one or more entries with TIME-DEPENDENT STATION PARAMETERS, including calibration parameters and polarity indicator. To speed up the search for station parameters, the current version of HYPOELLIPSE requires the station list to be in alphabetical order. The 3-letter codes must be grouped together preceding the 4-letter codes.

Alphabetical order is not required if the alternate version of subroutine PHAIDX, which is included in with the source code, is used. In either case, the first station should be near the center of the network, as it is used as a reference location for calculating the azimuth of approach of a plane wave. A fake station with the name AAA can be used as the first station. The program arrays are set up for a maximum of 500 stations. To change this limit, read the comments near the beginning of subroutine INPUT1.

Format for PRIMARY STATION PARAMETER records:

Item	Col. Nos.	Format
Station Name	1 - 4	A4
Latitude (Degrees)	5 - 6	I2
N or blank for North, S for South	7	A1
Latitude (Minutes)	8 - 12	F5.2
Longitude (Degrees)	14 - 16	I3
W or blank for West, E for East	17	A1
Longitude (Minutes)	18 - 22	F5.2

THE FOLLOWING ITEMS ARE OPTIONAL, AND IF LEFT BLANK THE DEFAULT VALUES WILL BE USED.

Item	Default Value	Col. Nos.	Format
Elevation (Meters)	0.0	24 - 27	I4
Preferred velocity model (1-10)	1	28 - 29	I2
Preferred layer thickness model (1-2)	1	30	I1
Layer thickness for model 1	0.0	31 - 34	F4.2
Layer thickness for model 2	0.0	35 - 38	F4.2
Preferred delay model (1-5)	1	39	I1
P-delay for model 1	0.0	40 - 43	F4.2
S-delay for model 1	0.0	44 - 47	F4.2
P-delay for model 2	0.0	48 - 51	F4.2
S-delay for model 2	0.0	52 - 55	F4.2
P-delay for model 3	0.0	56 - 59	F4.2
S-delay for model 3	0.0	60 - 63	F4.2
P-delay for model 4	0.0	64 - 67	F4.2
S-delay for model 4	0.0	68 - 71	F4.2
P-delay for model 5	0.0	72 - 75	F4.2
S-delay for model 5	0.0	76 - 79	F4.2
*Component, Blank or Z, N, or E Corresponds to Vertical, North-South and East-West.		80	A1

*Stations with N or E component are currently ignored by HYPOELLIPSE.

NOTE ON DELAYS: The total delay used for the S-phase is just the S-delay given on the station record. [Earlier versions of HYPOELLIPSE added a term equal to (VPVS ratio)*(P-delay)]

2.2.5.3) Time-dependent station parameters

Format for TIME-DEPENDENT STATION PARAMETER records:

Item	Default Value	Col. Nos.	Format
Station name		1 - 4	A4
*		5	A1
If any of the following items are left blank, default values will be used.			
Station weight (Multiplies the weight derived from weight code. See section 2.2.6.)	1.0	6 - 9	F4.2
System response code: 0 for Wood-Anderson 1 USGS Central California Network Standard 2 EV-17 and Develco 3 EV-17 and Teledyne 4 HS-10 and Develco 5 L-4C and Develco 6 L-4C and Teledyne 7 L-4C replacing HS-10 and Develco 8 Ten-day Recorders 9-17 User specified calibration curve (See 2.2.10) 18 Use U. of Alaska magnitude calculation (See 2.2.18)	1	10 - 11	I2
XMAG calibration constant-C10 (See 4.2)	0.0	12 - 16	F5.2
XMAG correction (added to amplitude magnitude)	0.0	17 - 20	F4.2

NOTE: If the number typed is the actual magnitude correction plus 10, the magnitude for this station will be computed and listed but not used in computing the average magnitude. For example, if XMAG correction = 10.2, a correction of +0.2 is applied to all XMAG's for this station, but none are used in the average magnitude for each event.

Item	Default Value	Col. Nos.	Format
FMAG weight (used to calculate weighted mean of FMAG's. If zero, FMAG not used and E for EXCLUDED is printed next to value in output.)	1.0	21 - 23	F3.1
FMAG correction (Multiplies the observed coda).	1.0	24 - 27	F4.2
P weight code replacement For this station, an arrival time record with P weight code of 0, 1, 2, or 3 will be replaced by this code. If blank, use assigned weight.	none	28	I1
S weight code replacement For this station an arrival time record with an S weight code of 0, 1, 2, or 3 will be replaced by this code. If blank, use assigned weight.	none	29	I1
Telemetry delay	0.0	30 - 33	F4.2
Polarity reversal indicator	0	34	I1

Indicator Value:	Focal Mechanism Symbol:
0 - Normal	Same as Phase record
1 - Reversed	Reverse of Phase record
2 - Probably normal	Question Mark
3 - Probably reversed	Question Mark
4 - Unknown	Question Mark

Item	Default Value	Col. Nos.	Format
Field gain setting (Not used by HYPOELLIPSE)	0	35 - 36	I2
Palmer attenuator setting (0, 1, or 2 Not used by HYPOELLIPSE)	0	37	I1
Year, month, and day	990000	38 - 43	I6
Hour and minute Time of expiration of information in these entries. If another entry with revised time dependent parameters does not follow, then this is time of station expiration.	0	44 - 47	I4

****** The items in columns 48-70 are not used by HYPOELLIPSE ******

Item	Default Value	Col. Nos.	Format
Tape polarity reversal indicator		48	I1
Tape channel		49 - 50	I2
Center frequency		51 - 55	I5
A1VCO 5 Hz, Calibration mm ptp		56 - 58	I3

Item	Default Value	Col. Nos.	Format
Expiration of station was due to a change in:			
Palmer attenuation		59	A1
Field gain		60	A1
Develocorder polarity		61	A1
Tape polarity		62	A1
Tape channel		63	A1
Center frequency		64	A1
Tape channel		65 - 66	I2
Center frequency		67 - 70	I4
******			
The following items allow amplitude measurements for a given station to be made on up to four additional recording systems, each with a different frequency response:			
System response code		72 - 73	I2
A1VCO 5 Hz, Calibration mm ptp		74 - 77	F4.0
XMAG Calibration constant-C10		78 - 82	F5.2
System response code		84 - 85	I2
A1VCO 5 Hz, Calibration mm ptp		86 - 89	F4.0
XMAG Calibration constant-C10		90 - 94	F5.2
System response code		96 - 97	I2
A1VCO 5 Hz, Calibration mm ptp		98 -101	F4.0
XMAG Calibration constant-C10		102-106	F5.2
System response code		108-109	I2
A1VCO 5 Hz, Calibration mm ptp		110-113	F4.0
Calibration constant-C10		114-118	F5.2
Coordinates of new station location:			
Revised minutes of latitude		119-123	F5.2
Revised minutes of longitude		124-128	F5.2
Revised elevation		129-132	I4

2.2.5.4) <u>End station list</u> - Format:END STATION LIST

A record with END typed starting in column 1 follows the last station record. The record immediately following the BEGIN STATION LIST record may be of the form JUMP FILENAME, where the station records are contained in the file 'FILENAME'. In this case, no END record is used in either the original input file or the jump file.

2.2.6 Arrival times

2.2.6.1) Arrival times next record

A record with ARRIVAL TIMES NEXT starting in column 1 signals the start of the arrival time records. Each earthquake consists of four types of records: SUMMARY ('/' or '\' in column 81), ARRIVAL TIME, COMMENT ('C*' in columns 1-2) and INSTRUCTION. If any summary records are present, the first record of the event must be the primary SUMMARY RECORD ('/' in column 81) and this record provides the starting location for the event unless the IGNORE SUMMARY RECORDS option is in effect (See sections 2.2.3.14 and 2.2.12). Each event must end with a series of one or more INSTRUCTION RECORDS. A maximum of 256 records may be associated with each event.

2.2.6.2) Arrival time record format

For each seismograph station recording the earthquake, an ARRIVAL TIME RECORD is typed as follows. A maximum of 256 phases, countine P and S phases, may be used for each earthquake.

Item	Col. Nos.	Format
Station name	1 - 4	A4
Alphanumeric symbol describing P-phase arrival (for example, I or E)	5	A1
Phase descriptor P - P-arrival read on vertical component N - P-arrival read on North-South component E - P-arrival read on East-West component If N or E is used, then neither the coda duration nor the maximum amplitude will be used and the first motion direction will not be plotted.	6	A1
First motion direction of P-arrival c, C, u, or U Compression d, D Dilatation + Poor compression - Poor dilatation Z Nodal, and not clearly up or down N Noisy . or Blank Not readable	7	A1
P-phase weight code 0 or blank Full weight 1 Partial weight 2 Partial weight 3 Partial weight 4, 5, 6, 7, 8 No weight	8	F1.0
If the P phase is a secondary arrival refracted along the bottom of the Ith layer, type the value of I here. If event is in the (I + 1)th layer, direct wave calculation is made. If the event is deeper than the (I + 1)th layer, the computed weight is reset to zero.	9	I1

Item	Col. Nos.	Format
Year, month, day, hour, minute	10 - 19	I10
Seconds of P arrival. If left blank, the assigned weight code will be set to 8 both during this run and on the archive output record.	20 - 24	F5.2
Seconds of S arrival	32 - 36	F5.2
S remark	37 - 39	A3
S phase weight code	40	F1.0
Maximum peak-to-peak amplitude in mm. Values from .001 to 9,999 are entered as positive. Negative entries are multiplied by -10,000 to allow for values of 10,000 to 9,990,000.	44 - 47	F4.0
Period of maximum amplitude in sec. If left blank, 0.1 will be used.	48 - 50	F3.2
Siemens gain state: 0 = high; 1 = low (X1/4)	61	I1
A1VCO gain range state. 0 = high; 1 = X 1/10; 2 = X 1/500	62	I1
Any remark	63 - 64	A2
Time correction in seconds	66 - 70	F5.2
F-P time interval, in sec, for FMAG calculation. In USGS practice, one measures the time between the first P-arrival and the point where the peak-to-peak amplitude of the signal drops below 1 cm on a Geotech Develocorder film viewer (X 20 magnification). If the F-P is less than 1.25 times the S-P time, then FMAG is not calculated. If P or S is given zero weight or if the ABS(P residual) plus ABS(S residual) is greater than 0.1 times the F-P time then the calculated S-P time is used.	71 - 75	F5.0
Polarity source code	105	A1
P Arrival source code	106	A1
S Arrival source code	107	A1
Amplitude source code	108	A1
Coda duration source code	109	A1
NHOP - Number of 0.27s satellite hops in telemetry path. If not left blank, this overrides the telephone line delay on the station list (See 2.2.5).	110	I1

2.2.6.3) <u>Instruction record</u>

After each set of arrival time records for a particular earthquake, at least one INSTRUCTION RECORD follows.

Item	Col. Nos.	Format
MORE Indicator for another instruction record following this one. Leave blank if no additional instruction records follow. Type MORE if another one follows. The earthquake will be processed once for each instruction record.	1 - 4	A4

Item	Col. Nos.	Format
DIST	1 - 4	A4
Compute velocity and azimuth of approach rather than earthquake hypocenter.		
S data indicator	18	I1
0 if S data is not to be used		
1 for use of S data in solution		
Fixed location indicator	19	I1
0 implies nothing fixed.		
1 implies depth fixed at trial depth.		
7 implies hypocenter fixed but origin time free.		
8 implies origin time fixed at trial origin time.		
9 implies location fixed at trial latitude, longitude, and depth. If origin time is entered on this record (cols. 74-80), or on a summary record, then origin time will also be fixed.		
Trial depth	20 - 24	F5.2
Trial latitude (Degrees)	41 - 42	F2.0
N or blank for North	43	A1
S for South		
Trial latitude (Minutes)	44 - 48	F5.2
Trial Longitude (Degrees)	54 - 56	F3.0
W or blank for West and E for East	57	A1
Trial longitude (Minutes)	58 - 62	F5.2
CUSP ID (not used by HYPOELLIPSE)	63 - 73	A11
Trial origin time (Minutes)	74 - 75	F2.0
Trial origin time (Seconds)	76 - 80	F5.2
Sequence Number - will be transferred to columns 92-96 of summary record.	92 - 96	A5

2.2.6.4) Comment records

Any phase record with C* in columns 1-2 will be printed out during program execution but otherwise ignored. There is no limit to the number of comment records per event, except that they count along with summary records, arrival time records, and the instruction record toward the maximum number of records per event - currently set at 256. In this way a comment can be made, for example:
C* Station XYZ may have cross-feed or
C* these readings may be from two earthquakes.

2.2.6.5) Jump records

If a record with 'JUMP FILENAME' beginning in column 1 is encountered then input is transferred to file 'FILENAME'. When an end-of-file is reached on the subsidiary input file, input resumes from the original file.

