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

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

By

John C. Lahr

Open-File Report
84-519

*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, and most recently on a USGS DEC VAX/VMS. June 29, 1984.

CONTENTS

NOTES

If a copy of the HYPOELLIPSE program is desired, the author can copy the program onto a balnk magnetic tape provided. The tape format is ANSI-standard label with ASCII characters, fixed-block length, 9-track, and 1600 density. Most of the program is written in FORTRAN IV language.

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 distribution between 0 and 1. Most computer systems have some equivalent subroutine available. Random numbers are used in two optional portions of the program (Chapter II, sections B.13 and B.15) that could be removed, if desired.

The files used by HYPOELLIPSE are:

FILE NO.	READ	WRITE	CONTENTS
8	X		Input control parameters and earthquake data
4		X	Summary record file which may be generated.
6		X	Final summary showing the average residual for each station.
9		X	Printed output from execution
1	X	X	Following a SAVE record, phase data is written to this scratch file. Following a RERUN record, the saved phase data is reread.
2	X	X	Station parameter scratch file.
3	X	X	Station parameter scratch file.
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.
11		X	Archive-phase file.

I. Introduction to HYPOELLIPSE

HYPOELLIPSE is a computer program for determining the hypocenters of local or near regional earthquakes and for each event the ellipsoid which encloses the 68°/° confidence volume. Traveltimes are determined from a horizontally layered crustal structure, from a linear increase of velocity with depth, or from a linear increase of velocity over a half-space. 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 crustal 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 first motions can be plotted on the printer using an equal area lower focal hemisphere projection. A map showing the location of each epicenter can be plotted directly on the printer, or a summary record output file can be used as input to another program for plotting on a graphic plotter. The azimuth and apparent velocity of a plane wave crossing the array from a distant source can also be determined.

This report doccuments the current version of HYPOELLIPSE which is operating on the USGS DEC VAX780/VMS computer in Menlo Park and supersedes the MULTICS version (LAHR, 1980). The most recent changes (April 1984) include the following:

1) The printed horizontal and vertical error limits (ERH and ERZ) have been rescaled so that they correspond to single variable 68% confidence limits. Earlier versions of the program printed 94% confidence limits. The 68% 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 preceed 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.

II. HYPOELLIPSE Users Guide

CONTENTS

CONTENTS

II. HYPOELLIPSE Users Guide

A. INTRODUCTION

HYPOELLIPSE has been developed to meet some of the research needs of the USGS Office of Earthquake Studies 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, crustal model, and a few sets of earthquake arrival times. Then review sections B.1 through B.4 for modifications to the default conditions or additional calculations which your data set require. After the run, refer to section C to interpret the printed output.

The choice of which crustal 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 crustal 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 B.3e would be set equal to 0.0. On the station list records (section B.5b) 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 crustal structures which are well known.

   In this case the multiple crustal structure option could be used. Each station would be assigned to one of the crustal 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 crustal structures in the earth will be poorly modeled. However, events deeper than the crustal 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 B.3 (f), when combined with assignment of one of three crustal 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 crustal 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 crustal model, but constant within each model. A more complex use would be to specify a VP/VS ratio which varies within each model.

B. 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 location of each station and its four-letter code and the crustal velocity model 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.

For the first two items above, the program scans columns 1 through 20 of each input record to determine what type of information it contains and then updates the appropriate program constant. If two records with the same specification in columns 1 through 20 are found, the second one encountered will update the value specified by the first. The input items described are listed below. The order of the sections B.1 through B.5 makes no difference except that B.4 must precede B.5.

B.1 Header content record

Optional. Used to write heading above each earthquake in the output. Type HEADER RECORD starting in column 1 and the desired heading starting in column 51.

B.2 Crustal structure records

Consists of up to 48 records with CRUSTAL STRUCTURE typed starting in column 1 on each record, velocity (km/sec) typed in columns 21 to 30, depth to top of layer typed in columns 31 to 40, and VP/VS ratio entered in columns 41 to 50. These 48 records may be divided among up to 10 different crustal models, each model consisting of up to 12 layers. The models are placed in order starting with model 1, and the first record of each model must have a depth of 0.0 km specified. The format for these records is (2A10, 3F10.4).

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

Any or all of the crustal models may be specified as a linear increase of velocity with depth of the form $V(Z) = V_0 + KZ$, where Z is the depth and V_0 and K are constants. To call this option into play, the first velocity is set equal to K, the second velocity is set equal to V_0, and the third velocity is set equal to 100 km/sec. The first depth must be 0.0, but the remaining two may be any monotonically increasing non-zero values.

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

$0 \leq Z \leq D \quad V(Z) = V_0 + KZ$

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

To use this option, the first model velocity is set equal to V_0, the second to K, the third to D, the fourth to V_H, and the fifth to 200. If this model is used in conjunction with TEST(2) = 0.0 (see section B.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 V_0 to V_0 - (K)(Elevation). The first depth must be 0.0, but the remaining depths may be any monotonically increasing non-zero values.

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:

CRUSTAL STRUCTURE	6.0	0.0
CRUSTAL STRUCTURE	7.5	20.0
CRUSTAL STRUCTURE	0.1	0.0
CRUSTAL STRUCTURE	3.0	1.0
CRUSTAL STRUCTURE	100.0	100.0
CRUSTAL STRUCTURE	4.0	0.0
CRUSTAL STRUCTURE	0.11	1.0
CRUSTAL STRUCTURE	30.0	2.0
CRUSTAL STRUCTURE	8.1	3.0
CRUSTAL STRUCTURE	200.0	4.0

a) Ratio of P-phase velocity to S-phase velocity

The VP/VS ratio may be specified for each crustal layer. If not specified, 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 CRUSTAL MODEL is input and leave the VP/VS columns blank on the CRUSTAL MODEL records.

Variation in VP/VS between models

Specify VP/VS on each crustal model record. Do not vary the VP/VS within a given model.

Variation in VP/VS 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 an 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 crustal model 2. (See section B.5)

One limitation of this feature is that S-P interval times (see section B.9) do not use the S model, but instead assume the constant VP/VS ratio defined by TEST(1).

B.3 Option records

This set of records is optional, and only those required need be included.

a) Printer option record
Type PRINTER OPTION starting in column 1 and code in column 20.

Code	Printed output
0	Only final solution
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.

If left out, default is Code = 1.

b) Summary option record
Type SUMMARY OPTION starting in column 1, the sign (+ or -) of code in column 19 and the code in column 20. See section D.1 for summary record format and B.14 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	Not used
+4	Not used
+5	Phase records in input format with corrected arrival times on FILE4

If left out, default is Code = 0.

c) Magnitude option record
Type MAGNITUDE OPTION starting in column 1 and code in column 20.

Code	Preferred magnitude used on summary record and in final line output (see sections B.16, C.5 and D.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 left out, default is Code = 0.

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 minus P)/10., or the S weight is zero, then the calculated rather than observed S-P interval is subtracted.

d) Quality option record
Type QUALITY OPTION starting in column 1, the sign (+ or -) of code in column 19, and the code in column 20. 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
±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. See section C.4 for definition of A, B, C, and D.

If left out, default is Code = +2.

e) <u>Variable layer option record</u>

This record is required for the variable layer thickness option. Type VARIABLE LAYER starting in column 1. In columns 19 to 20 type number of layer to be varied. Type value of VMOD in columns 21 to 30 (F10.4). VMOD determines how the layer thickness model is chosen.

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.

Type 1 in column 40 if an equal and opposite change in the thickness of the layer below the variable layer is not to be made.

Example of variable layer model variations in the case where the first layer thickness is variable:

CRUSTAL MODEL AS SPECIFIED ON CRUSTAL STRUCTURE RECORDS	CRUSTAL STRUCTURE WHEN VARIABLE 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.

f) <u>Crustal delay, crustal model, and starting depth option record</u>
By default, the crustal 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. To use this option type SELECT DELAY starting in column 1 and code in column 20. If code does not equal 0, then the subroutine USEDLY, which must be set up by the user, is used to control the following items:

CRUSTAL MODEL
: The crustal delay 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 B.12.

g) <u>Printer map</u>
Skip these records if a map on the printer is not desired. Depending upon the option selected, either a map is made after each event is located or just one map is made at the end of the data set prior to the final tabulation. For the individual solution maps the epicenter is designated by the depth of the event followed by the letter "z", and the station locations are given by numbers which are the corresponding P-phase residuals in tenths of a second. For the summary map the events are plotted as a 1. Two events at the same place plot at 2, three as a 3, 10 as an A, 11 as a B, 35 or more as a Z. The stations used for any of the earthquakes can optionally be plotted as *'s.

Records Required	Description	Columns	Format
Record 1)	MAP	1-3	A3
Record 2)	Latitude of top of map	1-10	F10.2
	Longitude of left of map (West is positive)	11-20	F10.2
	Number of minutes of longitude per letter space	21-30	F10.2
	Number of minutes of latitude per line space	31-40	F10.2
	Width of map field in spaces. If found = 0, will be set = 131.	41-50	I10
	Map Type 0 Map after each event 1 Map at end with stations 2 Map at end without stations	80	I1

Record 3) Up to 57 pairs of records, each defining one line of the map. Can include such items as tick marks, labels, station locations, etc. Line by line, from top to bottom. First record has row 1, spaces 1 to 80; the second row 1, spaces 81 to 131; the third row 2, spaces 1 to 80, etc.

