(200)
R290

72-224

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
National Center for Earthquake Research
345 Middlefield Road
Menlo Park, California 94025

HYPO71: A COMPUTER PROGRAM FOR DETERMINING HYPOCENTER, MAGNITUDE, AND FIRST MOTION PATTERN OF LOCAL EARTHQUAKES*

by

W. H. K. Lee and J. C. Lahr

U.S. Geological Survey
OPEN FILE REPORT
This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

*Work performed in cooperation with the Division of Reactor Development and Technology, Atomic Energy Commission.

CONTENTS

1. INTRODUCTION

HYPO71 is a computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes. It was primarily designed for processing large amounts of earthquake data recorded at close range on a dense network of seismographs. The present writeup is for the final version of HYPO71, which supersedes HYPO70.

For the last year and a half, HYPO70 and earlier versions of HYPO71 were extensively used to process earthquake data in central California. The complexity of crustal structure has led to the introduction of crustal models with variable first-layer thicknesses for individual stations. Modifications have also been made to improve earthquake locations for the NCER Alaskan network, which has station spacing of about 50 km and earthquakes with a wide range of focal depths.

The present writeup is intended as a manual for HYPO71 users. Emphasis has been placed upon how to use the program. We have greatly benefited from Eaton's computer program HYPOLAYR (Eaton, 1969), and wish to thank Jerry Eaton, Bob Hamilton, and Bob Page for their helpful discussions. Comments and criticisms of HYPO71 from users are welcome so that further improvements can be made.

HYPO71 differs considerably from HYPOLAYR (and its revised version HYPOMAG) in its scope and design. Although major results of HYPOLAYR (or HYPOMAG) could be reproduced with HYPO71, several additional features are available in HYPO71 to streamline routine data processing. Several schemes of detecting errors in input data are used to prevent erroneous solutions and premature termination. Options to make first-motion plots, calculate duration magnitudes, map residual minima and compute more realistic travel times are now available.

2. HOW TO USE HYPO71

HYPO71 was written in FORTRAN IV for IBM 360/65 or 360/67 computers, and is listed in Appendix 1. It may be executed under the FORTRAN H or WATFIV compilers and requires 150,000 bytes of core storage. For NCER users, a load module of HYPO71 has been created and stored on disk at the USGS computer. Since compilation and link-editing are not needed to execute a load module, considerable saving in computer time is achieved (about 2 minutes per run). In the following sections a step-by-step description of how to use the load module of HYPO71 is presented. A listing of a test run is illustrated in Appendix 2.

2.1 Deck Setup.

To execute the load module of HYPO71, the following deck setup is required:

(1) JOB card
(2) JCL cards
(3) DATA cards
(4) /* card

JOB card must be prepared according to the USGS Users' Manual. One should normally allow 1 second computer time and 100 lines printout for each earthquake. In addition, 5 seconds and 500 lines should be allowed for overhead.

2.2 JCL Cards.

JCL cards for executing the HYPO71 load module (stored on the USGS computer) are illustrated in Appendix 2.

2.3 Data Cards.

These cards contain the input data, and are set up as follows. A quick reference for variable names and formats of the input data is given in Figure 1. To denote a blank punch in the text, we use $_{\Delta}$.

Jan. 30, 1974.

REVISIONS OF HYPO71

by
W. H. K. Lee and J. C. Lahr
National Center for Earthquake Research
U. S. Geological Survey
Menlo Park, California 94025

1. INTRODUCTION

HYPO71 is a computer program written by Willie Lee and John Lahr for determining hypocenter, magnitude, and first motion pattern of local earthquakes. The program was dated December 21, 1971, and a user's manual was published as an open-file report of the U.S. Geological Survey on March 30, 1972. The present document describes revisions of HYPO71 and replaces the interim "addendum and erratum to HYPO71 manual" dated May 31, 1973.

HYPO71 was originally written to process local earthquake data recorded by a large seismic network in central California. For the past two years, this program has been applied to various local earthquake data by over a dozen users. It is therefore desirable to generalize HYPO71 for worldwide usage. In addition, a few "bugs" in HYPO71 were discovered and corrected. These program revisions were carried out by Willie Lee in December 1973.

Not all HYPO71 users need the new revised version of the program because the corrections may not be necessary for their applications. In particular, if your seismic stations are located in the northwestern quadrant of the world, and if you do not use the azimuthal weighting option, you do not need the new version. For those users who need the revised HYPO71, please write to Willie Lee and specify whether you need the program in EBCDIC punched code for IBM 360 or 370 computers or in BCD punched code for CDC computers.

2. PROGRAM REVISIONS

2.1 Station Locations

The original HYPO71 program assumes that the seismic stations are located in the northwestern quadrant of the world. Therefore, the azimuthal angles and consequently the first-motion plot will not be correct if the seismic stations are located in other quadrants of the world. The present revision removes this restriction by requiring specifications of which quadrant the seismic stations are located. This is carried out by punching either N (for North) or S (for South) after the latitude, and by punching either E (for East) or W (for West) after the longitude on every station card in the station list. The details for this operation are described in Section 3.1.

If no quadrant specifications are given, the program will assume it is the northwestern quadrant. All seismic stations must be located in the same quadrant. This restriction is not critical because one can always add a constant to station longitude (or latitude allowing for a small error) to transform all stations to the same quadrant. But one must remember to subtract this constant from the epicenter coordinates.

2.2 Azimuthal Weighting

We are grateful to Mr. Ray Buland of University of California at San Diego for pointing out two errors in the original HYPO71 program concerning the azimuthal weighting: (1) If any S-arrivals are used in the location, the azimuthal weighting is incorrect because the azimuths (array AZ) are computed from 1 to NRP (total number of P-arrivals) in subroutine OUTPUT, but indexed from 1 to NR (total number of P- and S-arrivals) in subroutine AZWTOS. (2) If IPRN is zero (i. e., no intermediate printout for every iteration step), then azimuthal weighting will not function at all because OUTPUT is not called, and so azimuths are not computed.

These two errors have been corrected in the revised HYPO71 program by computing the azimuths (indexed from 1 to NR) in subroutine AZWTOS.

2.3 Miscellaneous Corrections

The following minor "bugs" in the original HYPO71 program have been corrected even though they occur very infrequently:

(1) If the P-arrival of the station nearest to the earthquake epicenter was not used in the location (i. e., has zero weight either due to input specification or due to large residual, then DM (epicentral distance to the nearest station) is not computed correctly. This error has been corrected in the revised HYPO71 by computing DM to the nearest station that has positive weight for either P- or S-arrival.

(2) If a station has zero weight for P-arrival but positive weight for S-arrival, then GAP (largest azimuthal separation between stations) is not computed correctly. This error has been corrected in the revised HYPO71 by computing GAP from all stations that have positive weight for either P- or S-arrival.

(3) If the iteration is terminated in the first step, the original HYPO71 program will skip an extra page when KSEL is selected to be 1 (for starting each earthquake at a new page). This error has also been corrected.

3. CORRECTIONS TO HYPO71 MANUAL

3.1 Corrections due to Program Revisions

In order to specify which quadrant of the world the seismic stations are located, we need to punch either N or S after station latitude and to punch either E or W after station longitude. Therefore, please add the following to your HYPO71 Manual:

Station Format No. 1:

- P. 9: between line 13 and 14, add:
  Column = 14, Name = INS, Format = A1, Explanation = N for north latitude; S for south latitude, Examples = N or S.
- P. 9: between line 15 and 16, add:
  Column = 23, Name = IEW, Format = A1, Explanation = E for east longitude; W for west longitude, Examples = E or W.

Station Format No. 2:

- P. 10: between line 16 and 17, add:
  Column = 14, Name = INS, Format = A1, Explanation = N for north latitude; S for south latitude, Examples = N or S.
- P. 10: between line 19 and 20, add:
  Column = 24, Name = IEW, Format = A1, Explanation = E for east longitude; W for west longitude, Example = E or W

Appendix 1 (p. 41-90) of the HYPO71 Manual is a listing of the <u>original</u> HYPO71 program. This should be replaced by a listing of the <u>revised</u> HYPO71 program. However, it is too cumbersome to do so. Therefore, any user wishing to have a listing of the revised HYPO71 program should request it by writing to Willie Lee. Furthermore, Figure 1 (p. 5) should contain the additional latitude and longitude information given above.

3.2 Corrections due to Typographical Errors

The following corrections should be made in the HYPO71 Manual (the program itself is correct):

p. 18: line 4 from the bottom:
"If the system number (KLAS)...an earthquake event" should read "The system number (KLAS), and/or standard calibration (CALR) for any station may be changed from time to time by inserting a calibration card like an earthquake event."

p. 19: line 7: "21" should read "22", and add the following lines:
Column = 59-62, Name = CALX, Format = F4.1,
Explanation = New station calibration value (10 μv signal in mm),
Examples = 13.2

p. 38: line 5 from the bottom:
log(D) should read $\log(D^2)$

p. 40: line 4 from the bottom:
"Seismol. Soc. America Bull. [in preparation]." should be replaced by "<u>Open File Report</u>, <u>U. S. Geological Survey</u>, 28 pp., 1972.

4. ADDITIONAL TIPS FOR USING HYPO71

Locating local earthquakes accurately requires considerable efforts: one must have accurate station coordinates (better than ±0.1 km if possible), a reasonable crustal structure (from controlled explosions), and reliable P- and S-arrivals. No computer program will give correct answers if the input data contain errors. Therefore, one should not expect "miracles" from poor data, and one should always check his data carefully before feeding them to a computer program such as HYPO71. One should also remember that small residuals and standard errors are not sufficient to guarantee accurate hypocenter solution.

HYPO71 is designed to catch a few obvious mistakes in the input data, but users should not count on it to catch all their errors. HYPO71 also provides an accessment on the quality of the hypocenter solution (p. 22) and auxiliary information. Users are urged to study these outputs carefully. Finally, users should review p. 7-8 of the HYPO71 Manual concerning the "TEST VARIABLES." Values for "TEST VARIABLES" must be carefully chosen for a given application because they determine how the program goes about locating the earthquakes. The standard values in the program were developed for the large and closely spaced network of seismic stations in central California (with over 100 stations and station separation is usually less than 10 km).

For seismic network of less than, say, 10 or 20 stations, we would recommend trying TEST (03) = 0.5, and TEST (06) $\lesssim$ 1. (see p. 7 of HYPO71 Manual). In addition, the following comments may be helpful:

(1) TEST (01) should be set to a value approximately equal to the timing accuracy of P-arrivals in seconds.

(2) TEST (02) should be set to a value approximately equal to station spacing in kilometers.

(3) TEST (03) should be set according to the number and quality of P- and S-arrivals. In general, we recommend a value between 0.5 to 2. If TEST (03) = 0., a simple multiple regression is performed regardless whether the matrix is ill-conditioned (p. 27-29). This is not desirable because the hypocenter solution may be meaningless. On the other hand, if TEST (03) is set to 2 or greater, then Geiger's iteration may be terminated prematurely, before a good hypocenter is found.

(4) TEST (05) should be set to a value approximately equal to half the range of focal depth expected. For example, most earthquakes have focal depths between 0 and 10 km in central California. Therefore, we use a value of 5 km for trial focal depth (p. 11), and TEST (05) = 5 km.

(5) TEST(13) should be set to a value approximately equal to the standard error of epicenter in kilometers.

Finally, comments and criticisms of HYPO71 from users are welcome so that further improvements can be made. Users are urged to write or call Willie Lee (415-323-8111, Ext. 2630) should any problem occur in using HYPO71.

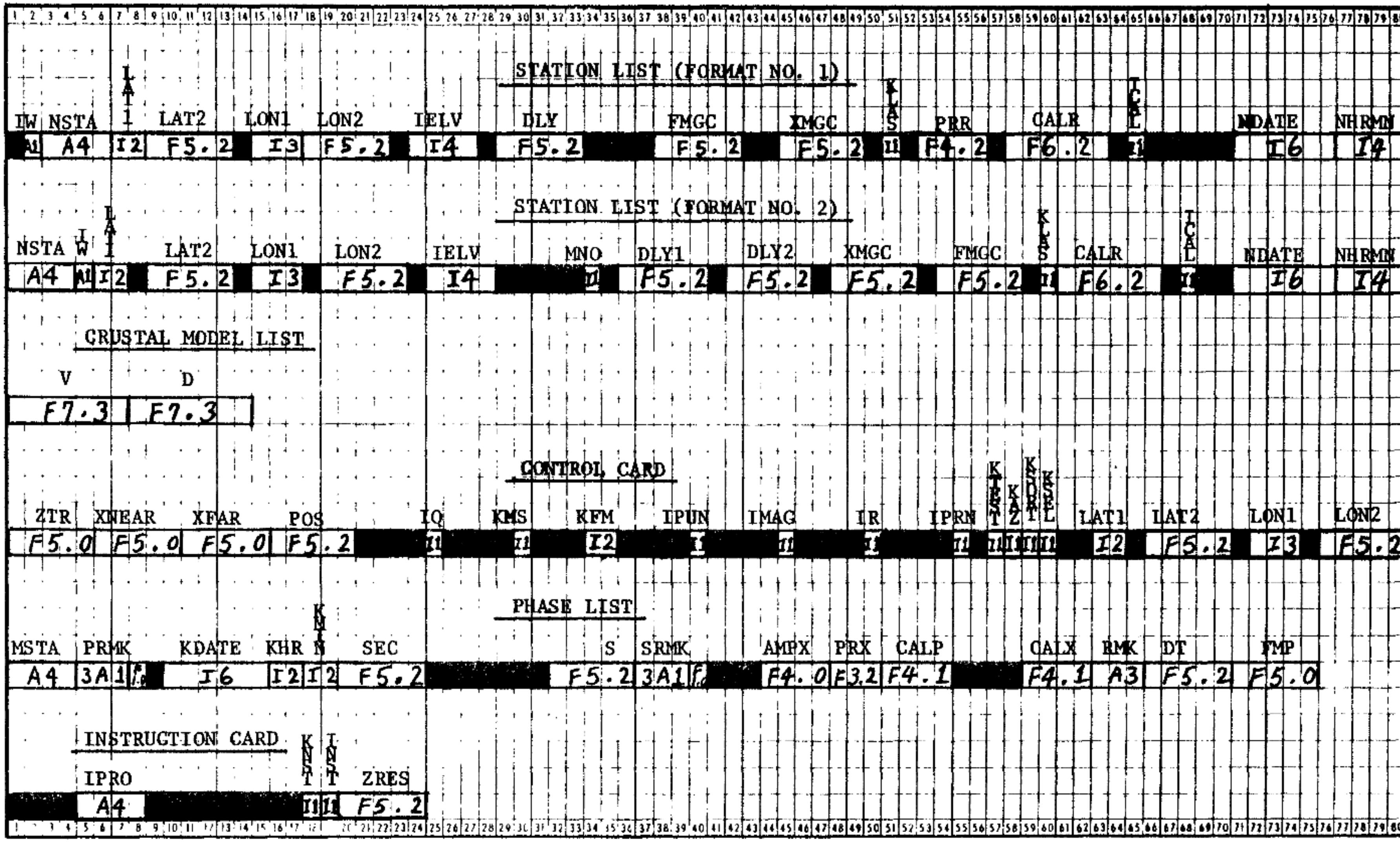


Figure 1. Variable Names and Formats of HYPO71 Input Data.

Item	Maximum Number of cards	Remarks	Page
(1) Heading card	1	optional	6
(2) Reset list	13	optional	6
(3) Selection card	1		8
(4) Station list	150		9
(5) Blank card	1	to signal end of (4)	
(6) Crustal model list	20		11
(7) Blank card	1	to signal end of (6)	
(8) Control card	1		11
(9) Phase list	100	repeated for each quake	14
(10) Instruction card	1	repeated for each quake	16
(11) Additional instruction list		optional	16
(12) Recycle card		optional, see below	

Previous items may be repeated by using a recycle card to be punched on columns 2 to 4

Columns (2 to 4)	Remarks
***	Repeat (1) to (12) by returning to (1)
$$$	Repeat (6) to (12) by returning to (6)
¢¢¢	Repeat (8) to (12) by returning to (8)

2.3-1 Heading Card. This card is optional and is used to write a heading above each earthquake in the output. Punch HEAD in columns 1 to 4, and the heading in columns 26 to 74.

2.3-2 Reset List. This list is optional and may contain any number of cards up to a maximum of 13. The purpose of this list is to reset values of the test variables used in the program. The standard values (initiated by the program) are appropriate for earthquakes recorded by the USGS California Network of stations. Careful consideration should be given to their definitions and the values appropriate to a given set of data before this program is used.

An example of a reset card is:

RESET$_{\Delta}$TEST(06)=0.75 starting at column 1. The subscript of the test variable must be punched in columns 12 and 13, and the value of the test variable must be punched in F-format in columns 16 to 25. Definitions for the test variables are given as follows:

Test Variable	Standard Value	Definition
TEST(01)	0.1 sec	TEST(01) is the cutoff value for RMS below which Jeffreys' weighting of residuals is not used.
TEST(02)	10 km	For each iteration step, if the epicentral adjustment ≥ TEST(02), this step is re-calculated without focal-depth adjustment.
TEST(03)	2.	Critical F-value for the stepwise multiple regression (Draper and Smith, 1966).
TEST(04)	0.05 km	If the hypocentral adjustment is less than TEST(04), Geiger's iteration is is terminated.
TEST(05)	5. km	If the focal-depth adjustment (DZ) is greater than TEST(05), DZ is reset to DZ / (K + 1), where K = DZ / TEST(5).
TEST(06)	4.	If no significant variable is found in the stepwise multiple regression, the critical F-value, TEST(03), is reduced to TEST(03)/TEST(06), and the regression is repeated. If TEST(06) ≤1., then the regression is repeated to find one variable, and the adjustment is made only if it is greater than TEST(06)* standard error.

Test Variable	Standard Value	Definition
TEST(07)	-0.87	Coefficients for calculating the duration magnitude (FMAG) (Lee, Bennett and Meagher, 1972): FMAG = -0.87 + 2 log(T) + 0.0035 D where T is signal duration in sec, and D is epicentral distance in km.
TEST(08)	2.00	
TEST(09)	0.0035	
TEST(10)	100 km	If the latitude or longitude adjustment (DX or DY) is greater than TEST(10), then DX is reset to DX/(J+1), and DY is reset to DY/(J+1), where J = D/TEST(10), D being the larger of DX or DY.
TEST(11)	8.	Maximum number of iterations in the hypocentral adjustment.
TEST(12)	0.5	If the focal-depth adjustment (DZ) would place the hypocenter in the air, then DZ is reset to DZ = -Z * TEST(12), where Z is the focal depth.
TEST(13)	1. km	Auxiliary RMS values are optionally calculated at ten points on a sphere of radius $\sqrt{3}$ * TEST(13) Eight of the ten points fall on the corners of a cube, with sides equal to 2 * TEST(13).

2.3-3 Selection Card. In HYPO71, travel time from a trial hypocenter to a station is calculated from a given crust model consisting of multiple horizontal layers. Each layer is specified by a P-velocity and the depth to the top of the layer. Additional complexity in crustal structure may be modeled in two ways:

a) Station Delay Model. The selection card is a blank, and the station delay is simply added to the calculated travel time for each station.

b) Variable First-Layer Model. The selection card has a 1 punched in Column 1. To account for different travel paths, the station delay at a given station is converted to an equivalent first-layer thickness. This then alters the crustal structure under this station. In other words, all stations have slightly different crustal structure: the P-velocities are the same, but the layer thickness of the first and second layers differ from station to station. In addition, two delays may be assigned to a given station corresponding to different earthquake source regions.

2.3-4 <u>Station List</u>. For each seismograph station, a station card must be punched. Use Station Format No. 1 for the Station Delay Model, and Station Format No. 2 for the Variable First-Layer Model.

<u>Station Format No. 1 (for Station Delay Model)</u>

Column	Name	Format	Explanation	Examples
2	IW	A1	If IW = *, then this station has zero weight assigned to its P and/or S reading(s).	Normally blank
3-6	NSTA	A4	Station name	SBSM or $_{\Delta}$MOB
7-8	LAT1	I2	Degree portion of latitude	37
9-13	LAT2	F5.2	Minute portion of latitude	15.72
15-17	LON1	I3	Degree portion of longitude	121
18-22	LON2	F5.2	Minute portion of longitude	30.45
24-27	IELV	I4	Elevation in meters*	1250 or $_{\Delta\Delta}$50
29-33	DLY	F5.2	Station delay in seconds	+0.20 or -0.08
38-42	FMGC	F5.2	Station correction for FMAG	+0.25 or -0.50
45-49	XMGC	F5.2	Station correction for XMAG	+0.25 or -0.50
51	KLAS	I1	System number is assigned for each station so that the frequency response curve of the seismometer and preamp is specified for the amplitude magnitude calculation (XMAG)	0 for Wood-Anderson 1 for NCER Standard 2 for EV-17 & Develco 3 for HS-10 & Teledyne 4 for HS-10 & Develco 5 for L-4C & Develco 6 for L-4C & Teledyne 7 for L-4C replacing HS-10 & Develco 8 for ten-day recorders
53-56	PRR	F4.2	Standard period for XMAG	0.15 or blank
58-63	CALR	F6.2	Standard calibration for XMAG	$_{\Delta}$10.50 or blank

* Elevation is not used in this program.

Station Format No. 1 (for Station Delay Model) --Continued

Column	Name	Format	Explanation	Examples
65	ICAL	I1	Calibration indicator: punch 1 if one always wants to use the standard calibration; otherwise leave it blank.	1 or blank
71-76	NDATE	I6	Year, month, and day	710625 or blank
77-80	NHRMN	I4	Hour and minute	1224 or blank

Station Format No. 2 (for Variable First-Layer Model)

Column	Name	Format	Explanation	Examples
1-4	NSTA	A4	Station name	SBSM or $_{\Delta}$MOB
5	IW	A1	If IW=*, then this station has zero weight assigned to its P or S readings.	Normally blank
6-7	LAT1	I2	Degree portion of latitude	37
9-13	LAT2	F5.2	Minute portion of latitude	15.72
15-17	LON1	I3	Degree portion of longitude	121
19-23	LON2	F5.2	Minute portion of longitude	30.45
25-28	IELV	I4	Elevation in meters	1250 or $_{\Delta\Delta}$50
34	MNO	I1	Preferred model number. If MNO=1 and this station is nearest to the earthquake, then model 1 is used.	1 or 2
36-40	DLY1	F5.2	Station delay for model 1 in sec.	+0.20 or -0.08
42-46	DLY2	F5.2	Station delay for model 2 in sec.	+0.20 or -0.08
48-52	XMGC	F5.2	Station correction for XMAG	+0.25 or -0.50
54-58	FMGC	F5.2	Station correction for FMAG	+0.25 or -0.50

Station Format No. 2 (for Variable First-Layer Model)

Column	Name	Format	Explanation	Examples
60	KLAS	I2	System number (see explanation in Station Format No. 1).	
61-66	CALR	F6.2	Standard calibration for XMAG	Δ10.50 or blank
68	ICAL	I1	Calibration indicator: punch 1 if the standard calibration is to be used; otherwise leave it blank.	1 or blank
71-76	NDATE	I6	Year, month and day	710625 or blank
77-80	NHRMN	I4	Hour and minute	1224 or blank

2.3-5 Crustal Model List. For each flat layer, a crustal model list card must be punched as follows:

Column	Name	Format	Explanation	Examples
1-7	V	F7.3	P-velocity in km/sec in a given layer	ΔΔ3.5ΔΔ
8-14	D	F7.3	Depth in km to the top of a given layer	ΔΔ0.00Δ for the first layer

2.3-6 Control Card. This card selects some of the options in HYPO71 and must be punched as follows:

Column	Name	Format	Explanation	Examples
1-5	ZTR	F5.0	Trial focal depth in km	ΔΔΔ5.
6-10	XNEAR	F5.0	Distance in km from epicenter where the distance weighting is 1	ΔΔ50.
11-15	XFAR	F5.0	Distance in km from epicenter beyond which the distance weighting is 0	Δ200.

2.3-6 Control Card -- Continued

Column	Name	Format	Explanation	Examples
16-20	POS	F5.2	Ratio of P-velocity to S-velocity	Δ1.78 is recommended
25	IQ	I1	Quality class of earthquake to be included in the summary of residuals	1 for class A 2 for A and B 3 for A, B, and C 4 for all
30	KMS	I1	Indicator to check missing data	0 for NOT checking 1 for checking
34-35	KFM	I2	Minimum number of first motion readings required before it is plotted. Leave it blank if no first motion plot is needed.	15 or blank
40	IPUN	I1	Indicator for punched cards	0 for no punched cards 1 for punching summary cards 2 for punching summary and station cards 3 for punching summary cards and new station list with revised residuals 4 for punching summary cards and new station list with revised system number and standard calibration.
45	IMAG	I1	Method of selecting earthquake magnitude (MAG)	0 for MAG = XMAG 1 for MAG = FMAG 2 for $MAG = \frac{XMAG + FMAG}{2}$
50	IR	I1	Number of new system response curves to be read in. Normally leave it blank unless one wishes to override the NCER system response curves. See page 54 (HYP00531 - HYP00536).	blank

2.3 Control Card -- Continued

Column		Name	Format	Explanation	Examples
55		IPRN	I1	Indicator for printed output. We recommend IPRN = 1	0 for final solution and station residuals 1 for above plus one line each per iteration 2 for above plus station residuals per iteration 3 for above plus details from stepwise multiple regression
57	CODE	KTEST	I1	If KTEST = 1, then auxiliary RMS values are calculated at ten points on a sphere centered at the hypocenter. This option will help to determine if the solution is at the RMS minimum.	1 or blank
58	CODE	KAZ	I1	If KAZ = 1, then azimuthal weighting of stations is applied. See page 29.	1 or blank
59	CODE	KSORT	I1	If KSORT = 1, then the stations are sorted by distance in the output	1 or blank
60	CODE	KSEL	I1	If KSEL = 1, then printed output for each earthquake will start at a new page.	1 or blank
63-64		LAT1	I2	Degree portion of the trial-hypocenter latitude	
66-70		LAT2	F5.2	Minute portion of the trial-hypocenter latitude	
72-74		LON1	I3	Degree portion of the trial-hypocenter longitude	
76-80		LON2	F5.2	Minute portion of the trial-hypocenter longitude	

Note: If columns 63-80 are blank, then location of the nearest station is used as trial-hypocenter (with addition of 0.1 minute to both latitude and longitude to avoid "ARCTAN (0/0)" in calculating the azimuth between epicenter and station).