2.2.7 Station parameter changes during run (see sections 2.2.5.2 and 2.2.5.3)

The station list record file may be set up so that station parameter changes will automatically be made as a set of data is run. Each station record has an expiration date and time. If left blank the year is set to 1999. But if, for example, the station calibration changed on 760120 at 1432 from 5.1 to 8.3, then two station records would be included in the file. The first would have 5.1 for calibration and an expiration of 7601201432. The second, which must directly follow the first, would be identical except 8.3 would replace 5.1 and the expiration date and time would be updated. As many station records as required can be grouped together like this. The expiration date of each station is checked against the current event time before each event is processed.

CAUTION: In order to use this system of automatic updating of station parameters, the earthquake data set must be run in chronological order. All updates for a particular station must also be in chronological order. Note that if the events are rerun, as described in section 2.2.11, then they will not be run in chronological order, so station parameter updating will not operate correctly and errors may result.

2.2.8 Change input items 2.2.1 through 2.2.5 during run

Any or all of these items may be changed as follows:

2.2.8.1) RESET record

Type RESET starting in column 1. This record is placed following the last instruction record of an event or set of events, and it switches the program to the input mode in which items 2.2.1 through 2.2.5 may be entered. All location parameters will remain in effect except those for which new 2.2.1-2.2.5 records are included. To switch back to reading phase records, terminate the 2.2.1-2.2.5 items with an ARRIVAL TIMES NEXT record.

2.2.8.2) RESET S record

Type RESET S starting in column 1. This is the same as RESET described above except that (1) a tabulation of average residuals will be printed for the set of events preceding the RESET S record, and (2) tabulation will begin anew on the events that follow.

2.2.8.3) STANDARD TEST

A record with STANDARD TEST starting in column 1 will reset input items 2.2.3 and 2.2.4 to default values. This record is placed after a RESET or RESET S record.

2.2.9 Use of S-P intervals

If the same time base is not available for some stations, it is still possible to use the recorded S-P intervals in the hypocentral solution. To do this, set the weight code assigned to the P-arrival (column 8) to 9, and the weight code assigned to the S-arrival (column 40) to that desired for the S-P interval. This option will only work with velocity models that have the same ratio of P-wave to S-wave velocity in each layer.

2.2.10 How to add your own calibration curves -
Format:CALIBRATION Integer

The user may supply the calibration tables for up to nine more seismic systems corresponding to system numbers 9 through 17. To do this, place a record with CALIBRATION starting in column 1 and the number of additional system calibration tables to be added beginning in column 19 in free format. Each table consists of two records with the values of RSPA for n = 1,20 on the first and n = 21,40 on the second. The format is (20F4.2). The first two records correspond to system number 9, the second two to number 10, etc., up to the total number of tables to be added. See Chapter 4 for the definition of RSPA(n).

2.2.11 How to run the same data more than once

A set of arrival time records may be run with a variety of velocity models, station lists, trial depths, or any other of the variable parameters defined in 2.2.1 through 2.2.5. First, place the ARRIVAL TIME records in a separate file (named PHDATA in the example below). Then set up the input file as in the this example:

```
Items 2.2.1 through 2.2.5 as desired for 1st run
ARRIVAL TIMES NEXT
JUMP PHDATA
RESET
New items 2.2.1 through 2.2.5 as desired for second run
ARRIVAL TIMES NEXT
JUMP PHDATA
```

* HYPOELLIPSE always assumes that the earthquakes being processed are in chronological order when keeping the station parameters up-to-date. Therefore, if the events being rerun span any changes in the station parameters, the station file will have to be included again prior rerunning the data.

2.2.12 Summary of first trial location specifications

For each parameter, the sources are given in order of decreasing priority.
LATITUDE AND LONGITUDE
1) INSTRUCTION RECORD, if specified (columns 41-44 contain some non-blank characters), else
2) SUMMARY RECORD, if specified (columns 15-18 contain some non-blank characters) - (See 2.2.3.14 to ignore summary records), else
3) TEST(3) and (4), if both not equal zero, else
4) Inversion of up to the first 10 P-arrival times.

DEPTH
1) INSTRUCTION RECORD, if specified (columns 21-24 contain some non-blank characters), else
2) SUMMARY RECORD, if specified (columns 31-34 contain some non-blank characters) - (See 2.2.3.14 to ignore summary records), else

3) Trial depth specified in SUBROUTINE USEDLY if the SELECT DELAY option code is not zero and USEDLY sets a depth not equal to 99999. (See 2.2.3.6), else
4) TEST(5), if not less than zero, else
5) Inversion of up to the first 10 P-arrival times, rounded to nearest 5 km and not less than 15 km or greater than TEST(36).

ORIGIN TIME

1) Computed from distribution of S vs P if TEST(49) equals -1 or -2 and the number of pairs of S and P times is greater than 2.
2) INSTRUCTION RECORD, if specified (columns 74-77 contain some non-blank characters), else
3) SUMMARY RECORD, if specified (columns 9-12 contain some non-blank characters) - (See 2.2.3.14 to ignore summary records), else
4) Computed from distribution of S vs P if TEST(49) equals 1 or 2 and the number of pairs of S and P times is greater than 2.
5) Define TO(i) = TP(i) - (TS(i) - TP(i))/(TEST(1) - 1.0) where
   TP(i) is the P arrival time at the i th station,
   TS(i) is the S arrival time at the i th station,
   TEST(1) is the Vp/Vs ratio
   Use the average value of TO(i) if at least one station has both P- and S- arrivals, else
6) Inversion of up to the first 10 P-arrival times.

NOTE: If TEST(38) is negative, then the origin time will be fixed at the average value of TO(i), unless TEST(49) is negative, in which case it will be fixed at the value determined by the Wadati plot (extrapolation of the (TS - TP) vs TP curve to the point where (TS - TP) equals zero).
NOTE: Starting parameters will not be taken from the summary record if the IGNORE SUMMARY RECORD option is in effect (See 2.2.3.14).

2.2.13 <u>Run data with random errors added - Method 1</u>

After a set of phase records, place a record with GAUSEP starting in column 1 in place of an instruction record. This is followed by a record with NGS, PERR, SERR in (I5, 2F5.2) format where: NGS is the number of random solutions per event location; PERR is the standard error to be used for P arrivals; and SERR is the standard error to be used for S arrivals.

Following these two records, place a series of records with the coordinates of each hypocenter for which a random calculation is desired. Include:

Z, ALADEG, INS, ALAMIN, ALODEG, IEW, ALOMIN
in (19x,F5.2,16x,F2.0,A1,F5.2,5x,F3.0,A1,F5.2) format, where
Z is the depth,
ALADEG is the degrees of latitude,
INS is N or S for North or South,
ALAMIN is the minutes of latitude,
ALODEG is the degrees of longitude,
IEW is E or W for East or West, and
ALOMIN is the minutes of longitude.

This series of records is terminated with a record which has ALADEG = 99.

The set of phase records before the GAUSEP record will determine which stations are used in each random solution, as well as which phases will be used (P, S, or P and S). Although the actual arrival times typed on the phase records will be ignored, they should not be left blank, as this would cause their weights to be set to zero.

2.2.14 Run data with random errors added - Method 2

In order to study the effectiveness of this inversion program for varying station distributions or earthquake distributions and for data corrupted by random errors, the following method may be used:
a) Generate a "fake" set of perfect phase data for the desired earthquake distribution. This can be done by setting up a group of arrival time records with the stations of interest and including arbitrary P- and S-phase data for each station. Then use a series of INSTRUCTION RECORDS, each with a fixed location indicator and one of the desired test earthquake locations (See 2.2.6.3). Run this data with SUMMARY OPTION 5 in order to generate the "fake" set of arrival time data. If these data were fed back into the program, the result should be the desired test earthquake locations, each with zero RMS residual.

b) In order to have random errors added to each arrival time, type a record with SCATTER starting in column 1, P standard error starting in column 20 (F5.2), and S standard error starting in column 32 (F5.2). Note that this format is fixed. These should be the standard errors for readings with 0 weight code. For readings with weight codes of 1, 2, and 3, larger deviations will be added, based on the WEIGHT OPTION parameters (see 2.2.3.13). Place this record directly before the first arrival time record of the fake data set. If an archive phase file is being generated, the arrival times will reflect the added random errors. Each time this job is run a new series of random numbers will be generated because the random number seed is initialized by the time, month, and year of the run.

If the velocity model is also changed, then one can also simulate the systematic errors introduced by not knowing the true earth structure.

2.2.15 How to generate an ARCHIVE-PHASE FILE

HYPOELLIPSE can optionally be used in a mode that utilizes and generates data in a data base that combines the raw data measurements of the phase records, the summary record, and certain derived parameters for each station such as distance, azimuth, and angle of incidence (Figure 2-1). To set up HYPOELLIPSE to generate this file, simply set SUMMARY OPTION equal to 2 or 3. When HYPOELLIPSE is run, FILE11 will be generated with input and derived parameters for each event. See 2.4.2 for format. The ARCHIVE-PHASE FILE for each event is generated as follows:

1) Write out summary record(s).
   - Case 1. The input event included either zero or one summary records.
     - Case 1a. A new earthquake solution was generated. Then: Write a summary record for the new solution and discard the previous summary record, if there was one.
     - Case 1b. A new solution was not generated. This could happen, for example, if all of the arrivals are weighted out. Then: Write out a FAKE summary record followed by the summary record previously associated with the event, if there was one.
   - Case 2. The input event included two or more summary records.
     - Case 2a. A new earthquake solution was generated. Then: Write out the new summary record followed by all but the first of the summary records previously associated with the event.
     - Case 2b. A new solution was not generated. Then: Write out a FAKE summary record followed by all of the summary records previously associated with the event.

2) For each station, write out an augmented phase record with original phase data and computed data.

3) Write out the original instruction record.

The generation of archive-phase files is not compatible with the option of running events with more than one instruction record (see 2.2.6.3, 'MORE' option).

OLD DATA BASE	NEW DATA BASE
Phase records with: raw data measurements. Summary reords with: derived earthqake solution parameters, such as location depth, origin time and magnitude. Printed listings with: derived station information, such as distance, azimuth, angle of incidence, and magnitude.	Archive-phase file with: raw and derived information for each station as well as the derived earthquake solution parameters.

Figure 2-1. Organization of the old and new data base structures. Raw and derived data that were previously stored in three files are now combined into a single ARCHIVE-PHASE FILE.

The ARCHIVE-PHASE FILE may be used as a HYPOELLIPSE input phase file. In that case, the starting location, depth, and origin time will be taken from the first summary record associated with the event unless overridden by a location, depth, or origin time on the instruction record (section 2.2.6.3). The format specification for reading an ARCHIVE-PHASE FILE phase record is as follows:

Item	Col. Nos.	Format
Station name	1 - 4	A4
Any two alphanumeric symbols to describe P phases	5 - 6	A2
First motion direction of P-arrival	7	A1
C or U — Compression		
D — Dilatation		
+ — Poor compression		
- — Poor dilatation		
N — Noisy		
Blank — Not readable		
Z — Nodal, and not clearly up or down		

Item (continued)	Col. Nos.	Format
P-phase weight code	8	F1.0
0 or blank full weight		
1 Partial weight		
2 Partial weight		
3 Partial weight		
4, 5, 6, 7, 8 No weight		
If the P phase is a secondary arrival refracted along the bottom of the Ith layer, type the value of I here. If event is in the (I + 1)th layer, a direct wave calculation will be made. Below that, the weight is reset to zero.	9	I1
Year, month, day, hour, minute	10 - 19	I10
Seconds of P arrival	20 - 24	F5.2
Distance (km)	*25 - 28	F4.1
AZM - Azimuth from epicenter to station	*29 - 31	F3.0
Seconds of S arrival	32 - 36	F5.2
S remark	37 - 39	A3
S-phase weight code	40	F1.0
AIN - Angle of ray leaving hypocenter	*41 - 43	F3.0
Maximum peak-to-peak amplitude in mm	44 - 47	F4.0
Period of maximum amplitude in sec. If left blank, the standard period as specified in the station list will be used.	48 - 50	F3.2
P travel time computed	*51 - 54	F4.2
P standard error	*55 - 57	F3.2
D, B, M, J, X, R, G, or * weight code (See 2.3.7 for definition)	* 58	A1
Siemens gain state: 0 = high; 1 = low (X1/4)	61	I1
A1VCO gain range state. 0 = high; 1 = X1/10; 2 = X1/500	62	I1
Remark	63 - 64	A2
Corrected first motion symbol	*65	A1
Time correction in seconds	66 - 70	F5.2
F-P time interval in sec. for FMAG	71 - 75	F5.0
P:RES - Residual of P-arrival in seconds	*76 - 80	F5.2
S standard error	*81 - 83	F3.2
D, B, M, J, X, R, G, or * weight code	* 84	A1
S:RES - Residual of S-arrival in seconds	*85 - 89	F5.2
P delay	*90 - 92	F3.2
S delay	*93 - 95	F3.2
P elevation delay	*96 - 98	F3.2
System response code	*99 - 100	I2
XMAG	*101 - 102	F2.1
FMAG	*103 - 104	F2.1
POLARITY SOURCE CODE	105	A1
P ARRIVAL SOURCE CODE	106	A1
S ARRIVAL SOURCE CODE	107	A1
AMPLITUDE SOURCE CODE	108	A1
CODA DURATION SOURCE CODE	109	A1

Item (continued)	Col. Nos.	Format
Number of satellite hops in telemetry path, each producing a delay of 0.27 seconds.	**110	I1

* These items are added to the original arrival time record.
** If the number of satellite hops is left blank, then the telemetry delay from the station list (section 2.2.5.3) is used and this entry is computed from (satellite delay / 0.27). If the number of satellite hops is not blank then the telemetry delay is computed from (number of hops * 0.27) and the telemetry delay in the station list, if any, is ignored.