Record 4) A record with END typed in columns 1 to 3.

h) Missing stations option record

Type MISSING STATIONS starting in column 1 and Code in column 20. If Code = 0 or is left blank, 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 30° or more are listed. If Code ≠ 0, the default, then a search for "missing" stations is not conducted.

i) Sort option record

Type SORT OPTION starting in column 1 and Code in column 20. If Code = 1, the default, then stations are listed in the output in order of increasing epicentral distance. If Code ≠ 1, stations are listed in the same order as the input arrival time records.

j) Compress option record

Type COMPRESS starting in column 1 and Code in column 20. If Code = 1, the default, then printout for each earthquake starts on a new page. If Code ≠ 1, the printout is compressed by not skipping to the top of a page for each solution.

k) Debug option record

Type DEBUG starting in column 1 and Code in column 20. If Code = 0, the default, then this option is not called into play and no additional record is needed. If Code ≠ 0, then the following record is required:

Debug limits record

The format is:

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

   5X,F5.2)
```

For example:

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

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 Residual with weight greater than 0.2 > 1.0 sec, or
Largest S Residual with 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, or
the change in depth less than 1.0 km from starting depth.

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

l) Tabulation option record
Type TABULATION OPTION starting in column 1 and Code in column 20.

If Code = 0 (the default), average residuals are tabulated following each set of events for P, S, and S-P readings given weight codes of 0, 1, 2, or 3 and not weighted out (given weight of 0.0) during processing. Average residuals are also tabulated for readings given weight codes of 0, 1, 2, or 3 but not used in the solution because a weight of 0.0 was entered on the station record.

If Code = 1, P and S average residuals are calculated in the same way as for Code = 0. However, in this case S-P average residuals are not calculated and in their place are put P reading average residuals given initial weight codes of 5, 6, 7, or 8.

m) Calibration option record
The station gain is taken into account in local magnitude (XMAG) calculations by specifying the amplitude (in mm peak-to-peak) on the seismogram of a 10 V rms 5 Hz test tone introduced into the system in place of the geophone. This is described further in Chapter IV. The measured amplitude, herein called the "Standard Calibration for XMAG," can be input to HYPOELLIPSE both on the station record (columns 65-69) and/or the arrival time record (columns 59-62).

When an arrival time record is read, the standard calibration read from it will be used in calculating XMAG unless at least one of the following conditions is met:

1) The value of standard calibration read from the arrival time record is less than .01, or

2) The code of the calibration option is equal to 0.

In other words, the value on the arrival time record will be used unless it is too small or the calibration option code is zero.

To use the calibration option, type CAL FROM STATION starting in column 1 and code in column 20.

Code	Program Operation
0 or blank	Use standard calibration from station list.
1	Use standard calibration from arrival time record unless it is less than .01, in which case use station list value. This is the default.
	If the code is set to 0 or blank, a message in the output will indicate that station list calibration values will be used.

n) Residual option record

We often check the computer output for large residuals and then recheck the original seismograms for errors. In doing this, people are sometimes influenced by the printed computer residual in how they revise their pick. This is very hazardous and not recommended because in many cases the true error is not reflected by the residuals.

To prevent this ill-advised feedback, the "preliminary option" may be used. Type RESIDUAL OPTION starting in column 1 and code in column 20.

Code	Program Operation
0 or blank	Print output in residual form as described below.
1	Print output in normal form. This is the default.

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 (R_p) is related to the calculated residual (R) as follows:

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

2) 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

B.4 Reset test records

These records have RESET TEST typed starting in column 1 and the test number in columns 19 and 20 (I2 format). The test value is typed in columns 21 to 30 (F10.4). 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, set velocity less than first layer velocity.
		---	Trial Location
3	0.0		First trial latitude (degrees). North positive If TEST(3) or (4) .eq. 0, use closest station.
4	0.0		First trial longitude (degrees). West positive. If TEST(3) or (4) .eq. 0, use closest station.
5	5.0		First trial depth (km).
6	-10.0	---	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.
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.

Test Number	Default Test Value		Description
8	1000.0	---	Plane Wave Solution (velocity and azimuth) Call VELAZM and go on to next earthquake if smallest epicentral distance is greater than this (km).
9	360.0		Call VELAZM and go on to next event if gap is greater than this (degree).
10	50.0	---	Distance Weighting Begin distance weighting on this iteration.
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 Begin azimuthal weighting on this iteration.