2.3-7 Phase list. For each seismographic station recording the earthquakes, a phase list card must be punched as follows. A maximum of 100 cards is allowed in the phase list.

Column	Name	Format	Explanation	Examples
1-4	MSTA	A4	Station name	SBSM or $_{\Delta}$MOB
5	PRMK	A1	Description of onset of P-arrival	I denotes impulsive or sharp E denotes emergent or gradual
6	PRMK	A1	"P" to denote P-arrival	P or blank
7	PRMK	A1	First motion direction of P-arrival	U = Up = C = Compression D = Down = Dilatation + = poor U or C - = poor D N = Noisy blank = Not readable
8	PRMK	F1.0	Weight assigned to P-arrival	0 or blank = Full weight 1 = 3/4 weight 2 = 1/2 weight 3 = 1/4 weight 4 = No weight
10-15	KDATE	I6	Year, month, and day of P-arrival	700105 for Jan. 5, 1970
16-17	KHR	I2	Hour of P-arrival	18
18-19	KMIN	I2	Minute of P-arrival	32
20-24	SEC	F5.2	Second of P-arrival	15.25
32-36	S	F5.2	Second of S-arrival	20.10

2.3-7 Phase list. -- Continued

Column	Name	Format	Explanation	Examples
37	SRMK	A1	Description of onset of S-arrival	I or E or blank
38		A1	"S" to denote S-arrival	S or blank
39		A1	First motion direction	U, or D, or +, or -, or N, or blank
40		F1.0	Weight assigned to S-arrival	Same as that for P-arrival at Column 8
44-47	AMPX	F4.0	Maximum peak-to-peak amplitude in mm	$_{\Delta}$24. or $_{\Delta\Delta}$24
48-50	PRX	F3.2	Period of the maximum amplitude in sec. Standard period (PRR) for this station as specified in the station list will be used if this field is blank.	.15
51-54	CALP	F4.1	Normally not used except as noted in next item.	
59-62	CALX	F4.1	Peak-to-peak amplitude of 10 μv calibration signal in mm. If this field is blank, then CALX = CALP. If again CALX is blank, then the standard calibration (CALR) for this station as specified in the station list will be used. If ICAL = 1 (in the station list for this station), then CALX will always be replaced by CALR.	$_{\Delta}$5.4
63-65	RMK	A3	Remark for this phase card. Any three characters (except CAL) may be used.	Q05 or blank
66-70	DT	F5.2	Time correction in sec. Normally not used for telemetered stations, so leave it blank.	blank

2.3-7 Phase list. -- Continued

Column	Name	Format	Explanation	Examples
71-75	FMP	F5.0	F-P time in sec. This is the duration time of earthquake. In NCER practice, one measures the time between the first P-arrival and that where the peak-to-peak amplitude of the seismic trace drops below 1 cm.	$_{\Delta\Delta}$15.

2.3-8 Instruction Card. At the end of the phase list for each earthquake, one instruction card must be punched as follows. For routine runs, one usually chooses free solution (i.e. let the program decide what is the best solution), so that the instruction card is simply a blank card.

Column	Name	Format	Explanation	Examples
5-8	IPRO	A4	Normally IPRO = blank. If IPRO = $_{\Delta}$**$_{\Delta}$, additional instruction card will follow .	blank or $_{\Delta}$**$_{\Delta}$
18	KNST	I1	KNST = 0 implies do not use S Data KNST = 1 Use S Data Add 5 if First motion plot is desired	0, 1, 5, or 6
19	INST	I1	INST = 0 implies don't fix depth INST = 1 fix depth INST = 9 fix lat, lon, and depth. See 2.4-1 below	0, 1, or 9
20-24	ZRES	F5.2	Trial focal-depth. Normally this field is left blank unless one wishes to replace ZTR (in the control card) by ZRES for this earthquake.	blank

2.3-9 Additional Instruction List. Additional instruction cards may be optionally added to obtain other solutions for the same earthquake data. They are punched as follows:

Column	Name	Format	Explanation
5-8	IPRO	A4	If this is the last card in the instruction list, IPRO = blank. If more instruction cards follow, IPRO = $_\Delta$**$_\Delta$.
18	KNST	I1	Same as that described in section 2.3-8.
19	INST	I1	
20-24	ZRES	F5.2	
28-29	LAT1	I2	Degree portion of trial-hypocenter latitude
31-35	LAT2	F5.2	Minute portion of trial-hypocenter latitude
37-39	LON1	I3	Degree portion of trial-hypocenter longitude
41-45	LON2	F5.2	Minute portion of trial-hypocenter longitude

2.4 Additional Options.

Several additional options are available in HYPO71, and are described as follows.

2.4-1 All Fixed Solution.

This option may be used to calculate the travel times to various stations for a known origin time and hypocenter (e.g. nuclear explosions or quarry blasts). This is achieved by specifying INST = 9, and an additional card must then be punched as follows:

Column	Name	Format	Explanation	Examples
1-5	ORG1	F5.0	Minute portion of origin time	ΔΔ15.
6-10	ORG2	F5.2	Second portion of origin time	10.05
11-15	LAT1	I5	Degree portion of latitude of hypocenter.	ΔΔΔ37
16-20	LAT2	F5.2	Minute portion of latitude of hypocenter.	15.50
21-25	LON1	I5	Degree portion of longitude of hypocenter.	ΔΔ121
26-30	LON2	F5.2	Minute portion of longitude of hypocenter.	32.45
31-35	Z	F5.2	Focal depth of hypocenter in km	Δ0.00

2.4-2 Use of S-Arrivals. HYPO71 mainly uses P-arrivals to locate earthquakes. If S-arrivals are punched, they appear in the output but are NOT used in the solution of hypocenter. If one wishes to use S-arrivals in the solution, one must set KNST = 1 on the instruction card (2.3-8 and 2.3-9).

2.4-3 Use of S-P Intervals. If the same time base is not available for some stations, it is still possible to include the recorded S-P intervals in the hypocentral solution. This is very useful when there are few available stations. The phase cards of the S-P interval data are punched as usual (see P. 14). However, the weight assigned to the P-arrival (column 8) must be 9, and the weight assigned to S-arrival (column 40) is that desired for the S-P interval.

2.4-4 Calibration Changes. If the system number (KLAS) and standard calibration (CALR) for any station are changed from time to time, any new calibration can be input like an earthquake event. In this case, the phase list and instruction card are replaced by one card punched as follows:

Column	Name	Format	Explanation	Examples
1-4	MSTA	A4	Station name	SBSM or $_{\Delta}$MOB
10-15	KDATE	I6	Year, month, and day of new calibration	700215
16-17	KHR	I2	Hour of new calibration	21
18-19	KMIN	I2	Minute of new calibration	54
21	KLAS	I1	New system number	1
63-65	RMK	A3	Must be "CAL"	CAL only

This option therefore allows an automatic updating of instrumental changes so that correct magnitudes based on amplitude data will be computed.

3. OUTPUTS OF HYPO71

Most outputs of HYPO71 are printed by the line-printer. Cards are punched only when the data must be read back into the computer for subsequent running of other computer programs. The printer outputs are generally self-explanatory; the following explanations may be helpful to the users. Results of the test run (listed in Appendix 2) is given in Appendix 3.

3.1 Iteration Output (optional).

If IPRN = 1 on the control card, a one-line output appears for each iteration. This information shows what happened in each adjustment from the trial hypocenter to the final hypocenter.

Heading	Explanation
I	Iteration step number. If a particular step is repeated, I is also repeated.
ORIG	Origin time in sec. Date, hour and minute are given in HYPOCENTER OUTPUT (Section 3.2).
LAT N LONG W Depth	Hypocenter location at Step I See Section 3.2 for details
DM	Epicentral distance in km to the nearest station
RMS	Root mean square error of time residuals in sec. corrected for average P & S residual (AVRPS).
SKD	For S and D explanation, see Section 3.2. K denotes the status of the critical F-value (CF) in the iteration step. See Section 4 for more details. For K = 0, CF = TEST(03) For K = 1, CF = TEST(03)/TEST(06) For K = 2, F-test is skiped in order to calculate error estimates For K = 3, On this step no variable met the F-test entrance criterion and termination will occur. For K = 4, F-test is skiped, and the most significant variable is found. This step is taken only if the adjustment is greater than TEST(06) times its standard error.

3.1 Iteration Output (optional). -- Continued

Heading	Explanation
CF	Critical F-value. Its value is controlled by K as described above.
ADJUSTMENTS (km)	Under these three columns, adjustments in km for the latitude (DLAT), longitude (DLON), and focal depth (DZ) from the multiple regression analysis are given.
PARTIAL F-VALUES	Under these three columns, the partial F-values for the hypocentral adjustments are given. Values not calculated are set equal to -1.00.
STANDARD ERRORS	Under these three columns, the standard errors for the hypocenter adjustments are given in km.
ADJUSTMENTS TAKEN	Under these three columns, the actual adjustments taken to reach the next trial hypocenter are given in km.

3.2 Hypocenter Output.

Heading	Example	Explanation
DATE	700630	Date of earthquake: Year, month, and day. In this case, it is June 30, 1970.
ORIGIN	1659 24.05	Origin time: hour, minute, and second (Greenwich civil time). In this case, it is 16 hr, 59 mn, and 24.05 sec.
LAT N	37-48.64	North latitude of epicenter in degrees and minutes: 37° 48.64' N.
LONG W	121-57.59	West longitude of epicenter in degrees and minutes: 121° 57.59' W.
DEPTH	3.62	Focal depth in km: 3.62 km. A '*' may follow the DEPTH to indicate a fixed focal depth solution.
MAG	1.35	Magnitude of the earthquake. User specifies its choice from XMAG and/or FMAG.
NO	15	Number of station readings used in locating the earthquake. P and S arrivals for the same station are regarded as 2 readings. If NO = 3, a fixed depth solution is given. If NO<3, no solution is given.

Heading	Example	Explanation
DM	2	Epicentral distance in km to the nearest station.
GAP	110	Largest azimuthal separation in degrees between stations.
M	1	Crustal model number. M is used for the Variable First-Layer Model only.
RMS	0.09	Root mean square error of time residuals in sec. $RMS = \sqrt{\Sigma R_i^2/NO}$, where R_i is the time residual for the i^{th} station.
ERH	0.4	Standard error of the epicenter in km.* $ERH = \sqrt{SDX^2 + SDY^2}$, where SDX and SDY are the standard errors in latitude and longitude, respectively, of the epicenter. If ERH = blank, this means that ERH cannot be computed because of insufficient data.
ERZ	1.2	Standard error of the focal depth in km.* If ERZ is blank, this means that ERZ cannot be computed either because focal depth is fixed in the solution or because of insufficient data.
Q	B	Solution quality of the hypocenter. This measure is intended to indicate the general reliability of the solution:

Q	Epicenter	Focal Depth
A	Excellent	good
B	good	fair
C	fair	poor
D	poor	poor

Q is taken as the average of QS and QD (defined below). For example, an A and a C yield a B, and two B's yield a B. When QS and QD are only one level apart, the lower one is used, i.e., an A and a B yield a B.

Heading	Example	Explanation
SQD	A|B	QS and QD rating, In this case, QS = A, and QD = B. QS is rated by the statistical measure of the solution as follows:

* Statistical interpretation of standard errors involves assumptions which may not be met in earthquake locations. Therefore the standard errors may not represent actual error limits.

QS	RMS (sec)	ERH (km)	ERZ (km)
A	< 0.15	≤ 1.0	≤ 2.0
B	< 0.30	≤ 2.5	≤ 5.0
C	< 0.50	≤ 5.0	
D	Others		

QD is rated according to the station distribution as follows:

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

Heading	Example	Explanation
ADJ	0.0	Last adjustment of hypocenter in km. Normally this is 0 or less than 0.05.
IN	0	Instruction code (KNST and INST in input)
NR	17	Number of station readings available. This includes readings which are not used in determining hypocenter.
AVR	0.00	Average of time residuals in sec. $AVR \equiv \sum_i R_i/NO$. Normally this is 0.
AAR	0.07	Average of the absolute time residuals in sec. $AAR \equiv \sum_i \lvert R_i \rvert /NO$.
NM	5	Number of station readings available for computing maximum amplitude magnitude (XMAG).
AVXM	1.4	Average of XMAG of available stations.
SDXM	0.1	Standard deviation of XMAG of available stations.
NF	3	Number of station readings available for computing F-P magnitude (FMAG).
AVFM	1.3	Average of FMAG of available stations.
SDFM	0.2	Standard deviation of FMAG of available stations.
I	4	Number of iterations to reach the final hypocenter.

Items from DATE to Q inclusive are repeated at the head of every first-motion plot. If summary cards are punched, these items occupy from column 1 to 80.* However, order for M, GAP, and DMIN are changed. A heading card is punched preceding the summary cards, if IPUN $\geq$ 1 on the control card.

3.3 Station Output.

After each hypocenter output of 2 lines, station output follows for each station.

Heading	Example	Explanation
STN	BOL	Station name.
DIST	1.3	Epicentral distance in km.
AZM	202	Azimuthal angle between epicenter to station measured from north in degrees.
AIN	94	Angle of incidence measured with respect to downward vertical.
PRMK	IPUO	This is PRMK from input data.
HRMN	1659	Hour and minute of arrival time from input data.
P-SEC	25.30	The second's portion of P-arrival time from input data.
TPOBS	1.25	Observed P-travel time in sec. TPOBS ≡ T + DT - ORG where T is the P-arrival time, ORG is the origin time, and DT is the time correction from input data.
TPCAL	1.09	Calculated travel time in sec.
DLY/H1	0.05 or 3.12	If the Station Delay Model is used, then DLY means the station delay in sec from the input station list. If the Variable First-Layer Model is used, then H1 means the thickness of the first-layer in km at this station.
P-RES	0.16	Residual of P-arrival in sec. If the Station Delay Model is used, then P-RES ≡ TPOBS - (TPCAL + DLY). If '**' follows P-RES, it means that in the Jeffreys' weighting, this P-arrival is not reliable. If the Variable First-Layer Model is used, then P-RES ≡ TPOBS - TPCAL.

* The punch format is given on page 60 (HYPO0744 - HYPO0746).

Heading	Example	Explanation
P-WT	1.06	Weight used in hypocenter solution for P-arrival. This weight is a combination of quality weight specified in the data and other selected weightings. WT's are always normalized so that the sum is equal to N Normalization is necessary so as to avoid distortion in computing standard errors.
AMX	15.0	Maximum amplitude in mm from input data.
PRX	0.10	Period of maximum amplitude in sec. from input data. If PRX is not given on the phase card, then PRR from the corresponding station card is used in the computation of XMAG, but is not printed here.
CALX	2.20	Calibration in mm used in computing XMAG. If CALX is blank in the phase card, then CALR from the corresponding station card is used and is printed here as CALX.
K	5	System number for the station from input data.
XMAG	1.60	Maximum amplitude magnitude computed from AMX, PRX, CALX and K. A * follows XMAG if XMAG - AVXM $\geq$ 0.5.
RMK	Q05	Remark from input data.
FMP	10.0	F-P in sec from input data.
FMAG	1.02	F-P magnitude computed from F-P and DIST. A * follows FMAG if FMAG - AVFM $\geq$ 0.5.
SRMK	$ES_{\Delta}2$	This is SRMK from input data.
S-SEC	26.50	The second's portion of S-arrival time from input data.
TSOBS	2.45	Observed S-travel time in sec. TSOBS $\equiv$ T + DT - ORG, where T is the S-arrival time, ORG is the origin time, and DT is the time correction from input data.
S-RES	-0.22	Residual of S-arrival in sec. If the Station Delay Model is used, then S-RES $\equiv$ TSOBS - POS* (TPCAL + DLY). If the Variable First-Layer Model is used, then S-RES $\equiv$ TSOBS - POS*TPCAL.
S-WT	0.5	Weight used in hypocenter solution for S-arrival. See explanation of P-WT for additional information.
DT	blank	Station time correction in sec. from input data. DT is used to correct all stations to the same time base.

If S-P interval data are used, the meanings of some of the above headings are changed as follows.

Heading	Explanation
P-RES	S-P residual in sec. It is defined by P-RES ≡ TSOBS - TPOBS - (POS - 1) (DLY + TPCAL) for the Station Delay Model. DLY is multiplied by zero for computing P-RES as above for the Variable First-Layer Model.
S-RES	Same as P-RES
P-WT	Weight used in hypocenter solution for S-P interval data.
S-WT	Will always be **** to denote S-P interval data.
TSOBS	Observed S-P interval in sec.

3.4 <u>Map of Auxiliary RMS Values</u>.

This is an optional output for which KTEST is set to 1 on the Control Card. RMS values are computed at 10 points on a sphere centered on the final hypocenter. Each RMS value corresponds to an origin time which has been corrected for the average residual of the P and S arrivals (AVRPS) given at that point. A 3 dimensional view of the auxiliary RMS values minus the final hypocenter RMS value is printed (DRMS). The view is looking down to the north-west.

4. COMPUTATIONAL PROCEDURES IN HYPO71

The program HYPO71 consists of a main program and 14 subroutines: ANSWER, AZWTOS, BLOCK DATA, FMPLOT, INPUT1, INPUT2, MISING, OUTPUT, SINGLE, SORT, SUMOUT, SWMREG, TRVDRV, and XFMAGS. A complete listing of the program (with a fair amount of comments) is given in Appendix 1. Before we give some program notes, a brief outline is given of Geiger's method (Geiger, 1912) of determining the hypocenter of local earthquakes.

4.1 Geiger's Method.

Let the coordinates of the i^{th} station be (x_i, y_i, z_i), and the observed arrival time be τ_i. Let t_i be the computed arrival time based on a trial solution [i.e., an assumed origin time (t), and hypocenter (x, y, z)]. If the time residual

$$R_i \equiv \tau_i - t_i \tag{1}$$

is small, Taylor expansion of it will give:

$$R_i = dt + \frac{\partial t_i}{\partial x} dx + \frac{\partial t_i}{\partial y} dy + \frac{\partial t_i}{\partial z} dz + e_i \tag{2}$$

Since the travel time and derivatives can be computed from the given crustal model, we may obtain the adjustment vector (dt, dx, dy, dz) by least squares, i.e., demanding that the error e_i be such that:

$$\Sigma\, e_i^2 = \text{a minimum} \tag{3}$$

where Σ denotes summation over all stations, i.e., $i = 1$ to $i = n$. This is accomplished by solving the following normal equations which are derived from applying condition (3) to equation (2):

$$\begin{aligned}
ndt + \Sigma a_i dx + \Sigma b_i dy + \Sigma c_i dz &= \Sigma R_i \\
\Sigma a_i dt + \Sigma a_i^2 dx + \Sigma a_i b_i dy + \Sigma a_i c_i dz &= \Sigma a_i R_i \\
\Sigma b_i dt + \Sigma a_i b_i dx + \Sigma b_i^2 dy + \Sigma b_i c_i dz &= \Sigma b_i R_i \\
\Sigma c_i dt + \Sigma a_i c_i dx + \Sigma b_i c_i dy + \Sigma c_i^2 dz &= \Sigma c_i R_i
\end{aligned} \tag{4}$$

where

$$a_i \equiv \frac{\partial t_i}{\partial x} \; ; \; b_i \equiv \frac{\partial t_i}{\partial y} \; ; \; c_i \equiv \frac{\partial t_i}{\partial z} \tag{5}$$

The improved origin time and hypocenter then becomes:

$$t + dt, \text{ and } (x + dx,\ y + dy,\ z + dz) \tag{6}$$

Now (6) may be taken as the next trial solution, and the same procedure is repeated until some cutoff criteria are met.

In the case of S-P interval data, τ_i and t_i become the observed and calculated S-P intervals respectively. Because there is no dependance on the origin time, equation (2) becomes

$$R_i = \frac{\partial t_i}{\partial x} dx + \frac{\partial t_i}{\partial y} dy + \frac{\partial t_i}{\partial z} dz + e_i \tag{7}$$

and the normal equations (4) are modified accordingly.

Since the normal equations (4) are a set of 4 simultaneous linear equations for four unknowns: dt, dx, dy, dz, they may be solved by the usual method of matrix inversion. In practice, however, this matrix is often ill-conditioned, and computational difficulties arise. In HYPO71 a new method of finding the adjustment vector is introduced. Instead of carrying out the traditional procedure (which is equivalent to a simple multiple regression), a step-wise multiple regression is used. Equation (2) defines the time residual R_i as a function of dt, dx, dy, and dz. A statistical analysis is first performed to see which independent variable should be included in the regression and the normal equations are then set up for only those significant variables. Therefore, the adjustment vector is obtained by solving a matrix which is never ill-conditioned. Furthermore, convergence to a final hypocenter solution is also more rapid.

4.2 Program Notes.

These notes serve as extended comments on HYPO71, and are given in the order of the program listing (see Appendix 1).

(1) MAIN: The main program controls the flow of data processing by initializations and calls to various subroutines.

(2) ANSWER: It prints the intermediate results of the regression analysis (SWMREG), and is used only for tracing the computation of a given earthquake.

(3) AZWTOS: It performs the azimuthal weighting of stations by quadrants. Each occupied quadrant is given an equal weight. The quadrants are set up so as to minimize the number of quadrants without stations.

(4) BLOCK DATA: Initialize values for short-distance calculation, and for various constants used in the program.

(5) FMPLOT: Plot first-motion pattern of the lower focal hemisphere in an equal area projection. It is modified from subroutine PPROJ (NCER PROGRAM LIBRARY No. S007) written by M. S. Hamilton. For each observation, we have the azimuth α, the angle of incidence β, and a symbol SYM, where $0° \leq \alpha \leq 360°$, $0° \leq \beta \leq 180°$, and SYM = C (or +) for compression, or D (or -) for dilatation.

If $\beta > 90°$, we let $\alpha = 180° + \alpha$ and $\beta = 180° - \beta$ so that all points plotted are in the lower focal hemisphere. The observation is transformed into polar coordinates (r,θ) in an equal area projection by the formulas:

$$r = \sqrt{2}\,\sin(\beta/2)$$

$$\theta = \alpha$$

A symbol is plotted on the graph at the point (r,θ). The symbol to be plotted is determined by the following rules:

If SYM = C, then plot one of the following:

C If no other observation occupies the position (r,θ).

B If one 'C' already occupies (r,θ).

A If two or more 'C' already occupy (r,θ).

X If at least one 'D' already occupies (r,θ).

If SYM = D, then plot one of the following:

D If no other observation occupies the position (r,θ).

E If one 'D' already occupies (r,θ).

F If two or more 'D' already occupy (r,θ).

X If at least one 'C' already occupies (r,θ).

If SYM = + or -, it is plotted only if the position (r,θ) is not occupied.

(6) INPUT 1: Read in heading card, reset test-variable list, station list, crustal model, and control card. If any array dimension is exceeded, an error message will be printed out and the program will then stop.

(7) INPUT 2: Read in phase list and instruction card. If 'CAL' is encountered in RMK columns, system number and standard calibration are revised.

(8) MISING: This subroutine checks if any station in the station list which should record the earthquake is missing from the input data. A "missing" station will be printed if its epicentral distance is less than the nearest

station, or if it would reduce the azimuthal gap between its two neighboring stations (EX-GAP) by not less than 30°. The latter check applies only to a radius of 25*$(MAG)^2$ km (100 km if MAG is not given of the final epicenter), where MAG is the earthquake magnitude. The amount by which the missing station would reduce the EX-GAP is given by RD-GAP.

(9) OUTPUT: See Section 3

(10) SINGLE: This routine processes one earthquake at a time, and involves the following steps.

a. Set up a trial hypocenter: The first trial epicenter is normally set to be the latitude and longitude of the station with the earliest P-arrival. 0.1' is added to the latitude and longitude of the trial epicenter to avoid difficulties in computing azimuthal angle. The first trial focal-depth is set equal to that given in the control card, unless specified on the instruction card. The first trial origin-time is set so that the average residual of P and S-arrivals is zero.

b. Geiger's adjustments: A maximum of 8 (TEST(11)) iterations are allowed in this DO loop to adjust the trial hypocenter to the final one. Latitude-longitude coordinates are converted to x-y coordinates using a short distances' calculation by Richter (1958, p. 701-705). Epicentral distance is then computed and distance weighting is combined with quality weighting. Other weightings (azimuthal and Jeffreys') are also included if chosen.
Subroutine TRVDRV (see Eaton, 1969, p. 26ff for details) is called to compute travel time and derivatives. S-arrivals are treated like P-arrivals by multiplying the calculated P travel time by the ratio of P-velocity/S-velocity. S-P interval data are treated analogously. Subroutine SWMREG is called to carry out a stepwise multiple regression of the time residuals and obtain the adjustment vector (dx, dy, dz, dt) and

its standard errors. If the horizontal adjustment, $\sqrt{dx^2 + dy^2}$, is greater than 10 km (TEST(02)), the adjustment vector is re-computed with fixed focal-depth. Focal-depth adjustment is restricted so that the hypocenter will not be placed in the air (see TEST(12)) and it must also not exceed 5 km (TEST(05)) in any one adjustment. These are accomplished by changing dz by the necessary amount, and any modification of dz is compensated by a change in dt. If the hypocentral adjustment, $\sqrt{dx^2 + dy^2 + dz^2}$, is less than 0.05 km (TEST(04)), then the iteration is terminated.

During the iteration process, if the RMS value increases, then the trial hypocenter is moved back by 1/5 of the previous adjustment, and the iteration step-number is not incremented. This procedure is repeated until the RMS value decreases or for a maximum of 4 times. The variable accounting for the largest portion of the adjustment is then deleted in the next multiple regression step.

c. Compute error estimates: Standard errors of adjustments dx, dy, and dz are computed by forcing subroutine SWMREG to make a simple multiple regression analysis. These errors correspond to the uncertainties involved if the final hypocenter were to be adjusted in all co-ordinates (x, y, z) once more.