The source codes used for Alaska data processing are given below. Also shown is the corresponding System Response Code, when a specific code is required for magnitude calculation.

Source Code	Response Code	
a, A		- Readings provided by the University of Alaska
B		- Published bulletin (EDR, ISC etc)
C		- Canadian data from magnetic tape
d, D		- U of Alaska Masscomp digital data
E	9	- Eclipse
F		- Film read by USGS at University of Alaska
H		- Helicorder
M		- SMA1 strong motion recorder
S	12	- Siemens playback from magnetic tape
T		- Alaska Tsunami Warning Center (teletype, corrected for satellite delay)
V	9	- Film viewer
1	9	- One film digitizer
2	10	- CUSP FM tape
4	9	- Four film digitizer
5		- Five-day recorder
P	11	- PCELOG
N		- NEIS (corrected for satellite delay)

Use of Polarity Source Code by HYPOELLIPSE:
Station records have two fields for keeping track of station polarity (see 2.2.5), the Polarity-Reversal-Indicator in column 34 and the Tape-Polarity-Reversal-Indicator in column 48, and these two indicators do not always agree. The Polarity-Reversal-Indicator is used in correcting the observed first motion unless the polarity source code is S, in which case the Tape-Polarity-Reversal-Indicator is used.

Use of Amplitude data by HYPOELLIPSE when the station system response code is not equal to 18:
If the amplitude source code is blank or does not have a system response code listed in the table above, then the station system response code and XMAG calibration constant (C10) are taken from columns 10-11 and 12-16 of the time-dependent station archive record. Otherwise, a C10 value corresponding the the appropriate system

response is sought from the station archive. If the archive does not have the needed C10 value, then a magnitude can not be computed.

Use of Amplitude data by HYPOELLIPSE when the station system response code equals 18:
In this case use the U of Alaska subroutine UOFAMAG (see 2.2.18).

2.2.16 <u>Close current ARCHIVE-PHASE FILE and open new one</u>

In some situations it is desirable to close the archive-phase file specified when the program was started and to open a new file with a different name. To do this, use a record with ARC in columns 1-3 and the new file name in columns 19-68. The ARC record must either be included with the initial input data or follow a RESET record. The following example illustrates a run in which P1.ARC corresponds to P1.PHA and P2.ARC corresponds to P2.PHA.

```
{Items 2.2.1 through 2.2.5}
ARC               P1.ARC
ARRIVAL TIMES NEXT
JUMP P1.PHA
RESET
ARC               P2.ARC
ARRIVAL TIMES NEXT
JUMP P2.PHA
```

2.2.17 <u>Use of magnitudes not determined by HYPOELLIPSE</u>

For some earthquakes it is desirable to use a magnitude calculated by another organization, and to enter this magnitude in columns 35-36 of the summary record as the preferred magnitude. In this situation MAGTYP in column 78 is also set to some code other than F, X, or A. For example, in Alaska we use the following codes:

B	PDE mb	H	Helicorder
C	Canadian ML		
G	Geophysical Institute		
P	Palmer ML		
S	PDE Ms		
O	Other		

When earthquakes are being rerun, if the summary record precedes the phase data (See 2.2.15) and has MAGTYP not equal to F, X, or A, then the preferred magnitude and MAGTYP on the newly generated summary record will not be changed. Thus, the preferred magnitude is preserved through repeated runs of HYPOELLIPSE.

2.2.18 <u>University of Alaska magnitudes</u>

The University of Alaska, Geophysical Institute, periodically calibrates each of its seismic stations, typically at six periods: 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 s. These data are maintained in a free-formatted table that consists of up to 1000 logical records ordered in the following manner: station_code, source_code, begin_yrmody, end_yrmody, npairs, period(1), sysmag(1), period(2), sysmag(2), ..., period(npairs), sysmag(npairs). Pairs must be in order of increasing period.

Item	Col. Nos.	Format
Station name	1 - 4	A4
Beginning date of calibration (eg., 881129)	5 -10	I6
Ending date of calibration	12 -17	I6
Magnification for 0.1 through 0.6 s	18 -77	6F10.0

The name of this file must be entered on a UOFACAL record included with the input data (See 2.2.3.18). Stations with system code equal to 18 (See section 2.2.5) will have an amplitude magnitude (XMAG) computed only if calibration data for the corresponding time period is found in the table.

2.3 PRINTED OUTPUT

The line-printer outputs of HYPOELLIPSE are generally self-explanatory. The following explanations may be helpful for first time users.

2.3.1 List of stations available (each station uses two lines in the printout)

Heading	Explanation
P THK	Preferred variable layer thickness. Either 1 or 2.
VAR LAYER THICKNESS 1 and 2	Two thicknesses may be specified for the variable layer.
P MOD	Number of velocity model to be used with this station. 1 through 10.
P DLY	Preferred delay. 1 through 5.
PDLY1, SDLY1	Model 1 time delays for P and S arrivals Followed by delays for models 2 through 5.
SYS	System response code. See 2.2.5 on station list for code number assignments.
CALR	Standard calibration for XMAG
XMGC	Amplitude magnitude correction
FMWT	Weight for F-P magnitudes
FMGC	F-P magnitude correction. Multiplies observed F-P interval.
WT P	Replace P-weight code of 0, 1, 2, or 3 with this. Ignored of equal to 10.
WT S	Replace S-weight code of 0, 1, 2, or 3 with this. Ignored of equal to 10.

Heading	Explanation
POL	Two codes are printed, the first for develocorder and the second for tape. If 1, then reverse observed polarity before plotting on focal-sphere. If .GT. 1, plot as question mark.
STAWT	The reading weight is multiplied by STAWT.
TLDLY	Correction to be added to the observed time Used for satellite delays for USGS Alaska data.
YRMODY	Year, month, and day of expiration of time-dependent station parameters.
HRMN	Hour and minute of expiration

2.3.2 Program specifications

The TEST variables and abbreviated definitions are printed out so that each run is well documented. The options used and the velocity models are also printed out.

2.3.3 Vp/Vs ratio

If the Vp/Vs-value option is in effect (see TEST(49), section 2.2.4) the computed VP/VS ratios are printed out. See Chapter 5 for an explanation of the calculations.

2.3.4 Iteration output

It is recommended that PRINTER OPTION 1 be used. One line will then be printed per iteration as follows:

Heading	Explanation
I	Iteration step. If a particular step is repeated, I is also repeated.
LAT	Minutes of latitude
LON	Minutes of longitude
DEPTH	In kilometers
*	If depth constrained.
RMS	If the residuals are Ri, i = 1, NO and the weights are Wi, then

$$RMS = \left[\frac{\Sigma_1^{NO} W_i R_i^2}{\Sigma_1^{NO} W_i} \right]^{1/2}$$

Heading	Explanation
NO	Number of P, S and S-P readings used
PRMS	RMS predicted for after the next step. See section 4.4 for discussion.
DAMP	Value of damping constant in use. See section 4.
AZ	Azimuth of principal direction of error ellipsoid in degrees
DP	Dip of principal direction of error ellipsoid in degrees
STEP	Calculated step in principal direction
SE	Length of this principal semiaxis of error ellipsoid
ADJUSTMENTS DLAT DLON DZ	The adjustments in the principal directions are converted into changes in latitude, longitude, and depth.
ADJST. TAKEN DLAT DLON DZ	This adjustment will be taken to reach the next iterative location. The limits imposed by the TEST variables have been applied.

2.3.5 Quality

2.3.5.1 Based on error estimates

This quality is based on SEH (the horizontal 68 percent confidence limit in the least well constrained direction) and SEZ (the 68 percent confidence limit for depth). See Chapter 3 for further explanation of SEH and SEZ. Note that the following limits are modified from those used previous to April 1984 to reflect revised definitions of ERH and ERZ.

Quality	Larger of SEH and SEZ
A	$\leq$ 1.34
B	$\leq$ 2.67
C	$\leq$ 5.35
D	> 5.35

2.3.5.2 Quality based on many parameters

SQD-HYPO71 Quality

S is the solution quality as defined in HYPO 71:

S	RMS	SEH*	SEZ**
A	< 0.15	≤ 1.0	≤ 2.0
B	< 0.30	≤ 2.5	≤ 5.0
C	< 0.50	≤ 5.0	
D	Others		

* SEH is the horizontal 68 percent confidence limit in the least well constrained direction.

** SEZ is 68 percent confidence limit for depth.

Q is used just as a spacer between S and D qualities.

D is the station distribution quality as defined in HYPO71:

D	NO	GAP	DMIN
A	≥ 6	≤ 90	≤ DEPTH or 5 km
B	≥ 6	≤ 135	≤ 2*DEPTH or 10 km
C	≥ 6	≤ 180	≤ 50 km
D	Others		

DMIN is the distance to the nearest station.

2.3.6 Final summary output lines

Heading	Explanation
SE OF ORIG	Standard deviation of origin time.
NO ITER	Total number of iterations.
DMAX	Final value of XFAR, based on TEST(12) and TEST(46).
SEQ NO	Sequence number - taken from columns 92-96 of summary record preceeding this event.
Date Origin Lat Lon Depth	If solution based only on S-P data, an * will follow date.
MAG	Preferred magnitude. Also entered on summary record in columns 35-36. See 2.2.3.3, 2.2.17, and 2.4.1.
NO	Number of P, S, and S-P readings used in the solution.
D1	Distance to the closest station used in the solution.

Heading	Explanation
GAP	Largest azimuthal separation in degrees between stations as seen from the epicenter.
D	Number of delay model used (1 to 5)
RMS	If the residuals are Ri, i = 1, NO and the weights are Wi, then

$$RMS = \left[\frac{\Sigma_1^{NO} W_i R_i^2}{\Sigma_1^{NO} W_i} \right]^{1/2}$$

AVWT	Weights are normalized so that their sum equals NO by dividing each weight by the average weight, AVWT.
SEH	Horizontal 68 percent confidence limit for the least well constrained direction.
SEZ	68 percent confidence limit for depth.
Q - HYPO71	Average of S and D qualities defined in C.4. Rounded to lower quality when necessary.
SQD	S and D qualities defined in C.4.
ADJ	Length (km) of final adjustment of hypocenter.
I	S data indicator. 0 - S not used 1 - S is used
N	Fixed location indicator. 0 - nothing fixed 1 - depth fixed at trial depth 8 - origin time fixed at trial origin time 9 - location fixed at trial hypocenter
NR	Total number of P, S, and S-P readings regardless of weight.
AVR	Average weighted residual.
AAR	Average of the absolute value of the weighted residuals.
NM	Number of stations at which amplitude magnitude (SMAG) was calculated.

Heading	Explanation
AVXM	Average XMAG.
SDXM	Standard deviation of XMAG's calculated.
NF	Number of stations at which F-P magnitude (FMAG) was calculated.
AVFM	Average FMAG.
SDFM	Standard deviation of FMAG's calculated.

2.3.7 Detailed station output

TRAVEL TIMES AND DELAYS:

Heading	Explanation
STN	Station name
C	Component blank - vertical N - north-south horizontal E - east-west horizontal
PHA	Phase P - P-phase S - S-phase SMP - S minus P interval
REMK	Phase remark (columns 508 of phase record)
P	First motion polarity, corrected as per station history
PSEC	Seconds of P-arrival as typed on arrival time record
SSEC	Seconds of S-arrival as typed on arrival time record
RESID	Residual in seconds If a character follows the residual the meaning is: D Weight reduced to zero by distance weighting. B Weight reduced to zero by boxcar weighting. M Weight reduced to zero by truncation weighting. J Residual is greater than 3 standard deviations from the mean. Used with Jeffrey's weighting. X Weight reduced to zero during critical station run (see TEST(44)). R Computed weight less than 0.0005, so set to zero. G Beyond distance weighting cutoff but included in order to reduce gap (See TEST(46)). * Large residual flagged by RESIDUAL OPTION (See 2.2.3.12).

Heading	Explanation
STD-ER	Standard error(s) used for this arrival in hypocentral solution. The weight assigned to each phase is proportional to the inverse square of the standard error of the phase.
DIST	Epicentral distance of station (km)
AZM	Azimuth of station from epicenter (degree)
AIN	Angle of ray leaving hypocenter measured with respect to downward vertical (degree)
TC	Station clock correction in sec. from arrival time record. Added to observed arrival time.
C	Velocity model used for this travel time
VTHK	This is the thickness of the variable layer in km for the velocity model used.
TTOB	Travel time observed (sec)
TTCAL	Travel time calculated (sec)
DELAY	Station delay in seconds for model preferred by closest station
EDLY	Elevation delay (sec)
RMK	Remark from columns 63-64 of phase record
STN	Station name
SOURCES	Phase data sources followed by number of satellite hops, columns 105-110 of original phase record.