14	50.0	---	Truncation Weighting Begin weighting out large residuals on this iteration. Truncating weighting.
15	10.0		Give zero weight to residuals greater than this (sec).
16	50.0	---	Boxcar Weighting Begin boxcar weighting on this iteration. (See also TEST(34) and (35)).
17	2.0		Give zero weight to residuals greater than this times the standard deviation (sec).
18	50.0	---	Jeffrey's Weighting 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
22	35.0	---	Limit change in focal depth to approximately this amount (km).
23	0.5	---	If move would take earthquake above surface, move this proportion of the way to the surface.

Test Number	Default Test Value	Description
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	--- Accelerate solution if this equals 1.0. May help in some cases of poor convergence.
28	400.0	--- To fix the hypocenter on a plane, set absolute value of this equal to azimuth of plunge line of plane (0° to 360° measured clockwise from North). If negative, then a free solution will be determined starting at the best location on the plane. If this equals 400.0, then do not fix hypocenter on plane. (See also TEST(30).
29	0.3	--- Used in calculation of the error ellipsoid (sec). If there are zero degrees of freedom, this is used as the standard error of the readings. If this is negative, the standard error of the readings is always set equal to minus this (sec).
30	0.0	--- Dip of plunge vector for hypocenter fixed on plane.
31	-1.15	--- Duration Magnitude C1, constant (See also TEST(40) and (43)).
32	2.0	C2, *log((F-P) * FMGC)
33	0.0035	C3, *DELTA
34	0.0	--- Jeffrey's or Boxcar Weighting For Jeffrey's or boxcar weighting, if the RMS becomes less than this, use this instead of RMS in assigning station weights.
35	0.0	--- Number of stations required in each quadrant for Jeffrey's weighting or boxcar weighting by quadrant. If less than 5, do not weight by quadrant.

Test Number	Default Test Value	Description
36	2.0	--- Assigned arrival time weight-code-weights raised to this power. If 2.0 is used, then a weight code of 2 should correspond to a reading with twice the uncertainty as a reading given weight code 0.
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 earthquakes with and then 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
41	0.0	--- Not used
42	0.0	--- Average magnitude is calculated from the closest N = TEST(42) stations that report a magnitude. If TEST(42) = 0, all magnitudes calculated are used in average.
43	0.0	--- Duration magnitude C5, *(log ((F-P) *FMGC)**2)
44	0.0	--- If equal 1, rerun events with only most critical stations. See note below.
45	0.0	--- X scale factor for focal mechanism plots. Adjust for printer in use. See C.8.
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.

Note on TEST(46)

When this distance weighting option is in use (TEST(46) $\neq$ 0), then stations that would be weighted out due to distance will not be weighted out if they reduce a gap of more than 100° by 50° or more.

Note on 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. Critical stations are defined to be:

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

b) More distant stations with P-phase readings are considered one at a time and added only if they reduce a gap of greater than 72° by 5° or more;

c) S-arrivals are also used when available at "critical" stations.

   If there is no S-arrival at at any critical station, then S is used from the closest non-critical station.

B.5 Station list records

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 B.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 spanning 12 years has been developed, so 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.

a) First record has BEGIN STATION LIST typed in columns 1-18, CODE in columns 19-20, and the date of the first event to be run (Year, month, and day, F10.4, e.g., 821028.) in columns 21-30. The date of the first event is optional and can be left blank. If the station list contains many stations that expired before the time of the first event, specifying the starting date will eliminate the expired stations from the initial printed station list.

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. The name of the indexed file follows the BEGIN STATION LIST record. No END record follows the name of the indexed file (see B.5 c). Stations will be updated to the date specified 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..

b) 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. Alphabetical order is not required if the alternate version of subroutine PHAIDX, which is included in with the source code, is used. 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. See TEST(8).

The program arrays are set up for a maximum of 500 stations. To change this limit, see comments near start of SUBROUTINE INPUT1.

c) A record with END typed starting in column 1 follows the last station record.

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 crustal 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 ignored by HYPOELLIPSE.

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 B.6.)	1.0	6 - 9	F4.2
System response code:	1	10 - 11	I2

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

Item	Default Value	Col. Nos.	Format
XMAG calibration constant-C10 (See chapter IV, B.)	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.	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.	none	29	I1
Telephone line 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 following items are not used by HYPOELLIPSE ******

	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
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