(11) SORT: This is a utility subroutine to sort X_i, i = 1, . . ., N by increasing value.

(12) SUMOUT: This subroutine prints a table of the number and percentage of earthquakes in each quality class, Q, (see P. 22). It also prints a summary of travel time, X-magnitude, and F-magnitude residuals by station.

(13) SWMREG: This subroutine computes the Geiger adjustment vector (and its standard errors) by a step-wise multiple regression of travel time residuals. The method used here is that given in Draper and Smith (1966, p. 178-195), and will be briefly summarized as follows:

Equation (2) of Section 4.1 may be written more compactly as

$$e_i = Y_i - B_o - \sum_{j=1}^{3} B_j X_{j,i} \quad \text{for } i=1,\ldots,n$$

If there are stations with only S-P intervals then this equation is modified to the form:

$$e_i = Y_i - X_{o,i} B_o - \sum_{j=1}^{3} B_j X_{j,i} \quad \text{for } i = 1,\ldots,n$$

where $Y_i = R_i$

$$B_o = dt;\ B_1 = dx;\ B_2 = dy;\ B_3 = dz$$

$$X_{1,i} = \partial t_i/\partial x;\ X_{2,i} = \partial t_i/\partial y;\ X_{3,i} = \partial t_i/\partial z$$

$$X_{o,1} = \begin{cases} 1 \text{ for P or S data} \\ 0 \text{ for S-P interval data} \end{cases}$$

$$\text{let } Q = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (Y_i - X_{o,i} B_o - \sum_{j=1}^{3} B_j X_{j,i})^2$$

By minimizing the sum of the squares, Q, the maximum likelihood estimates of B_o, B_1, B_2, and B_3 will be obtained.

Setting $\frac{\partial Q}{\partial B_i} = 0$ yields these four equations. In the following 3 pages, repeated indices i imply summation over i = 1, . . . , n.

$$X_{o,i}\, X_{o,i}\, B_o + \sum_{j=1}^{3} B_j\, X_{o,i}\, X_{j,i} = X_{o,i}\, Y_i$$

$$X_{1,i}\, X_{o,i}\, B_o + \sum_{j=1}^{3} B_j\, X_{1,i}\, X_{j,i} = X_{1,i}\, Y_i$$

$$X_{2,i}\, X_{o,i}\, B_o + \sum_{J=1}^{3} B_j\, X_{2,i}\, X_{j,i} = X_{2,i}\, Y_i$$

$$X_{3,i}\, X_{o,i}\, B_o + \sum_{j=1}^{3} B_j\, X_{3,i}\, X_{j,i} = X_{3,i}\, Y_i$$

We can solve the first of these four equations for B_o.

Of the n original equations let q be the number based upon S-P interval data. Then set $m = n - q$.

$$X_{o,i}\, X_{o,i} = m$$

Define $\tilde{V}_j = \frac{1}{m} \sum_{i=1}^{n} X_{o,i}\, V_{j,i}$

Then:

$$B_o = \tilde{Y} - \sum_{j=1}^{3} B_j\, \tilde{X}_j$$

Use this value of B_o in the other three equations. Kth equation (k may equal 1, 2, or 3) becomes

$$X_{k,i}\, X_{o,i}\, \tilde{Y} + \sum_{j=1}^{3} (B_j\, X_{k,i}\, X_{j,i} - B_j\, X_{k,i}\, X_{o,i}\, \tilde{X}_j) = X_{k,i} Y_i \;,$$

or

$$\sum_{j=1}^{3} X_{k,i}\, (X_{j,i} - X_{o,i}\, \tilde{X}_j)\, B_j = X_{k,i}\, (Y_i - X_{o,i}\, \tilde{Y}).$$

But note that:

$$(X_{k,i} - X_{o,i}\tilde{X}_k)(X_{j,i} - X_{o,i}\tilde{X}_j) = X_{k,i}(X_{j,i} - X_{o,i}\tilde{X}_j) + X_{o,i}X_{o,i}\tilde{X}_j\tilde{X}_k - X_{o,i}X_{j,i}\tilde{X}_k$$

$$= X_{k,i}(X_{j,i} - X_{o,i}\tilde{X}_j) + m\tilde{X}_j\tilde{X}_k - m\tilde{X}_j\tilde{X}_k$$

The K^{th} equation can then be written:

$$\sum_{j=1}^{3}(X_{k,i} - X_{o,i}\tilde{X}_k)(X_{j,i} - X_{o,i}\tilde{X}_j)B_j = (X_{k,i} - X_{o,i}\tilde{X}_k)(Y_i - X_{o,i}\tilde{Y})$$

for k = 1, 2, or 3

These are a set of 3 simultaneous linear algebraic equations in the B_j and are known as the normal equations. They can be solved by a number of methods. Here we choose the abbreviated Doolittle method which is a variation of the usual Gaussian elimination. At each stage in the elimination, we make a decision as to what variable shall next be included in the regression.

The computational procedure is basically applying linear transformations to the augmented correlation matrix A:

$$A = \begin{pmatrix} R_{11} & R_{12} & R_{13} & R_{14} & 1 & 0 & 0 \\ R_{21} & R_{22} & R_{23} & R_{24} & 0 & 1 & 0 \\ R_{31} & R_{32} & R_{33} & R_{34} & 0 & 0 & 1 \\ R_{41} & R_{42} & R_{43} & R_{44} & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

where $$R_{jk} = \frac{\sum_{i=1}^{n}(X_{j,i} - X_{o,i}\tilde{X}_j)(X_{k,i} - X_{o,i}\tilde{X}_k)}{\left[\Sigma(X_{j,i} - X_{o,i}\tilde{X}_j)^2\ \Sigma(X_{k,i} - X_{o,i}\tilde{X}_k)^2\right]^{1/2}}$$

with the understanding that

$$X_{4,i} \equiv Y_i \text{ and } \tilde{X}_4 \equiv \tilde{Y}.$$

In the program, we use

$$S_{jk} = \sum_{i=i}^{n} (X_{j,i} - X_{o,i}\tilde{X}_j)(X_{k,i} - X_{o,i}\tilde{X}_k)$$

$$= X_{j,i}X_{k,i} - X_{o,i}X_{j,i}\tilde{X}_k + m\tilde{X}_j\tilde{X}_k - X_{o,i}X_{k,i}\tilde{X}_j$$

$$= X_{j,i}X_{k,i} - \frac{(X_{o,i}X_{j,i})(X_{o,i}X_{k,i})}{m} + m\tilde{X}_j\tilde{X}_k - m\tilde{X}_k\tilde{X}_j$$

and set $R_{jk} = \dfrac{S_{jk}}{\left[(S_{jj})(S_{kk})\right]^{1/2}}$

Matrix A is successively transformed whenever a variable (X_k) enters or leaves the regression. Whether a variable enters (or leaves) the regression depends only on whether the variance obtained by adding the variable to the regression is significant (or insignificant) at a specified F-level. This is accomplished by computing:

$$F_k = (\Phi - 1)\, V_k/(A_{44} - V_k)$$

where Φ is the degrees of freedom (n-1-number of variables in regression), and

$$V_k = A_{k4}A_{4k}/A_{kk}$$

If F_k exceeds the specified critical F-value (CF), then variable X_k enters the regression by transforming the elements of matrix A in two steps. First we compute

$$T_{kj} = A_{kj}/A_{kk} \quad \text{for } j=1,\ldots,7.$$

$$T_{ij}(i\neq k) = A_{ij} - A_{ik}A_{kj}/A_{kk} \text{ for } i=1,\ldots,7 \quad \text{and } j=1,\ldots,7.$$

We then replace elements of matrix A by that of matrix T just computed. Similarly to delete a variable from the regression we compute

$$F_k = \Phi A_{k4}^2 \ / \ (A_{44}A_{k+4,k+4})$$

If F_k is less than the specified critical F-value (CF), then variable X_k leaves the regression by transforming the elements of matrix A in two steps. First we compute

$$T_{kj} = A_{kj}/A_{k+4,k+4} \quad \text{for } j=1,\ldots,7.$$

$$T_{ij}\ (i\neq k, j\neq k) = A_{ij} - A_{i,k+4}A_{k+4,j}/A_{k+4,k+4}$$

$$T_{ik}(i\neq k) = A_{ik} - A_{i,k+4}/A_{k+4,k+4}$$

$$\text{for } i=1,\cdots,7 \quad \text{and } j=1,\cdots,7.$$

Then we replace elements of matrix A by that of matrix T just computed. After all variables are examined, we obtain the regression coefficients and their standard errors by

$$B_j = A_{j4} \sqrt{S_{44}/S_{jj}}$$

$$E_j = \sqrt{S_{44}A_{44}/\Phi} \quad \sqrt{A_{j+4,j+4}/S_{jj}}$$

where $S_{jk} = \Sigma\ (X_{ji}X_{ki}) - (\Sigma X_{ji})\ (\Sigma X_{ki})/n$

for $j=1,\ldots,4$ and $k=1,\ldots,4$.

The regression constant is then obtained by

$$B_o = \tilde{Y} - \sum_{j=1}^{3} B_j \tilde{X}_j .$$

Because all indices are dummies, they are named differently in the program. Furthermore, a simple extension takes into account the weighting factors provided that they are normalized to equal the number of observations.

(14) TRVDRV: This subroutine is a modification of TRVDRV written by J. P. Eaton (Eaton, (1969). It computes the travel time and derivatives for a horizontal-layer model.

(15) XFMAGS: This subroutine computes maximum amplitude magnitude (XMAG) and F-P magnitude (FMAG) for each station. The former is computed according to Eaton (1970). In brief:

$$XMAG = \log(A/2C) - R_{kf} - B_1 + B_2 \log D + G$$

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

C = Calibration peak-to-peak amplitude in mm.

R_{kf} = Frequency response of system number k and frequency f ($f = 1/\tau$, where τ is the period in sec.)

$$B_1 = 0.15, \quad B_2 = 0.80 \quad \text{for } 1 \text{ km} \le D \le 200 \text{ km}$$

$$B_1 = 3.38, \quad B_2 = 1.50 \quad \text{for } 200 \text{ km} \le D \le 600 \text{ km}$$

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

G = station XMAG correction.

FMAG is computed according to an empirical equation (Lee, Bennett and Meagher, 1972):

$$FMAG = C_1 + C_2 \log F + C_3\Delta + \gamma$$

where

C_1 = -0.87, or TEST(07)

C_2 = 2.0, or TEST(08)

C_3 = 0.0035, or TEST(09)

F = F-P time in sec.

Δ = epicentral distance in km.

γ = station FMAG correction.

REFERENCES

Draper, N. R., and H. Smith, Applied regression analysis, 407 pp., John Wiley & 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, Open File Report, U.S. Geological Survey, 155 pp., 1969.

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

Lee, W. H. K., R. E. Bennett, and K. L. Meagher, A method of estimating magnitude of local earthquakes from signal duration: Seismol. Soc. America Bull. [in press].

Richter, C. F., Elementary Seismology, 768 pp., Freeman and Co., San Francisco, 1958.