MAGNITUDE DATA:

Heading	Explanation
SOURCE	Amplitude source code from column 108 of arrival time record
SYS	System response used in computing magnitude
C10	XMAG calibration constant
AMX	Maximum amplitude in mm from input data
GR	A1VCO gain range state, 0 - normal; 1 - X1/10; 2 - X1/500
INK	Siemens playback gain, 0 - high; 1 - low (X1/4)

Heading	Explanation
AMF	Maximum amplitude, corrected for gain state and Ssiemens gain
PER	Period of wave where maximum amplitude was read. If PR is not given on arrival time record, then standard period from station archive is used. The default is 0.1s.
XMAG	Amplitude magnitude. An * follows XMAG if XMAG - AVXM > 0.5.
FMP	F-P time interval in seconds.
FMAG	Coda magnitude. An * follows FMAG if FMAG - AVFM > 0.5. An E follows if the FMAG weight for this station is zero. An S follows if the coda was too short with respect to the S-P time for a coda magnitude to be computed.

2.3.8 Auxiliary RMS sphere output

At times there may be a concern that the final iterative earthquake location is not the best one possible. If TEST(6) .NE. 0.0, then the RMS residual is calculated at 14 points on a sphere of radius = TEST(6) centered on the final hypocenter. If the hypocenter is at a minimum of RMS in space, then all the points on the sphere will have larger RMS values than the center point. The DRMS is the RMS on the sphere minus the RMS at the center and will be positive for good locations.

The average DRMS values at the ends of seven diagonals through the sphere are calculated. These are printed in order of poorest to greatest location control and are specified by their down dip azimuths.

If TEST(6) is negative and if a point on the sphere has lower RMS than the center of the sphere, iteration will resume at that point in order to improve the solution. This is allowed only once per earthquake solution to prevent an infinite loop condition from arising.

A tabulation is printed listing the number of readings used, the RMS at the center, the minimum DRMS, the average DRMS, and a quality based upon these values as follows:

Q	NUMBER	RMS	MIN DRMS	AVE DRMS
A	≥ 6	≤ 0.2	≥ 0.3	
B	≥ 5	≤ 0.4	≥ 0.15	
C	≥ 4	≤ 0.4		≥ 0.5
D	Others			

2.3.9 Focal mechanism plot

If the number of first motions is greater than or equal TEST(7) a focal mechanism plot will be made on the printer. The diagram is an equal-area projection of the lower hemisphere of the radiation field. The symbol printed is as follows:

+	1 or more +'s
C	1 compression
B	2 compressions
A	3 or more compressions
X	Any combination of compressions and dilatations
-	1 or more -'s
D	1 dilatation
E	2 dilatations
F	3 or more dilatations
?	Indicates that although a first motion was reported, the station polarity is uncertain.

A +, -, or ? is printed only if the position is not occupied by a compression or a dilatation.
If TEST(7) < 0 a second plot will be made showing station names on the focal sphere. Use TEST(45) = .1379 for 8.5 inch paper and TEST(45) = .10106 for 11 inch paper.

2.3.10 Final Tabulation

At the end of each run of a set of earthquakes a table is printed which gives the number of earthquakes within each quality specification. There is also a table which shows for each station the number of times the station was used (N), the average weight (WT), the weighted average residual (AVE), and the standard deviation of the residuals (SD).

For P- and S-arrivals there are sets of two columns in the table. The first bases the weight for the ith residual from the kth event only on the final weight prior to normalization, WTik, used in locating the kth event. The second also includes an event weighting factor, F, based upon the number of arrivals and their weights used in locating each event. For the kth event:

Fk = SUMWTk * (NRWT - 4)/NRWTk, NRWTk greater than 4

Fk = 0.0, NRWTk less than or equal 4

where NRWTk is the number of readings used in locating the kth event, and SUMWTk is the sum of the weights (WTik) of the arrivals of the kth event. Inclusion of the factor F in the weights used to compute the average station residual will bring the average residual into closer agreement with the modification in station correction that would be obtained from a joint inversion of all of the events for both location and station correction. Pavlis and Hokanson (1985) suggested using SUMWTk for this purpose. The addition of the degree of freedom term, (NRWT - 4)/NRWT should further improve the technique, in that the residual pattern for an event with few degrees of freedom will be unlikely to reflect the true station residuals. For data sets consisting of a large number of events, iterative modification of the station corrections using this table of averages and then relocating the earthquakes will give approximately the same results as joint inversion for both locations and station corrections (Pavlis and Booker, 1983; Pavlis and Hokanson, 1985).

If a station is given zero weight on its station record (section 2.2.5) it will be included in the tabulation even though it has not been used in any of the solutions. In this case the station name will be proceeded by a 'W'. If a station is assigned a P-weight code replacement of 4-8 on the time-dependent station parameter record (section 2.2.5.3), then the summary will include average P-residual information even though the P-arrivals were not used, and the P-residual standard deviation will be followed by a 'P'. The S-residual standard deviation will be followed by an 'S' in analogous situations. In either this case or the case where the station weight is zero the weight used in tabulation is based on the P-weight-code on the arrival time record (See section 2.2.6).

WARNING: The station weight and the P- and S-weight replacement codes are time dependent parameters specified in the station list. The final tabulation assumes, however, that the station weight for a given station was either zero or non-zero during the entire run, and similarly, that the weight code replacements either were or were not within the range 4-8 or not during the entire run. If these assumptions are not correct, the tabulation will be in error.

2.4 SUMMARY RECORD OUTPUT

The summary record output is controlled by the SUMMARY OPTION record described in section C.3. The station records are generated in the same format as the input station records. The other formats are given below.

2.4.1 Summary record

To save space no decimal points are used. Use the format for reading given below.

Item	Col. Nos.	Format for Reading
KDATE - year, month, day	1 - 6	I6
Origin time		
KHRMN - hour, minute,	7 - 10	I4
seconds	11 - 14	F4.2
LAT degrees	15 - 16	I2
N or S	17	A1
LAT minutes	18 - 21	F4.2
LON degrees	22 - 24	I3
E or W	25	A1
LON minutes	26 - 29	F4.2
DEPTH (km)	30 - 34	F5.2
PREFERRED MAGNITUDE	35 - 36	F2.1
NO - Number of P, S, and S-P readings used in the solution	37 - 39	I3
GAP - Largest azimuthal separation in degrees between stations as seen from the epicenter (deg.)	40 - 42	I3
D1 - Distance to closest station used in solution (km)	43 - 45	F3.0
RMS (sec)	46 - 49	F4.2
Azimuth of axis 1 of error ellipsoid (deg)	50 - 52	I3
Dip of axis 1 (deg)	53 - 54	I2
SE - length of ellipsoid semiaxis 1 (km)	55 - 58	F4.2
Azimuth of axis 2 of error ellipsoid (deg)	59 - 61	I3
Dip of axis 2 (deg)	62 - 63	I2
SE - length of ellipsoid semiaxis 2 (km)	64 - 67	F4.2
Average XMAG	68 - 69	F2.1
Average FMAG	70 - 71	F2.1
SE - length of ellipsoid semiaxis 3 (km)	73 - 76	F4.2

Item	Col. Nos.	Format for Reading
Quality - either error ellipsoid quality or HYPO quality depending upon Quality Option Record. (See section 2.2.3.4)	77	A1
MAGTYP - F, X, A, or K to indicate which type of magnitude is entered in columns 35-36. (See section 2.2.3.3)	78	A1
NSWT - Number of S-phase arrivals used in solution.	79 - 80	I2
/ or \	81	A1
[The primary summary record is always first and has a / in column 81. If an archive file has more than one summary record, the second and subsequent records will have a \ in column 81.]		
First 4 characters of instruction record	82 - 85	A4
Month data was run	86 - 87	I2
Year data was run	88 - 89	I2
S data indicator, from column 18 of instruction record.	90	I1
Fixed location indicator, from column 19 of instruction record	91	I1
Sequence number	92 - 96	A5
S-P time at closest station used in solution. Blank if either P or S is not used. Set to 9999 if S-P .GE. 100.	97 -100	F4.2
ZUP - Computed with GLOBAL option.	101 -102	F2.1
ZDN - Computed with GLOBAL option.	103 -104	F2.1
Vp/Vs - Computed slope of Ts vs Tp. Only computed if TEST(49) is not equal 0.	105 -108	F4.2
Number of readings weighted out due to Jeffrey's, truncation, or boxcar weighting.	109 -110	I2

2.4.2 Phase records in input format with corrected arrival times

This option will create a "perfect" set of data which then may be used to check the HYPOELLIPSE program. For example, one might want to know how well the program would work on events in some particular region. Fixed solutions specifying this epicentral region could be run with SUMMARY OPTION 5 and test earthquakes would be generated. The "perfect" data will be generated as follows:

Item	Col. Nos.	Format for Reading
Station name	1 - 4	A4
KDATE	10 - 15	I6
KHRMN	16 - 19	I4
SPEC - P - arrival time	20 - 24	F5.2
SSEC - S - arrival time	32 - 36	F5.2

2.5 SUMMARY OF IMPORTANT FORMATS

Formats are illustrated here for many of the input and output items. Each field includes a typical entry, an abbreviated explanation, and the format for reading the field. For more details, refer to the sections indicated.

2.5.1 Crust (See section 2.2.2)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

C R U S T	5 . 1 0 . 0 1 . 7 8 VELOCITY DEPTH-TO-TOP VP/VS-RATIO
A18	3 REAL NUMBERS WITH FREE FORMAT IN COLUMNS 19 - 80

2.5.2 Header (See section 2.2.3.15)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

H E A D E R	ANY HEADING IN COLUMNS 19 - 68
A18	A50

2.5.3 Reset test (See section 2.2.4)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

R E S E T T E S T	2 1 1 5 . TEST # NEW VALUE
A18	2 REAL NUMBERS WITH FREE FORMAT IN COLUMNS 19 - 80

2.5.4 Station - primary (See section 2.2.5)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

B R K	6 0	N	2 6 . 2 3		1 4 0	W	2 8 . 2 2		2 4 0	2	2	2 0 0	6 0 0	5	0	0
ST NAME	LAT		LAT MIN		LONG		LONG MIN		ELEV	MOD	T	THK1	THK2	D	PDLY 1	SDLY 1
A4	I2	A	F5.2		I3	A	F5.2		I4	I2	I	F4.2	F4.2	A	F4.2	F4.2

48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

0	0	0	0	2 0	1 0	3 0	- 3 0	Z
PDLY 2	SDLY 2	PDLY 3	SDLY 3	PDLY 4	SDLY 4	PDLY 5	SDLY 5	C
4.2	F4.2	F4.2	F4.2	F4.2	F4.2	F4.2	F4.2	A

2.5.5 Station - time dependent (See section 2.2.5)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

B R K	*	0	9	1 0 2		1 . 0	1 . 0			- . 3	0	3	2	8 0 0 1 0 1	2 3 0 5
ST NAME	*	ST WT	SYS	XMG CAL	XMG COR	FMG W	FMG COR	P	S	TEL DLY	D	GN	A	YR MO DY	HR MN
A4	A	F4.2	I2	F5.2	F4.2	F3.1	F4.2	I	I	F4.2	I	I2	I	I6	I4

48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94

1	1 3	3 0 6 0	4 9	A	G	D	T	C	F	1 2	3 0 6 0		1 0	3 3	1 2 . 2 1		1 1	4 1	1 5 . 3 4
T	CHN	CTR FREQ	A 5HZ							TAP	CENTR F		SYS	5HZ CAL	XMAG C10		SYS	FHZ CAL	XMAG C10
I	I2	I5	I3	A	A	A	A	A	A	I2	I4		I2	F4.0	F5.2		I2	F4.0	F5.2

95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132

	1 2	7 8	8 . 7 6		1 3	1 5 4	5 . 2 1	5 8 . 2 1	5 8 . 2 1	3 9 0
	SYS	FHZ CAL	XMAG C10		SYS	FHZ CAL	XMAG C10	REVIS LAT	REV LON	REV ELE
	I2	F4.0	F5.2		I2	F4.0	F5.2	F5.2	F5.2	I4

2.5.6 Arrival time (See section 2.2.6.2)

Columns	1–4	5–6	7	8	9	10–19	20–24	25–31	32–36	37–39	40	41–43	44–47
Example	BRK	I P	U	2		7 9 0 8 0 6 1 0 4 1	1 5 . 3 1		1 9 . 3 8	E S	3		2 2
Field	ST NAME		MA	WI	I	YR MO DY HR MN	SEC		S-SEC	SRMK	WI		MX AMP
Format	A4	A2				I10	F5.2		F5.2	A3	I		F4.0