B.6 Arrival time records

a) A record with ARRIVAL TIMES NEXT typed starting in column 1 signals the start of the arrival time records.

b) For each seismograph station recording the earthquake, an arrival time record is typed as follows. A maximum of 100 P and/or S phases may be used for each earthquake.

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 C or U compression D Dilatation + Poor compression - Poor dilatation N-Noisy Blank-not readable	7	A1
P-phase weight code 0 or blank full weight 1 2 Partial Weight 3 Weight = ((4.-Code)/4)**TEST(36) 4, 5, 6, 7, 8 no weight	8	F1.0

Item	Col. Nos.	Format
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. If the event is deeper than the (I + 1)th layer, the weight is reset to zero.	9	I1
Year, month, day, hour, minute	10 - 19	I10
Seconds of P arrival	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	44 - 47	F4.0
Period of maximum amplitude in sec. If left blank, 0.1 will be used.	48 - 50	F3.2
Peak-to-peak amplitude of 10 μv calibration in mm. If this is blank, then the standard calibration from the station records is used.	59 - 62	F4.1
Any remark	63 - 65	A3
Time correction in seconds	66 - 70	F5.2
F-P time interval, in sec, for FMAG calculation. In NCER 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. 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
Any alphanumeric data. Not used by HYPOELLIPSE, but passed along to the archive file if SUMMARY OPTION 2 is in effect. (see B.14)	76 -109	A34

c) After each set of arrival time records for a particular earthquake, at least one INSTRUCTION RECORD follows. See section B.14 for specification of trial parameters.

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
S data indicator 0 if S data is not to be used 1 for use of S data in solution	18	I1

Item	Col. Nos.	Format
Fixed location indicator 0 implies nothing fixed. 1 implies depth fixed at trial depth. 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.	19	I1
Trial depth	20 - 24	F5.2
Trial latitude (Degrees)	41 - 42	F2.0
N or blank for North S for South	43	A1
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
Trial origin time (Minutes)	74 - 75	F2.0
Trial origin time (Seconds)	76 - 80	F5.2

d) Comment records

Any phase record with station name C*** 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.

B.7 Station parameter changes during run

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 be directly behind 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 B.11, then they will not be run in chronological order, so station parameter updating will not operate correctly and errors may result.

B.8 Change input items B.1 through B.5 during run

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

a) 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 B.1 through B.5 may be entered. All location parameters will remain in effect except those for which new B.1-B.5 records are included. To switch back to reading phase records, terminate the B.1-B.5 items with an ARRIVAL TIMES NEXT record.

b) RESET S record
Type RESET S starting in column 1. This is the same as RESET described above except that a tabulation of average residuals will be printed for the set of events preceding the RESET S record.

c) STANDARD TEST
A record with STANDARD TEST starting in column 1 will reset input items B.3 and B.4 to default values. This record is placed after a RESET or RESET S record.

B.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.

B.10 How to add your own calibration curves

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 along with input items B.1-B.5 with CALIBRATION typed starting in column 1 and the number of additional system calibration tables to be added in column 20. 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 IV, for the definition of RSPA(n).

B.11 How to run the same data more than once

A set of arrival time records may be run with a variety of crustal models, station lists, trial depths, or any other of the variable parameters defined in B.1 through B.5 by using the SAVE and RERUN control records. Following a SAVE record, all ARRIVAL TIME records are written to the file FILE1 before they are processed. A RERUN record causes FILE1 to be rewound and read in for reprocessing. In this example, the arrival time records are run three different ways. This option can not be used with SUMMARY OPTION ±2 because that option also uses FILE1.

Items B.1 through B.5 as desired for 1st run
ARRIVAL TIMES NEXT
SAVE
File of arrival time records of many earthquakes. These events will be saved in FILE1.

RESET
New items B.1 through B.5 as desired for second run
ARRIVAL TIMES NEXT
RERUN

RESET
New items B.1 through B.5 as desired for third run
ARRIVAL TIMES NEXT
RERUN

B.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, else
2) SUMMARY RECORD, if specified, else
3) TEST(3) and (4), if both not equal zero, else
4) Closest station coordinates.

DEPTH
1) INSTRUCTION RECORD, if specified, else
2) SUMMARY RECORD, is specified, else
3) Trial depth specified in SUBROUTINE USEDLY if the SELECT DELAY option code is not zero (see B.3f), else
4) TEST(5)

ORIGIN TIME
1) INSTRUCTION RECORD, if specified, else
2) SUMMARY RECORD, if specified, else
3) 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
4) Earliest P-arrival time minus (TRIAL DEPTH/5.0) minus 1.0

NOTE: If TEST(38) is negative, then the origin time will be fixed at the average value of TO(i).

B.13 How to run an earthquake a specified number of times, each time randomly varying each of the observed arrival times

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.

B.14 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 I-1). To set up HYPOELLIPSE to generate this file, simply set SUMMARY OPTION equal to 2.