APPENDIX 1. A Listing of HYPO71

```
C------- PROGRAM: HYPO71 (DEC. 21, 1971) --------------------------------HYP00001
      INTEGER*2 SYM                                                     HYP00002
      REAL*8 TIME1,TIME2                                                HYP00003
      REAL LAT,LON,LAT2,LON2,LATEP,LONEP,MAG,LATR,LONR                  HYP00004
      COMMON /A3/ NRES(2,151),NXM(151),NFM(151),SR(2,151),SRSQ(2,151),  HYP00005
     1       SRWT(2,151),SXM(151),SXMSQ(151),SFM(151),SFMSQ(151),QNO(4) HYP00006
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40) HYP00007
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)HYP00008
      COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180)HYP00009
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,    HYP00010
     1       SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)     HYP00011
      COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101),         HYP00012
     1       RMK(101),WRK(101),TP(101),DT(101),COSL(701)                HYP00013
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR HYP00014
      COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDXS,LATEP,LONEP  HYP00015
      COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN       HYP00016
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)   HYP00017
      COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,IEXIT            HYP00018
      COMMON /A23/ AIN(101),RMS,ADJ,SYM(101)                            HYP00019
C-----------------------------------------------------------------------HYP00020
C------- RESET SOME LIMITS OF ERROR HANDLING FACILITY OF IBM FORTH -----HYP00021
      CALL ERRSET(207,256,1,0)                                          HYP00022
      CALL ERRSET(208,256,1,0)                                          HYP00023
      CALL ERRSET(209,256,1,0)                                          HYP00024
      CALL ERRSET(251,256,1,0)                                          HYP00025
      CALL ERRSET(255,256,1,0)                                          HYP00026
C------- SET UP SINE & COSINE TABLES FOR CALCULATING DISTANCES ---------HYP00027
      DO 10 I=1,180                                                     HYP00028
      PI=I*.0349066                                                     HYP00029
      CP(I)=COS(PI)                                                     HYP00030
   10 SP(I)=SIN(PI)                                                     HYP00031
      DO 20 I=1,701                                                     HYP00032
   20 COSL(I)=COS((I-1)*.0017453)                                       HYP00033
   30 M=0                                                               HYP00034
C------- INPUT STATION LIST, CRUSTAL MODEL, & CONTROL CARD -------------HYP00035
   40 CALL INPUT1                                                       HYP00036
      IF(IPUN .EQ. 0) GO TO 44                                          HYP00037
      WRITE(7,41)                                                       HYP00038
   41 FORMAT(' DATE    ORIGIN    LAT N    LONG W    DEPTH    MAG NO GAP HYP00039
     1DMIN  RMS  ERH  ERZ QM')                                          HYP00040
C-------- INITIALIZE SUMMARY OF RESIDUALS -------------------------------HYP00041
   44 DO 48 L=1,NS                                                      HYP00042
      NRES(1,L)=0                                                       HYP00043
      NRES(2,L)=0                                                       HYP00044
      NXM(L)=0                                                          HYP00045
      NFM(L)=0                                                          HYP00046
      SR(1,L)=0.                                                        HYP00047
      SR(2,L)=0.                                                        HYP00048
      SRSQ(1,L)=0.                                                      HYP00049
      SRSQ(2,L)=0.                                                      HYP00050
      SRWT(1,L)=0.                                                      HYP00051
```

```
      SRWT(2,L)=0.                                                      HYP00052
      SXM(L)=0.                                                         HYP00053
      SXMSQ(L)=0.                                                       HYP00054
      SFM(L)=0.                                                         HYP00055
      SFMSQ(L)=0.                                                       HYP00056
   48 CONTINUE                                                          HYP00057
      DO 49 I=1,4                                                       HYP00058
   49 QNO(I)=0.                                                         HYP00059
      XFN=XFAR-XNEAR+0.000001                                           HYP00060
      TIME1=0.D+00                                                      HYP00061
   50 CALL INPUT2                                                       HYP00062
C------- TO PROCESS ONE EARTHQUAKE -------------------------------------HYP00063
      IF (M .EQ. 1) GO TO 900                                           HYP00064
      IF (NR .GE. 1) GO TO 100                                          HYP00065
      WRITE(6,55)                                                       HYP00066
   55 FORMAT( ///,' ***** EXTRA BLANK CARD ENCOUNTERED *****')          HYP00067
      GO TO 50                                                          HYP00068
  100 CALL SINGLE                                                       HYP00069
      IF (IEXIT .EQ. 1) GO TO 50                                        HYP00070
C------- COMPUTE SUMMARY OF MAGNITUDE RESIDUALS ----------------------- HYP00071
  110 IF (JAV .GT. IQ) GO TO 50                                         HYP00072
      DO 150 I=1,NRP                                                    HYP00073
      IF  (XMAG(I) .EQ. BLANK) GO TO 120                                HYP00074
      JI=KDX(I)                                                         HYP00075
      DXMAG=XMAG(I)-AVXM                                                HYP00076
      NXM(JI)=NXM(JI)+1                                                 HYP00077
      SXM(JI)=SXM(JI)+DXMAG                                             HYP00078
      SXMSQ(JI)=SXMSQ(JI)+DXMAG**2                                      HYP00079
  120 IF  (FMAG(I) .EQ. BLANK) GO TO 150                                HYP00080
      JI=KDX(I)                                                         HYP00081
      DFMAG=FMAG(I)-AVFM                                                HYP00082
      NFM(JI)=NFM(JI)+1                                                 HYP00083
      SFM(JI)=SFM(JI)+DFMAG                                             HYP00084
      SFMSQ(JI)=SFMSQ(JI)+DFMAG**2                                      HYP00085
  150 CONTINUE                                                          HYP00086
      GO TO 50                                                          HYP00087
  900 CONTINUE                                                          HYP00088
C------- END OF ONE DATA SET: PRINT SUMMARY OF RESIDUALS & RETURN ------HYP00089
      CALL SUMOUT                                                       HYP00090
      IF (MSTA(NR+1) .EQ. MSTAR) GO TO 30                               HYP00091
      M=1                                                               HYP00092
      IF (MSTA(NR+1) .EQ. MDOL) GO TO 40                                HYP00093
      M=2                                                               HYP00094
      IF (MSTA(NR+1) .EQ. MCENT) GO TO 40                               HYP00095
      STOP                                                              HYP00096
      END                                                               HYP00097
```

```
      SUBROUTINE ANSWER(A,S,XMEAN,SIGMA,IDX,PHI,L,M,MM,PF,NDX,ADX)
C------- PRINT INTERMEDIATE RESULTS OF REGRESSION ANALYSIS (SWMREG) ---
      REAL*8 ADX
      DIMENSION A(7,7),S(4,4)
      DIMENSION XMEAN(1),SIGMA(1),IDX(1),B(4),BSE(4),PF(1)
C-----------------------------------------------------------------------
      DO 410 I=1,MM
      WRITE(6,400) (A(I,J),J=1,MM)
  400 FORMAT(7E18.8)
  410 CONTINUE
      FVE=1.-A(M,M)
      B0=XMEAN(M)
  450 YSE=77.7
      IF (PHI .GE. 1) YSE=SIGMA(M)*SQRT(ABS(A(M,M)/PHI))
      DO  5 I=1,L
      IF (IDX(I).EQ.0) GO TO  5
      B(I)=A(I,M)* SQRT(ABS(S(M,M)/S(I,I)))
      BSE(I)=YSE* SQRT(ABS(A(I+M,I+M)/S(I,I)))
      B0=B0-B(I)*XMEAN(I)
    5 CONTINUE
      WRITE(6,10) ADX,NDX,FVE,YSE,B0
   10 FORMAT(/,' VARIABLE ', A8, '................',I5
     2,       /,' FRACTION OF VARIATION EXPLAINED..',E18.8
     3,       /,' STANDARD ERROR OF Y..............',E18.8
     4,       /,' CONSTANT IN REGRESSION EQUATION..',E18.8)
      WRITE(6,20)
   20 FORMAT(/,' VARIABLE     COEFFICIENT      STANDARD ERROR'
     1,'      PARTIAL F-VALUE')
      DO 40 I=1,L
      IF (IDX(I).EQ.0) GO TO 40
      WRITE(6,30) I,B(I),BSE(I),PF(I)
   30 FORMAT(I5,3E20.6)
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AZWTOS                                                 HYP00133
C------- AZIMUTHAL WEIGHTING OF STATIONS BY QUADRANTS ------------------HYP00134
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)HYP00135
      COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180)HYP00136
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)            HYP00137
      COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)                  HYP00138
      DIMENSION TX(4),TXN(4),KTX(4),KEMP(101)                           HYP00139
C-----------------------------------------------------------------------HYP00140
      J=0                                                               HYP00141
      DO 10 I=1,NR                                                      HYP00142
      IF (WT(I) .EQ. 0.) GO TO 10                                       HYP00143
      J=J+1                                                             HYP00144
      TEMP(J)=AZ(I)                                                     HYP00145
   10 CONTINUE                                                          HYP00146
      CALL SORT(TEMP,KEY,J)                                             HYP00147
      GAP=TEMP(1)+360.-TEMP(J)                                          HYP00148
      IG=1                                                              HYP00149
      DO 20 I=2,J                                                       HYP00150
      DTEMP=TEMP(I)-TEMP(I-1)                                           HYP00151
      IF (DTEMP .LE. GAP) GO TO 20                                      HYP00152
      GAP=DTEMP                                                         HYP00153
      IG=I                                                              HYP00154
   20 CONTINUE                                                          HYP00155
      TX(1)=TEMP(IG)-0.5*GAP                                            HYP00156
      TX(2)=TX(1)+90.                                                   HYP00157
      TX(3)=TX(1)+180.                                                  HYP00158
      TX(4)=TX(1)+270.                                                  HYP00159
      DO 124 I=1,4                                                      HYP00160
      TXN(I)=0.                                                         HYP00161
      IF (TX(I) .LT. 0.) TX(I)=TX(I)+360.                               HYP00162
      IF (TX(I).GT.360.) TX(I)=TX(I)-360.                               HYP00163
  124 CONTINUE                                                          HYP00164
      CALL SORT(TX,KTX,4)                                               HYP00165
      DO 130 I=1,NR                                                     HYP00166
      IF (WT(I) .EQ. 0.) GO TO 130                                      HYP00167
      IF (AZ(I) .GT. TX(1)) GO TO 126                                   HYP00168
  125 TXN(1)=TXN(1)+1.                                                  HYP00169
      KEMP(I)=1                                                         HYP00170
      GO TO 130                                                         HYP00171
  126 IF (AZ(I) .GT. TX(2)) GO TO 127                                   HYP00172
      TXN(2)=TXN(2)+1.                                                  HYP00173
      KEMP(I)=2                                                         HYP00174
      GO TO 130                                                         HYP00175
  127 IF (AZ(I) .GT. TX(3)) GO TO 128                                   HYP00176
      TXN(3)=TXN(3)+1.                                                  HYP00177
      KEMP(I)=3                                                         HYP00178
      GO TO 130                                                         HYP00179
  128 IF (AZ(I) .GT. TX(4)) GO TO 125                                   HYP00180
      TXN(4)=TXN(4)+1.                                                  HYP00181
      KEMP(I)=4                                                         HYP00182
  130 CONTINUE                                                          HYP00183
```

```
      XN=4
      IF (TXN(1).EQ.0.) XN=XN-1
      IF (TXN(2).EQ.0.) XN=XN-1
      IF (TXN(3).EQ.0.) XN=XN-1
      IF (TXN(4).EQ.0.) XN=XN-1
      FJ=J/XN
      DO 150 I=1,NR
      IF (WT(I) .EQ. 0.) GO TO 150
      KI=KEMP(I)
      WT(I)=WT(I)*FJ/TXN(KI)
  150 CONTINUE
      RETURN
      END
```

```
      BLOCK DATA                                                        HYP00197
C------- INITIALIZE CONSTANTS IN COMMON STATEMENTS ---------------------HYP00198
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)HYP00199
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)            HYP00200
      COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)                  HYP00201
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR HYP00202
      COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE                HYP00203
      COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC   HYP00204
      DATA CA/  1.855365,1.855369,1.855374,1.855383,1.855396,1.855414,  HYP00205
     1 1.855434,1.855458,1.855487,1.855520,1.855555,1.855595,1.855638,  HYP00206
     2 1.855683,1.855733,1.855786,1.855842,1.855902,1.855966,1.856031,  HYP00207
     3 1.856100,1.856173,1.856248,1.856325,1.856404,1.856488,1.856573,  HYP00208
     4 1.856661,1.856750,1.856843,1.856937,1.857033,1.857132,1.857231,  HYP00209
     5 1.857331,1.857435,1.857538,1.857643,1.857750,1.857858,1.857964,  HYP00210
     6 1.858074,1.858184,1.858294,1.858403,1.858512,1.858623,1.858734,  HYP00211
     7 1.858842,1.858951,1.859061,1.859170,1.859276,1.859384,1.859488,  HYP00212
     8 1.859592,1.859695,1.859798,1.859896,1.859995,1.860094,1.860187,  HYP00213
     9 1.860279,1.860369,1.860459,1.860544,1.860627,1.860709,1.860787,  HYP00214
     A 1.860861,1.860934/                                               HYP00215
      DATA CB/  1.842808,1.842813,1.842830,1.842858,1.842898,1.842950,  HYP00216
     1 1.843011,1.843085,1.843170,1.843265,1.843372,1.843488,1.843617,  HYP00217
     2 1.843755,1.843903,1.844062,1.844230,1.844408,1.844595,1.844792,  HYP00218
     3 1.844998,1.845213,1.845437,1.845668,1.845907,1.846153,1.846408,  HYP00219
     4 1.846670,1.846938,1.847213,1.847495,1.847781,1.848073,1.848372,  HYP00220
     5 1.848673,1.848980,1.849290,1.849605,1.849922,1.850242,1.850565,  HYP00221
     6 1.850890,1.851217,1.851543,1.851873,1.852202,1.852531,1.852860,  HYP00222
     7 1.853188,1.853515,1.853842,1.854165,1.854487,1.854805,1.855122,  HYP00223
     8 1.855433,1.855742,1.856045,1.856345,1.856640,1.856928,1.857212,  HYP00224
     9 1.857490,1.857762,1.858025,1.858283,1.858533,1.858775,1.859008,  HYP00225
     A 1.859235,1.859452/                                               HYP00226
      DATA MBK,DOT,MSTAR,MDOL,MCENT/'    ',' .  ',' ***',' $$$','    '/ HYP00227
      DATA ISTTT/' ** '/                                                HYP00228
      DATA BLANK,STAR4,CLASS/'    ','****','A','B','C','D'/,QUES/'?'/   HYP00229
      DATA LMAX,MMAX,NMAX/21,101,151/,CRMK,ISTAR,IONE/'CAL','*','1   '/ HYP00230
      DATA AHEAD/'    ','    ','    ','    ','    ','    ','    ',       HYP00231
     1 '    ','    ','    ','    ','    '/                               HYP00232
      END                                                               HYP00233
```

```
      SUBROUTINE FMPLOT                                                 HYP00234
C------- PLOT FIRST-MOTION DIRECTIONS OF THE LOWER FOCAL HEMISPHERE     HYP00235
C------- IN EQUAL AREA PROJECTION, WHERE C DENOTES COMPRESSION AND      HYP00236
C------- D DENOTES DILATATION ------------------------------------------HYP00237
      INTEGER*2 GRAPH(95,59),SYM,TEMP                                   HYP00238
      INTEGER*2 BORD,BLANK,PL,CR,DOT,SI,A,B,C,D,E,F,CD,SN,UP            HYP00239
      REAL LAT2,LON2,MAG                                                HYP00240
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40) HYP00241
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,G(4,101),ZSQ,NRP,DF(101)HYP00242
      COMMON /A7/ KP,KZ,KOUT,WT(101),O(4),SE(4),XMEAN(4),CP(180),SP(180)HYP00243
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,    HYP00244
     1        SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)    HYP00245
      COMMON /A10/ ANIN(101),AZ(101),OOOO(101),CA(71),CB(71)            HYP00246
      COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,    HYP00247
     1        IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR HYP00248
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)   HYP00249
      COMMON /A23/ AIN(101),RMS,ADJ,SYM(101)                            HYP00250
      DATA BORD,BLANK,PL,CR,DOT,SI/'*',' ','+','-','.','I'/             HYP00251
      DATA A,B,C,D,E,F,CD,SN,UP/'A','B','C','D','E','F','X','N','U'/    HYP00252
      DATA NOX,NOY,IX,IY,NOY1,NOX2,NOY2/95,59,39,24,57,48,30/           HYP00253
      DATA RMAX,XSCALE,YSCALE,ADD/3.937008,0.101064,0.169643,4.75/      HYP00254
C-----------------------------------------------------------------------HYP00255
      NFMR=0                                                            HYP00256
      NO=FNO                                                            HYP00257
      DO 1 I=1,NRP                                                      HYP00258
      IF (SYM(I) .EQ. SN) SYM(I)=BLANK                                  HYP00259
      IF (SYM(I) .EQ. BLANK) GO TO 1                                    HYP00260
      IF (SYM(I) .EQ. UP) SYM(I)=C                                      HYP00261
      NFMR=NFMR+1                                                       HYP00262
    1 CONTINUE                                                          HYP00263
      IF (NFMR .LT. KFM) RETURN                                         HYP00264
      WRITE(6,2)                                                        HYP00265
    2 FORMAT(1H1,'  DATE    ORIGIN     LAT N    LONG W    DEPTH    MAG NOHYP00266
     1 GAP DMIN  RMS  ERH  ERZ Q M')                                    HYP00267
      WRITE(6,5) KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,Z,RMK2     HYP00268
     1,MAG,NO,IGAP,DMIN,RMS,ERH,SE(3),Q,KNO                             HYP00269
    5 FORMAT(2X,I6,1X,2I2,F6.2,I3,'-',F5.2,I4,'-',F5.2,A1,F6.2,A1       HYP00270
     1,F6.2,I3,I4,F5.1,F5.2,2F5.1,1X,A1,1X,I1)                          HYP00271
      DO 10 I=1,NOX                                                     HYP00272
      DO 10 J=1,NOY                                                     HYP00273
   10 GRAPH(I,J)=BLANK                                                  HYP00274
      DO 20 I=1,180                                                     HYP00275
      X=RMAX*CP(I)+ADD                                                  HYP00276
      Y=RMAX*SP(I)+ADD                                                  HYP00277
      JX=X/XSCALE+1.5                                                   HYP00278
      JY=Y/YSCALE+.5                                                    HYP00279
      JY=NOY-JY-1                                                       HYP00280
   20 GRAPH(JX,JY)=BORD                                                 HYP00281
      IT=NOX2-IX-1                                                      HYP00282
      GRAPH(IT,NOY2)=CR                                                 HYP00283
      IT=NOX2+IX+1                                                      HYP00284
```

```
      GRAPH(IT,NOY2)=CR                                                 HYP00285
      IT=NOY2-IY-1                                                      HYP00286
      GRAPH(NOX2,IT)=SI                                                 HYP00287
      IT=NOY2+IY+1                                                      HYP00288
      GRAPH(NOX2,IT)=SI                                                 HYP00289
      DO 50 I=1,NRP                                                     HYP00290
      IF (SYM(I) .EQ. BLANK) GO TO 50                                   HYP00291
      IF (AIN(I) .GT. 90.) GO TO 31                                     HYP00292
      ANN=AIN(I)                                                        HYP00293
      AZZ=AZ(I)*.0174533                                                HYP00294
      GO TO 32                                                          HYP00295
   31 ANN=180.-AIN(I)                                                   HYP00296
      AZZ=(180.+AZ(I))*.0174533                                         HYP00297
   32 R=RMAX*1.414214*SIN(ANN*.0087266)                                 HYP00298
      X=R*SIN(AZZ)+ADD                                                  HYP00299
      Y=R*COS(AZZ)+ADD                                                  HYP00300
      JX=X/XSCALE+1.5                                                   HYP00301
      JY=Y/YSCALE+.5                                                    HYP00302
      JY=NOY-JY-1                                                       HYP00303
      TEMP=GRAPH(JX,JY)                                                 HYP00304
C-----OVER-WRITE TEMP IF IT IS EQUAL TO BLANK,DOT,*,+,OR -               HYP00305
      IF ((TEMP.EQ.BLANK).OR.(TEMP.EQ.BORD).OR.(TEMP.EQ.PL)             HYP00306
     1.OR.(TEMP.EQ.CR).OR.(TEMP.EQ.DOT)) GO TO 47                       HYP00307
C-----TEMP IS OCCUPIED SO IF SYS(I)=+ OR - SKIP THIS STATION            HYP00308
      IF ((SYM(I).EQ.PL).OR.(SYM(I).EQ.CR)) GO TO 50                    HYP00309
      IF (SYM(I) .EQ. C) GO TO 40                                       HYP00310
      IF (GRAPH(JX,JY) .NE. D) GO TO 35                                 HYP00311
      GRAPH(JX,JY)=E                                                    HYP00312
      GO TO 50                                                          HYP00313
   35 IF (GRAPH(JX,JY) .NE. E) GO TO 37                                 HYP00314
      GRAPH(JX,JY)=F                                                    HYP00315
      GO TO 50                                                          HYP00316
   37 IF (GRAPH(JX,JY) .EQ. F) GO TO 50                                 HYP00317
      GRAPH(JX,JY)=CD                                                   HYP00318
      GO TO 50                                                          HYP00319
   40 IF (GRAPH(JX,JY) .NE. C) GO TO 43                                 HYP00320
      GRAPH(JX,JY)=B                                                    HYP00321
      GO TO 50                                                          HYP00322
   43 IF (GRAPH(JX,JY) .NE. B) GO TO 45                                 HYP00323
      GRAPH(JX,JY)=A                                                    HYP00324
      GO TO 50                                                          HYP00325
   45 IF (GRAPH(JX,JY) .EQ. A) GO TO 50                                 HYP00326
      GRAPH(JX,JY)=CD                                                   HYP00327
      GO TO 50                                                          HYP00328
   47 GRAPH(JX,JY)=SYM(I)                                               HYP00329
   50 CONTINUE                                                          HYP00330
      GRAPH(NOX2,NOY2)=BORD                                             HYP00331
      WRITE(6,61)                                                       HYP00332
   61 FORMAT(1H0,67X,'O')                                               HYP00333
      DO 80 I=3,NOY1                                                    HYP00334
      IF (I .EQ .NOY2) GO TO 70                                         HYP00335
```

```
      WRITE(6,65) (GRAPH(J,I),J=1,NOX)                                  HYP00336
   65 FORMAT(1H ,20X,95A1)                                              HYP00337
      GO TO 80                                                          HYP00338
   70 WRITE(6,75) (GRAPH(J,I),J=1,NOX)                                  HYP00339
   75 FORMAT(1H ,16X,'270 ',95A1,' 90')                                 HYP00340
   80 CONTINUE                                                          HYP00341
      WRITE(6,85)                                                       HYP00342
   85 FORMAT(67X,'180')                                                 HYP00343
      RETURN                                                            HYP00344
      END                                                               HYP00345
```

```
      SUBROUTINE INPUT1
C------- INPUT STATION LIST,CRUSTAL MODEL,AND CONTROL CARD ------------
      INTEGER HEAD/'HEAD'/
      REAL*8 TIME1,TIME2
      REAL LAT,LON,LAT2,LON2,LATR,LONR
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),
     1        PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151)
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40)
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR
      COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDXS,LATEP,LONEP
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW
      COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)
      COMMON /A20/ V(21),D(21),VSQ(21),THK(21),TID(21,21),DID(21,21)
      COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE
      COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
      DIMENSION BHEAD(12), ATEST(15)
C---------------------------------------------------------------------
      DO 350 I=1,15
      ATEST(I) = 1.23456
  350 CONTINUE
      WRITE(6,300)
  300 FORMAT(1H1)
      IF (M-1) 1,100,200
C------- INITIALIZE TEST VARIABLES -----------------------------------
    1 TEST(1)=0.10
      TEST(2)=10.
      TEST(3)=2.
      TEST(4)=0.05
      TEST(5)=5.
      TEST(6)= 4.
      TEST(7)=-0.87
      TEST(8)=+2.00
      TEST(9)=+0.0035
      TEST(10)=100.
      TEST(11)=8.0
      TEST(12)=0.5
      TEST(13)= 1.
      IFLAG=0
C------- INPUT RESET TEST-VARIABLE CARDS AND SELECTION CARD -----------
      DO 5 I=1,16
      READ(5,4) ISW,J,  TESTJ,BHEAD
    4 FORMAT(A4,T12, I2,T16,F9.4,12A4)
   11 IF ((ISW.EQ.MBK).OR.(ISW.EQ.IONE)) GO TO 6
      IF(ISW .NE. HEAD) GO TO 12
      DO 13 II=1,12
      AHEAD(II)= BHEAD(II)
   13 CONTINUE
      GO TO 5
```

```
   12 IFLAG=1                                                           HYP00397
      ATEST(J)=TESTJ                                                    HYP00398
    5 CONTINUE                                                          HYP00399
    6 WRITE(6,14) AHEAD                                                 HYP00400
   14 FORMAT(40X,12A4)                                                  HYP00401
      WRITE(6,2)                                                        HYP00402
    2 FORMAT(///,' ********** PROGRAM: HYPO71 (DEC. 21, 1971) **********HYP00403
     1',     ///,13X,'TEST(1)  TEST(2)  TEST(3)  TEST(4)  TEST(5)  TEST(6HYP00404
     2)  TEST(7)  TEST(8)  TEST(9) TEST(10) TEST(11) TEST(12) TEST(13)')HYP00405
      WRITE(6,3) (TEST(I),I=1,13)                                       HYP00406
    3 FORMAT(' STANDARD ',13F9.4)                                       HYP00407
      IF (IFLAG .EQ. 0) GO TO 8                                         HYP00408
      DO 16 I = 1,15                                                    HYP00409
      IF(ATEST(I) .NE. 1.23456) TEST(I)=ATEST(I)                        HYP00410
   16 CONTINUE                                                          HYP00411
      WRITE(6,7) (TEST(I),I=1,13)                                       HYP00412
    7 FORMAT(' RESET TO ',13F9.4)                                       HYP00413
C------- SQUARE SOME TEST-VARIABLES FOR LATER USE ---------------------HYP00414
    8 TEST(1)=TEST(1)**2                                                HYP00415
      TEST(2)=TEST(2)**2                                                HYP00416
      TEST(4)=TEST(4)**2                                                HYP00417
C------- INPUT STATION LIST -------------------------------------------HYP00418
      IF (ISW .EQ. IONE) GO TO 10                                       HYP00419
      KNO=1                                                             HYP00420
      WRITE(6,9)                                                        HYP00421
    9 FORMAT(/,4X,'L     STN  LAT N   LONG W',' ELV DELAY',5X          HYP00422
     1,'FMGC  XMGC KL  PRR  CALR IC      DATE HRMN')                    HYP00423
      GO TO 20                                                          HYP00424
   10 WRITE(6,15)                                                       HYP00425
   15 FORMAT(/,4X,'L   STN  LAT N    LONG W    ELV     M  DLY1  DLY2',  HYP00426
     1' XMGC FMGC KL CALR IC   DATE HRMN')                              HYP00427
   20 DO 50 L=1,NMAX                                                    HYP00428
      IF (ISW .EQ. IONE) GO TO 30                                       HYP00429
      READ(5,25) IW(L),NSTA(L),LAT1,LAT2,LON1,LON2,IELV(L),DLY(1,L)     HYP00430
     1,FMGC(L),XMGC(L),KLAS(L),PRR(L),CALR(L),ICAL(L),NDATE(L),NHRMN(L) HYP00431
   25 FORMAT(1X,A1,A4,I2,F5.2,1X,I3,F5.2,1X,I4,F6.2,4X,F5.2,2X,F5.2,1X  HYP00432
     1,I1,F5.2,F7.2,1X,I1,5X,I6,I4)                                     HYP00433
      IF (NSTA(L) .EQ. MBK) GO TO 60                                    HYP00434
      WRITE(6,26) L,IW(L),NSTA(L),LAT1,LAT2,LON1,LON2,IELV(L),DLY(1,L)  HYP00435
     1,FMGC(L),XMGC(L),KLAS(L),PRR(L),CALR(L),ICAL(L),NDATE(L),NHRMN(L) HYP00436
   26 FORMAT(I5,3X,A1,A4,I2,F5.2,1X,I3,F5.2,1X,I4,F6.2,4X,F5.2,2X,F5.2  HYP00437
     1,1X,I1,F5.2,F7.2,1X,I1,5X,I6,I4)                                  HYP00438