Columns	48–50	51–58	59–62	63–64	65	66–70	71–75
Example	1		1 0 0	T L		0	2 0 0
Field	PER		CAL A	RMK		TIME COR	F-P TIME
Format	F3.2		F4.1	A2		F5.2	F5.0

2.5.7 Instruction (See section 2.2.6.3)

Columns	1–4	5–18	19	20	21–25	26–41	42–43	44	45–47
Example	M O R E		1	0			6 1	N	3 1 . 5
Field	IPRO		SI	FI	TRIAL Z		LAT		LAT MIN
Format	A4				F5.2		2.0	A	F5.2

Columns	48	49–53	54–56	57	58–62	63–72	73–74	75–80
Example	2		1 4 2	W	5 9 . 0 1		4 2	4 0 . 1 3
Field			LON		LON MIN	CUSP ID	MIN	SECONDS
Format			F3.0		F5.2	A10	2.0	F5.2

2.5.8 Archive arrival time (See section 2.2.15)

Columns	Value	Field	Format
1–4	B R K	ST NAME	A4
5–6	I P		A2
7	U	MA	A
8	2	WI	I
9			I
10–19	7 9 0 8 0 6 1 0 4 1	YR MO DY HR MN	I10
20–24	1 5 . 3 1	SEC	F5.2
25–28	6 2	DIST	F4.1
29–31	2 9	AZIM	I3
32–36	1 9 . 3 8	S-SEC	F5.2
37–39	E S	SRMK	A3
40	3	WI	I
41–43	1 0 5	A INC	I3
44–47	2 2	MX AMP	F4.0
48–50	1	PER	F3.2
51–54	2 1 3 8	PTT CAL	F4.2
55–57	9 0	P SE	F3.2
58	M	MRA	A
59–62	1 0 0	CAL A	F4.1
63–64	T L	RMK	A2
65	D	MA	A
66–70	0	TIM COR	F5.2
71–75	2 0 0	F-P TIME	F5.0
76–80	6 2 1	P RESIDU	F5.2
81–83	1 3 1	S SE	F3.2
84		RA	A
85–89	8 2	S RESIDU	F5.2
90–92	0	PDLY	F3.1
93–95	0	SDLY	F3.1
96–98	2 9	EDLY	F3.1
99–100	1	SYS	I2
101–102	1 6	XMG	2.1
103–104	2 3	FMG	2.1
105	E	PA	A
106	E	PA	A
107	E	SA	A
108	E	AA	A
109	E	CA	A
110	1	HI	I

2.5.9 Summary (See section 2.4.1)

Columns	1–6	7–10	11–14	15–16	17	18–21	22–24	25	26–29	30–34	35–36	37–39	40–42	43–45	46–49
Example	7 9 0 8 0 6	1 0 4 1	0 5 1 E	4 3	N	1 6 3 2	1 2 2	W	4 9 5 3	5 3 2	4 2	1 5	2 2 0	8 2	4 9 2
Field	YR MO DY	HR MN	SEC	LAT		LAT MIN	LON		LON MIN	DEPTH	MAG	N STA	GAP	DIST1	RMS
Format	I6	I4	F4.2	I2	A	F4.2	I3	A	F4.2	F5.2	2.1	I3	I3	F3.0	F4.2

Columns	50–52	53–54	55–58	59–61	62–63	64–67	68–69	70–71	72	73–76	77	78	79–80	81	82–85	86–89	90	91	92–94
Example	3 1	2	8 2 2	1 2 1	4	6 3 8	2 0	2 2		1 2 5 7	C	F	3	/	M O R E	1 0 7 9	1	0	E 0 1
Field	AZIM	DIP	STD ER	AZIM	DIP	STD ER	XMG	FMG		STD ER	QA	MA	N S	/	INST	MO YR	SI	FI	SEQ
Format	I3	I2	F4.2	I3	I2	F4.2	2.1	2.1		F4.2	A	A	I2	A	A4	A4	I	I	A5

Columns	95–96	97–100	101–102	103–104	105–108	109–110
Example	9 3	7 8 1	5	4	1 7 7	3
Field	NUM	S-P TIM	ZUP	ZDN	VP/VS	WTO
Format		F4.2	2.1	2.1	F4.2	I2

Chapter 3 Error Estimates

3.1 ERROR ELLIPSOID

There are three components that enter into the computation of the hypocentral error ellipsoid:

1) The estimated standard error of arrival times with zero weight code (SEZWC),
2) The weight code assigned to each arrival time, and
3) For each station, the partial derivatives of travel time with respect to latitude, longitude, and depth for the final hypocenter.

There are two options for assigning SEZWC, which is used to scale the ellipsoid. If TEST(29) is positive, then SEZWC is reset for each event to be equal to the RMS residual. This has the disadvantage that the RMS may vary significantly from event to event, and usually reflects more than simply random errors in the arrival time readings. If there are very few readings the RMS may be smaller than the true reading error, or the RMS may be larger due to systematic errors caused by an inappropriate velocity model. As an alternative, SEZWC may be fixed for all events to -TEST(29) if TEST(29) is less than zero. In this case the error ellipsoid will not reflect systematic errors or blunders (very large but rare arrival time errors), but will give an indication of the relative error between nearby events located with similar station distributions. If this latter option is used, the RMS residual of each event as well as the size of the error ellipsoid should be monitored for poor hypocentral solutions.

Large error ellipsoid axes are often the result of partial derivatives with respect to one parameter that are all very small or all nearly equal. For example, for an earthquake near the center of a single ring of stations, the partial derivatives with respect to depth will be nearly the same for all of the stations. This leads to a trade off between depth and origin time because the partial derivative of travel time with respect to origin time is also the same for all stations (always equal to 1.0).

The semimajor principal axes of the 68 percent joint confidence ellipsoid are output on the SUMMARY RECORD for each earthquake. The printed output also includes two horizontal single 68 percent confidence estimates, the larger being called SEH, and the single variable 68 percent confidence estimate for depth, SEZ. The relationship of these error estimates to the error ellipsoid is shown in Figure 3-1. The relationship between a joint two dimensional probability distribution (Pxy) and a one dimensional distribution (Px) is illustrated in Figure 3-2. For each value of x, Px is equal to the integral over y of the joint probability function Pxy. The ratio between s, the 68 percent confidence limit for x, and m, the maximum deviation of the 68 percent joint confidence ellipse in the x direction, is equal to the square root of the ratio of the 68 percent value of chi-square with one degree of freedom to the 68 percent value of chi-square with two degrees of freedom. Similarly, the scaling relationship between the shadow of the joint hypocentral ellipsoid and the joint epicentral region is based on chi-square values for two and three degrees of freedom (Figure 3-3).

DEGREES OF FREEDOM	CHI SQUARE VALUE	SQUARE ROOT OF CHI SQUARE
1	1.00	1.00
2	2.30	1.53
3	3.51	1.87

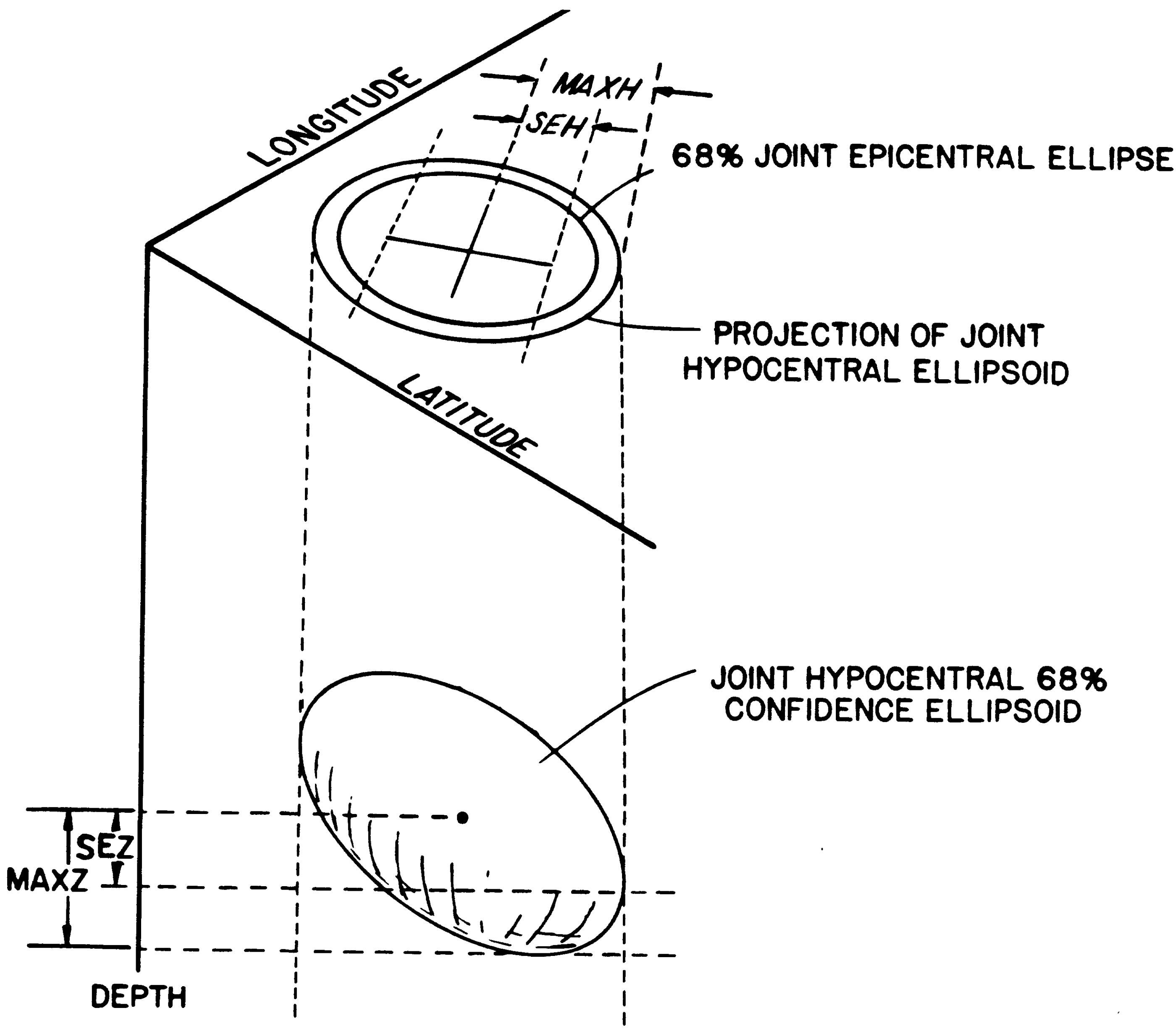


Figure 3-1. Error ellipsoid relationships. SEH = MAXH/1.87. SEZ = MAXZ/1.87.

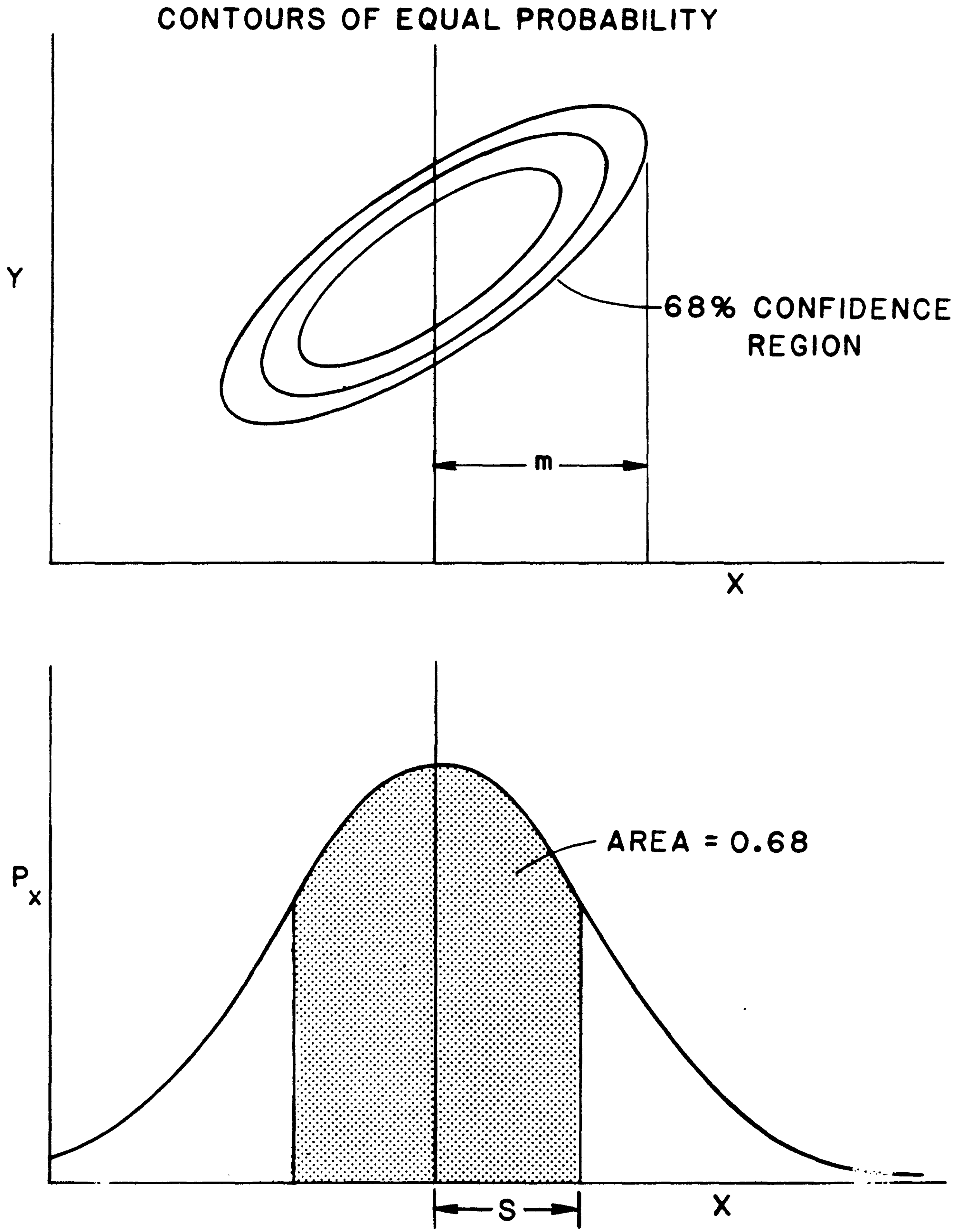


Figure 3-2. Upper: Contours of equal probability in two dimensional probability distribution (Pxy). Lower: One dimensional probability distribution (Px) with same x scale as in upper figure.