When HYPOELLIPSE is run, FILE11 will be generated with input and derived parameters for each event. See D.2 for format.

The structure of the ARCHIVE-PHASE FILE for each event is as follows:

1) Summary records.

   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.
   - Case 1b. A new solution was not generated. This could be caused, for example, because all of the arrivals were weighted out.
     Then: Write out the summary record previously associated with the event, if there was one, followed by a FAKE summary record.

   Case 2. The input event included two or more summary records.

   - Case 2a. A new earthquake solution was generated.
     Then: Write out all but the last of the summary records previously associated with the event followed by the new summary record.
   - Case 2b. A new solution was not generated.
     Then: Write out all of the summary records previously associated with the event followed by a FAKE summary record.

2) For each station, write out a 109-character record with original phase data and computed data.

3) Write out the original instruction record with the date of the HYPOELLIPSE run added. The month (JAN = 01) is placed in columns 25-26 and the year (1981 = 81) is placed in columns 27-28.

OLD DATA BASE	NEW DATA BASE
PHASE RECORDS WITH RAW DATA MEASUREMENTS	ARCHIVE-PHASE FILE WITH: RAW AND DERIVED INFORMATION FOR EACH STATION AS WELL AS THE DERIVED EARTHQUAKE SOLUTION PARAMETERS
SUMMARY RECORDS WITH: DERIVED EARTHQUAKE 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.	

Figure I-1. Schematic diagram showing the 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 last summary record associated with the event unless overridden by a location, depth, or origin time on the instruction record. The format specification for reading an ARCHIVE-PHASE FILE phase record created 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		
P-phase weight code	8	F1.0
0 or blank full weight		
1, 2, 3 — Partial weight, Weight = ((4.-Code)/4)**TEST(36)		
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

Item (continued)	Col. Nos.	Format
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 weight, final	55 - 57	F3.2
D, B, M, or * weight code (See C.6 for definition)	58	A1
Peak-to-peak amplitude of 10 μv calibration in mm. If this is blank, then the standard calibration from the station records is used.	59 - 62	F4.1
Any remarks except CAL	63 - 65	A3
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 weight, final	81 - 83	F3.2
D, B, M, 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

The source codes used for Alaska data processing are given below. They are not used by HYPOELLIPSE.

E - Eclipse
1 - One film digitizer
4 - Four file digitizer
V - Film viewer
S - Semens playback
H - Helicorder
5 - Five-day recorder
M - SMA1 strong motion recorder
C - Canadian data from magnetic tape
B - Publisned bulletin (EDR, ISC etc)
A - University of Alaska
T - Alaska Tsunami Warning Center

B.15 How to run a set of data with random errors added to each observed P- and S- phase arrival time

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 B.6.c). 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). Place this record directly before the first arrival time record of the fake data set. Each time these sets of data are run a new series of random numbers will be generated because the random number seed is initialized by the time, month, and year.

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

B.16 Use of magnitudes not determined by HYPOELLIPSE

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 m_b
C Canadian M_L
G Geophysical Institute
P Palmer M_L
S PDE M_S
O Other
H Helicorder

When earthquakes are being rerun, if the last summary record preceding the phase data (see B.14) 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.

C. PRINTED OUTPUT

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

C.1 List of stations available

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 crustal 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 B.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.
POL	If 1, then reverse observed polarity before plotting on focal-sphere. If .GT. 1, plot as question mark.
STAWT	The reading weight is raised to the power TEST(36) and then 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

C.2 Program specifications

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

C.3 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
RMS	If the residuals are R_i, i = 1, N and the weights are W_i, then

$$RMS = \left(\frac{\sum^{NO} W_i (R_i)^2}{DOF} \right)^{\frac{1}{2}}$$

(DOF equals the number of degrees of freedom, usually NO - 4)

Heading	Explanation
NO	Number of P, S and S-P readings used
PRMS	RMS predicted for after the next step. See Chapter IV D for discussion.
DAMP	Value of damping constant in use. See Section IV.
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.

C.4 Quality

a) Based on error estimates

This quality is based on ERH (the horizontal 68 per-cent confidence limit in the least well constrained direction) and ERZ (the 68 per-cent confidence limit for depth). See Chapter III for further explanation of ERH and ERZ. Note that these limits are modified from those used previous to April 1984 to reflect revised definitions of ERH and EHZ.

Quality	Larger of ERH and ERZ
A	≤ 1.34
B	≤ 2.67
C	≤ 5.35
D	> 5.35

b) Quality based on many parameters

SQD-HYPO71 Quality

S is the solution quality as defined in HYPO 71:

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

* ERH is the horizontal 68 per-cent confidence limit in the least well constrained direction.