      GO TO 40                                                          HYP00439
   30 READ(5,35) NSTA(L),IW(L),LAT1,LAT2,LON1,LON2,IELV(L),MNO(L)       HYP00440
     1,DLY(1,L),DLY(2,L),XMGC(L),FMGC(L),KLAS(L),CALR(L),ICAL(L)        HYP00441
     2,NDATE(L),NHRMN(L)                                                HYP00442
   35 FORMAT(A4,A1,I2,1X,F5.2,1X,I3,1X,F5.2,1X,I4,5X,I1                 HYP00443
     1,4F6.2,1X,I1,F6.2,1X,I1,2X,I6,I4)                                 HYP00444
      IF (NSTA(L) .EQ. MBK) GO TO 60                                    HYP00445
      WRITE(6,36) L,NSTA(L),IW(L),LAT1,LAT2,LON1,LON2,IELV(L),MNO(L)    HYP00446
     1,DLY(1,L),DLY(2,L),XMGC(L),FMGC(L),KLAS(L),CALR(L),ICAL(L)        HYP00447
```

```
     2,NDATE(L),NHRMN(L)
  36 FORMAT(I5,2X,A4,A1,I2,1X,F5.2,1X,I3,1X,F5.2,1X,I4,5X,I1
    1,4F6.2,1X,I1,F6.2,1X,I1,2X,I6,I4)
      PRR(L)=0.
  40 LAT(L)=60.*LAT1+LAT2
      LON(L)=60.*LON1+LON2
      MDATE(L)=NDATE(L)
      MHRMN(L)=NHRMN(L)
      KLSS(L)=KLAS(L)
      CALS(L)=CALR(L)
  50 CONTINUE
      WRITE(6,55)
  55 FORMAT(///,' ***** ERROR: STATION LIST EXCEEDS ARRAY DIMENSION')
      STOP
  60 NS=L-1
C------- INPUT CRUSTAL MODEL ------------------------------------------
 100 WRITE(6,105)
 105 FORMAT(///,7X,'CRUSTAL MODEL 1',/,5X,'VELOCITY     DEPTH')
      DO 130 L=1,LMAX
      READ(5,115) V(L),D(L)
 115 FORMAT(2F7.3)
      IF (V(L) .LT. 0.01) GO TO 140
      WRITE(6,125) V(L),D(L)
 125 FORMAT(3X,2F10.3)
      DEPTH(L)=D(L)
      VSQ(L)=V(L)**2
 130 CONTINUE
      WRITE(6,135)
 135 FORMAT(///,' ***** ERROR: CRUSTAL MODEL EXCEEDS ARRAY DIMENSION')
      STOP
 140 NL=L-1
      N1=NL-1
C-----LAYER THICKNESS THK,F & G TERMS
      DO 145 L=1,N1
      THK(L)=D(L+1)-D(L)
 145 H(L)=THK(L)
C---- COMPUTE TID AND DID
      DO 150 J=1,NL
      G(1,J)=SQRT(ABS(VSQ(J)-VSQ(1)))/(V(1)*V(J))
      G(2,J)=SQRT(ABS(VSQ(J)-VSQ(2)))/(V(2)*V(J))
      G(3,J)=V(1)/SQRT(ABS(VSQ(J)-VSQ(1))+0.000001)
      G(4,J)=V(2)/SQRT(ABS(VSQ(J)-VSQ(2))+0.000001)
      IF (J .LE. 1) G(1,J)=0.
      IF (J .LE. 2) G(2,J)=0.
      IF (J .LE. 1) G(3,J)=0.
      IF (J .LE. 2) G(4,J)=0.
      DO 150 L=1,NL
      F(L,J)=1.
      IF (L .GE. J) F(L,J)=2.
 150 CONTINUE
      DO 165 J=1,NL
```

```
      DO 165 M=1,NL
      TID(J,M)=0.
  165 DID(J,M)=0.
      DO 170 J=1,NL
      DO 170 M=J,NL
      IF (M .EQ. 1) GO TO 170
      M1=M-1
      DO 160 L=1,M1
      SQT=SQRT(VSQ(M)-VSQ(L))
      TIM=THK(L)*SQT/(V(L)*V(M))
      DIM=THK(L)*V(L)/SQT
      TID(J,M)=TID(J,M)+F(L,J)*TIM
  160 DID(J,M)=DID(J,M)+F(L,J)*DIM
  170 CONTINUE
      IF (ISW .NE. IONE) GO TO 200
C---- VARIABLE FIRST LAYER
      VC=V(1)*V(2)/SQRT(VSQ(2)-VSQ(1))
      DO 180 I=1,NS
      FLT(1,I)=DLY(1,I)*VC+D(2)
  180 FLT(2,I)=DLY(2,I)*VC+D(2)
C------- INPUT CONTROL CARD -------------------------------------------
  200 WRITE(6,205)
  205 FORMAT(///,' ZTR XNEAR XFAR  POS   IQ  KMS  KFM IPUN IMAG   IR'
     1,' IPRN CODE   LATR       LONR')
      READ(5,215) ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,IPRN
     1,KTEST,KAZ,KSORT,KSEL,LAT1,LAT2,LON1,LON2
  215 FORMAT(3F5.0,F5.2,7I5,1X,4I1,2(I4,F6.2))
      WRITE(6,215) ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,IPRN
     1,KTEST,KAZ,KSORT,KSEL,LAT1,LAT2,LON1,LON2
      LATR=60.*LAT1+LAT2
      LONR=60.*LON1+LON2
      IF (IR .EQ. 0) RETURN
      DO 240 I=1,IR
      READ(5,225) (QSPA(I,J),J=1,40)
  225 FORMAT(20F4.2)
      WRITE(6,235) I,(QSPA(I,J),J=1,40)
  235 FORMAT(/,' QSPA(',I1,'): ',20F5.2,/,10X,20F5.2)
  240 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INPUT2                                                 HYP00539
C------- INPUT PHASE LIST ----------------------------------------------HYP00540
      INTEGER*2 SYM                                                     HYP00541
      REAL*8 TIME1,TIME2                                                HYP00542
      REAL LAT2,LON2,LATEP,LONEP,MAG                                    HYP00543
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),   HYP00544
     1       PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151) HYP00545
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)HYP00546
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,    HYP00547
     1       SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)     HYP00548
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)            HYP00549
      COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,    HYP00550
     1       IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR HYP00551
      COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101),         HYP00552
     1       RMK(101),WRK(101),TP(101),DT(101),COSL(701)                HYP00553
      COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)                  HYP00554
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR HYP00555
      COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDXS,LATEP,LONEP  HYP00556
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW   HYP00557
      COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN       HYP00558
      COMMON /A18/ S(101),SRMK(101),WS(101),TS(101),NOS,QRMK(101)       HYP00559
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)   HYP00560
      COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,IEXIT            HYP00561
      COMMON /A23/ AIN(101),RMS,ADJ,SYM(101)                            HYP00562
      COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC   HYP00563
      DIMENSION ICARD(20)                                               HYP00564
C-----------------------------------------------------------------------HYP00565
   10 PMIN=9999.                                                        HYP00566
      IDXS=0                                                            HYP00567
      DO 20 I=1,NS                                                      HYP00568
      KSMP(I)=0                                                         HYP00569
   20 JDX(I)=0                                                          HYP00570
   25 L=1                                                               HYP00571
   30 READ(5,35,END=300) MSTA(L),PRMK(L),W(L),JTIME,JMIN(L),P(L),S(L)   HYP00572
     1,SRMK(L),WS(L),AMX(L),PRX(L),CALP,CALX(L),RMK(L),DT(L),FMP(L)     HYP00573
     2,AZRES(L),SYM(L),AS,ICARD,QRMK(L),IPRO                            HYP00574
   35 FORMAT(2A4,T8,F1.0,T10,I8,I2,F5.2,T32,F5.2,A4,T40,F1.0,T44,F4.0   HYP00575
     1,F3.2,F4.1,T59,F4.1,A3,F5.2,F5.0,T21,A4,T7,A1,T32,A4,T1,20A4      HYP00576
     2,T63,A1,T5,A4)                                                    HYP00577
      IF ((MSTA(L).EQ.MSTAR).OR.(MSTA(L).EQ.MDOL).OR.(MSTA(L).EQ.MCENT))HYP00578
     1GO TO 300                                                         HYP00579
      IF (MSTA(L).EQ.MBK) GO TO 350                                     HYP00580
      IF (CALX(L) .LT. 0.01) CALX(L)=CALP                               HYP00581
      DO 40 I=1,NS                                                      HYP00582
      IF (MSTA(L) .EQ. NSTA(I)) GO TO 50                                HYP00583
   40 CONTINUE                                                          HYP00584
      WRITE(6,45) ICARD,MSTA(L)                                         HYP00585
   45 FORMAT(///,' ***** ',20A4,' ***** DELETED: ',A4,' NOT ON STATION LHYP00586-
     1IST')                                                             HYP00587
      GO TO 30                                                          HYP00588
   50 KDX(L)=I                                                          HYP00589
```

```
      LDX(L)=0                                                          HYP00590
      JDX(I)=1                                                          HYP00591
      IF (FMP(L) .LE. 0.) FMP(L)=BLANK                                  HYP00592
      IF (L .GT. 1) GO TO 60                                            HYP00593
      KTIME=JTIME                                                       HYP00594
      KDATE=KTIME/100                                                   HYP00595
      KHR=KTIME-KDATE*100                                               HYP00596
   60 IF (JTIME .EQ. KTIME) GO TO 70                                    HYP00597
      WRITE(6,65) ICARD                                                 HYP00598
   65 FORMAT(///,' ***** ',20A4,' ***** DELETED: WRONG TIME')           HYP00599
      GO TO 30                                                          HYP00600
   70 IF (RMK(L) .EQ. CRMK) GO TO 200                                   HYP00601
   80 W(L)=(4.-W(L))/4.                                                 HYP00602
      IF (IW(I) .EQ. ISTAR) W(L)=0.                                     HYP00603
      TP(L)=60.*JMIN(L)+P(L)+DT(L)                                      HYP00604
      WRK(L)=BLANK                                                      HYP00605
      IF (W(L) .EQ. 0.) GO TO 90                                        HYP00606
      IF (W(L) .GT. 0.) GO TO 89                                        HYP00607
C------- SMP DATA: RESET WEIGHT ----------------------------------------HYP00608
      W(L)=(4.-WS(L))/4.                                                HYP00609
      KSMP(L)=1                                                         HYP00610
      IF(TP(L).GE.PMIN) GO TO 95                                        HYP00611
      PMIN=TP(L)                                                        HYP00612
      NEAR=L                                                            HYP00613
      GO TO 95                                                          HYP00614
   89 IF (TP(L) .GE. PMIN) GO TO 90                                     HYP00615
      PMIN=TP(L)                                                        HYP00616
      NEAR=L                                                            HYP00617
   90 IF (AS .EQ. BLANK) GO TO 100                                      HYP00618
C------- S DATA --------------------------------------------------------HYP00619
      IDXS=1                                                            HYP00620
      LDX(L)=1                                                          HYP00621
      WS(L)=(4.-WS(L))/4.                                               HYP00622
      IF (IW(I) .EQ. ISTAR) WS(L)=0.                                    HYP00623
   95 TS(L)=60.*JMIN(L)+S(L)+DT(L)                                      HYP00624
  100 L=L+1                                                             HYP00625
      IF (L .LT. MMAX) GO TO 30                                         HYP00626
      WRITE(6,105)                                                      HYP00627
  105 FORMAT(///,' ***** ERROR: PHASE LIST EXCEEDS ARRAY DIMENSION; EXTRHYP00628
     1A DATA TREATED AS NEXT EARTHQUAKE')                               HYP00629
      GO TO 350                                                         HYP00630
C------- CALIBRATION CHANGE IN STATION LIST ----------------------------HYP00631
  200 IF (P(L) .NE. 0.) KLAS(I)=P(L)                                    HYP00632
      CALR(I)=CALX(L)                                                   HYP00633
      TIME2=1.D+06*KDATE+1.D+04*KHR+1.D+02*JMIN(L)                      HYP00634
      IF (TIME2 .GE. TIME1) GO TO 250                                   HYP00635
      WRITE(6,205)                                                      HYP00636
  205 FORMAT(///,' ********** THE FOLLOWING EVENT IS OUT OF CHRONOLOGICAHYP00637
     1L ORDER **********')                                              HYP00638
  250 WRITE(6,255) KDATE,KHR,JMIN(L),MSTA(L),KLAS(I),CALR(I)            HYP00639
  255 FORMAT(///,' ***** ',I6,1X,2I2,' ***** CALIBRATION CHANGE FOR ',A4HYP00640
```

```
     1,': KLAS = ',I1,', CALR = ',F4.1)
      MDATE(I)=KDATE
      MHRMN(I)=100*KHR+JMIN(L)
      TIME1=TIME2
      GO TO 10
  300 M=1
      NR=L-1
      RETURN
  350 M=0
  400 NR=L-1
      RETURN
      END
```

```
      SUBROUTINE MISING
C------- CHECK MISSING STATIONS ----------------------------------------
      REAL*8 TIME1,TIME2
      REAL LAT,LON,LAT2,LON2,LATEP,LONEP,MAG
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),
     1      PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151)
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40)
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180)
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,
     1      SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)
      COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,
     1      IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR
      COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101),
     1      RMK(101),WRK(101),TP(101),DT(101),COSL(701)
      COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR
      COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDXS,LATEP,LONEP
C-----------------------------------------------------------------------
      IHD=0
      NJ=J+1
      TEMP(NJ)=TEMP(1)+360.
      TDEL=25.*MAG**2
      IF (MAG .EQ. BLANK) TDEL=100.
      DO 30 I=1,NS
      IF (JDX(I) .EQ. 1) GO TO 30
      AVL=(LAT(I)+LATEP)/120.
      M1=AVL+1.5
      M2=AVL*10.+1.5
      DXI=(LON(I)-LONEP)*CA(M1)*COSL(M2)
      DYI=(LAT(I)-LATEP)*CB(M1)
      DELI=SQRT(DXI**2+DYI**2)+0.000001
      IF (DELI .GT. TDEL) GO TO 30
      AZI=ATAN2(-DXI,DYI)*57.29578
      IF (AZI .LT. 0.) AZI=360.+AZI
      IF (AZI .LE. TEMP(1)) AZI=AZI+360.
      DO 10 J=2,NJ
      IF (AZI .LT. TEMP(J)) GO TO 20
   10 CONTINUE
      J=NJ
   20 EXGAP=TEMP(J)-TEMP(J-1)
      RDGAP=TEMP(J)-AZI
      TGAP=AZI-TEMP(J-1)
      IF (TGAP .LT. RDGAP) RDGAP=TGAP
      IF ((DELI.GT.DMIN).AND.(RDGAP.LT.30.)) GO TO 30
      IF (AZI .GE. 360.) AZI=AZI-360.
      IF (IHD .EQ. 1) GO TO 22
      WRITE(6,5)
    5 FORMAT(/,10X,'MISSING STATION  DELTA   AZIM  EX-GAP  RD-GAP')
```

```
      IHD=1
   22 WRITE(6,25) NSTA(I),DELI,AZI,EXGAP,RDGAP
   25 FORMAT(21X,A4,2F7.1,2F8.1)
   30 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE OUTPUT
C------- OUTPUT HYPOCENTER -------------------------------------------------
      INTEGER*2 SYM
      REAL*8 TIME1,TIME2
      REAL LAT,LON,LAT2,LON2,LATEP,LONEP,MAG
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),
     1       PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151)
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40)
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180)
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,
     1       SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)
      COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,
     1       IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR
      COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101),
     1       RMK(101),WRK(101),TP(101),DT(101),COSL(701)
      COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR
      COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDXS,LATEP,LONEP
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW
      COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN
      COMMON /A18/ S(101),SRMK(101),WS(101),TS(101),NOS,QRMK(101)
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)
      COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,IEXIT
      COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE
      COMMON /A23/ AIN(101),RMS,ADJ,SYM(101)
      COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
      DIMENSION FMT1(32),FMT2(24),FMT3(32),FMT4(16),DEMP(101),SYMBOL(5)
      DATA FMT1/'(1X,','I6,A','1,2I','2,F6','.2,I','3,A1',',F5.','2,I4',
     1          ',A1,','F5.2',',A1,','F6.2',',A1,','F6.2',',2I3',',I4,',
     2          'I2,F','5.2,','F5.1',',    ','F5.1',',2(1','X,A1','),2A',
     3          '1,F5','.2,2','I3,2','F5.2',',2(I','3,2F','5.1)',',I2)'/
      DATA FMT2/'(I6,','1X,2','I2,F','6.2,','I3,A','1,F5','.2,I','4,A1',
     1          ',F5.','2,A1',',F6.','2,A1',',    ','F6.2',',I3,','I4,F',
     2          '5.1,','F5.2',',    ','F5.1',',    ','F5.1',',3A1',')   '/
      DATA FMT3/'(1X,','A4,F','6.1,','2I4,','1X,A','4,1X',',2I2',',4F6',
     1          '.2, ','F6.2',',A2,','F4.2',',I4,','I3,F','6.2,','I2, ',
     2          'F4.1',',A1,','1X,A','3,  ','I4, ','F4.1',',A1,','1X,A',
     3          '4, 3','F6.2',',A2,','F4.2',',    ','F6.2',',T6,','A1) '/
      DATA FMT4/'(A4,','3F6.','1,1X',',A4,','2F6.','2,F5','.1, ','F6.2',
     1          ',1X,','A3, ','F6.2',',I7,','   2','I2,2','I4,A','1)  '/
      DATA SYM1,SYM2,F1,F2,G1,G2/'-','|','F6.2','F5.1','A6  ','  A5'/
      DATA F4,F5,F6,G3,G4/'F4.1','I4, ','F4.2','A4  ','A4, '/
      DATA SYMBOL/' ','1','2','Q','*'/,ZDOT/'0.  '/
C--------------------------------------------------------------------------
      IF ((IPRN.GE.2) .OR. (KP.EQ.1)) CALL XFMAGS
      LAT1=LATEP/60.
      LAT2=LATEP-60.*LAT1
      LON1=LONEP/60.
```

```
      LON2=LONEP-60.*LON1
      ADJ=SQRT(ADJSQ)
      RMS=SQRT(RMSSQ)
      JHR=KHR
      OSAVE = ORG
      IF (ORG .GE. 0.) GO TO 5
      ORG=ORG+3600.
      KHR=KHR-1
    5 KMIN=ORG/60.0
      SEC=ORG-60.0*KMIN
      ERH=SQRT(SE(1)**2+SE(2)**2)
      NO=FNO
      RMK1=BLANK
      RMK2=BLANK
      RMKO=BLANK
C---- KZ=1 FOR FIXED DEPTH; ONF=0 FOR ORIGIN TIME BASED ON SMP'S
      IF (ONF .EQ. 0.) RMKO=STAR4
      IF (KZ .EQ. 1) RMK2=STAR4
      J=0
      DO 10 I=1,NRP
      IF((DX(I).EQ.0.).AND.(DY(I).EQ.0.)) GO TO 8
      AZ(I)=ATAN2(-DX(I),DY(I))*57.29578
      GO TO 9
    8 AZ(I)= 999.
    9 IF (AZ(I) .LT. 0.) AZ(I)=360.+AZ(I)
      AIN(I)=ARSIN(ANIN(I))*57.29578
      IF (AIN(I) .LT. 0.) AIN(I)=180.+AIN(I)
      AIN(I)=180.-AIN(I)
      IF (WT(I) .EQ. 0.) GO TO 10
      J=J+1
      TEMP(J)=AZ(I)
   10 CONTINUE
      CALL SORT(TEMP,KEY,J)
      GAP=TEMP(1)+360.-TEMP(J)
      DO 20 I=2,J
      DTEMP=TEMP(I)-TEMP(I-1)
      IF (DTEMP .GT. GAP) GAP=DTEMP
   20 CONTINUE
      IGAP=GAP+0.5
      DO 25 I=1,NRP
   25 DEMP(I)=DELTA(I)
      CALL SORT(DEMP,KEY,NRP)
      DMIN=DEMP(1)
      IDMIN=DMIN+0.5
      OFD=Z
      TFD=2.*Z
      IF (OFD .LT. 5.) OFD=5.
      IF (TFD .LT. 10.) TFD=10.
      JS=4
      IF ((RMS.LT.0.50).AND.(ERH.LE.5.0)) JS=3
      IF ((RMS.LT.0.30).AND.(ERH.LE.2.5).AND.(SE(3).LE.5.0)) JS=2
```

```
      IF ((RMS.LT.0.15).AND.(ERH.LE.1.0).AND.(SE(3).LE.2.0)) JS=1        HYP00812
      JD=4                                                              HYP00813
      IF (NO .LT. 6) GO TO 30                                           HYP00814
      IF ((GAP.LE.180.).AND.(DMIN.LE.50.)) JD=3                         HYP00815
      IF ((GAP.LE.135.).AND.(DMIN.LE.TFD)) JD=2                         HYP00816
      IF ((GAP.LE. 90.).AND.(DMIN.LE.OFD)) JD=1                         HYP00817
   30 JAV=(JS+JD+1)/2                                                   HYP00818
      Q=CLASS(JAV)                                                      HYP00819
      QS=CLASS(JS)                                                      HYP00820
      QD=CLASS(JD)                                                      HYP00821
   50 TIME2=SEC+1.D+02*KMIN+1.D+04*KHR+1.D+06*KDATE                     HYP00822
      IF(IPRN .EQ. 0) GO TO 52                                          HYP00823
      IF(NI .NE. 1) GO TO 60                                            HYP00824
      IF(NDEC .GE. 1) GO TO 60                                          HYP00825
   52 KKYR=KDATE/10000                                                  HYP00826
      KKMO=(KDATE-KKYR*10000)/100                                       HYP00827
      KKDAY=(KDATE-KKYR*10000-KKMO*100)                                 HYP00828
      IF(KSEL) 501,501,505                                              HYP00829
  501 WRITE(6,502)                                                      HYP00830
  502 FORMAT(///)                                                       HYP00831
      GO TO 535                                                         HYP00832
  505 WRITE(6,506)                                                      HYP00833
  506 FORMAT(1H1)                                                       HYP00834
   51 WRITE(6,53) AHEAD,KKYR,KKMO,KKDAY,KHR,KMIN                        HYP00835
   53 FORMAT(/,30X,12A4,T112,I2,'/',I2,'/',I2,4X,I2,':',I2)             HYP00836
  535 IF( TIME2 - TIME1 .GT. -20.)GO TO 60                              HYP00837
      WRITE(6,54)                                                       HYP00838
   54 FORMAT(' ***** FOLLOWING EVENT IS OUT OF ORDER *****')            HYP00839
   60 IF ((KP.EQ.1) .AND. (IPRN.EQ.0)) GO TO 67                         HYP00840
      IF (IPH .EQ. 1) GO TO 62                                          HYP00841
      WRITE(6,61)                                                       HYP00842
   61 FORMAT(/,59X,'  ADJUSTMENTS (KM)  PARTIAL F-VALUES  STANDARD ERRORHYP00843
     1S  ADJUSTMENTS TAKEN',/,                                          HYP00844
     2 '  I  ORIG  LAT N    LONG W   DEPTH  DM  RMS AVRPS SKD   CF   DLAHYP00845
     3T  DLON     DZ  DLAT  DLON    DZ  DLAT  DLON    DZ  DLAT  DLON   DHYP00846
     4Z')                                                               HYP00847
      IF (IPRN .EQ. 1) IPH=1                                            HYP00848
   62 WRITE(6,63) NI,SEC,LAT1,LAT2,LON1,LON2,Z,RMK2,IDMIN,RMS,AVRPS,    HYP00849
     1 QS,KF,QD,FLIM,B(2),B(1),B(3),AF(2),AF(1),AF(3),SE(2),SE(1),      HYP00850
     2 SE(3),Y(2),Y(1),Y(3)                                             HYP00851
   63 FORMAT(I3,F6.2,I3,'-',F5.2,I4,'-',F5.2,F6.2,A1,I3,F5.2,F6.2,      HYP00852
     1 1X,A1,I1,A1,13F6.2)                                              HYP00853
      IF (KP .EQ. 0) GO TO 100                                          HYP00854
   67 JNST=KNST*10+INST                                                 HYP00855
      IF (NM .EQ. 0) AVXM=0.                                            HYP00856
      IF (NF .EQ. 0) AVFM=0.                                            HYP00857
      FMT1(14)=F1                                                       HYP00858
      FMT1(19)=F2                                                       HYP00859
      FMT1(21)=F2                                                       HYP00860
      FMT2(14)=F1                                                       HYP00861
      FMT2(20)=F2                                                       HYP00862
```

```
      FMT2(22)=F2
      IF (MAG .NE. BLANK) GO TO 68
      FMT1(14)=G1
      FMT2(14)=G1
   68 IF (SE(3) .NE. 0.) GO TO 70
      SE(3)=BLANK
      FMT1(21)=G2
      FMT2(22)=G2
   70 IF (ERH .NE. 0.) GO TO 72
      ERH=BLANK
      FMT1(19)=G2
      FMT2(20)=G2
   72 WRITE(6,75)
   75 FORMAT(//, '  DATE     ORIGIN     LAT N     LONG W     DEPTH     MAG NO
     1 DM GAP M  RMS   ERH   ERZ Q SQD  ADJ IN NR  AVR  AAR NM AVXM SDXM N
     2F AVFM SDFM I')
   80 WRITE(6,FMT1)KDATE,RMKO,KHR,KMIN,SEC,LAT1,SYM1,LAT2,LON1,SYM1,LON2
     1,RMK1,Z,RMK2,MAG,NO,IDMIN,IGAP,KNO,RMS,ERH,SE(3),Q,QS,SYM2,QD,ADJ
     2,JNST,NR,AVR,AAR,NM,AVXM,SDXM,NF,AVFM,SDFM,NI
      IF (IPUN .EQ. 0) GO TO 100
      IF ((QRMK(1).NE.SYMBOL(4)).AND.(QRMK(1).NE.SYMBOL(5)))
     1QRMK(1)=SYMBOL(1)
      SYM3=SYMBOL(KNO+1)
      WRITE(7,FMT2) KDATE,KHR,KMIN,SEC,LAT1,SYM1,LAT2,LON1,SYM1,LON2
     1,RMK1,Z,RMK2,MAG,NO,IGAP,DMIN,RMS,ERH,SE(3),QRMK(1),Q,SYM3
  100 IF (KP .EQ. 1) GO TO 105
      IF(IPRN .LE. 1) GO TO 300
  105 WRITE(6,110)
  110 FORMAT(/,'  STN  DIST AZM AIN PRMK HRMN P-SEC TPOBS TPCAL DLY/H1 P
     1-RES P-WT AMX PRX CALX K XMAG RMK FMP FMAG SRMK S-SEC TSOBS S-RES
     2 S-WT    DT')
      DO 200 I=1,NRP
      K=I
      IF (KSORT .EQ. 1) K=KEY(I)
      KJI=KDX(K)
      TPK=TP(K)-ORG
      IF (TPK .LT. 0.) TPK=TPK+3600.
      FMT3(10)=F1
      IF ((AZRES(K).NE.DOT).AND.(AZRES(K).NE.BLANK).AND.
     1(AZRES(K).NE.ZDOT)) GO TO 114
      X(4,K)=BLANK
      FMT3(10)=G1
  114 RMK3=BLANK
      IF (XMAG(K) .EQ. BLANK) GO TO 115
      IF (ABS(XMAG(K)-AVXM) .GE. 0.5) RMK3=STAR4
  115 RMK4=BLANK
      IF (FMAG(K) .EQ. BLANK) GO TO 130
      IF (ABS(FMAG(K)-AVFM) .GE. 0.5) RMK4=STAR4
  130 FMT3(17)=F4
      FMT3(21)=F5
      FMT3(22)=F4
```

```
      FMT4(8)=F1
      FMT4(11)=F1
      IF (XMAG(K) .NE. BLANK) GO TO 160
      FMT3(17)=G3
      FMT4(8)=G1
  160 IF (FMAG(K) .NE. BLANK) GO TO 162
      FMT3(21)=G4
      FMT3(22)=G3
      FMT4(11)=G1
  162 FMT3(26)=F1
      FMT3(28)=F6
      IAZ=AZ(K)+0.5
      IAIN=AIN(K)+0.5
      IAMX=AMX(K)
      IPRX=100.*PRX(K)+0.5
      IFMP=FMP(K)
      IF (LDX(K) .NE. 0) GO TO 163
C-----CHECK FOR SMP DATA
      IF (KSMP(K) .EQ. 0) GO TO 165
      SRES=X(4,K)
      RMK5=BLANK
      SWT=11111.
      TSK=S(K)-P(K)
      GO TO 168
  163 KK=LDX(K)
      SRES=X(4,KK)
      RMK5=WRK(KK)
      SWT=WT(KK)
  164 TSK=TS(K)-ORG
      GO TO 168
  165 S(K)=BLANK
      TSK=BLANK
      SRES=BLANK
      RMK5=BLANK
      SWT=BLANK
      FMT3(26)=G1
      FMT3(28)=G3
  168 FMT3(30)=F1
      DLYK=DLY(KNO,KJI)
      IF (ISW .EQ. IONE) DLYK=FLT(KNO,KJI)
      DTK=DT(K)
      IF (DTK .NE. 0.) GO TO 170
      DTK=BLANK
      FMT3(30)=G1
  170 WRITE(6,FMT3) MSTA(K),DELTA(K),IAZ,IAIN,PRMK(K),JHR,JMIN(K),P(K)
     1,        TPK,T(K),DLYK,X(4,K),WRK(K),WT(K),IAMX,IPRX,CAL(K)
     2,KLAS(KJI),XMAG(K),RMK3,RMK(K),IFMP,FMAG(K),RMK4,SRMK(K),S(K)
     3,TSK,SRES,RMK5,SWT,DTK,IW(KJI)
      IF (IPUN .NE. 2) GO TO 200
      ISEC = 100.*SEC
      WRITE(7,FMT4) MSTA(K),DELTA(K),AZ(K),AIN(K),PRMK(K),TPK,X(4,K)
```

```
   1,WT(K),XMAG(K),RMK(K),FMAG(K),KDATE,KHR,KMIN,ISEC,KJI,SYM3
200 CONTINUE
    IF (IPUN .NE. 2) GO TO 300
    WRITE(7,205)
205 FORMAT(' $$$')
300 KHR = JHR
    ORG = OSAVE
    RETURN
    END
```

```
      SUBROUTINE SINGLE
C-------- SOLUTION FOR A SINGLE EARTHQUAKE ----------------------------
      INTEGER*2 SYM
      REAL*8 TIME1,TIME2
      REAL LATRT, LONRT, LATSV, LONSV
      REAL LAT,LON,LAT2,LON2,LATEP,LONEP,MAG,LATR,LONR
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),
     1       PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151)
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)
      COMMON /A3/ NRES(2,151),NXM(151),NFM(151),SR(2,151),SRSQ(2,151),
     1       SRWT(2,151),SXM(151),SXMSQ(151),SFM(151),SFMSQ(151),QNO(4)
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40)
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180)
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,
     1       SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)
      COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,
     1       IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR
      COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101),
     1       RMK(101),WRK(101),TP(101),DT(101),COSL(701)
      COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)
      COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR
      COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDXS,LATEP,LONEP
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW
      COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN
      COMMON /A18/ S(101),SRMK(101),WS(101),TS(101),NOS,QRMK(101)
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)
      COMMON /A20/ V(21),D(21),VSQ(21),THK(21),TID(21,21),DID(21,21)
      COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,IEXIT
      COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE
      COMMON /A23/ AIN(101),RMS,ADJ,SYM(101)
      COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
      DIMENSION SUM(5),YSAVE(4),WF(41),ALZ(10),LA(10),LO(10)
      DATA WF/.95,0.95,0.95,0.95,0.95,0.95,0.94,0.94,0.94,0.93,
     1       0.92,0.92,0.91,0.90,0.88,0.87,0.85,0.83,0.80,0.77,
     2       0.73,0.69,0.64,0.59,0.53,0.47,0.41,0.34,0.28,0.23,
     3       0.18,0.14,0.11,0.08,0.06,0.04,0.03,0.02,0.01,0.01,0./
      DATA LA/1,1,1,1,0,0,-1,-1,-1,-1/,
     1     LO/+1,-1,+1,-1,0,0,+1,-1,+1,-1/,
     2     ALZ/-1.0,-1.0,+1.0,+1.0,-1.732,+1.732,-1.0,-1.0,+1.0,+1.0/
C-----------------------------------------------------------------------
      AVRPS = 0.0
      IEXIT=0
      LATRT=0.
      ZRES=P(NR+1)
      KNST=JMIN(NR+1)/10
      INST=JMIN(NR+1)-KNST*10
      NRP=NR
   30 IF (IDXS .EQ. 0) GO TO 80
C------- TREAT S DATA BY AUGMENTING P DATA ----------------------------
```

```
      NOS=0
      DO 65 I=1,NRP
      IF (LDX(I) .EQ. 0) GO TO 65
      NOS=NOS+1
      NRS=NRP+NOS
      TP(NRS)=TS(I)
      W(NRS)=WS(I)
      KSMP(NRS)=0
      IF ((KNST.NE.1).AND.(KNST.NE.6)) W(NRS)=0.
      KDX(NRS)=KDX(I)
      LDX(I)=NRS
      WRK(NRS)=BLANK
   65 CONTINUE
      NR=NRP+NOS
C------- INITIALIZE TRIAL HYPOCENTER ------------------------------------
   80 K=KDX(NEAR)
      SVY1 = 0.0
      SVY2 = 0.0
      SVY3 = 0.0
      ERLMT = 0.
      DO 25 I = 1,3
      ISKP(I)=0
   25 CONTINUE
      IF (INST .NE. 9) GO TO 90
      READ(5,85) ORG1,ORG2,LAT1,LAT2,LON1,LON2,Z
   85 FORMAT(F5.0,F5.2,I5,F5.2,I5,2F5.2)
      ORG=60.*ORG1+ORG2
      LATEP=60.*LAT1+LAT2
      LONEP=60.*LON1+LON2
      GO TO 105
   90 IF (NR .GE. 3) GO TO 100
   96 WRITE(6,97)
   97 FORMAT(///,' ***** INSUFFICIENT DATA FOR LOCATING THIS QUAKE:')
      IF( NRP .EQ. 0 ) NRP = 1
      DO 98 L=1,NRP
   98 WRITE(6,99) MSTA(L),PRMK(L),KDATE,KHR,JMIN(L),P(L),S(L)
   99 FORMAT(5X,2A4,1X,I6,2I2,F5.2,7X,F5.2)
      IEXIT=1
      IF (NRP .EQ. 1) RETURN
      GO TO 575
  100 Z=ZTR
      IF (AZRES(NRP+1).NE. BLANK) Z=ZRES
      ORG=PMIN-Z/5.-1.
      IF(LATRT.EQ.0.) GO TO 102
      LATEP=LATRT
      LONEP=LONRT
      GO TO 105
  102 IF (LATR .EQ. 0.) GO TO 104
      LATEP=LATR
      LONEP=LONR
      GO TO 105
```

```
  104 LATEP=LAT(K)+0.1
      LONEP=LON(K)+0.1
  105 ADJSQ=0.
      IPH=0
      NDEC=0
      PRMSSQ=100000.
      IF (ISW .EQ. IONE) KNO=MNO(K)
      IF(ISW .EQ. IONE) FLTEP=FLT(KNO,K)
      NIMAX=TEST(11)+.0001
C------- GEIGER'S ITERATION TO FIND HYPOCENTRAL ADJUSTMENTS ------------
  109 NI = 1
      IF (INST .EQ. 9) NI=NIMAX
  111 IF(ERLMT .EQ. 0.) GO TO 110
      LATEP = LATSV + LA(NA)*DELAT
      LONEP = LONSV + LO(NA)*DELON
      Z = ZSV + ALZ(NA)*DEZ
      IF(Z .LT. 0.) Z=0.
  110 FMO=0.
      FNO=0.
      DO 112 I=1,5
  112 SUM(I)=0.
C------- CALCULATE EPICENTRAL DISTANCE BY RICHTER'S METHOD -------------
      DO 120 I=1,NR
      JI=KDX(I)
      AVL=(LAT(JI)+LATEP)/120.
      M1=AVL+1.5
      M2=AVL*10.+1.5
      DX(I)=(LON(JI)-LONEP)*CA(M1)*COSL(M2)
      DY(I)=(LAT(JI)-LATEP)*CB(M1)
      DELTA(I)=SQRT(DX(I)**2+DY(I)**2)+0.000001
      WT(I)=W(I)
      IF (NI .LE. 1) GO TO 115
C------- DISTANCE WEIGHTING --------------------------------------------
      IF (DELTA(I) .LE. XNEAR) GO TO 115
      WT(I)=W(I)*(XFAR-DELTA(I))/XFN
      IF (WT(I) .LT. 0.005) WT(I)=0.
  115 IF (WT(I) .EQ. 0.) GO TO 120
      IF (KSMP(I) .EQ. 1) FMO=FMO+1.