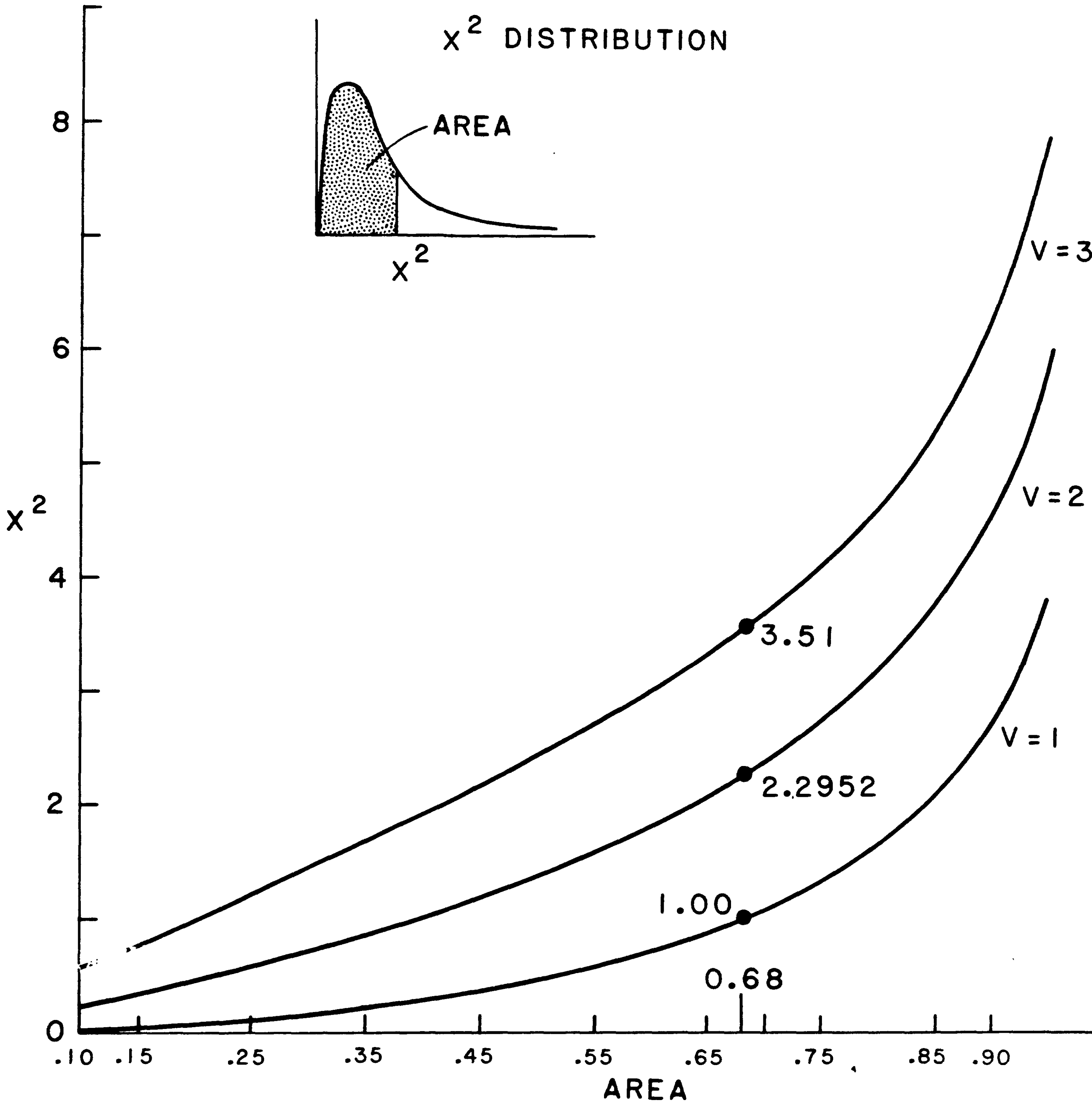


Figure 3-3. Chi-square versus area plots for 1, 2, and 3 degrees of freedom.

3.2 GLOBAL LIMITS ON DEPTH

The error ellipsoid is computed from the partial derivatives of travel time with respect to latitude, longitude and depth, evaluated at the final hypocenter determined for the earthquake. The travel times are not linear, however, so the error ellipsoid is an appropriate measure of the errors only to the extent that the partial derivatives are linear in the region nearby the final location and that there is only one spatial minimum of RMS. Earthquakes in southern Alaska often have a minimum in RMS at two different depths, and sometimes neither minimum is significantly lower than the other. To help deal with these events, and also as a check on the error ellipsoid, the maximum upward and downward shifts of the depth that still have RMS less than RMSLIM are computed and added to each summary record when the GLOBAL option is used (See section 2.2.3.11). RMSLIM is defined so that the depth limits correspond to one standard deviation in depth.

RMSLIM = SQRT(RMSZERO**2 + (YSE**2)/N)

where RMSZERO is the RMS of the final solution, YSE is the estimated standard error of the readings, and N is the number of phases used.

Nine events from southern Alaska are plotted in cross section in Figure 3-4. The final computed hypocenter, the projected error ellipsoid, and the depth limits computed with the GLOBAL option are all shown. Note that the final hypocenter is not necessarily centered within the range of acceptable depths. In some cases this is due to the depth range spanning a local maximum and in others it is due to the iteration stopping because the minimum is essentially flat over a finite depth range. Also note that the error ellipsoid may indicate either a larger or smaller depth error than is indicated by the computed depth range. Although the depth range is indicated by a vertical line segment, the epicenter is not fixed during the search for alternative depths, so the true spatial pattern of alternative solutions is not indicated in this plot.

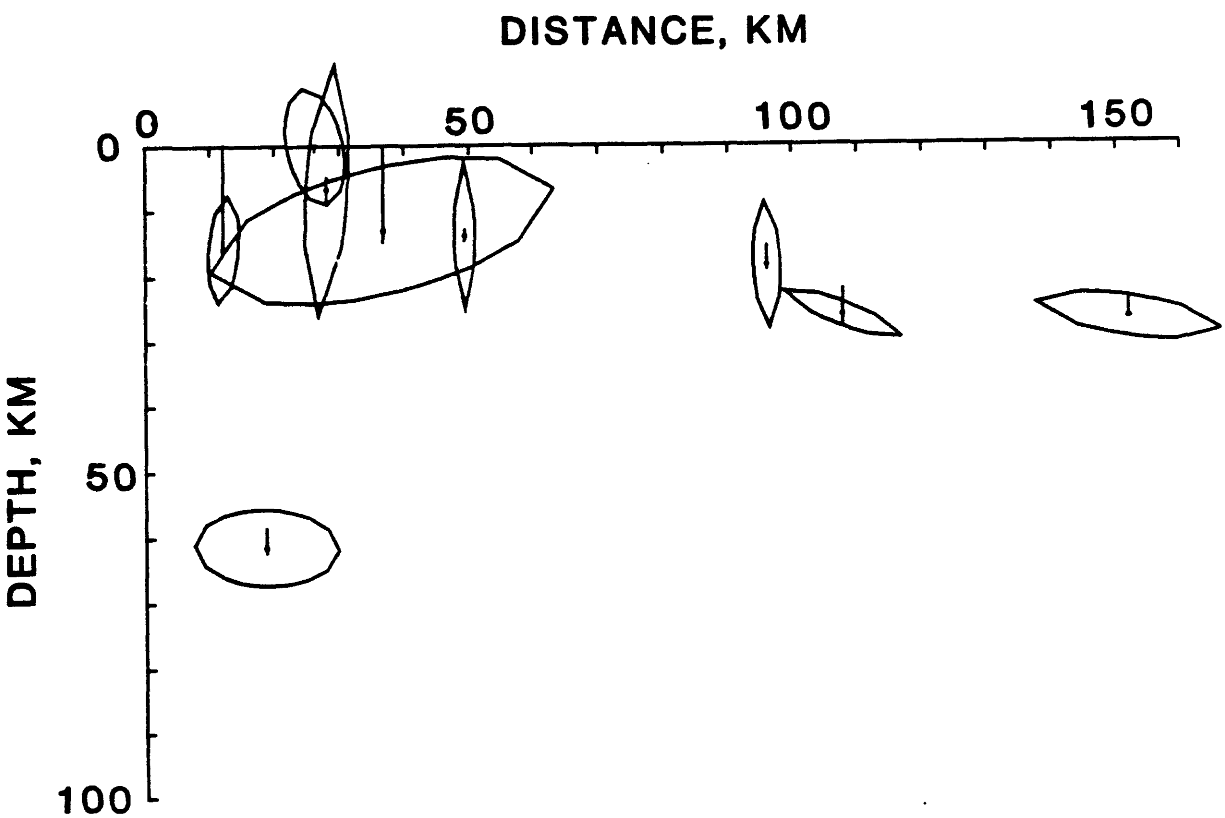


Figure 3-4. Cross section showing relationship between hypocenters, error ellipsoids and depth ranges computed with the GLOBAL option.

Chapter 4 Magnitude Determinations

Magnitudes may be calculated from the maximum amplitude on the seismogram (XMAG) or from the length of time from the P arrival to the end of the coda (FMAG). These two methods will be described briefly.

4.1 CODA MAGNITUDE, FMAG

The FMAG is calculated according to an empirical equation (Lee and others, 1972; Lahr and others, 1975; Bakun and Lindh, 1977) which has been found to be in reasonable agreement with the local Richter magnitude scale.

$$FMAG = C1 + C2\ \log10(F\ c) + C3\ D + C4\ Z + C5\ (\log10(F\ c))^2$$

where:

- C1, C2, C3, C4, and C5 are found empirically and correspond to the test variables 31, 32, 33, 40, and 43.
- F = F-P time (s), defined to be the time between the P phase arrival and the time when the coda drops to 1 cm p-p amplitude on a Geotech Model 6585 film viewer.
- D = Epicentral distance in km.
- Z = Hypocentral depth in km.
- c = Station FMAG correction

For California,		for Alaska,	
C1 =	-0.87	C1 =	-1.15
C2 =	2.0	C2 =	2.0
C3 =	0.0035	C3 =	0.0
C4 =	0.0	C4 =	0.007
C5 =	0.0	C5 =	0.0

The station correction (c) is not added to the coda magnitude calculated, but is used as a multiplier of the observed coda. Therefore a station with no correction should have FMAG correction equal to 1.0. If the station record has no entry for FMAG correction, then the correction will be set equal to 1.0. The fifth term in the formula,

$$C5\ (\log10(F\ c))^2$$

can be used to compensate for the nonlinear relationship of log(F) with magnitude (Bakun and Lindh, 1977).

If a negative code is used for MAGNITUDE OPTION then the F minus P coda length from the arrival time record will be converted into the F minus S coda length by subtraction of the S-P time. This formulation may be useful for earthquakes with wide depth variations, but is now only experimental.

Coda magnitude will not be computed for a station if the portion of the coda following the S arrival is less than 20 per cent of the total coda duration. This prevents FMAG from being computed from stations without a significant coda following the S phase.

4.2 LOCAL RICHTER MAGNITUDE, XMAG

4.2.1 Background and Calibration

In order to understand the calculation of XMAG, it is necessary to review the system calibration as described by Eaton (1970).