** ERZ is 68 per-cent 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.

C.5 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 B.3c, B.16, and D.1.
NO	Number of P, S, and S-P readings used in the solution.
D1	Distance to the closest station used in the solution.
GAP	Largest azimuthal separation in degrees between stations as seen from the epicenter.
D	Number of crustal delay model used (1 to 5)
RMS	Root mean square residual, RMS:

$$RMS = \left(\frac{\sum^{NO} W_i (R_i)^2}{DOF} \right)^{1/2}$$

(DOF equals the number of degrees of freedom, usually NO - 4)

Heading	Explanation
ERH	Horizontal 68 per-cent confidence limit for the least well constrained direction.
ERZ	68 per-cent 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

Heading	Explanation
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.
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.

C.6 Detailed station output

One line of print for each station.

Heading	Explanation
STN	Station name
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)
PSEC	Seconds of P-arrival as typed on arrival time record
PRMK	Columns 5-8 of arrival time record
TCOR	Station clock correction in sec. from arrival time record. Added to observed arrival time.

Heading	Explanation
TTOB	Travel time observed for P (sec)
TTCAL	Travel time calculated for P (sec)
C	Crustal model used for this travel time
DELAY	Station delay in seconds for model preferred by closest station
EDLY	Elevation delay (sec)
P-RES	Residual of P-arrival in seconds P-RES=TTOB-TTCAL-DELAY-EDLY If a character follows the P:RES 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.
P-WT	Weight used for this P-arrival in hypocentral solution. It is a product of the weight specified on the arrival time record and the other weights selected. Weights are normalized so that their sum is equal to NO, the number of P, S, and S-P readings used in the solution.
THIK	This is the thickness of the variable layer in km for the crustal model used.
SSEC	Seconds of S-arrival as typed on arrival time record
SRMK	Columns 37-40 of arrival time record
TTOB	Travel time observed for S (sec)
TTCAL	Travel time calculated for S (sec)
S-RES	Residual of S-arrival in seconds. S-RES=TTOB-TTCAL-TEST(1)*(DELAY + EDLY)-SDELAY A, D, B, M, or * may follow the S:RES. See P:RES for the meaning of each one.
S-WT	Weight used for this S-arrival
AMX	Maximum amplitude in mm from input data
PR	Period of wave where maximum amplitude was read. If PR is not given on arrival time record, then standard period from the optional station continuation record is used. Default is 0.1 seconds.

Heading	Explanation
XMAG	Maximum amplitude magnitude. An * follows XMAG if XMAG - AVXM ≥ 0.5.
R	Remark from columns 63-65 of arrival time record
FMP	F-P time interval in seconds
FMAG	F-P magnitude. An * follows FMAG if FMAG - AVFM ≥ 0.5.

C.7 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			

C.8 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 -'s
D	1 dilatation
E	2 dilatations
F	3 or more dilatations
Q	(Question mark) Indicates that although a first motion was reported, the station polarity is uncertain.

A +, - or question mark 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.

C.9 Printer map for each event

A one-page map will be made for each event if the option is specified in the option records.

C.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 and for each delay model the number of times the station was used (N), the average weight (WT), the average weighted residual (AVE), and the standard deviation of the residuals (SD).

If a station is given zero weight on its station record (section B.5) it will be included in the tabulation even though it has not been used in any of the solutions. For the purposes of the table, the weight used in the tabulation is derived from the weight code on the arrival time record (section B.6).

D. 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.

D.1 Summary record with error ellipse data

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
SIZE AND ORIENTATION OF ERROR ELLIPSOID:		
Azimuth (deg)	50 - 52	I3
Dip (deg)	53 - 54	I2
SE - length of ellipsoid semiaxis	55 - 58	F4.2
Azimuth (deg)	59 - 61	I3
Dip (deg)	62 - 63	I2
SE - length of ellipsoid semiaxis	64 - 67	F4.2
Average XMAG	68 - 69	F2.1
Average FMAG	70 - 71	F2.1
SE - length of third ellipsoid semiaxis	73 - 76	F4.2
Quality - either error ellipsoid quality or HYPO quality depending upon Quality Option Record. See section B.3.	77	A1

Item	Col. Nos.	Format for Reading
MAGTYP - F, X, A, or K to indicate which type of magnitude is entered in columns 35-36. (See section B.3c)	78	A1
NSWT - Number of S-phase arrivals used in solution.	79 - 80	I2
/	81	A1
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

D.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

E. SUMMARY OF IMPORTANT FORMATS

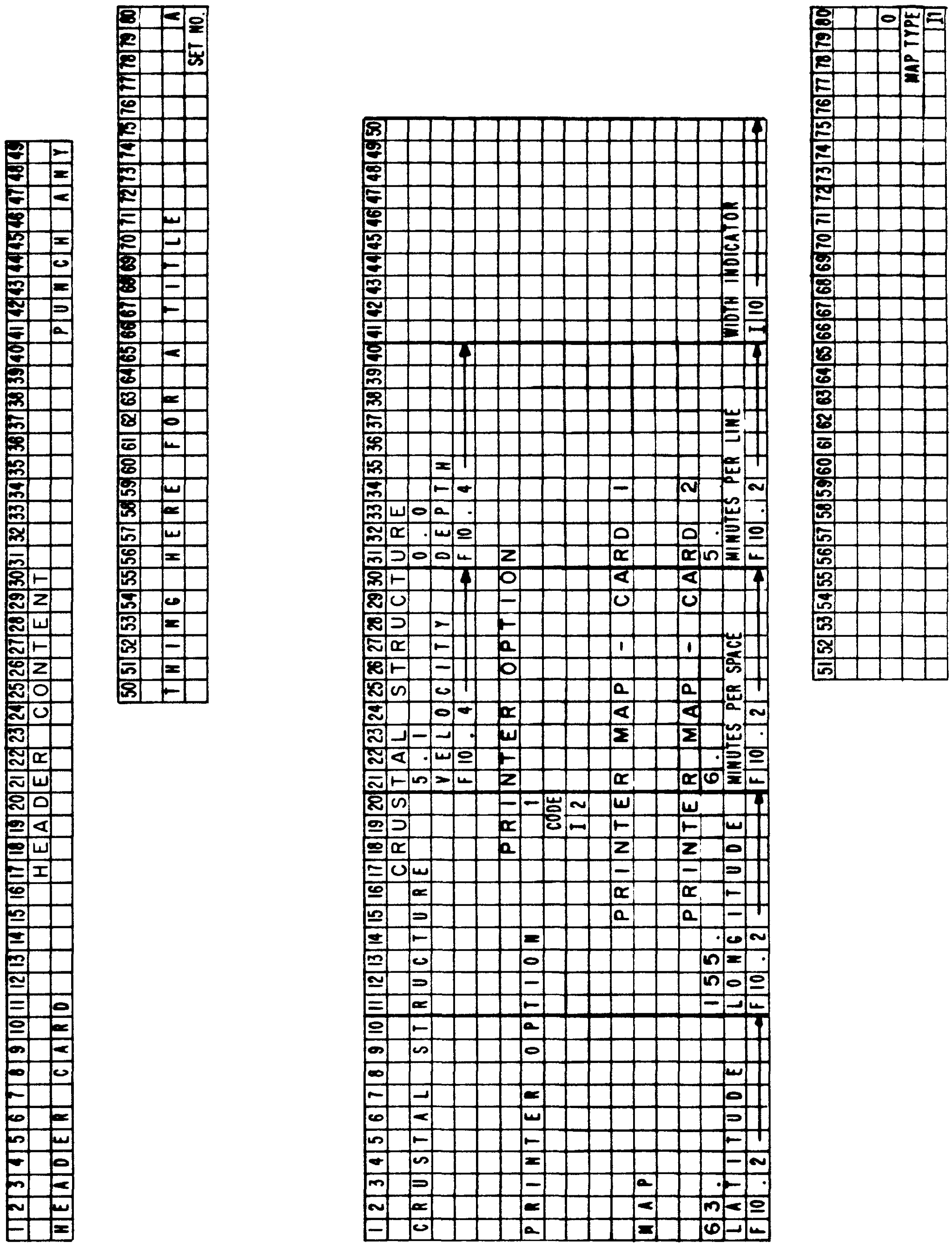
Formats are illustrated here for many of the input and output items. There are up to four rows for each item labeled T, S, E, and F.

T Gives TYPE of item.
S Sample (Hypothetical).
E Explanation (Very terse, refer to section B or D for more detail).
F Format used to read item.

E. Summary of Important Formats (continued)

1. Input Items

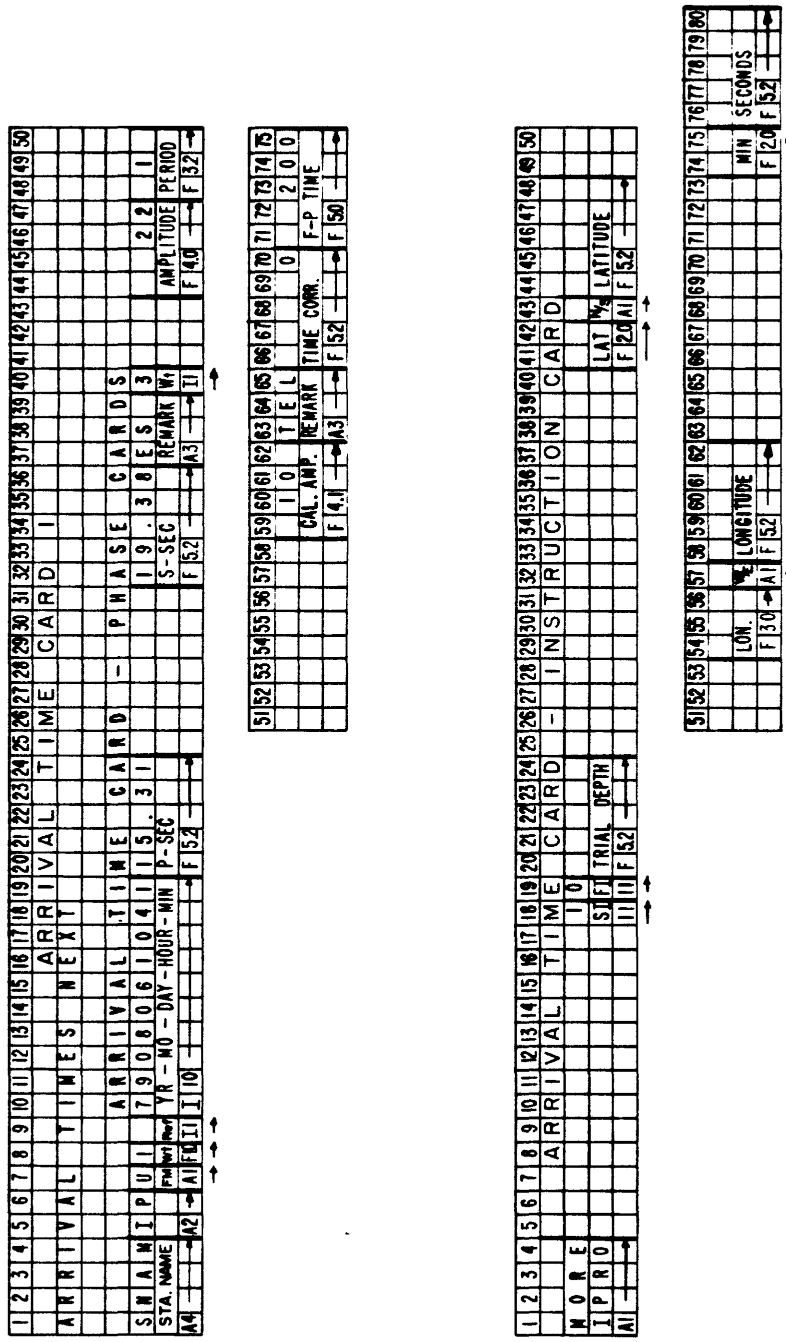
Header Content
Crustal Structure
Option Card
Printer Map



E. Summary of Important Formats (continued)

1. Input Items (continued)

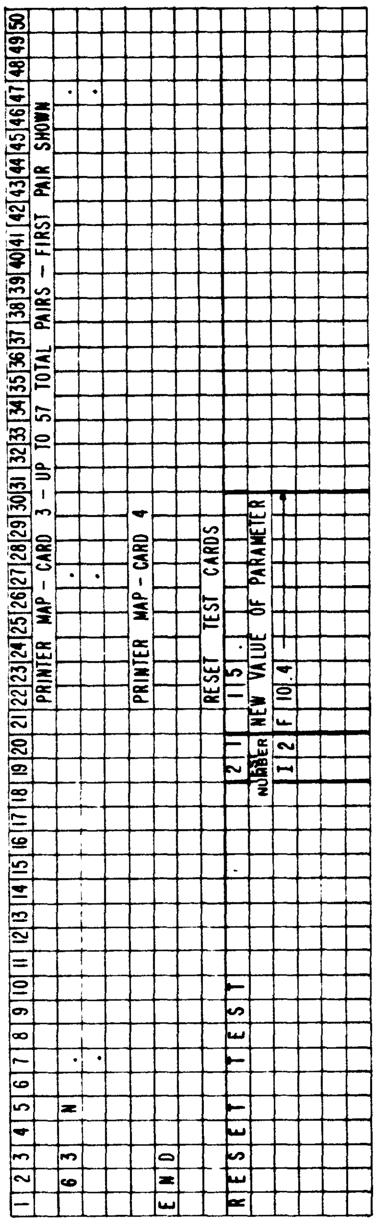
Arrival Time Cards

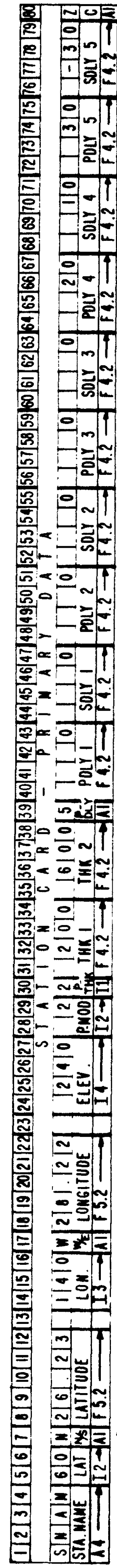


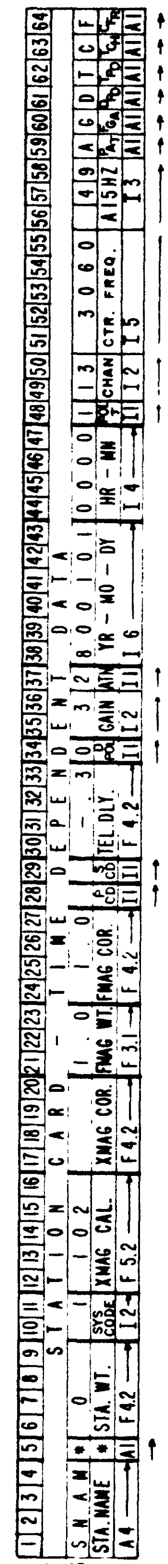
E. Summary of Important Formats (continued)

1. Input Items (continued)

Printer Map (continued)
Reset Test Card