      FNO=FNO+1.
      SUM(4)=SUM(4)+WT(I)
  120 CONTINUE
      IF (FNO .LT. 3.) GO TO 96
      AVWT=SUM(4)/FNO
C------- NORMALIZE DISTANCE WEIGHTS ------------------------------------
      SUM(4)=0.0
      DO 122 I=1,NR
  122 WT(I)=WT(I)/AVWT
      IF ((NI.LE.2).OR.(KAZ.EQ.0)) GO TO 130
C------- AZIMUTHAL WEIGHTING -------------------------------------------
      CALL AZWTOS
C------- COMPUTE TRAVEL TIMES & DERIVATIVES ----------------------------
```

```
  130 ZSQ=Z**2
      CALL TRVDRV
      FDLY=1.
      IF (ISW .EQ. IONE) FDLY=0.
C------- CALCULATE TRAVEL TIME RESIDUALS X(4,I) & MODIFY THE DERIV'S ---
  140 DO 150 I=1,NR
      JI=KDX(I)
      IF (I .LE. NRP) GO TO 145
C------- S PHASE DATA ---------------------------------------------------
      T(I)=POS*T(I)
      X(1,I)=POS*X(1,I)
      X(2,I)=POS*X(2,I)
      X(3,I)=POS*X(3,I)
      X(4,I)=TP(I)-T(I)-ORG-POS*DLY(KNO,JI)*FDLY
      GO TO 150
  145 IF (KSMP(I) .EQ. 0) GO TO 146
C------- S-P DATA -------------------------------------------------------
      X(1,I)=(POS-1.)*X(1,I)
      X(2,I)=(POS-1.)*X(2,I)
      X(3,I)=(POS-1.)*X(3,I)
      X(4,I)=TS(I)-TP(I)-(POS-1.)*(DLY(KNO,JI)*FDLY+T(I))
      GO TO 150
C------- P TRAVEL TIME RESIDUAL -----------------------------------------
  146 X(4,I)=TP(I)-T(I)-ORG-DLY(KNO,JI)*FDLY
  150 CONTINUE
C------- COMPUTE AVR, AAR, RMSSQ, & SDR ---------------------------------
      ONF=0.0
      DO 152 I=1,NR
      ONF = ONF + WT(I)*(1-KSMP(I))
      XWT = X(4,I)*WT(I)
      SUM(1)=SUM(1)+XWT
      SUM(2)=SUM(2)+ABS(XWT)
      SUM(3)=SUM(3)+X(4,I)*XWT
      SUM(5)=SUM(5)+XWT*(1-KSMP(I))
  152 CONTINUE
      IF(FNO .GT. FMO) AVRPS=SUM(5)/(ONF)
      AVR=SUM(1)/FNO
      AAR=SUM(2)/FNO
      RMSSQ=SUM(3)/FNO
      SDR=SQRT(ABS(RMSSQ-AVR**2))
      DO 153 I=1,5
      SUM(I)= 0.0
  153 CONTINUE
      IF (RMSSQ .GE. TEST(1)) GO TO 154
      IF(ERLMT .EQ. 1.) GO TO 167
      IF(INST.EQ.9) GO TO 501
      IF(NI .GE. 2) GO TO 167
      GO TO 165
C------- JEFFREYS' WEIGHTING --------------------------------------------
  154 FMO=0.
      FNO=0.
```

```
      DO 160 I=1,NR                                                     HYPO1178
      WRK(I)=BLANK                                                      HYPO1179
      IF (WT(I) .EQ. 0.) GO TO 160                                      HYPO1180
      K=10.*ABS(X(4,I)-AVR)/SDR+1.5                                     HYPO1181
      IF (K .GT. 41) K=41                                               HYPO1182
      WT(I)=WT(I)*WF(K)                                                 HYPO1183
      IF (K .GT. 30) WRK(I)=STAR4                                       HYPO1184
      IF (WT(I) .LT. 0.005) WT(I)=0.                                    HYPO1185
      IF (WT(I) .EQ. 0.) GO TO 160                                      HYPO1186
      IF (KSMP(I) .EQ. 1) FMO=FMO+1.                                    HYPO1187
      FNO=FNO+1.                                                        HYPO1188
      SUM(4)=SUM(4)+WT(I)                                               HYPO1189
  160 CONTINUE                                                          HYPO1190
      IF (FNO .LT. 3.) GO TO 96                                         HYPO1191
      AVWT=SUM(4)/FNO                                                   HYPO1192
      SUM(4)=0.0                                                        HYPO1193
      ONF=0.0                                                           HYPO1194
      DO 164 I=1,NR                                                     HYPO1195
      WT(I)=WT(I)/AVWT                                                  HYPO1196
      ONF = ONF + WT(I)*(1-KSMP(I))                                     HYPO1197
      XWT=X(4,I)*WT(I)                                                  HYPO1198
      SUM(5)=SUM(5)+XWT*(1-KSMP(I))                                     HYPO1199
  164 CONTINUE                                                          HYPO1200
C------- RECALCULATE AVRPS ---------------------------------------------HYPO1201
      IF(ERLMT .EQ. 1.) GO TO 163                                       HYPO1202
      IF(INST .NE. 9) GO TO 163                                         HYPO1203
      AVRPS = 0.0                                                       HYPO1204
      IF(FNO .NE. FMO) AVRPS = SUM(5)/ONF                               HYPO1205
      GO TO 501                                                         HYPO1206
  163 IF(FNO.EQ.FMO) AVRPS=0.0                                          HYPO1207
      IF(FNO.EQ.FMO) GO TO 167                                          HYPO1208
      AVRPS=SUM(5)/(ONF)                                                HYPO1209
      SUM(5)=0.0                                                        HYPO1210
      IF(ERLMT .EQ. 1.) GO TO 167                                       HYPO1211
C------- RESET FIRST ORIGIN TIME ---------------------------------------HYPO1212
      IF(NI.GE. 2) GO TO 167                                            HYPO1213
  165 ORG=ORG+AVRPS                                                     HYPO1214
      DO 166 I=1,NR                                                     HYPO1215
      IF(KSMP(I) .EQ. 0) X(4,I)=X(4,I)-AVRPS                            HYPO1216
      XWT=WT(I)*X(4,I)                                                  HYPO1217
      SUM(5)=SUM(5)+XWT*(1 - KSMP(I))                                   HYPO1218
      SUM(2)=SUM(2)+ABS(XWT)                                            HYPO1219
      SUM(3)=SUM(3)+X(4,I)*XWT                                          HYPO1220
  166 CONTINUE                                                          HYPO1221
      IF(FNO .GT. FMO) AVRPS=SUM(5)/(ONF)                               HYPO1222
      AAR=SUM(2)/FNO                                                    HYPO1223
      RMSSQ = SUM(3)/FNO                                                HYPO1224
      GO TO 169                                                         HYPO1225
C------- FOR NI>1, COMPUTE AAR, & RMSSQ AS IF AVRPS=0. -----------------HYPO1226
  167 DO 168 I=1,NR                                                     HYPO1227
      XWT=WT(I)*(X(4,I)-AVRPS*(1-KSMP(I)))                              HYPO1228
```

```
      SUM(2)=SUM(2)+ABS(XWT)
      SUM(3)=SUM(3)+(X(4,I)-AVRPS*(1-KSMP(I)))*XWT
  168 CONTINUE
      AAR=SUM(2)/FNO
      RMSSQ=SUM(3)/FNO
      IF(ERLMT .EQ. 0.) GO TO 169
C------- OUTPUT RMS ERROR OF AUXILIARY POINTS -------------------------
      L = LATEP/60.
      ALA = LATEP - 60.*L
      L = LONEP/60.
      ALO = LONEP - 60.*L
      RMSX= SQRT(RMSSQ)
      DRMS = RMSX - RMSSV
      GO TO (1,2,3,4,5,6,1,2,3,4), NA
    1 WRITE(6,801) ALA,ALO,Z,AVRPS,RMSX,DRMS
  801 FORMAT(5F10.2,10X,F6.2)
      GO TO 174
    2 WRITE(6,802) ALA,ALO,Z,AVRPS,RMSX,DRMS
  802 FORMAT(5F10.2,28X,F6.2)
      GO TO 174
    3 WRITE(6,803) ALA,ALO,Z,AVRPS,RMSX,DRMS
  803 FORMAT(5F10.2,13X,'(',F6.2,')')
      GO TO 174
    4 WRITE(6,804) ALA,ALO,Z,AVRPS,RMSX,DRMS
  804 FORMAT(5F10.2,31X,'(',F6.2,')')
      IF(NA .EQ. 10) GO TO 550
      GO TO 174
    5 WRITE(6,805) ALA,ALO,Z,AVRPS,RMSX,DRMS
  805 FORMAT(/5F10.2,19X,F6.2)
      WRITE(6,807) RMSSV
  807 FORMAT(40X,F10.2,23X,'0.00')
      GO TO 174
    6 WRITE(6,806) ALA,ALO,Z,AVRPS,RMSX,DRMS
  806 FORMAT(5F10.2,22X,'(',F6.2,')'/)
  174 NA = NA + 1
      GO TO 111
C------- CHECK IF SOLUTION IS BETTER THAN PREVIOUS ONE ----------------
  169 IF((NI .EQ. 1) .AND. (NDEC .EQ. 0)) GO TO 170
      IF(PRMSSQ.GE.RMSSQ) GO TO 170
      NDEC = NDEC +1
      IF(NDEC .GT. 1) GO TO 175
      DO 177 I= 1,3
      B(I) = 0.0
      AF(I)=-1.0
      SE(I) = 0.0
  177 CONTINUE
      NI = NI -1
      BM1=Y(1)
      BM2=Y(2)
      BM3=Y(3)
      BMAX = ABS(Y(1))
```

```
      IIMAX = 1
      DO 176 I = 2,3
      IF(ABS(Y(I)).LE.BMAX) GO TO 176
      BMAX = ABS(Y(I))
      IIMAX = I
  176 CONTINUE
      ISKP(IIMAX)=1
      Y(1)=-BM1/5.
      Y(2)=-BM2/5.
      Y(3)=-BM3/5.
      Y(4)=-Y(1)*XMEAN(1)-Y(2)*XMEAN(2)-Y(3)*XMEAN(3)
      XADJSQ=Y(1)**2+Y(2)**2+Y(3)**2
      KP=0
      IF(XADJSQ .LT. 4.*TEST(4)/25.) GO TO 170
  175 IF(NDEC .EQ. 5) GO TO 170
      GO TO 325
C------- STEPWISE MULTIPLE REGRESSION ANALYSIS OF TRAVEL TIME RESIDUALS-
  170 IF(NDEC .GE. 1) NI = NI + 1
      IF (INST.EQ.1) GO TO 250
      IF(ISKP(3) .EQ. 1) GO TO 250
      IF (INST .EQ. 9) GO TO 501
      IF ((FNO.EQ.3) .AND. (FMO.LT.3)) GO TO 250
C---- FREE SOLUTION
  200 KZ=0
      KF=0
      CALL SWMREG
C------- AVOID CORRECTING DEPTH IF HORIZONTAL CHANGE IS LARGE ----------
      IF (Y(1)**2+Y(2)**2 .LT. TEST(2)) GO TO 300
C---- FIXED DEPTH SOLUTION
  250 KZ=1
      KF=0
      CALL SWMREG
C------- LIMIT FOCAL DEPTH CHANGE & AVOID HYPOCENTER IN THE AIR --------
  300 DO 275 I= 1,3
      ISKP(I)=0
  275 CONTINUE
      OLDY1=Y(1)
      OLDY2=Y(2)
      OLDY3=Y(3)
      ABSY1=ABS(Y(1))
      ABSY2=ABS(Y(2))
      ABSY3=ABS(Y(3))
      IF(ABSY1.GT.ABSY2) GO TO 305
      ABSGR=ABSY2
      GO TO 308
  305 ABSGR=ABSY1
  308 IF(ABSY3.LE.TEST(5)) GO TO 310
      I=ABSY3/TEST(5)
      Y(3)=Y(3)/(I+1)
  310 IF((Z+Y(3)).GT. 0.0) GO TO 315
      Y(3)=-Z*TEST(12)+.000001
```

```
      ISKP(3) = 1
C------- LIMIT HORIZONTAL ADJUSTMENT OF EPICENTER ---------------------
  315 IF(ABSGR.LE.TEST(10)) GO TO 320
      I=ABSGR/TEST(10)
      Y(1)=Y(1)/(I+1)
      Y(2)=Y(2)/(I+1)
  320 Y(4)=Y(4)-(Y(3)-OLDY3)*XMEAN(3)-(Y(1)-OLDY1)*XMEAN(1)
     1 -(Y(2)-OLDY2)*XMEAN(2)
      XADJSQ=Y(1)**2+Y(2)**2+Y(3)**2
      KP=0
      NDEC=0
  325 IF (IPRN .GE. 1) CALL OUTPUT
      IF(NDEC .GE. 1) GO TO 330
C------- TERMINATE ITERATION IF HYPOCENTER ADJUSTMENT < TEST(4) --------
      IF (XADJSQ .LT. TEST(4)) GO TO 500
  330 IF(NI .EQ. NIMAX) GO TO 500
C------- ADJUST HYPOCENTER ---------------------------------------------
  350 AVL=LATEP/60.
  375 M1=AVL+1.5
      M2=AVL*10.+1.5
      DY1 =Y(1)/(CA(M1)*COSL(M2))
      DY2 =Y(2)/CB(M1)
      LATEP=LATEP+DY2
      LONEP=LONEP+DY1
      Z=Z+Y(3)
      ORG=ORG+Y(4)
      SVY1 = Y(1)
      SVY2 = Y(2)
      SVY3 = Y(3)
      ADJSQ=XADJSQ
      IF(NDEC .EQ. 0) PRMSSQ=RMSSQ
      IF(NDEC.GE.1) GO TO 110
  400 NI = NI + 1
      IF(NI .LE. NIMAX) GO TO 111
C------- RESET ORIGIN TIME ---------------------------------------------
  500 ORG=ORG+XMEAN(4)
      GO TO 502
  501 XMEAN(4)=0.0
  502 DO 505 I=1,5
  505 SUM(I)=0.0
      SUMM = 0.0
      DO 510 I=1,NR
      IF (KSMP(I) .EQ. 0) X(4,I)=X(4,I)-XMEAN(4)
      IF (WT(I) .EQ. 0.) GO TO 510
      IF(INST .NE. 9) GO TO 509
      XWTS=WT(I)*(X(4,I)**2)
      IF(KSMP(I) .EQ. 0) XWTS=WT(I)*((X(4,I)-AVRPS)**2)
      SUMM = SUMM + XWTS
  509 XWT=X(4,I)*WT(I)
      SUM(1)=SUM(1)+XWT
      SUM(2)=SUM(2)+ABS(XWT)
```

```
      SUM(3)=SUM(3)+X(4,I)*XWT                                          HYPO1382
      SUM(5)=SUM(5)+XWT*(1-KSMP(I))                                     HYPO1383
  510 CONTINUE                                                          HYPO1384
      RM9SV = SUMM/FNO                                                  HYPO1385
      AVR=SUM(1)/FNO                                                    HYPO1386
      AVRPS = 0.0                                                       HYPO1387
      IF(FNO .GT. FMO) AVRPS=SUM(5)/ONF                                 HYPO1388
      AAR=SUM(2)/FNO                                                    HYPO1389
      RMSSQ=SUM(3)/FNO                                                  HYPO1390
C------- COMPUTE ERROR ESTIMATES BY SULVING FULL NORMAL EQUATION -------HYPO1391
  520 KF=2                                                              HYPO1392
      KP=1                                                              HYPO1393
      KZ=0                                                              HYPO1394
      CALL SWMREG                                                       HYPO1395
      DO 521 I =1,3                                                     HYPO1396
  521 Y(I)=0.0                                                          HYPO1397
      IF(INST.EQ.1) KZ = 1                                              HYPO1498
      CALL OUTPUT                                                       HYPO1399
      IF (KMS .EQ. 1) CALL MISING                                       HYPO1400
      IF ((KNST.GE.5) .OR. (KFM.GE.1)) CALL FMPLOT                      HYPO1401
      QNO(JAV)=QNO(JAV)+1.                                              HYPO1402
      IF (JAV .GT. IQ) GO TO 523                                        HYPO1403
C------- COMPUTE SUMMARY OF TRAVEL TIME RESIDUALS ----------------------HYPO1404
      DO 522 I=1,NRP                                                    HYPO1405
      IF ((WT(I).EQ.0.) .OR. (KSMP(I).EQ.1))  GO TO 522                 HYPO1406
      JI=KDX(I)                                                         HYPO1407
      NRES(KNO,JI)=NRES(KNO,JI)+1                                       HYPO1408
      SR(KNO,JI)=SR(KNO,JI)+X(4,I)*WT(I)                                HYPO1409
      SRSQ(KNO,JI)=SRSQ(KNO,JI)+X(4,I)**2*WT(I)                         HYPO1410
      SRWT(KNO,JI)=SRWT(KNO,JI)+WT(I)                                   HYPO1411
  522 CONTINUE                                                          HYPO1412
  523 IF (KTEST .NE. 1) GO TO 550                                       HYPO1413
C------- COMPUTE RMS AT AUXILIARY POINTS -------------------------------HYPO1414
      RMSSV = SQRT(RMSSQ)                                               HYPO1415
      IF(INST.EQ.9) RMSSV = SQRT(RM9SV)                                 HYPO1416
      ERLMT = 1.                                                        HYPO1417
      LATSV = LATEP                                                     HYPO1418
      LONSV = LONEP                                                     HYPO1419
      ZSV = Z                                                           HYPO1420
      AVL = LATEP/60.                                                   HYPO1421
      M1 = AVL + 1.5                                                    HYPO1422
      M2 = AVL*10. + 1.5                                                HYPO1423
      DELAT = TEST(13)/CB(M1)                                           HYPO1424
      DELON = TEST(13)/(CA(M1)*COSL(M2))                                HYPO1425
      DEZ = TEST(13)                                                    HYPO1426
      WRITE (6,525)                                                     HYPO1427
  525 FORMAT (/'          LAT          LON            Z       AVRPS          RMS  HYPO1428
     1                    DRMS'/)                                       HYPO1429
      NA=1                                                              HYPO1430
      GO TO 111                                                         HYPO1431
  550 TIME1=TIME2                                                       HYPO1432
```

```
  575 CONTINUE
C------- CHECK FOR MULTIPLE SOLUTIONS OF THE SAME EARTHQUAKE -----------
      IF(IPRO.NE.ISTTT) RETURN
      NR=NRP
      NRP1=NR +1
      READ(5,600)  CHECK,IPRO,KNST,INST,ZRES,LAT1,LAT2,LON1,LON2,
     1 AZRES(NRP1)
      WRITE(6,601) CHECK,IPRO,KNST,INST,ZRES,LAT1,LAT2,LON1,LON2
  601 FORMAT(//2A4,9X,2I1,F5.2,1X,2(I4,F6.2),'--- RUN AGAIN ---')
  600 FORMAT(2A4,9X,2I1,F5.2,1X,2(I4,F6.2),T21,A4)
      LATRT=60.*LAT1+LAT2
      LONRT=60.*LON1+LON2
      IF(CHECK.EQ.BLANK) GO TO 30
      WRITE(6,610) CHECK
  610 FORMAT(/' ERROR ',A4,' SKIPPED.   INST. CARD DID NOT FOLLOW ***')
      RETURN
      END
```

```
      SUBROUTINE SORT(X,KEY,NO)                                         HYPO1450
      DIMENSION X(NO),KEY(NO)                                           HYPO1451
C-----------------------------------------------------------------------HYPO1452
      DO 1 I=1,NO                                                       HYPO1453
 1    KEY(I)=I                                                          HYPO1454
      MO=NO                                                             HYPO1455
 2    IF (MO-15) 21,21,23                                               HYPO1456
 21   IF (MO-1) 29,29,22                                                HYPO1457
 22   MO=2*(MO/4)+1                                                     HYPO1458
      GO TO 24                                                          HYPO1459
 23   MO=2*(MO/8)+1                                                     HYPO1460
 24   KO=NO-MO                                                          HYPO1461
      JO=1                                                              HYPO1462
 25   I=JO                                                              HYPO1463
 26   IF (X(I)-X(I+MO)) 28,28,27                                        HYPO1464
 27   TEMP=X(I)                                                         HYPO1465
      X(I)=X(I+MO)                                                      HYPO1466
      X(I+MO)=TEMP                                                      HYPO1467
      KEMP=KEY(I)                                                       HYPO1468
      KEY(I)=KEY(I+MO)                                                  HYPO1469
      KEY(I+MO)=KEMP                                                    HYPO1470
      I=I-MO                                                            HYPO1471
      IF (I-1) 28,26,26                                                 HYPO1472
 28   JO=JO+1                                                           HYPO1473
      IF (JO-KO) 25,25,2                                                HYPO1474
 29   RETURN                                                            HYPO1475
      END                                                               HYPO1476
```

```
      SUBROUTINE SUMOUT                                                 HYPO1477
C------- OUTPUT SUMMARY OF TIME AND MAGNITUDE RESIDUALS ----------------HYPO1478
      REAL LAT,LON,LAT2,LON2                                            HYPO1479
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),   HYPO1480
     1       PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151) HYPO1481
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)   HYPO1482
      COMMON /A3/ NRES(2,151),NXM(151),NFM(151),SR(2,151),SRSQ(2,151),  HYPO1483
     1       SRWT(2,151),SXM(151),SXMSQ(151),SFM(151),SFMSQ(151),QNO(4) HYPO1484
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40) HYPO1485
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)HYPO1486
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW   HYPO1487
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)   HYPO1488
      COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE                HYPO1489
      DIMENSION AVRES(4,151),SDRES(4,151)                               HYPO1490
C-----------------------------------------------------------------------HYPO1491
      QSUM=QNO(1)+QNO(2)+QNO(3)+QNO(4)                                  HYPO1492
      IF (QSUM .EQ. 0.) GO TO 72                                        HYPO1493
      WRITE(6,5) (QNO(I),I=1,4),QSUM                                    HYPO1494
    5 FORMAT(1H1,' ***** CLASS:      A     B     C     D TOTAL *****'   HYPO1495
     1,//,7X,'NUMBER:',5F6.1)                                           HYPO1496
      DO 10 I=1,4                                                       HYPO1497
   10 QNO(I)=100.*QNO(I)/QSUM                                           HYPO1498
      WRITE(6,15)(QNO(I),I=1,4)                                         HYPO1499
   15 FORMAT(/,12X,'%:',4F6.1)                                          HYPO1500
      WRITE(6,20)                                                       HYPO1501
   20 FORMAT(///,10X,'TRAVELTIME RESIDUALS (MODEL=1)',5X                HYPO1502
     1,'TRAVELTIME RESIDUALS (MODEL=2)',5X,'X-MAGNITUDE RESIDUALS'      HYPO1503
     2,6X,'F-MAGNITUDE RESIDUALS',/,' STATION   NRES    SRWT   AVRES   SHYPO1504
     3DRES        NRES    SRWT   AVRES   SDRES          NXM    AVXM    SDXMHYPO1505
     4         NFM     AVFM     SDFM')                                  HYPO1506
      DO 70 I=1,NS                                                      HYPO1507
      DO 30 J=1,4                                                       HYPO1508
      AVRES(J,I)=0.                                                     HYPO1509
   30 SDRES(J,I)=0.                                                     HYPO1510
      IF (NRES(1,I) .EQ. 0) GO TO 35                                    HYPO1511
      AVRES(1,I)=SR(1,I)/SRWT(1,I)                                      HYPO1512
      SDRES(1,I)=SQRT(SRSQ(1,I)/SRWT(1,I)-AVRES(1,I)**2+0.000001)       HYPO1513
   35 IF (NRES(2,I) .EQ. 0) GO TO 40                                    HYPO1514
      AVRES(2,I)=SR(2,I)/SRWT(2,I)                                      HYPO1515
      SDRES(2,I)=SQRT(SRSQ(2,I)/SRWT(2,I)-AVRES(2,I)**2+0.000001)       HYPO1516
   40 IF (NXM(I) .EQ. 0) GO TO 50                                       HYPO1517
      AVRES(3,I)=SXM(I)/NXM(I)                                          HYPO1518
      SDRES(3,I)=SQRT(SXMSQ(I)/NXM(I)-AVRES(3,I)**2+0.000001)           HYPO1519
   50 IF (NFM(I) .EQ. 0) GO TO 60                                       HYPO1520
      AVRES(4,I)=SFM(I)/NFM(I)                                          HYPO1521
      SDRES(4,I)=SQRT(SFMSQ(I)/NFM(I)-AVRES(4,I)**2+0.000001)           HYPO1522
   60 WRITE(6,65) NSTA(I),NRES(1,I),SRWT(1,I),AVRES(1,I),SDRES(1,I)     HYPO1523
     1,NRES(2,I),SRWT(2,I),AVRES(2,I),SDRES(2,I),NXM(I),AVRES(3,I)      HYPO1524
     2,SDRES(3,I),NFM(I),AVRES(4,I),SDRES(4,I)                          HYPO1525
   65 FORMAT(4X,A4,2X,I5,3F8.2,6X,I5,3F8.2,2(6X,I5,2F8.2))              HYPO1526
   70 CONTINUE                                                          HYPO1527
```

```
   72 IF (IPUN .NE. 3) GO TO 200
C------- PUNCH STATION LIST WITH REVISED DELAYS AND XMGC ---------------
      IF (ISW .EQ. IONE) GO TO 80
      WRITE(6,75)
   75 FORMAT(1H1,' ***** NEW STATION LIST *****'
     1,///,     4X,'I    STN   LAT N    LONG W   ELV DELAY',5X,'FMGC  XMGC KL
     2  PRR  CALR  IC  IS    DATE HRMN')
      GO TO 90
   80 WRITE(6,85)
   85 FORMAT(1H1,' ***** NEW STATION LIST *****'
     1,///,4X,'I    STN    LAT N     LONG W    ELV      M  DLY1  DLY2'
     2,'  XMGC  FMGC K  CALR IC  DATE HRMN')
   90 DO 120 I=1,NS
      DLY(1,I)=DLY(1,I)+AVRES(1,I)
      DLY(2,I)=DLY(2,I)+AVRES(2,I)
      XMGC(I)=XMGC(I)+AVRES(3,I)
      FMGC(I)=FMGC(I)+AVRES(4,I)
      LAT1=LAT(I)/60.
      LAT2=LAT(I)-60.*LAT1
      LON1=LON(I)/60.
      LON2=LON(I)-60.*LON1
      IF (ISW .EQ. IONE) GO TO 115
      WRITE(6,105) I,NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),DLY(1,I)
     1,FMGC(I),XMGC(I),KLSS(I),PRR(I),CALS(I),ICAL(I),NDATE(I),NHRMN(I)
  105 FORMAT(I5,2X,A4,I2,F5.2,1X,I3,F5.2,I5,F6.2,4X,F5.2,2X,F5.2,I2
     1,1X,F4.2,1X,F6.2,I2,5X,I6,I4)
      WRITE(7,110) NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),DLY(1,I)
     1,FMGC(I),XMGC(I),KLSS(I),PRR(I),CALS(I),ICAL(I),NDATE(I),NHRMN(I)
  110 FORMAT(2X,A4,I2,F5.2,1X,I3,F5.2,I5,F6.2,T38,F5.2,T45,F5.2
     1,I2,1X,F4.2,1X,F6.2,I2,T71,I6,I4)
      GO TO 120
  115 WRITE(6,116)I,NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),MNO(I),DLY(1,I)
     1,DLY(2,I),XMGC(I),FMGC(I),KLSS(I),CALS(I),ICAL(I)
     2,NDATE(I),NHRMN(I)
  116 FORMAT(I5,2X,A4,I3,'-',F5.2,I4,'-',F5.2,I5,I6,2F6.2
     1,2F6.2,I2,F6.2,I2,2X,I6,I4)
      WRITE(7,117) NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),MNO(I),DLY(1,I)
     1,DLY(2,I),XMGC(I),FMGC(I),KLSS(I),CALS(I),ICAL(I)
     2,NDATE(I),NHRMN(I)
  117 FORMAT(A4,I3,'-',F5.2,I4,'-',F5.2,I5,I6,2F6.2
     1,2F6.2,I2,F6.2,I2,2X,I6,I4)
  120 CONTINUE
      RETURN
C------- PUNCH STATION LIST WITH REVISED CALIBRATIONS ------------------
  200 IF (IPUN .NE. 4) RETURN
      IF (ISW .EQ. IONE) GO TO 205
      WRITE(6,75)
      GO TO 206
  205 WRITE(6,85)
  206 DO 220 I=1,NS
      LAT1=LAT(I)/60.
```

```
      LAT2=LAT(I)-60.*LAT1
      LON1=LON(I)/60.
      LON2=LON(I)-60.*LON1
      IF (ISW .EQ. IONE) GO TO 210
      WRITE(6,105) I,NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),DLY(1,I)
     1,FMGC(I),XMGC(I),KLAS(I),PRR(I),CALR(I),ICAL(I),MDATE(I),MHRMN(I)
      WRITE(7,110) NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),DLY(1,I)
     1,FMGC(I),XMGC(I),KLAS(I),PRR(I),CALR(I),ICAL(I),MDATE(I),MHRMN(I)
      GO TO 220
  210 WRITE(6,116)I,NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),MNO(I),DLY(1,I)
     1,DLY(2,I),XMGC(I),FMGC(I),KLAS(I),CALR(I),ICAL(I)
     2,MDATE(I),MHRMN(I)
      WRITE(7,117) NSTA(I),LAT1,LAT2,LON1,LON2,IELV(I),MNO(I),DLY(1,I)
     1,DLY(2,I),XMGC(I),FMGC(I),KLAS(I),CALR(I),ICAL(I)
     2,MDATE(I),MHRMN(I)
  220 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SWMREG
C------- COMPUTE GEIGER ADJUSTMENTS BY STEP-WISE MULTIPLE REGRESSION OF
C        TRAVEL TIME RESIDUALS -----------------------------------------
      REAL*8 ENT,ELM,FMT
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A7/ KP,KZ,KOUT,W(101),Y(4),BSE(4),XMEAN(4),CP(180),SP(180)
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)
      COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,IEXIT
      COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
      DIMENSION XSUM(4),SIGMA(4),IDX(4),V(3),PF(3),A(7,7),T(7,7),S(4,4)
      DATA L,M,MM,M1/3,4,7,5/,ENT,ELM/'ENTERING','LEAVING.'/
C-----------------------------------------------------------------------
      KFLAG=0
      SVTEST = TEST(3)
      ONF=0.0
      FLIM = TEST(3)
      DO 2 I=1,3
      AF(I)=-1.00
    2 CONTINUE
      DO 5 I=1,NR
      ONF=ONF + W(I)*(1-KSMP(I))
    5 CONTINUE
      DO 10 I=1,MM
      DO 10 J=1,MM
   10 A(I,J)=0.
C-----COMPUTE MEANS,STANDARD DEVIATIONS,AND CORRECTED SUMS OF SQUARE
      DO 40 I=1,M
      XSUM(I)=0.
      XMEAN(I)=0.
      DO 40 J=1,M
   40 S(I,J)=0.
      DO 50 K=1,NR
      DO 50 I=1,M
      TEMP=X(I,K)*W(K)
      ETMP=TEMP*(1-KSMP(K))
      XSUM(I)=XSUM(I)+ETMP
      DO 50 J=I,M
   50 S(I,J)=S(I,J)+TEMP*X(J,K)
      DO 70 I=1,M
      IF (ONF .EQ. 0.) GO TO 65
      XMEAN(I)=XSUM(I)/ONF
      DO 60 J=I,M
   60 S(I,J)=S(I,J)-XSUM(I)*XSUM(J)/ONF
   65 A(I,I)=1.
      IF (S(I,I) .LT. 0.000001) S(I,I)=0.000001
      SIGMA(I)=SQRT(S(I,I))
   70 CONTINUE
C-----COMPUTE AND AUGMENT CORRELATION MATRIX A
      DO 80 I=1,L
      I1=I+1
```

```
      DO 80 J=I1,M
      A(I,J)=S(I,J)/(SIGMA(I)*SIGMA(J))
   80 A(J,I)=A(I,J)
      PHI=FNO-1.
      DO 120 I=M1,MM
      A(I-M,I)=1.
  120 A(I,I-M)=-1.
  130 DO 140 I=1,M
      B(I)=0.
      Y(I)=0.
      BSE(I)=0.
  140 IDX(I)=0
      IF (IPRN .LT. 3) GO TO 150
      WRITE(6,45)
   45 FORMAT(///, '***** DATA *****',//,4X,'K',8X,'W'
     1,14X,'X1',14X,'X2',14X,'X3',14X,'X4',/)
      DO 47 K=1,NR
      WRITE(6,46) K,W(K),(X(I,K),I=1,M)
   46 FORMAT(I5,8E16.8)
   47 CONTINUE
      WRITE(6,75) (XMEAN(I),I=1,M)
   75 FORMAT(/,' MEAN',16X,8E16.8)
      WRITE(6,76) (SIGMA(I),I=1,M)
   76 FORMAT(/,' SIGMA',15X,7E16.8)
      WRITE(6,77)
   77 FORMAT(///,' ***** CORRECTED SUMS OF SQUARES MATRIX *****',/)
      DO 78 I=1,M
   78 WRITE(6,95) (S(I,J),J=1,M)
      WRITE(6,85)
   85 FORMAT(///,' ***** CORRELATION MATRIX R *****',/)
      DO 90 I=1,M
   90 WRITE(6,95) (A(I,J),J=1,M)
   95 FORMAT(7E18.8)
C-----STEPWISE MULTIPLE REGRESSION
      WRITE(6,125) NR,L,TEST(3)
  125 FORMAT(///, '********** STEPWISE MULTIPLE REGRESSION ANALYSIS'
     1,' **********',//' NUMBER OF DATA.....................',I5
     2,              /,' NUMBER OF INDEPENDENT VARIABLES...',I5
     3,              /,' CRITICAL F-VALUE..................',F8.2)
  150 DO 300 NSTEP=1,L
      NU=0
      MU=0
      IF (IPRN .LT. 3) GO TO 155
      WRITE(6,154) NSTEP,KZ,KF
  154 FORMAT(//,' ***** STEP NO.',I2,' *****',5X,'KZ =',I2,5X,'KF =',I2)
C-----FIND VARIABLE TO ENTER REGRESSION
  155 VMAX=0.
      MAX=NSTEP
      DO 160 I=1,L
      IF(ISKP(I).EQ.1) GO TO 160
      IF (IDX(I) .EQ. 1) GO TO 160
```

```
      IF ((I.EQ.3).AND.(KZ.EQ.1)) GO TO 160
      V(I)=A(I,M)*A(M,I)/A(I,I)
      IF (V(I) .LE. VMAX) GO TO 160
      VMAX=V(I)
      MAX=I
  160 CONTINUE
      F=0.0
      IF(VMAX.EQ.0.0) GO TO 163
      F=(PHI-1.)*VMAX/(A(M,M)-VMAX)
      IF(F .GE. 1000.) F=999.99
  163 AF(MAX)=F
      IF(KF .GE. 2) GO TO 165
      IF (F .LT. TEST(3)) GO TO 400
  165 IF ((MAX.EQ.3).AND.(KZ.EQ.1)) GO TO 300
  166 NU=MAX
      IDX(NU)=1
      PHI=PHI-1.
C-----COMPUTE MATRIX T FOR THE ENTRANCE OF VARIABLE X(NU)
      DO 170 J=1,MM
  170 T(NU,J)=A(NU,J)/A(NU,NU)
      DO 180 I=1,MM
      IF (I .EQ. NU) GO TO 180
      DO 175 J=1,MM
  175 T(I,J)=A(I,J)-A(I,NU)*A(NU,J)/A(NU,NU)
  180 CONTINUE
      DO 190 I=1,MM
      DO 190 J=1,MM
  190 A(I,J)=T(I,J)
      DO 200 I=1,L
      IF (IDX(I) .EQ. 0) GO TO 200
      IF (ABS(A(M,M)*A(I+M,I+M)) .LT. .000001 ) GO TO 195
      PF(I)=PHI*A(I,M)**2/(A(M,M)*A(I+M,I+M))
      IF(PF(I) .GE. 1000.0) PF(I)=999.99
      AF(I) = PF(I)
      GO TO 200
  195 PF(I) = 999.99
  200 CONTINUE
      IF (IPRN .LT. 3) GO TO 210
      CALL ANSWER(A,S,XMEAN,SIGMA,IDX,PHI,L,M,MM,PF,NU,ENT)
  210 IF (KF .EQ. 2) GO TO 300
      IF(KF .GE. 3) GO TO 450
C-----FIND VARIABLE TO LEAVE REGRESSION
      DO 250 K=1,L
      IF (IDX(K) .EQ. 0) GO TO 250
      IF (PF(K) .GE. TEST(3)) GO TO 250
      MU=K
      F=PF(MU)
      IDX(MU)=0
      PHI=PHI+1.
      DO 220 J=1,MM
  220 T(MU,J)=A(MU,J)/A(MU+M,MU+M)
```

```
      DO 230 I=1,MM
      IF (I .EQ. MU) GO TO 230
      DO 225 J=1,MM
      IF (J .EQ. MU) GO TO 225
      T(I,J)=A(I,J)-A(I,MU+M)*A(MU+M,J)/A(MU+M,MU+M)
  225 CONTINUE
  230 CONTINUE
      DO 240 I=1,MM
      IF (I .EQ. MU) GO TO 240
      T(I,MU)=A(I,MU)-A(I,MU+M)/A(MU+M,MU+M)
  240 CONTINUE
      DO 245 I=1,MM
      DO 245 J=1,MM
  245 A(I,J)=T(I,J)
      IF (IPRN .LT. 3) GO TO 250
      CALL ANSWER(A,S,XMEAN,SIGMA,IDX,PHI,L,M,MM,PF,MU,ELM)
  250 CONTINUE
  300 CONTINUE
C-----CHECK TERMINATION CONDITION
  400 KOUT=0
      DO 410 I=1,L
  410 KOUT=KOUT+IDX(I)
      B(4)=XMEAN(M)
      IF (KOUT .NE. 0) GO TO 450
      IF(KF .NE. 1) GO TO 420
      KF = 3
      GO TO 150
  420 TEST(3)= TEST(3)/TEST(6)
      FLIM=TEST(3)
      KF=1
      KFLAG = 0
      IF(TEST(6) .GT. 1.) GO TO 150
      KFLAG = 1
      KF = 4
      GO TO 150
C-----COMPUTE REGRESSION CONSTANT,COEFFICIENTS,AND STANDARD ERRORS
  450 YSE=77.7
      IF (PHI .GE. 1) YSE=SIGMA(M)*SQRT(ABS(A(M,M)/PHI))
      DO 500 I=1,L
      IF (IDX(I) .EQ. 0) GO TO 500
      B(I)=A(I,M)*SQRT(S(M,M)/S(I,I))
      BSE(I)=YSE*SQRT(ABS(A(I+M,I+M)/S(I,I)))
      IF(KF .NE. 3) Y(I)=B(I)
      IF(KFLAG .EQ. 0) GO TO 480
      IF(ABS(B(I)) .LE. TEST(6)*BSE(I)) Y(I)=0.
  480 IF(PHI .LT. 1.) BSE(I) = 0.
      B(4)=B(4)-Y(I)*XMEAN(I)
  500 CONTINUE
      IF(KF .NE. 3) Y(4)=B(4)
      TEST(3)=SVTEST
      RETURN
```