At any frequency f:

Ground Motion 2h mm -> Geophone EP microv -> Telemetry -> Viewer screen 2A mm

Seismometer Response $SP(F) = \frac{EP}{2h}$ microvolts/mm

System Response $V(f) = \frac{2A}{EP}$ mm/microvolt

Total Harmonic Magnification $MF(f) = SP \times V = \frac{A}{h}$ mm(viewer)/mm(ground)

The system response at some frequency f may be calculated from the response at a particular frequency fo multiplied by the ratio of the response at f to the response at fo

$$V(f) = V(fo) * \frac{V(f)}{V(fo)}$$

If the Develocorder amplitude A is measured for input signals EP of constant amplitude and varying frequency f then the ratio

$\frac{V(f)}{V(fo)} = \frac{A(f)}{A(fo)}$ may be calculated as a function of frequency f.

Thus $V(f) = V(fo) * \frac{A(f)}{A(fo)}$

V(fo) is calculated for fo = 5 hz for a 10 microV rms input signal. 10 microV rms equals to 28.28 microV p-p. Let the amplitude A(5) for this signal be C10.

$$V(f) = \frac{C10}{28.28} * \frac{A(f)}{A(5)}$$

The formula for geophone response is:

$$SP(f) = \frac{2\, Pi\, f^3\, G_{LE}}{[(F^2 - f^2)^2 + 4B^2\, Fo^2\, f^2]^{1/2}}$$

where: Fo = natural frequency
B = damping constant
G_{LE} = motor constant microvolts/mm/s

TGN(f) is defined to be SP(f) divided by 28.28.
Thus the total harmonic magnification is:

$$MF(f) = SP * V = \frac{2Pi\ f^3\ G_{LE}}{[(Fo^2 - f^2)^2 + 4B^2\ Fo^2 f^2]^{1/2}} * \frac{C10}{28.28} * \frac{A(f)}{A(5)}$$

Using the definition of TGN(f) this becomes:

$$MF(f) = C10 * \frac{A(f)}{A(5)} * TGN(f)$$

MF(f) = "Gain"	*	System frequency response	*	Seismometer response divided by 28.28	mm(viewer)/mm(ground)

To calculate magnitudes equivalent to the local Richter magnitude it is necessary to calculate the amplitude (f) that would have been read on the seismogram from a Wood-Anderson seismograph. The magnification of the Wood-Anderson is

$$MWA(f) = \frac{2800\ f^2}{[(Fo^2 - f^2)^2 + 4B^2\ Fo^2\ f^2]^{1/2}} \quad \text{mm(WA record)/mm(ground)}$$

with Fo = 1.25, B = 0.8.

Therefore, the amplitude that would be measured on a Wood-Anderson record is:

$$B(f) = \frac{A(f)}{MF(f)} * MWA(f)$$

$$B(f) = \frac{A(f)}{C10} * \frac{MWA(f)}{TGN(f)} * \frac{A(5)}{A(f)}$$

$$B(f) = A(f) * \frac{MWA(f)}{TGN(f)} * \frac{A(5)}{A(f)} / C10$$

B(f) = A(f)	*	$\frac{MWA(f)}{TGN(f)} * \frac{A(5)}{A(f)}$	/	C10
Amplitude p-p in mm measured on viewer. f is also measured on the viewer.		Value is determined by interpolation in the table corresponding to the system in use.		Station calibration from station record.

It is convenient to carry out the interpolation in terms of the table:

$$RSPA(n) = \log \frac{TGN(f_n)A(f_n)}{MWA(f_n)A(5)} \quad \text{vs} \quad \log(f_n)$$

where $\log(f_n) = -2.0 + 0.1n$.

For the eight standard systems these values are stored for n = 15,34 corresponding to frequency from 0.316 to 25.119 hz or to period from 3.162 to 0.040 s.

4.2.2 Computer Formula used for XMAG

The formula for computing Richter's local magnitude is

$$XMAG = \log(A/2C10) - R_{kf} \quad - \quad B_1 + B_2 \log^2 X \quad + \quad G$$

log of maximum zero to peak amplitude in mm as recorded on a standard Wood-Anderson seismograph.	Approximation to Richter's logAo	Station Correction

where:

R_{kf} = frequency response of system number k for frequency f interpolated from table of RSPA(n).

A = Maximum peak-to-peak amplitude in mm.

C10 = USGS J202 calibration peak-to-peak amplitude for 10 microV rms, 5 hz preamplifier input.

B_1 = 0.15
for 1 km $\leq$ D < 200 km
B_2 = 0.80

B_1 = 3.38
for 200 km $\leq$ D $\leq$ 600 km
B_2 = 1.50

X = $D^2 + Z^2$, where D is the epicentral distance and Z the focal depth in km.

G = Station XMAG correction.

Figure 4-1 shows a comparison of log Ao from Richter (1958) and the approximation used in this program. Subroutine XFMAGS calculates the Richter magnitude for hypocentral distances, D, of 0.1 to 600. km.

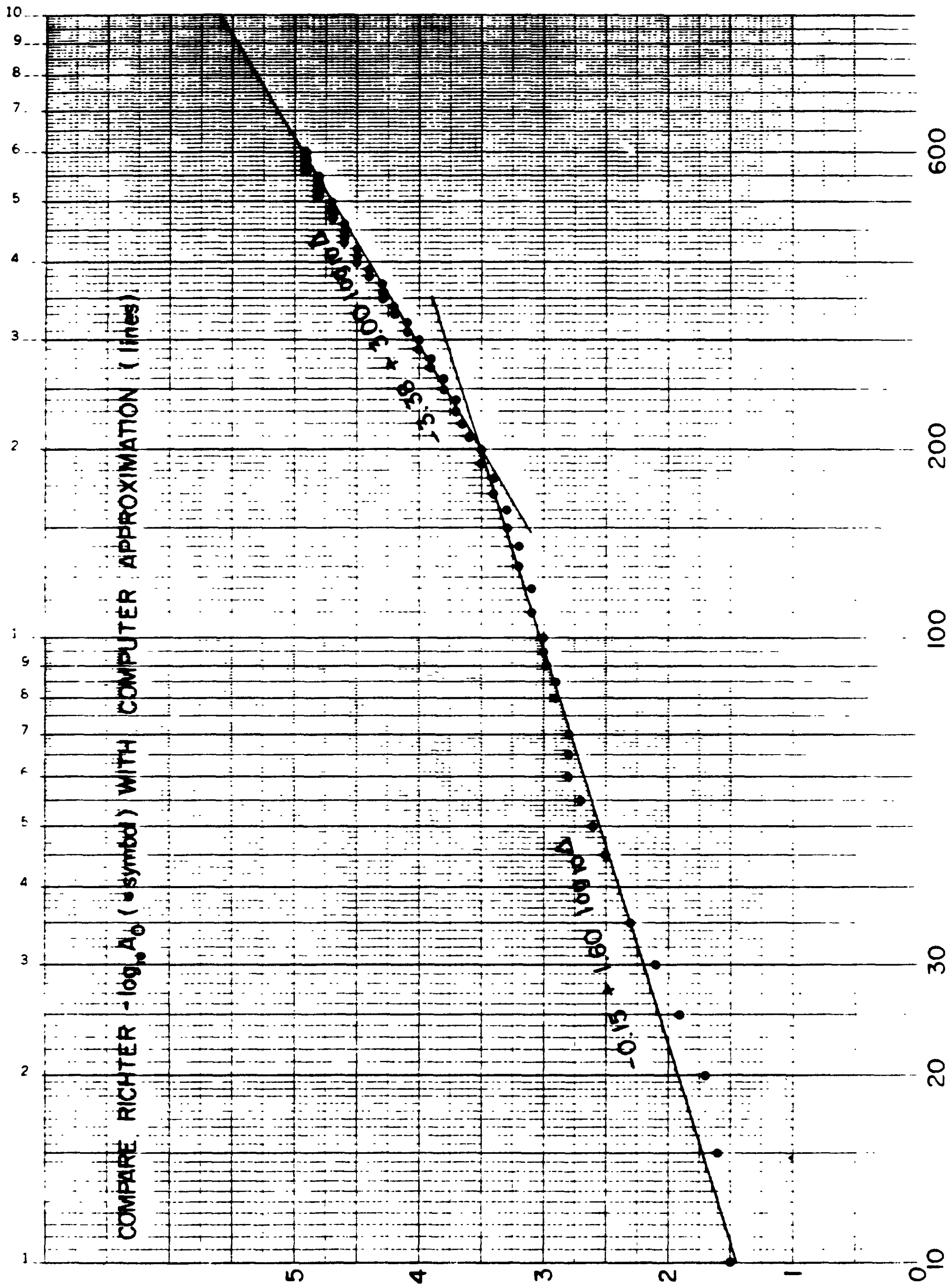


Figure 4-1. Comparison of log Ao from Richter (1958) and the approximation used in this program.

4.2.3 Calibration Curves for the AlVCO

For the AlVCO (Rogers and others, 1980), calibration parameters have been computed for RSPA(n) from the following equation:

RSPA(n) = LOG10(MF(Fn)/MWA(Fn)), where

Fn is the is defined by log(Fn) = -2.0 + 0.1n
MF is the magnification of an ideal AlVCO when set to gain zero, and
MWA is the maginfication of a Wood-Anderson instrument.

To account for variations in gain setting and other variations from instrument to instrument, the C10 value is defined to be:

C10 = (2 exp N) * MAMP/PAMP, where

MAMP is the measured amplitude of the 5 Hz calibration signal and
PAMP is the theoretical signal level for an ideal instument.

Chapter 5 Determination of Vp/Vs Ratio

If the P and S phases of an earthquake are read at two or more stations and if the ratio of the P velocity to the S velocity (Vp/Vs) is assumed to be a constant, then the Vp/Vs ratio and origin can be computed. If P and S arrival pairs are available from more than two stations, then in general a plot of S arrival time versus P arrival time will not define a single straight line, so some "best fitting" line must be found in order to estimate the slope (Vp/Vs) and origin time. Since both the P and the S arrival times are subject to random errors, it is not appropriate to compute the least square regression of P on S (which assumes S has no errors) or the regression of S on P (which assumes P has no errors). Instead, errors in both P and S should be taken into account by minimizing (Madansky, 1959)

$$T = \mathrm{SUM}\ (i = 1 \text{ to } n)\ W_i * (S_i - A - B * P_i)^2$$

where, $B = V_p/V_s$, A is the S axis intercept, and

for the i^{th} of n stations:

S_i is the S arrival time

P_i is the P arrival time

$W_i = (E_{S_i}^2 + B^2 * E_{P_i}^2)^{-1}$

E_{S_i} = C times the standard error of the S arrival time

E_{P_i} = C times the standard error of the P arrival time

[The standard errors are computed from the assigned wieght codes for P and S. C is an arbitrary constant.]

Although there are closed solutions to this problem if the standard errors variances of S and P are not functions of i (Madansky, 1959), an iterative technique was developed for use with seismic data for which the variance is estimated for each reading. In computing the sum to be minimized for a given value of B, the data are first centered by subtracting the weighted mean of the S arrivals from each S arrival time and the weighted mean of the P arrivals from each P arrival time:

$$SC_i = S_i - \frac{\mathrm{SUM}\ W_i * S_i}{\mathrm{SUM}\ W_i} \qquad PC_i = P_i - \frac{\mathrm{SUM}\ W_i * S_i}{\mathrm{SUM}\ W_i}$$

then the sum (T) to be minimized is computed from:

$$T = \mathrm{SUM}\ W_i * (SC_i - B * PC_i)^2$$

To find the value of B that minimizes T, T is initially computed for five values of B defined by:

$$B_k = BL_2 - DB_2 * (k - 3) \ , \ k = 1 \text{ to } 5$$

where $DB_2 = 0.6$ and BL_2 is the average of the weighted least squares regression slope of S on P and the inverse of the weighted regression slope of P on S. The slope is then compared for the five values of B defined by :

$$B_k = BL_2 - DB_2 * (k - 3) \ , \ k = 1 \text{ to } 5$$

where $DB_2 = 0.4 * DB_1$ and $BL_2 =$ the value of B_k which gave the minimum sum T in the previous step. This process is repeated 6 more times, so that B is resolved to the nearest 0.001 units.

The printed output includes the VP/VS ratio and the standard error of the VP/VS ratio computed from S regressed on P and also from P regressed on S. The standard error of the slope computed using both P and S weights is estimated from the square root of the sum of squares of the standard deviations computed for S regressed on P and for P regressed on S.

Chapter 6 Generating Travel Time Tables with Program TTGEN

[This chapter is excerpted from HYPOINVERSE manual (Klein, 1985) with a only a few minor modifications.]

6.1 USE OF TRAVEL TIME TABLE

The program reads a travel time table generated independently of the location process, and calculates travel time, travel time derivatives, and emergence angles at the source by interpolation from the table. Three point (parabolic) interpolation is used within the table, and linear extrapolation is used beyond the table. The table itself is a condensed grid of travel times as a function of distance and depth, so that travel times for shallow nearby sources may be accurately modeled without wasting space on deep or distant grid points where the travel time curve changes slowly. The user may generate his own travel time table empirically, with another program, or use the travel time generating program TTGEN to prepare a table from a given velocity-depth function.