Station List







E. Summary of Important Formats (continued)

2. Output Items

Extended Phase File

Summary Card with Error Ellipsoid Data

Without Error Ellipsoid Data

Extended Phase File (T: EXTENDED PHASE FILE - CREATED BY SQUASH)

Columns	S (sample)	E (field)	F (format)
1–4	SNAM	STA. NAME	A4
5–6	IP	I/E	A2
7	U		A1
8	1	wt	F1.0
9		Ref	I1
10–19	7908061041	YR-MO-DAY-HR-MIN	I10
20–24	15.31	P-SECONDS	F5.2
25–28	62	DISTANCE	F4.1
29–31	29	AZIM	I3
32–36	19.38	S-SECONDS	F5.2
37–39	ES	REMARK	A3
40	3	wt	I1
41–43	105	ANG. INC	I3
44–47	22	AMPLITUDE	F4.0
48–50	1	PERIOD	F3.2
51–54	2138	P.TRAV.TIME	F4.2
55–57	0	P.WT.	F3.2
58	M	M	A1
59–62	10	CAL. AMP.	F4.1
63–65	TEL	REMARK	A3
66–70	0	TIME COR.	F5.2
71–75	200	F-P TIME	F5.0
76–80	621	P RESIDUAL	F5.2
81–83	131	S Wt	F3.2
84			A1
85–89	82	S RESIDUAL	F5.2
90–92	0	P DELAY	F3.1
93–95	0	S DELAY	F3.1
96–98	29	ELV. DLY	F3.1
99–100	1	RCODE	I2
101–102	16	XMAG	I2
103–104	23	FMAG	I2
105	E	SOURCE: POL	A1
106	E	SOURCE: P	A1
107	E	SOURCE: S	A1
108	E	SOURCE: [illegible]	A1
109	E	SOURCE: [illegible]	A1

Summary Card with Error Ellipsoid Data (T: SUMMARY CARD - WITH ERROR ELLIPSE DATA)

Columns	S (sample)	E (field)	F (format)
1–6	790806	YR-MO-DAY	I6
7–10	1041	HR MIN	I4
11–14	0513	SECONDS	F4.2
15–16	43	LAT	I2
17	N	N/S	A1
18–21	1632	LATITUDE	F4.2
22–24	122	LONG.	I3
25	W	W/E	A1
26–29	4953	LONG.	F4.2
30–34	532	DEPTH	F5.2
35–36	42	MAG	F2.1
37–39	15	NO. STA	I3
40–42	220	GAP	I3
43–45	82	DIST-1	F3.0
46–49	49	RMS	F4.2
50–52	31	AZIM	I3
53–54	2	DIP	I2
55–58	822	STD ERROR	F4.2
59–61	121	AZIM	I3
62–63	4	DIP	I2
64–67	638	STD ERROR	F4.2
68–69	20	AVG. XMAG	F2.1
70–71	22	AVG. FMAG	F2.1
72–76	1257	STD. ERROR	F4.2
77	C	Q	A1
78	A	Sol/F/X	A1
79–80	3	No. of S	I2
81	/		A1
82–85	MORE		A4
86–89	1079	MON YR	A4
90	1	SI	I1
91	0	FI	I1
92	E		A1
93–96	0193	SEQ. NO.	I4
97–100	781	S-P TIME	F4.2

Summary Card Without Error Ellipsoid Data (T: SUMMARY CARD - WITHOUT ERROR ELLIPSE DATA (HYPO71))

Columns	S (sample)	E (field)	F (format)
1–6	790806	YR-MO-DAY	I6
7–11	1041	HR-MIN	I4
12–17	05.13	SECONDS	F6.2
18–20	43	LAT.	I2
21	N	N/S	A1
22–26	16.32	LATITUDE	F5.2
27–30	122	LON.	I3
31	W	W/E	A1
32–36	49.53	LONGITUDE	F5.2
37–43	5.23	DEPTH	F6.2
44	*	FD	A1
45–50	4.20	MAGNITUDE	F6.2
51–53	15	NO.	I3
54–57	220	GAP	I4
58–62	82.0	DIST.-3	F5.1
63–67	4.90	RMS	F5.2
68–72	8.2	ERROR — HORZ	F5.1
73–77	13.3	ERROR — VERT.	F5.1
78		QU	A1
79	C	Q	A1
80	A	Sol/F/X	A1

III. Error Estimates

The semimajor principal axes of the 68 °/∘ joint confidence ellipsoid are output on the SUMMARY RECORD for each earthquake. The printed output also includes two horizontal single 68 per-cent confidence estimates, the larger being called ERH, and the single variable 68 °/∘ confidence extimate for depth, ERZ. The relationship of these error estimates to the error ellipsoid is shown in Figure III-1. The relationship between a joint two dimensional probability distribution (P_{xy}) and a one dimensional distribution (P_x) is illustrated in Figure III-2. For each value of x, P_x is equal to the integral over y of the joint probabilty function P_{xy}. The ratio between s, the 68 °/∘ confidence limit for x, and m, the maximum deviation of the 68 °/∘ joint confidence ellipse in the x direction, is equal to the square root of the ratio of the 68 °/∘ value of chi-square with one degree of freedom to the 68 per-cent 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 III-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

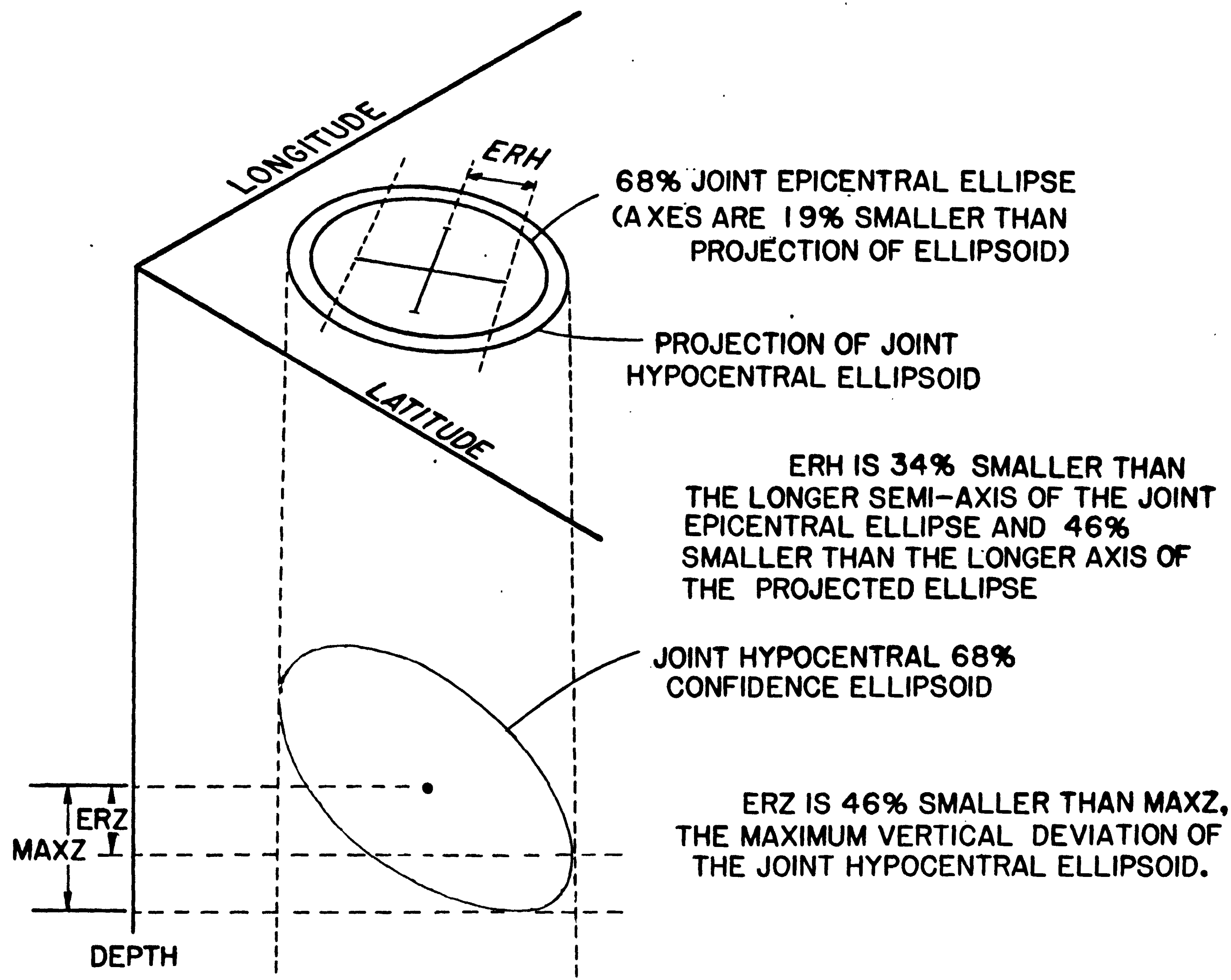

LONGITUDE
ERH
68% JOINT EPICENTRAL ELLIPSE
(AXES ARE 19% SMALLER THAN
PROJECTION OF ELLIPSOID)
PROJECTION OF JOINT
HYPOCENTRAL ELLIPSOID
LATITUDE
ERH IS 34% SMALLER THAN
THE LONGER SEMI-AXIS OF THE JOINT
EPICENTRAL ELLIPSE AND 46%
SMALLER THAN THE LONGER AXIS OF
THE PROJECTED ELLIPSE
JOINT HYPOCENTRAL 68%
CONFIDENCE ELLIPSOID
ERZ
MAXZ
ERZ IS 46% SMALLER THAN MAXZ,
THE MAXIMUM VERTICAL DEVIATION OF
THE JOINT HYPOCENTRAL ELLIPSOID.
DEPTH

Figure III-1

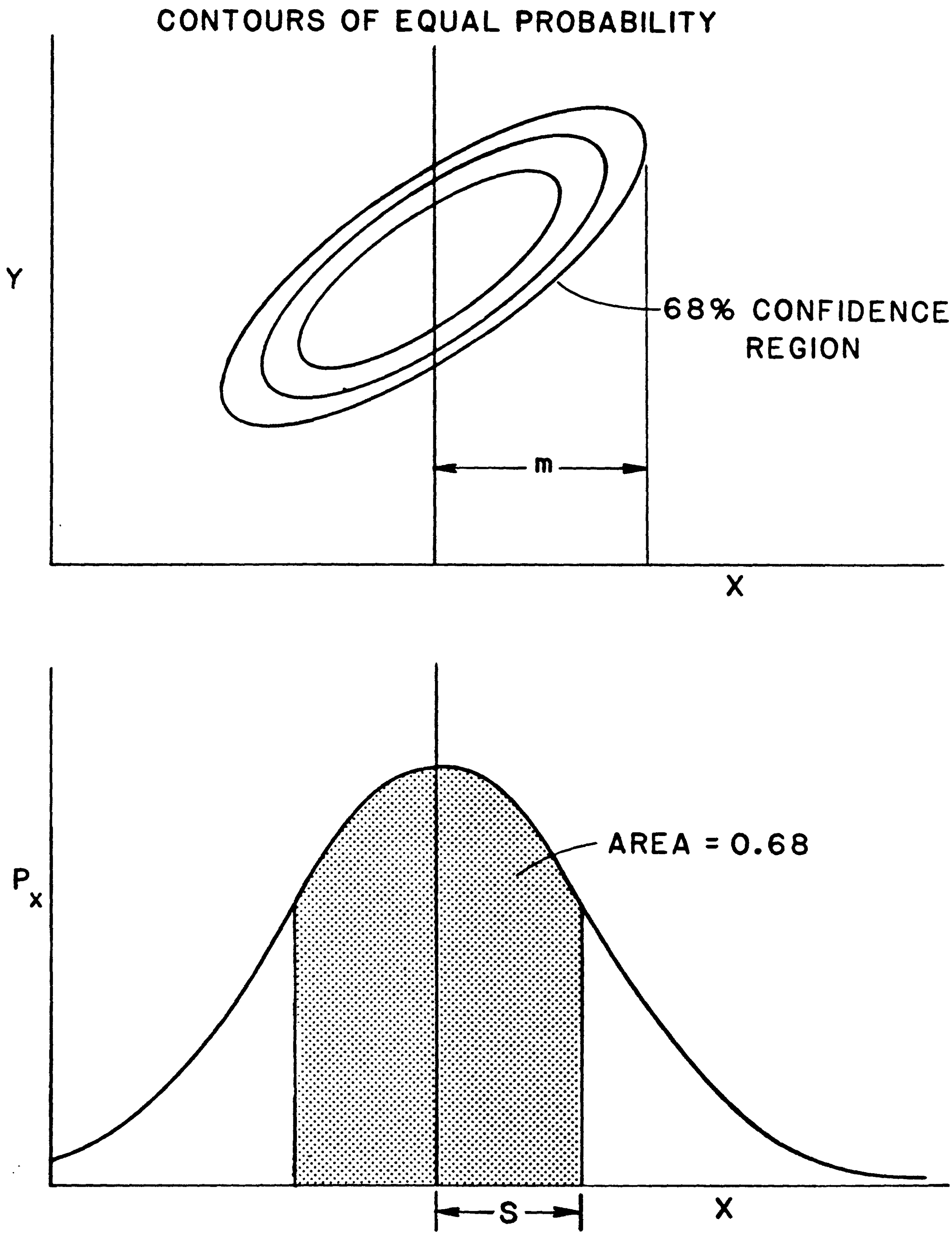
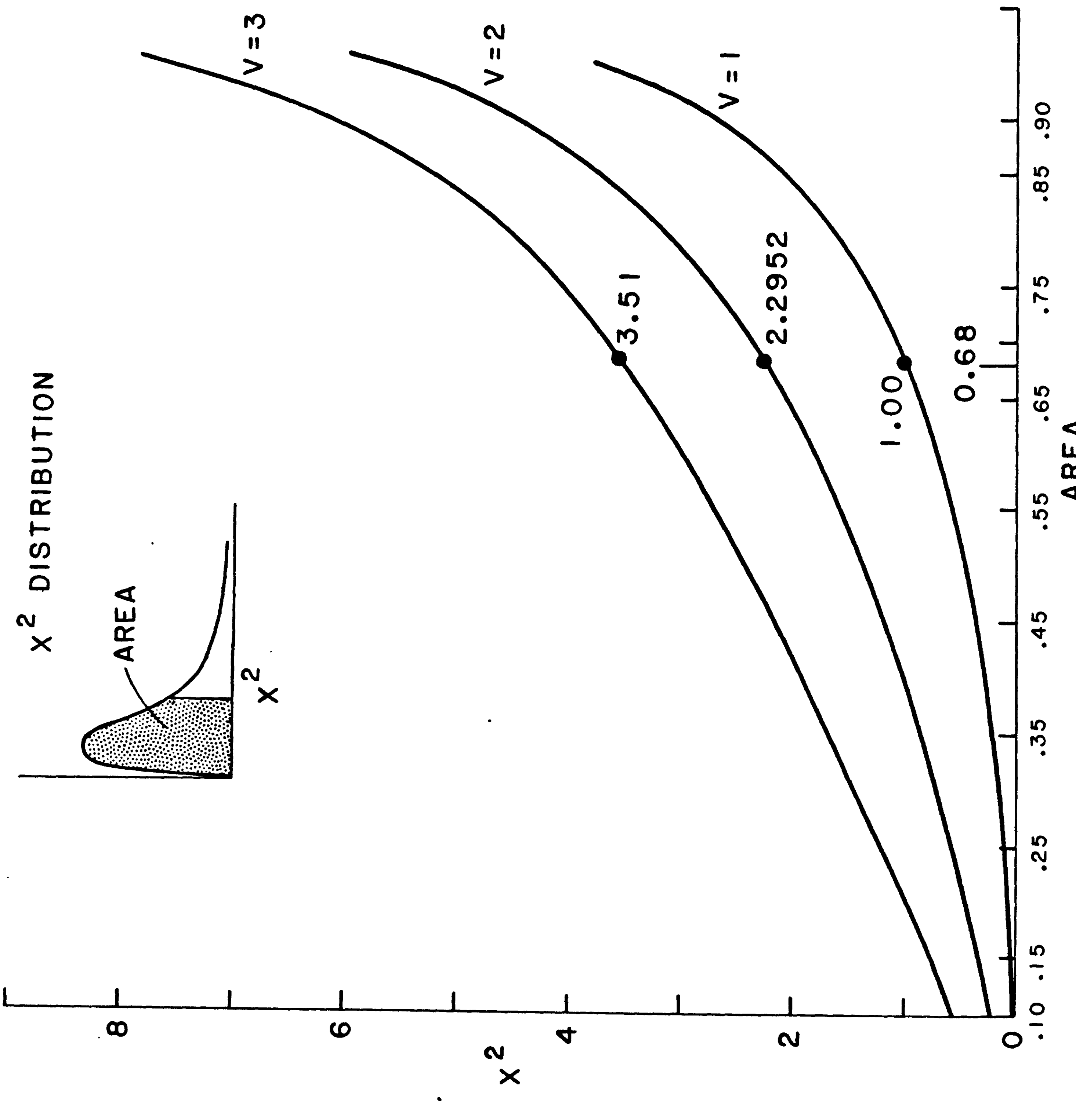

CONTOURS OF EQUAL PROBABILITY
Y
68% CONFIDENCE REGION
m
X
AREA = 0.68
P_x
S
X

Figure III-2.



X^2 DISTRIBUTION
AREA
X^2
V=3
V=2
V=1
3.51
2.2952
1.00
0.68
8
6
4
2
0
X^2
.10 .15 .25 .35 .45 .55 .65 .75 .85 .90

IV. 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.

(A) Coda length magnitude, FMAG.

The FMAG is calculated according to an empirical equation (Lee et al., 1972, Lahr et al., 1973) which has been found to be in reasonable agreement with the local Richter magnitude scale.

$$FMAG = C_1 + C_2 \log_{10} (F\gamma) + C_3 \Delta + C_4 Z + C_5 (\log_{10} (F\gamma))^2$$

where

C_1, C_2, C_3 and C_4 are found empirically and correspond to the test variables 31, 32, 33, and 40.

F = F-P time defined to be the length of time in sec between the the P phase arrival and the time when the coda drops to 1 cm p-p amplitude on the Geotech Model 6585 film viewer.

Δ = Epicentral distance in km.

Z = Hypocentral depth in km.

γ = Station FMAG correction.

For California,		For Alaska,	
	C_1 = -0.87		C_1 = -1.15
	C_2 = 2.0		C_2 = 2.0
	C_3 = 0.0035		C_3 = 0.0035
	C_4 = 0.0		C_4 = 0.007
	C_5 = 0.0		C_5 = 0.0

Three recent changes to the coda magnitude equations in HYPOELLIPSE are:

1) The station correction (γ) is not added to the coda magnitude calculated, but is used as a multiplier of the coda observed. Therefore a station with no correction should have FMAG correction equal to 1.0. If the station card has no entry for FMAG correction, then it will be set equal to 1.0.

2) A fifth term is included in the formula of the form

$$C_5 \left((\log_{10} F\gamma)^2 \right)$$

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

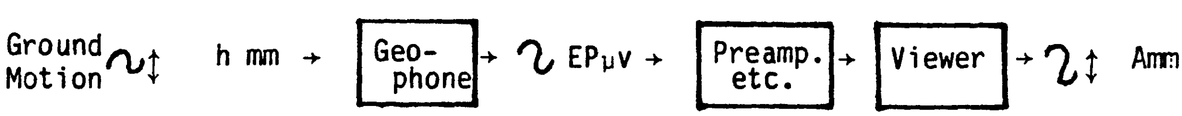