END HYP01801

```
      SUBROUTINE TRVDRV
C------- COMPUTE TRAVEL TIME AND DERIVATIVES FROM CRUSTAL MODEL --------
      REAL*8 TIME1,TIME2
      REAL LAT,LON
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,
     1        SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)
      COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW
      COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)
      COMMON /A20/ V(21),D(21),VSQ(21),THK(21),TID(21,21),DID(21,21)
      COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE
      COMMON /A24/ FLTEP
      DIMENSION TINJ(21),DIDJ(21),TR(21)
C-----------------------------------------------------------------------
      IF (ISW .EQ. IONE) GO TO 5
C-----INITIALIZATION FOR FIXED LAYER MODEL ----------------------------
      DO  1 L=1,NL
      IF (D(L) .GT. Z) GO TO  2
    1 CONTINUE
      JL=NL
      GO TO  3
    2 JJ=L
      JL=L-1
    3 TKJ=Z-D(JL)
      TKJSQ=TKJ**2+0.000001
      IF (JL .EQ. NL) GO TO  5
      DO   4 L=JJ,NL
      SQT=SQRT(VSQ(L)-VSQ(JL))
      TINJ(L)=TID(JL,L)-TKJ*SQT/(V(L)*V(JL))
    4 DIDJ(L)=DID(JL,L)-TKJ*V(JL)/SQT
      XOVMAX=V(JJ)*V(JL)*(TINJ(JJ)-TID(JL,JL))/(V(JJ)-V(JL))
    5 DO 300 I=1,NR
      IF (ISW .NE. IONE) GO TO 45
C-----INITIALIZATION FOR VARIABLE LAYER MODEL -------------------------
      JI=KDX(I)
      DEPTH(2)=FLT(KNO,JI)
      IF (Z .LT. FLTEP) DEPTH(2)=0.5*(FLT(KNO,JI)+FLTEP)
      THK(1)=DEPTH(2)
      THK(2)=D(3)-DEPTH(2)
      DH1=THK(1)-H(1)
      DH2=THK(2)-H(2)
      DO 10 L=1,NL
      IF (DEPTH(L) .GT. Z) GO TO 20
   10 CONTINUE
      JL=NL
      GO TO 30
   20 JJ=L
      JL=L-1
```

```
   30 TKJ=Z-DEPTH(JL)
      TKJSQ=TKJ**2+0.000001
      IF (JL .EQ. NL) GO TO 100
C-----CALCULATION FOR REFRACTED WAVES -----------------------------------
      DO 40 L=JJ,NL
      SQT=SQRT(VSQ(L)-VSQ(JL))
      TIX=F(1,JL)*DH1*G(1,L)+F(2,JL)*DH2*G(2,L)+TID(JL,L)
      DIX=F(1,JL)*DH1*G(3,L)+F(2,JL)*DH2*G(4,L)+DID(JL,L)
      TINJ(L)=TIX-TKJ*SQT/(V(L)*V(JL))
   40 DIDJ(L)=DIX-TKJ*V(JL)/SQT
      TIX=F(1,JL)*DH1*G(1,JL)+F(2,JL)*DH2*G(2,JL)+TID(JL,JL)
      XOVMAX=V(JJ)*V(JL)*(TINJ(JJ)-TIX)/(V(JJ)-V(JL))
      GO TO 50
   45 IF (JL .EQ. NL) GO TO 100
   50 DO 60 M=JJ,NL
   60 TR(M)=TINJ(M)+DELTA(I)/V(M)
      TMIN=999.99
      DO 70 M=JJ,NL
      IF (TR(M) .GT. TMIN) GO TO 70
      IF (DIDJ(M) .GT. DELTA(I)) GO TO 70
      K=M
      TMIN=TR(M)
   70 CONTINUE
      IF (DELTA(I) .LT. XOVMAX) GO TO 90
C-----TRAVEL TIME & DERIVATIVES FOR REFRACTED WAVE
   80 T(I)=TR(K)
      DTDD=1.0/V(K)
      DTDH=-SQRT(VSQ(K)-VSQ(JL))/(V(K)*V(JL))
      ANIN(I)=-V(JL)/V(K)
      GO TO 260
C-----CALCULATION FOR DIRECT WAVE ---------------------------------------
   90 IF (JL .NE. 1) GO TO 100
      SQT=SQRT(ZSQ+DELTA(I)**2)
      TDJ1=SQT/V(1)
      IF (TDJ1 .GE. TMIN) GO TO 80
C-----TRAVEL TIME & DERIVATIVES FOR DIRECT WAVE IN FIRST LAYER
      T(I)=TDJ1
      DTDD=DELTA(I)/(V(1)*SQT)
      DTDH=Z/(V(1)*SQT)
      ANIN(I)=DELTA(I)/SQT
      GO TO 260
C-----FIND A DIRECT WAVE THAT WILL EMERGE AT THE STATION
  100 XBIG=DELTA(I)
      XLIT=DELTA(I)*TKJ/Z
      UB=XBIG/SQRT(XBIG**2+TKJSQ)
      UL=XLIT/SQRT(XLIT**2+TKJSQ)
      UBSQ=UB**2
      ULSQ=UL**2
      DELBIG=TKJ*UB/SQRT(1.000001-UBSQ)
      DELLIT=TKJ*UL/SQRT(1.000001-ULSQ)
      J1=JL-1
```

```
      DO 110 L=1,J1
      DELBIG=DELBIG+(THK(L)*UB)/SQRT(VSQ(JL)/VSQ(L)-UBSQ)
  110 DELLIT=DELLIT+(THK(L)*UL)/SQRT(VSQ(JL)/VSQ(L)-ULSQ)
      DO 170 LL=1,25
      IF (DELBIG-DELLIT .LT. 0.02) GO TO 180
      XTR=XLIT+(DELTA(I)-DELLIT)*(XBIG-XLIT)/(DELBIG-DELLIT)
      U=XTR/SQRT(XTR**2+TKJSQ)
      USQ=U**2
      DELXTR=TKJ*U/SQRT(1.000001-USQ)
      DO 120 L=1,J1
  120 DELXTR=DELXTR+(THK(L)*U)/SQRT(VSQ(JL)/VSQ(L)-USQ)
      XTEST=DELTA(I)-DELXTR
      IF (ABS(XTEST) .LE. 0.02) GO TO 190
      IF (XTEST) 140,190,150
  140 XBIG=XTR
      DELBIG=DELXTR
      GO TO 160
  150 XLIT=XTR
      DELLIT=DELXTR
  160 IF (LL .LT. 10) GO TO 170
      IF (1.0-U .LT. 0.0002) GO TO 190
  170 CONTINUE
  180 XTR=0.5*(XBIG+XLIT)
      U=XTR/SQRT(XTR**2+TKJSQ)
      USQ=U**2
  190 IF (1.0-U .GT. 0.0002) GO TO 220
C-----IF U IS TOO NEAR 1, COMPUTE TDIR AS WAVE ALONG THE TOP OF LAYER JL
      IF (ISW .EQ. IONE) GO TO 195
      TDC=TID(JL,JL)+DELTA(I)/V(JL)
      GO TO 200
  195 TIX=F(1,JL)*DH1*G(1,JL)+F(2,JL)*DH2*G(2,JL)+TID(JL,JL)
      TDC=TIX+DELTA(I)/V(JL)
  200 IF (JL .EQ. NL) GO TO 210
      IF (TDC .GE. TMIN) GO TO 80
  210 T(I)=TDC
      DTDD=1.0/V(JL)
      DTDH=0.0
      ANIN(I)=0.9999999
      GO TO 260
C-----TRAVEL TIME & DERIVATIVES FOR DIRECT WAVE BELOW FIRST LAYER
  220 TDIR=TKJ/(V(JL)*SQRT(1.0-USQ))
      DO 240 L=1,J1
  240 TDIR=TDIR+(THK(L)*V(JL))/(VSQ(L)*SQRT(VSQ(JL)/VSQ(L)-USQ))
      IF (JL .EQ. NL) GO TO 245
      IF (TDIR .GE. TMIN) GO TO 80
  245 T(I)=TDIR
      SRR=SQRT(1.-USQ)
      SRT=SRR**3
      ALFA=TKJ/SRT
      BETA=TKJ*U/(V(JL)*SRT)
      DO 250 L=1,J1
```

```
      STK=(SQRT(VSQ(JL)/VSQ(L)-USQ))**3
      VTK=THK(L)/(VSQ(L)*STK)
      ALFA=ALFA+VTK*VSQ(JL)
  250 BETA=BETA+VTK*V(JL)*U
      DTDD=BETA/ALFA
      DTDH=(1.0-V(JL)*U*DTDD)/(V(JL)*SRR)
      ANIN(I)=U
C-----SET UP PARTIAL DERIVATIVES FOR REGRESSION ANALYSIS --------------
  260 X(1,I)=-DTDD*DX(I)/DELTA(I)
      X(2,I)=-DTDD*DY(I)/DELTA(I)
      X(3,I)=DTDH
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE XFMAGS
C------- COMPUTE X-MAGNITUDE AND F-MAGNITUDE ---------------------------
      REAL LAT,LON,MAG
      COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151),
     1         PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151)
      COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)
      COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40)
      COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)
      COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,
     1         SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)
      COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW
      COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)
      DIMENSION RSPA(8,20)
      DATA ZMC1,ZMC2,PWC1,PWC2/0.15,3.38,0.80,1.50/,BLANK/'    '/
      DATA RSPA/-0.02, 1.05,-0.15,-0.13, 0.66, 0.55, 0.17, 0.42,
     2          0.14, 1.18,-0.01, 0.01, 0.79, 0.66, 0.27, 0.64,
     3          0.30, 1.29, 0.12, 0.14, 0.90, 0.76, 0.35, 0.84,
     4          0.43, 1.40, 0.25, 0.27, 1.00, 0.86, 0.43, 0.95,
     5          0.55, 1.49, 0.38, 0.41, 1.08, 0.93, 0.49, 1.04,
     6          0.65, 1.57, 0.53, 0.57, 1.16, 1.00, 0.55, 1.13,
     7          0.74, 1.63, 0.71, 0.75, 1.23, 1.07, 0.63, 1.24,
     8          0.83, 1.70, 0.90, 0.95, 1.30, 1.15, 0.72, 1.40,
     9          0.92, 1.77, 1.07, 1.14, 1.38, 1.25, 0.83, 1.50,
     A          1.01, 1.86, 1.23, 1.28, 1.47, 1.35, 0.95, 1.62,
     B          1.11, 1.96, 1.35, 1.40, 1.57, 1.46, 1.08, 1.73,
     C          1.20, 2.05, 1.45, 1.49, 1.67, 1.56, 1.19, 1.84,
     D          1.30, 2.14, 1.55, 1.58, 1.77, 1.66, 1.30, 1.94,
     E          1.39, 2.24, 1.65, 1.67, 1.86, 1.76, 1.40, 2.04,
     F          1.47, 2.33, 1.74, 1.76, 1.95, 1.85, 1.50, 2.14,
     G          1.53, 2.41, 1.81, 1.83, 2.03, 1.93, 1.58, 2.24,
     H          1.56, 2.45, 1.85, 1.87, 2.07, 1.97, 1.62, 2.31,
     I          1.53, 2.44, 1.84, 1.86, 2.06, 1.96, 1.61, 2.31,
     J          1.43, 2.36, 1.76, 1.78, 1.98, 1.88, 1.53, 1.92,
     K          1.25, 2.18, 1.59, 1.61, 1.82, 1.72, 1.37, 1.49/
C-----------------------------------------------------------------------
      NM=0
      AVXM=0.
      SDXM=0.
      NF=0
      AVFM=0.
      SDFM=0.
      DO 40 I=1,NRP
      XMAG(I)=BLANK
      RAD2=DELTA(I)**2+ZSQ
      IF ((RAD2.LT.1.).OR.(RAD2.GT.360000.)) GO TO 30
      JI=KDX(I)
      K=KLAS(JI)
      AMXI=ABS(AMX(I))
      CAL(I)=CALX(I)
      IF ((CAL(I).LT.0.01).OR.(ICAL(JI).EQ.1)) CAL(I)=CALR(JI)
      IF ((AMXI.LT.0.01).OR.(CAL(I).LT.0.01)) GO TO 30
```

```
      IF ((K.LT.0).OR.(K.GT.8)) GO TO 30
      XLMR=0.
      IF (K .EQ. 0) GO TO 20
      PRXI=PRX(I)
      IF (PRXI .LT. 0.01) PRXI=PRR(JI)
      IF (IR .EQ. 0) GO TO 10
      IF ((PRXI.GT.20.).OR.(PRXI.LT.0.033)) GO TO 30
      FQ=10.*ALOG10(1./PRXI)+20.
      IFQ=FQ
      XLMR=QSPA(K,IFQ)+(FQ-IFQ)*(QSPA(K,IFQ+1)-QSPA(K,IFQ))
      GO TO 20
   10 IF ((PRXI.GT.3.).OR.(PRXI.LT.0.05)) GO TO 30
      FQ=10.*ALOG10(1./PRXI)+6.
      IFQ=FQ
      XLMR=RSPA(K,IFQ)+(FQ-IFQ)*(RSPA(K,IFQ+1)-RSPA(K,IFQ))
   20 BLAC=ALOG10(AMXI/(2.*CAL(I)))-XLMR
      RLD2=ALOG10(RAD2)
      BLNT=ZMC1-PWC1*RLD2
      IF (RAD2 .GE. 40000.) BLNT=ZMC2-PWC2*RLD2
      XMAG(I)=BLAC-BLNT+XMGC(JI)
      NM=NM+1
      AVXM=AVXM+XMAG(I)
      SDXM=SDXM+XMAG(I)**2
   30 FMAG(I)=BLANK
      IF (FMP(I) .EQ. BLANK) GO TO 40
      FMAG(I)=TEST(7)+TEST(8)*ALOG10(FMP(I))+TEST(9)*DELTA(I)+FMGC(JI)
      NF=NF+1
      AVFM=AVFM+FMAG(I)
      SDFM=SDFM+FMAG(I)**2
   40 CONTINUE
      IF (NM .EQ. 0) GO TO 50
      AVXM=AVXM/NM
      SDXM=SQRT(SDXM/NM-AVXM**2)
   50 IF (NF .EQ. 0) GO TO 60
      AVFM=AVFM/NF
      SDFM=SQRT(SDFM/NF-AVFM**2)
   60 IF (NM .EQ. 0) AVXM=BLANK
      IF (NF .EQ. 0) AVFM=BLANK
      IF (IMAG-1) 70,80,90
   70 MAG=AVXM
      RETURN
   80 MAG=AVFM
      RETURN
   90 MAG=0.5*(AVXM+AVFM)
      IF (AVXM .EQ. BLANK) GO TO 80
      IF (AVFM .EQ. BLANK) GO TO 70
      RETURN
      END
```