6.2 ALLOWABLE VELOCITY MODELS INPUT TO TTGEN

Velocity models consist of from 2 to 15 points at which the user specifies velocity and depth. Linear velocity gradients are assumed to connect the points. The last point fixes the velocity and depth of the homogeneous half-space underlying the model. The halfspace velocity must be the greatest of any velocities specified to insure that rays can be refracted along the top of the halfspace.

The use of linear gradients smooths out the discontinuities in travel time derivatives which result from homogeneous layer models, and gives a more realistic spread in emergence angles of downgoing rays than is possible with modeling rays as refracted from discontinuities.

One buried low velocity zone is permitted in the model. This means that velocity may not decrease with depth except for one group of adjacent velocity points. Hypocenters that occur within a low velocity zone may produce a shadow zone at the surface, and rays in this distance range are calculated as if refracted along the layer above the low velocity zone.

TTGEN can handle models with homogeneous layers, (zero gradients), but velocity discontinuities (infinite gradients) are not allowed. Velocity gradients should assume reasonable values such as 0.0 or between 0.02 and 8.0 km/s/km in the interest of numerical stability.

TTGEN operates by shooting rays out from the source and calculating time, distance, and other parameters where (and if) they emerge at the surface. Layers with steep gradients (such as might be used to model a Moho transition) can produce reverse branches in the travel time curve, and such layers should be at least 0.3 km thick to insure that enough rays will bottom in the layer to define the travel time curve properly. Errors can be introduced in the final travel time table by undersampling a too complicated or irregular velocity model with too few rays.

6.3 USING THE PROGRAM TTGEN

At depth intervals specified by the user, the program shoots rays with increasing ray parameter starting with vertically emergent rays, and calculates distance, travel time, and other parameters for each ray (see outputs of TTGEN section). At each depth, a printed listing of these results is produced, noting any reverse branches or rays lost to a low velocity waveguide. The program then produces the final travel time table by interpolating travel times at distance intervals specified by the user. Interpolation is done in the first arrival from among the various branches including refractions from the halfspace and top of a low velocity zone.

6.4 INPUT TO TTGEN FROM THE FILE TTMOD

All model parameters including depth, distance, and ray intervals at which computations are to be performed are specified in a velocity model file. The program uses reduced travel times for the table to save space. One specifies the inverse of the reducing velocity REDV (in s/km) to use in calculation. The reduced travel time is the absolute time minus distance times REDV. The values of reduced travel time passed to the location program with the table are limited to the range 0 to 32 s, and the user is responsible for choosing a suitable reducing velocity to stay within these limits. Using a reducing velocity equal to the halfspace velocity is a good choice.

The user specifies the amount by which the independent parameter Q is incremented to calculate the distance and time for rays of various ray parameter and emergence angle. Ray parameter P and emergence angle PHI are functions of Q as follows:

$$PHI = 2 * TAN^{-1} \frac{Q}{(ZH + 1/2)}$$

$$P = \frac{SIN\ (PHI)}{VH}$$

where ZH and VH are depth and velocity at the hypocenter, respectively. Q is a better independent parameter than either P or PHI since it gives a greater density of rays for deeper penetrations. This also gives the distant travel time points a distance spacing comparable to nearby points.

The parameter Q is incremented as follows. It takes on the value 0.0 and NQ1 values at increments of DQ1, then NQ2 values at increments of DQ2. The largest value of Q is thus NQ1 * DQ1 + NQ2 * DQ2, and the greatest number of rays (maximum value of NQ1 + NQ2) is 200. Ray calculation stops when downgoing rays begin to penetrate the halfspace, and travel times appropriate to a refracted ray are used beyond this point. Values of DQ1 = .08, NQ1 = 100, DQ2 = 0.4, and NQ2 = 100 are a good first try, and generally insure that the entire travel time curve can be adequately defined by less than 200 rays.

The grid points in distance and depth at which travel times are calculated for output to the final table are determined by eight parameters similar in concept to the Q parameters described above. Travel times are calculated at depths of 0.0 and NZ1 values at increments of DZ1, then NZ2 values at increments of DZ2. This permits a fine grid spacing for shallow depths and a coarse spacing at greater depths where the travel time curve will be smoother. Similarly, travel times are calculated at distances of 0.0, DD1, 2DD1, up to ND1 * DD1, and then at ND2 values in increments of DD2. Presently the maximum value of NZ1 + NZ2 is 27, and ND1 + ND2 may be as large as 41.

6.5 VELOCITY MODEL INPUT FORMAT (PROMPT IS GIVEN FOR THE NAME OF THIS FILE)

Line	Columns	Format	Example	Explanation
1	1-8	4A2	TTPR	Printed output filename with .DAT extension added, eg. TTPR.DAT.
1	9-16	4A2	TAB	Travel time table output filename, with .DAT extension added, eg. TAB.DAT. Plot file table output filename, eg. TABxxx.DAT where xxx = DEPTH and one file is generated for each depth in travel time table. Each file contains distance (km), travel time (s) and reduced travel time (s).
1	17-26	F10.2	0.12	REDV, one over the reducing velocity used to condense the travel time plots and tables.
1	27-36	F10.2	1.78	Vp/Vs velocity ratio.
*2	1-5	F5.2	.08	DQ1 Parameters for incrementing the
2	6-10	I5	100	NQ1 independent parameter Q governing ray
2	11-15	F5.2	.04	DQ2 spacing (see Text).
2	16-20	I5	100	NQ2
*3	1-5	F5.2	4.	DZ1 Parameters for incrementing the grid
3	6-10	I5	12	NZ1 spacing in depth (see text).
3	11-15	F5.2	10.	DZ2
3	16-20	I5	15	NZ2
*4	1-5	F5.2	4.	DD1 Parameters for incremenating the grid
4	6-10	I5	26	ND1 spacing in distance (see text).
4	11-15	F5.2	15.	DD2
4	16-20	I5	15	ND2
5	1-20	10A2	Alaska	Title to appear within travel time table.
*6	1-5	F5.2	5.6	Velocity of first point (km/s).
6	6-10	F5.2	0.0	Depth of first point (km). This format is repeated for each velocity-depth point of the model, one line per point, up to a total of 15 points. The first depth must be 0.0 km. The last point given sets the velocity and depth of the halfspace.

* Lines 2, 3, 4, and 6 are read in free format in this implementation.

6.6 OUTPUTS OF TTGEN

The condensed travel time table contains all the information necessary to identify itself and be used by HYPOELLIPSE.

The printed output of TTGEN contains one tabulation for each depth grid point. One line is printed for each ray calculation until the deepening rays reach the halfspace. The tabulated data is as follows:

J	The ray index used to reference rays defining the endpoints of a shadow zone or reversed branches.
Q	The user-defined parameterizing variable. Equal increments of Q are designed to give a greater density of deeper rays where they are needed to define the travel time curve.
EM.ANG	Emergence angle of ray at the source, measured in degrees from zenith.
P	Ray parameter in s/km.
DIST	Distance in km at which ray reaches the surface. If DIST = -1, then the ray is trapped in a waveguide and does not reach the surface.
TIME	Travel time in s.
REDUCED	Reduced travel time in s, given by TTIME - DIST * REDV, where REDV is one over the reducing velocity.
L.BOT	The layer in which downgoing rays bottom.
Z.BOT	The depth at which downgoing rays bottom.
V.BOT	The velocity at which downgoing rays bottom.
DDIF	Distance difference between this and the preceding ray. DDIF is negative on reverse branches.
BR	Branch number. It is incremented by 1 each time a new forward branch is encountered.
AMP	Relative amplitude of the ray at the surface assuming an isotropic source and geometrical spreading. It is just the ratio of the area of a ring on a unit sphere surrounding the source to the corresponding area at which rays emerge at the earth's surface.
AMP*R2	Amplitude times distance squared. Used to estimate the difference between actual and ideal inverse-square spreading.
REMK	Remark such as RB (reversed branch) or WG (ray in wave guide).

Chapter 7 Acknowledgements

This computer program is one of a series of hypocenter programs developed at the U. S. Geological Survey and draws heavily on the previous programs. Eaton (1969) wrote the first USGS program, outlined the basic principles of Geiger's method, determined how to calculate traveltimes, magnitude, etc. Lee (1970) made major modifications to Eaton's program to make it computationally more efficient, to use stepwise multiple regression, to use azimuthal and Jeffrey's weighting, and to greatly improve the output format. Lee and Lahr (1972) further modified Lee's program to use S minus P interval time and to facilitate user modification of the iteration controlling parameters. The first-motion plotting routine is adapted from a program by M. S. Hamilton. The use of secondary refraction arrivals was suggested and first implemented by P. Papanek. The azimuth and apparent velocity routine was adapted from a program by H. M. Iyer. The method for solving the regression equations and finding the standard error ellipse was developed by J. C. Lahr. The traveltime routine, originally written by Eaton, was considerably modified by P. L. Ward and F. W. Klein. The program for generating a travel time table (TTGEN) and the subroutines for interpolating travel times from the table were modified only slightly from F. W. Klein's HYPOINVERSE location programs. The overall control logic and computational details were extensively modified from the Lee and Lahr (1972) version of HYPO71 by J. C. Lahr and P. L. Ward. The linear velocity over a half-space traveltime subroutines were written by W. Gawthrop. Distance and azimuth are calculated using a subroutine written by B. R. Julian. With this subroutine there is no longer a limit of 70 N. to 70 S. (as in pre-1982 versions of HYPOELLIPSE) and distance and azimuth determinations are more accurate. Correspondence with J. A. Snoke have been instrumental in clarifing the relationship between the error ellipsoid and other error estimates. The program has benefitted from many discussions with C. D. Stephens and A. G. Lindh and early manual reviews by W. H. Bakun and R. A. White. Many helpful corrections and revisions to the current version were made at the suggestion of C. D. Stephens.

Chapter 8 References

Bakun, W. H., and Lindh, A. G., 1977, Local magnitudes, seismic moments and coda durations for earthquakes near Oroville, California, Bulletin of the Seismological Society of America, 67, p. 615-629.
Draper, N. R., and Smith, H., 1966, Applied regression analysis, 407 pp., John Wiley and Sons, New York.
Eaton, J. P., 1969, HYPOLAYR, a computer program for determining hypocenters of local earthquakes in an earth consisting of uniform flat layers over a half space, U.S. Geological Survey Open-File Report, 155 p.
Eaton, J. P., 1970, Harmonic magnification of the complete telemetered seismic system, from seismometer to film viewer screen, U.S. Geological Survey Open File Report, 23 pp.
Geiger, L., 1912, Probability method for the determination of earthquake epicenters from the arrival time only, (translated from Geiger's 1910 German article) Bulletin of St. Louis University, 8 (1), p. 56-71.
Jeffreys, H., 1961, Theory of Probability, (3rd ed.) Oxford at the Clarendon Press, London, p. 214-216,
Klein, F. W., 1985, User's guide to HYPOINVERSE, a program for VAX and Professional 350 computers to solve for earthquake locations, U.S. Geological Survey Open-File Report 85-515, 53 p.
Lahr, J. C., Page, R. A., and Thomas, J. A., 1975, Catalog of earthquakes in south central Alaska, April-June 1972, U.S. Geological Survey, Open-File Report, 30 p.
Lahr, J. C., 1980, HYPOELLIPSE/MULTICS: A computer program for determining local earthquakes hypocentral parameters, magnitude, and first motion pattern, U.S. Geological Survey Open-File Report 80-59, 59 p.
Lahr, J. C., 1984, HYPOELLIPSE/VAX: A computer program for determining local earthquakes hypocentral parameters, magnitude, and first motion pattern, U.S. Geological Survey Open-File Report 84-519, 76 p.
Lahr, J. C., 1980, SQUASH/MULTICS: A computer program to be used in conjunction with HYPOELLIPSE to generate an augmented phase data archive, U.S. Geological Survey Open-File Report 80-375, 11 p.
Lee, W. H. K., Bennett, R. E., and Meagher, K. L., 1972, A method of estimating magnitude of local earthquakes from signal duration: U.S. Geological Survey Open-File Report, 28 p.
Lee, W. H. K., and Lahr, J. A., 1972, HYPO71: a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes, U.S. Geological Survey Open-File Report, 100 pp.
Pavlis, G. L. and Booker, J. R., 1983, Progressive multiple event location (PMEL): Bulletin of the Seismological Society of America, V. 73, p. 1753-1777.
Pavlis, G. L., and Hokanson, N. B., 1985, Separated earthquake location, Journal of Geophysical Research, V. 90, p. 12777-12789.
Madansky, A., 1959, The fitting of straight lines when both variables are subject to error, Journal of the American Statistical Association, V. 54, p. 173-205.
Rogers, J. A., Maslak, Sam, and Lahr, J. C., 1980, A seismic electronic system with automatic calibration and crystal reference, U. S. Geological Survey Open-File Report 80-324, 130p.