3) If a negative code is used for MAGNITUDE OPTION then the F minus P coda length from the arrival time card will be converted into the F minus S coda length by subtraction of the S-P time. This formulation may be useful for earthquakes with wide depth variations, but is now only experimental.

(B) Local Richter Magnitude, XMAG.

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:



$$\text{Seismometer Response } SP(f) = \frac{EP}{2h}$$

$$\text{System Response } V(f) = \frac{2A}{EP}$$

$$\text{Total Harmonic Magnification } MF(f) = SP \times V = \frac{A}{h}$$

The system response at some frequency f may be calculated from the response at a particular frequency f_0 multiplied by the ratio of the response at f to the response at f_0

$$V(f) = V(f_0) \times \frac{V(f)}{V(f_0)}$$

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

$\frac{V(f)}{V(f_0)} = \frac{A(f)}{A(f_0)}$ may be calculated as a function of frequency f.

Thus $V(f) = V(f_0) \times \frac{A(f)}{A(f_0)}$

$V(f_0)$ is calculated for $f_0 = 5$ hz for a 10μV rms input signal. 10μV rms corresponds to 28.28 μV p-p. Let the amplitude A(5) for this signal be C_{10}.

$$V(f) = \frac{C_{10}}{28.28} \times \frac{A(f)}{A(5.0)}$$

The formula for geophone response is:

$$SP(f) = \frac{2\pi f^3 G_{LE}}{\left[(F_0^2 - f^2)^2 + 4\beta^2 F_0^2 f^2\right]^{1/2}}$$

where: F_0 = natural frequency
β = damping constant
G_{LE} = motor constant v/mm/sec

TGN(f) is defined to be SP(f) divided by 28.28.

Thus the total harmonic magnification is

$$MF(f) = SP \times V = \frac{2\pi f^3 \quad G_{LE}}{\left[(F_o^2 - f^2)^2 + 4\beta^2 F_o^2 f^2\right]^{1/2}} \times \frac{C_{10}}{28.28} \times \frac{A(f)}{A(5.0)}$$

Using the definition of TGN(f) this becomes:

$$MF(f) = C_{10} \times \frac{A(f)}{A(5.0)} \times TGN(f)$$

"Gain" x System frequency response x Seismometer response divided by 28.28

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

$$MWA(f) = \frac{2800 f^2}{\left[(F_o^2 - f^2)^2 + 4\beta^2 F_o^2 f^2\right]^{1/2}}$$

with $F_o = 1.25, \beta = 0.8$.

Therefore:

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

$$B(f) = \frac{A(f)}{C_{10}} \times \frac{MWA(f)}{TGN(f)} \times \frac{A(5.0)}{A(f)}$$

$$B(f) = A(f) \times \frac{MWA(f)}{TGN(f)} \times \frac{A(5.0)}{A(f)} \div C_{10}$$

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 input on station card.

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

$$RSPA(n) = \log \frac{TGN(f_n)A(f_n)}{MWA(f_n)A(5.0)} \qquad \text{vs } \log(f_n)$$

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 seconds.

2) User supplied Calibration Curves.

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 card after the "OPTION CARDS" with CALIBRATION punched starting in column 1 and the number of additional system calibration tables to be added in column 20. Each table consists of two cards 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 cards correspond to system number 9, the second two to number 10, etc., up to the total number of tables to be added.

3) Computer Formula used for XMAG.

The formula for computing Richter's local magnitude is

$$XMAG = \log_{10}(A/2C_{10}) - R_{kf} \quad - \quad B_1 + B_2 \log_{10} D^2 \quad + \quad G$$

$\log_{10}$ of maximum zero to peak amplitude in mm as recorded on a standard Wood-Anderson seismograph.	Approximation to Richter's $\log_{10} A_o$	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.

C_{10} = USGS J202 calibration peak-to-peak amplitude for $10\mu v$ rms, 5 hz preamplifier input.

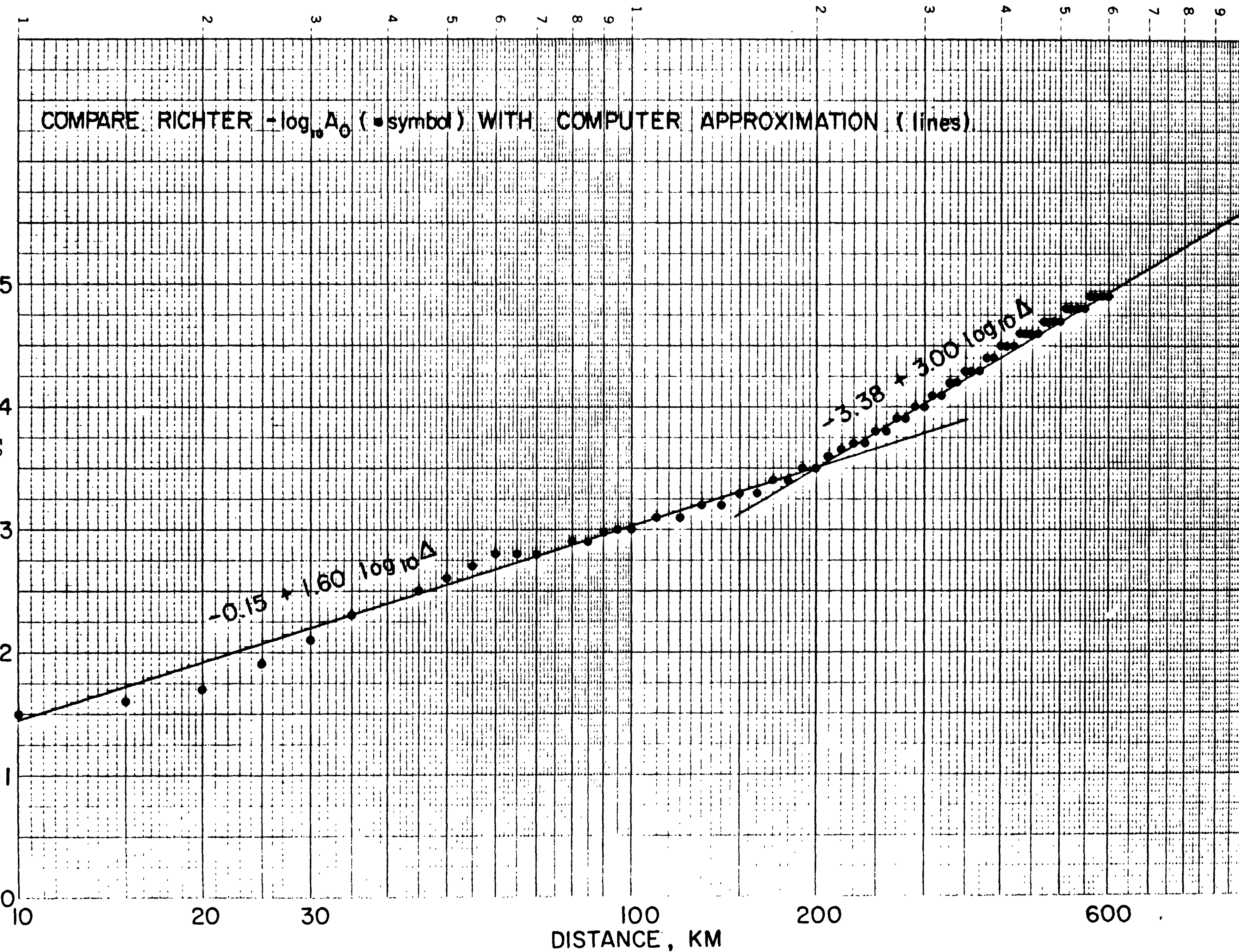
B_1 = 0.15, B_2 = 0.80 } for 1 km $\leq$ D $\leq$ 200 km

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

D = $\sqrt{\Delta^2 + Z^2}$, where Δ is the epicentral distance and Z the focal depth in km.

G = Station XMAG correction.

Figure 1 shows a comparison of $\log_{10}$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.


COMPARE RICHTER $-\log_{10} A_0$ (• symbol) WITH COMPUTER APPROXIMATION (lines).
$-0.15 + 1.60 \log_{10} \Delta$
$-3.38 + 3.00 \log_{10} \Delta$
DISTANCE, KM
10
20
30
100
200
600
0
1
2
3
4
5

V. Acknowledgements

This computer program is one of a series of hypocenter programs developed at the Office of Earthquake Studies of 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 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. R. A. White reviewed the current version of the manual.

VI. References

Bakun, W. H., and A. G. Lindh, Local magnitudes, seismic moments and coda durations for earthquakes near Oroville, California, Bull. Seism. Soc. Am., 67, 615-629.

Draper, N. R., and H. Smith, Applied regression analysis, 407 pp., John Wiley and Sons, New York, 1966.

Eaton, J. P., 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 pp., 1969.

Eaton, J. P., Harmonic magnification of the complete telemetered seismic system, from seismometer to film viewer screen, U.S. Geological Survey Open File Report, 23 pp., 1970.

Geiger, L., 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), 56-71, 1912.

Jeffreys, H., Theory of Probability, (3rd ed.) Oxford at the Clarendon Press, London, p. 214-216, 1961

Lahr, J. C., R. A. Page and J. A. Thomas. Catalog of earthquakes in south central Alaska, April-June 1972, U.S. Geological Survey, Open-File Report, 30. p., 1974.

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., 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., R. E. Bennett, and K. L. Meagher, A method of estimating magnitude of local earthquakes from signal duration: U.S. Geological Survey Open-File Report, 28 pp., 1972.

Lee, W. H. K., and J. C. Lahr, HYPO71: a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes, U.S. Geological Survey Open-File Report, 100 pp., 1972.