APPENDIX 2. A Listing of a Test Run of HYPO71*

* We have modified the real data to include some errors for demonstrations.

```
//MG992603 JOB (975200,C642,3,5,1000),'LEE - 800',CLASS=D
//GO   EXEC   PGM=E230,REGION=150K,TIME=2
//STEPLIB   DD DSNAME=A975200.MG9E230.HYPO71,UNIT=SYSDA,
//   VOL=SER=TEMPAA,DISP=SHR
//FT06F001 DD SYSOUT=A
//FT07F001 DD SYSOUT=B
//FT05F001 DD *
HEAD                          SOME SANTA ROSA QUAKES FOR TESTING HYPO71
RESET TEST(06)=1.

  SR013842.55 12259.17       -0.15      0.40     0.25 8
  SR023827.28 12304.80       0.09       0.40     0.25 8
  SR033814.15 12251.29       0.12       0.40     0.25 8
  SR043817.20 12231.92       0.14       0.40     0.25 8
  SR053829.55 12224.33       0.07       0.40     0.25 8
  SR063842.58 12232.22       -0.19      0.40     0.25 8
  SR073832.20 12242.78       0.03       0.40     0.25 8
  SR8A3835.50 12249.38       0.04       0.40     0.25 8
  SR083835.92 12248.25       0.07       0.40     0.25 8
  SR093829.42 12251.00       -0.19      0.40     0.25 8
  SR103825.00 12238.75       -0.16      0.40     0.25 8
  SR113833.58 12239.48       0.02       0.40     0.25 8
  SR123833.95 12246.20       0.13       0.40     0.25 8
  SR133828.50 12241.10       -0.01      0.40     0.25 8
  SR143823.08 12249.38       0.01       0.40     0.25 8
  SR153829.40 12235.95       0.07       0.40     0.25 8
  SR163832.02 12258.55       0.04       0.40     0.25 8
  SR173845.95 12248.35                  0.40     0.25 8
  SR183817.75 12244.48       -0.11      0.40     0.25 8
  SR193840.25 12240.08       -0.05      0.40     0.25 8

3.30   0.0
5.00   1.0
5.70   4.0
6.70   15.0
8.00   25.0

   5.  50. 100. 1.78    2        18          1          1    11
SR01EP-2 691005111259.78                                                      12
SR02IPU0 691005111259.42                                                      10
SR03IPD0 691005111258.41                  23. .15         0.65
SR04IPU0 691005111258.05      62.45ISU0   29. .20         0.78
SR05IPU0 691005111258.12                                                      15
SR06IPD0 691005111258.53      62.59IS 0                       CLP
SR07IPD0 691005111254.81
SR8AIP+1 691005111256.51
SR09IPU0 691005111255.66                                      CLP
SR10IPU0 691005111254.80
SR11IPD0 691005111255.32
SR12IPD0 691005111255.77
SR13IPD0 691005111254.89
```

```
SR15IPU0 691005111255.21
SR16IPD0 691005111258.04
SR18IPD0 691005111256.94
SR19IPD0 691005111257.26
                10
SR01IPD0 691005120651.22
SR02IPU0 691005120651.02
SR03IPD0 691005120650.49
SR04IPU0 691005120649.66                                                   16
SR05IPU0 691005120649.72       53.70ES 2
SR06IPD0 691005120650.10       54.20ESN4
SR07IPD0 691005120646.38                                                   18
SR8AIPU0 691005120648.09
SR09IPU0 691005120647.23
SR10IPU0 691005120646.40
SR11IPD0 691005120646.89
SR12IPD0 691005120647.32
SR20IPD0 691005120648.88
SR13IPD0 691005120645.46
SR14IPD0 691005120657.78
SR15IPU0 691005120646.80
SR16IPU0 691005120649.47
SR18IPD0 691005120648.55
SR19IPD0 691005120648.88

SR03IP-1 691005061210.13
SR04IPD9 691005061210.40       14.30ISD0                        DT?
SR05IP-1 691005061209.04                                                   25
SR06IPD0 691005061209.75       13.94ES 2
SR07IPD0 691005061206.45                                                   30
SR09IPU0 691005061207.29                                                   28
SR10IPU0 691005061206.10                                                   27
SR11IPD0 691005061206.78
SR12IP-1 691005061207.35
SR13IPD0 691005061205.79
SR15IPU0 691005061206.44
SR16IP-1 691005061209.52
SR18IPD0 691005061208.50
SR19IPD0 691005061208.61       12.00IS 0                                   45

SR01EP 2 691005111259.78
SR02IPU0 691005111259.42                                                   10
SR04IPU0 691005120649.66       54.03IS 0                                    8

/*
//
```

APPENDIX 3. Printed Results of the HYPO71 Test Run

SOME SANTA ROSA QUAKES FOR TESTING HYPO71

```
********** PROGRAM: HYPO71 (DEC. 21, 1971) **********

           TEST(1)  TEST(2)  TEST(3)  TEST(4)  TEST(5)  TEST(6)  TEST(7)  TEST(8)  TEST(9) TEST(10) TEST(11) TEST(12) TEST(13)
STANDARD   0.1000  10.0000   2.0000   0.0500   5.0000   4.0000  -0.8700   2.0000   0.0035 100.0000   8.0000   0.5000   1.0000
RESET TO   0.1000  10.0000   2.0000   0.0500   5.0000   1.0000  -0.8700   2.0000   0.0035 100.0000   8.0000   0.5000   1.0000

  L     STN  LAT N    LONG W  ELV DELAY      FMGC  XMGC KL  PRR  CALR IC     DATE HRMN
  1    SR013842.55 12259.17   0 -0.15      0.40   0.25 8 0.0   0.0  0          0    0
  2    SR023827.28 123 4.80   0  0.09      0.40   0.25 8 0.0   0.0  0          0    0
  3    SR033814.15 12251.29   0  0.12      0.40   0.25 8 0.0   0.0  0          0    0
  4    SR043817.20 12231.92   0  0.14      0.40   0.25 8 0.0   0.0  0          0    0
  5    SR053829.55 12224.33   0  0.07      0.40   0.25 8 0.0   0.0  0          0    0
  6    SR063842.58 12232.22   0 -0.19      0.40   0.25 8 0.0   0.0  0          0    0
  7    SR073832.20 12242.78   0  0.03      0.40   0.25 8 0.0   0.0  0          0    0
  8    SR8A3835.50 12249.38   0  0.04      0.40   0.25 8 0.0   0.0  0          0    0
  9    SR083835.92 12248.25   0  0.07      0.40   0.25 8 0.0   0.0  0          0    0
 10    SR093829.42 12251.00   0 -0.19      0.40   0.25 8 0.0   0.0  0          0    0
 11    SR103825.00 12238.75   0 -0.16      0.40   0.25 8 0.0   0.0  0          0    0
 12    SR113833.58 12239.48   0  0.02      0.40   0.25 8 0.0   0.0  0          0    0
 13    SR123833.95 12246.20   0  0.19      0.40   0.25 8 0.0   0.0  0          0    0
 14    SR133828.50 12241.10   0 -0.01      0.40   0.25 8 0.0   0.0  0          0    0
 15    SR143823.08 12249.38   0  0.01      0.40   0.25 8 0.0   0.0  0          0    0
 16    SR153829.40 12235.95   0  0.07      0.40   0.25 8 0.0   0.0  0          0    0
 17    SR163832.02 12258.55   0  0.04      0.40   0.25 8 0.0   0.0  0          0    0
 18    SR173845.95 12248.35   0  0.0       0.40   0.25 8 0.0   0.0  0          0    0
 19    SR183817.75 12244.48   0 -0.11      0.40   0.25 8 0.0   0.0  0          0    0
 20    SR193840.25 12240.08   0 -0.05      0.40   0.25 8 0.0   0.0  0          0    0


   CRUSTAL MODEL 1
  VELOCITY     DEPTH
     3.300     0.0
     5.000     1.000
     5.700     4.000
     6.700    15.000
     8.000    25.000


ZTR XNEAR XFAR  PDS   IQ  KMS  KFM IPUN IMAG   IR IPRN CODE  LATR      LONR
 5.  50. 100. 1.78    2    0   18    0    1    0    1 0011  0  0.0    0  0.0
```

```
                              SOME SANTA ROSA QUAKES FOR TESTING HYPO71                                        69/10/ 5    11:12

                                                                ADJUSTMENTS (KM)  PARTIAL F-VALUES  STANDARD ERRORS  ADJUSTMENTS TAKEN
 I  ORIG   LAT N     LONG W    DEPTH  DM  RMS AVRPS SKD    CF   DLAT   DLON    DZ  DLAT   DLON    DZ  DLAT  DLON    DZ  DLAT  DLON    DZ
 1 52.57 38-25.10 122-38.85   5.00    0 0.97 -0.00 D0A   2.00   5.80   4.50  6.82126.34 47.95 16.15  0.52  0.65  1.70  5.80  4.50  3.41
 2 53.05 38-28.23 122-41.94   8.41    1 0.19 -0.25 B0A   2.00   0.67  0.0    0.0   4.43 -1.00  0.02  0.32  0.0   0.0   0.67  0.0   0.0
 3 52.82 38-28.59 122-41.94   8.41    1 0.16  0.01 B4A   2.00   0.15  0.0    0.0   0.27 -1.00 -1.00  0.29  0.0   0.0   0.0   0.0   0.0
 3 52.83 38-28.59 122-41.94   8.41    1 0.16 -0.00 B2A   2.00   0.15  0.00 -0.16   0.23  0.00  0.02  0.31  0.37  1.11  0.0   0.0   0.0

 DATE     ORIGIN     LAT N     LONG W     DEPTH     MAG NO DM GAP M  RMS   ERH   ERZ Q SQD  ADJ IN NR  AVR  AAR NM AVXM SDXM NF AVFM SDFM I
691005 1112 52.83 38-28.59 122-41.94     8.41     1.81 19  1  59 1 0.16   0.5   1.1 B B|A 0.67 10 19-0.00 0.13  2  1.7  0.0  3  1.8  0.1 3

 STN  DIST AZM AIN PRMK HRMN P-SEC TPOBS TPCAL DLY/H1 P-RES P-WT AMX PRX CALX K XMAG RMK FMP FMAG SRMK S-SEC TSOBS S-RES  S-WT    DT
SR13   1.2  98 171 IPD0 1112 54.89  2.06  1.69 -0.01  0.38  0.80   0   0  0.0  8
SR07   6.8 350 137 IPD0 1112 54.81  1.98  2.14  0.03 -0.18  1.06   0   0  0.0  8
SR10   8.1 145 131 IPU0 1112 54.80  1.97  2.30 -0.16 -0.17  1.06   0   0  0.0  8
SR15   8.8  80 129 IPU0 1112 55.21  2.38  2.40  0.07 -0.09  1.10   0   0  0.0  8
SR11   9.9  21 125 IPD0 1112 55.32  2.49  2.55  0.02 -0.08  1.10   0   0  0.0  8
SR12  11.7 328 120 IPD0 1112 55.77  2.94  2.82  0.19 -0.06  1.10   0   0  0.0  8
SR09  13.3 277 116 IPU0 1112 55.66  2.83  3.06 -0.19 -0.04  1.10   0   0  0.0  8      CLP
SR8A  16.7 320 111 IP+1 1112 56.51  3.68  3.62  0.04  0.02  0.82   0   0  0.0  8
SR18  20.4 190 106 IPD0 1112 56.94  4.11  4.23 -0.11 -0.01  1.10   0   0  0.0  8
SR19  21.7   7 105 IPD0 1112 57.26  4.43  4.45 -0.05  0.03  1.10   0   0  0.0  8
SR16  25.0 285 103 IPD0 1112 58.04  5.21  5.00  0.04  0.17  1.06   0   0  0.0  8
SR04  25.6 145 102 IPU0 1112 58.05  5.22  5.12  0.14 -0.04  1.10  29  20  0.78 8 1.7                 ISU0 62.45  9.62  0.26  1.00
SR05  25.7  86 102 IPU0 1112 58.12  5.29  5.12  0.07  0.10  1.08   0   0  0.0  8           15 2.0
SR06  29.5  29 101 IPD0 1112 58.53  5.70  5.78 -0.19  0.11  1.08   0   0  0.0  8      CLP          IS 0 62.59  9.76 -0.13  1.06
SR03  30.0 207 100 IPD0 1112 58.41  5.58  5.87  0.12 -0.40  0.68  23  15  0.65 8 1.7
SR02  33.3 266  99 IPU0 1112 59.42  6.59  6.44  0.09  0.06  1.10   0   0  0.0  8           10 1.6
SR01  36.0 316  98 EP-2 1112 59.78  6.95  6.90 -0.15  0.20  0.52   0   0  0.0  8           12 1.8


***** SR20IPD0 691005120648.88                                                      ***** DELETED: SR20 NOT ON STATION LIST
```

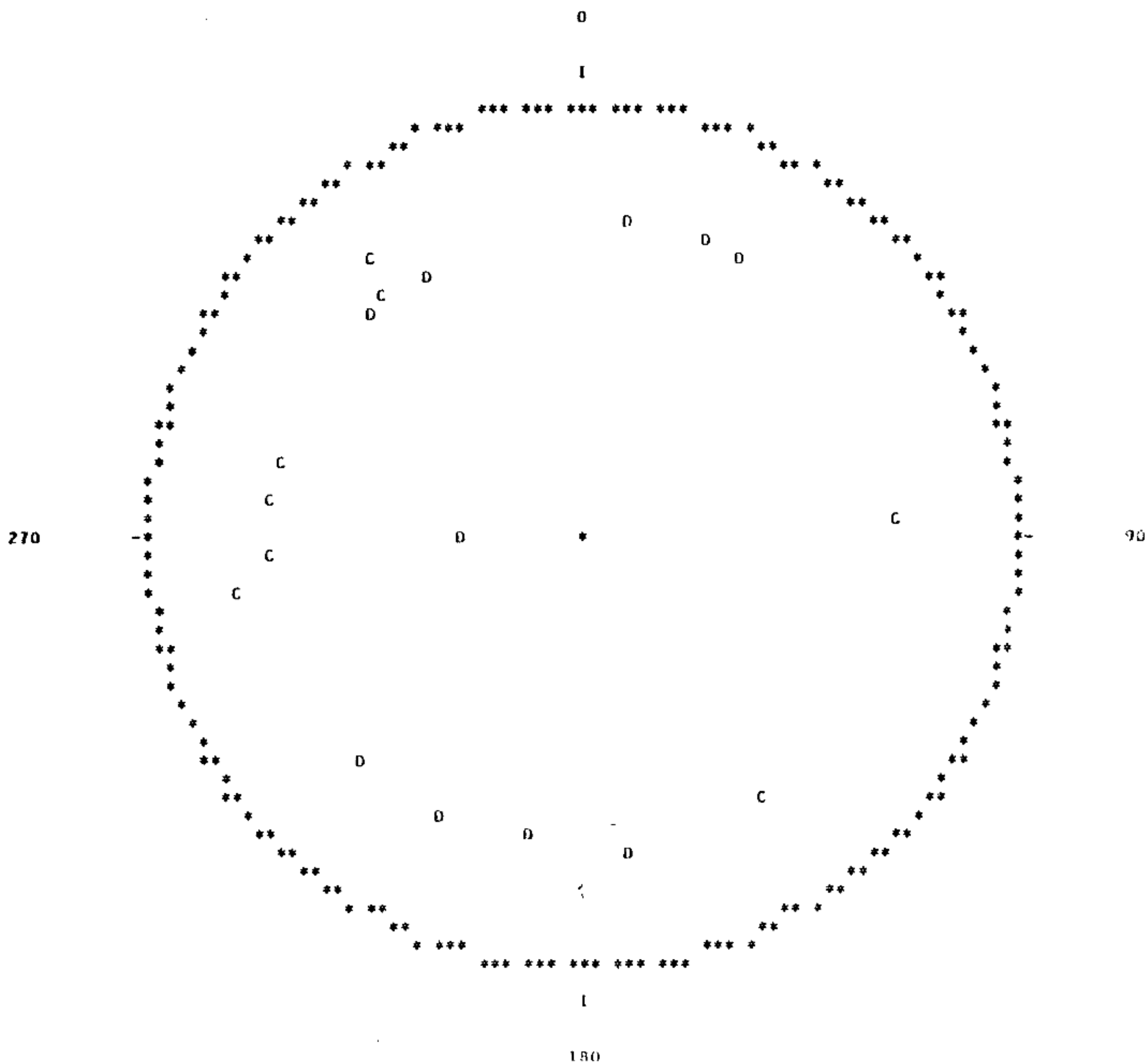
```
                              SOME SANTA ROSA QUAKES FOR TESTING HYPO71                                                   69/10/ 5    12: 6

                                                                     ADJUSTMENTS (KM)   PARTIAL F-VALUES   STANDARD ERRORS   ADJUSTMENTS TAKEN
 I  ORIG  LAT N     LONG W    DEPTH   DM  RMS AVRPS SKD    CF    DLAT   DLON     DZ  DLAT  DLON     DZ  DLAT  DLON     DZ  DLAT   DLON     DZ
 1 44.52 38-28.60 122-41.20  5.00     0 0.15  0.00 A0A   2.00 -0.13   1.29 -0.78   2.04173.22   8.64  0.09  0.10   0.26 -0.13   1.29 -0.78
 2 44.58 38-28.53 122-42.08  4.22     1 0.04 -0.01 A0A   2.00  0.0    0.0  -0.47 -1.00  0.06   4.41  0.0   0.0    0.22  0.0    0.0  -0.47
 2 44.57 38-28.53 122-42.08  3.75     1 0.04 -0.02 A0A   2.00  0.0    0.0    0.0  -1.00 -1.00 -1.00  0.0   0.0    0.0   0.0    0.0    0.09
 3 44.57 38-28.53 122-42.08  3.85*    1 0.03 -0.01 A4A   2.00  0.0  -0.01    0.0  -1.00  0.02 -1.00  0.0   0.08   0.0   0.0    0.0    0.0
 3 44.56 38-28.53 122-42.08  3.85     1 0.03 -0.00 A2A   2.00  0.00 -0.07   0.19  0.00  0.75   3.13  0.07  0.08   0.11  0.0    0.0    0.0


  DATE     ORIGIN     LAT N     LONG W     DEPTH      MAG NO DM GAP M  RMS   ERH  ERZ Q SQD  ADJ IN NR  AVR  AAR NM AVXM SDXM NF AVFM SDFM I
691005 12 6 44.56 38-28.53 122-42.08     3.85     2.05 17  1  59 1 0.03  0.1  0.1 A A|A 0.09  0 20-0.00 0.03  0  0.0  0.0  2  2.0  0.0 3

  STN  DIST AZM AIN PRMK HRMN P-SEC TPOBS TPCAL DLY/H1 P-RES P-WT AMX PRX CALX K XMAG RMK FMP FMAG SRMK S-SEC TSUBS S-RES  S-WT     DT
 SR13   1.4  92 158 IPD0 12 6 45.46  0.90  0.93 -0.01 -0.02  1.00   0   0  0.0 8
 SR07   6.9 352 115 IPD0 12 6 46.38  1.82  1.73  0.03  0.06  1.00   0   0  0.0 8          18 2.1
 SR10   8.1 143 111 IPU0 12 6 46.40  1.84  1.96 -0.16  0.04  1.00   0   0  0.0 8
 SR15   9.1  80 109 IPU0 12 6 46.80  2.24  2.14  0.07  0.04  1.00   0   0  0.0 8
 SR11  10.1  22  61 IPD0 12 6 46.89  2.33  2.32  0.02 -0.01  1.00   0   0  0.0 8
 SR12  11.7 329  61 IPD0 12 6 47.32  2.76  2.60  0.19 -0.03  1.00   0   0  0.0 8
 SR09  13.1 277  61 IPU0 12 6 47.23  2.67  2.84 -0.19  0.02  1.00   0   0  0.0 8
 SR14  14.6 226  61 IPD0 12 6 57.78 13.22  3.12  0.01 10.09**0.0    0   0  0.0 8
 SR8A  16.7 321  61 IPU0 12 6 48.09  3.53  3.48  0.04  0.01  1.00   0   0  0.0 8
 SR18  20.2 190  61 IPD0 12 6 48.55  3.99  4.10 -0.11  0.00  1.00   0   0  0.0 8
 SR19  21.9   8  61 IPD0 12 6 48.88  4.32  4.39 -0.05 -0.02  1.00   0   0  0.0 8
 SR16  24.8 285  61 IPU0 12 6 49.47  4.91  4.90  0.04 -0.01  1.00   0   0  0.0 8
 SR04  25.7 145  61 IPU0 12 6 49.66  5.10  5.05  0.14 -0.09  1.00   0   0  0.0 8          16 2.0
 SR05  25.9  86  61 IPU0 12 6 49.72  5.16  5.09  0.07  0.00  1.00   0   0  0.0 8                 ES 2 53.70  9.14 -0.04  0.0
 SR06  29.7  29  61 IPD0 12 6 50.10  5.54  5.76 -0.19 -0.02  1.00   0   0  0.0 8                 ESN4 54.20  9.64 -0.27  0.0
 SR03  29.8 207  61 IPD0 12 6 50.49  5.93  5.78  0.12  0.04  1.00   0   0  0.0 8
 SR02  33.1 266  61 IPU0 12 6 51.02  6.46  6.36  0.09  0.02  1.00   0   0  0.0 8
 SR01  35.9 316  61 IPD0 12 6 51.22  6.66  6.85 -0.15 -0.03  1.00   0   0  0.0 8
```

DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	Q	M
691005	12 6 44.56	38-28.53	122-42.08	3.85	2.05	17	59	1.4	0.03	0.1	0.1	A	1



```
                         SOME SANTA ROSA QUAKES FOR TESTING HYPO71                                                 69/10/ 5     6:12
***** FOLLOWING EVENT IS OUT OF ORDER *****

                                                                      ADJUSTMENTS (KM)  PARTIAL F-VALUES   STANDARD ERRORS   ADJUSTMENTS TAKEN
  I  ORIG  LAT N     LONG W    DEPTH  DM  RMS AVRPS SKD    CF    DLAT   DLON    DZ   DLAT  DLON     DZ  DLAT  DLON     DZ   DLAT  DLON     DZ
  1  4.41 38-28.60 122-41.20   5.00    0 0.15  0.00 B0A  2.00 -0.37 -0.46  2.82  3.18  3.59 23.82  0.21  0.24  0.58 -0.37 -0.46  2.82
  2  4.28 38-28.40 122-40.88   7.82    0 0.07 -0.06 A4A  2.00  0.0  -0.10  0.0  -1.00  0.20 -1.00  0.0   0.22  0.0   0.0   0.0   0.0
  2  4.23 38-28.40 122-40.88   7.82    0 0.07  0.00 A2A  2.00 -0.02 -0.11  0.11  0.01  0.70  0.05  0.20  0.24  0.52  0.0   0.0   0.0

  DATE    ORIGIN    LAT N    LONG W     DEPTH     MAG NO DM GAP M  RMS  ERH  ERZ Q SQD  ADJ IN NR  AVR  AAR NM AVXM SDXM NF AVFM SDFM I
691005  612  4.23 38-28.40 122-40.88    7.82    2.55 14  0  67 1 0.07  0.3  0.5 A A|A 2.88  0 16-0.00 0.05  0  0.0  0.0  5  2.5  0.2 2

  STN  DIST AZM AIN PRMK HRMN P-SEC TPOBS TPCAL DLY/H1 P-RES P-WT AMX PRX CALX K XMAG RMK FMP FMAG SRMK S-SEC TSOBS S-RES  S-WT    DT
 SR13   0.4 300 177 IPD0  612  5.79  1.56  1.57 -0.01 -0.00 1.08   0  0  0.0  8
 SR10   7.0 154 133 IPU0  612  6.10  1.87  2.09 -0.16 -0.06 1.08   0  0  0.0  8            27 2.4
 SR15   7.4  76 132 IPU0  612  6.44  2.21  2.14  0.07  0.00 1.08   0  0  0.0  8
 SR07   7.6 339 131 IPD0  612  6.45  2.22  2.16  0.03  0.03 1.08   0  0  0.0  8            30 2.5
 SR11   9.8  12 123 IPD0  612  6.78  2.55  2.48  0.02  0.06 1.08   0  0  0.0  8
 SR12  12.9 323 115 IP-1  612  7.35  3.12  2.95  0.19 -0.02 0.81   0  0  0.0  8
 SR09  14.8 277 111 IPU0  612  7.29  3.06  3.27 -0.19 -0.02 1.08   0  0  0.0  8            28 2.5
 SR18  20.4 195 104 IPD0  612  8.50  4.27  4.20 -0.11  0.19 1.08   0  0  0.0  8
 SR19  22.0   3 103 IPD0  612  8.61  4.38  4.47 -0.05 -0.03 1.08   0  0  0.0  8            45 2.9  IS 0 12.00  7.77 -0.09  0.0
 SR05  24.2  85 102 IP-1  612  9.04  4.81  4.84  0.07 -0.10 0.81   0  0  0.0  8            25 2.4
 SR04  24.5 148 102 IPD9  612 10.40  6.17  4.90  0.14 -0.03 1.08   0  0  0.0  8      DT?          ISD0 14.30  3.90 -0.03  ****
 SR16  26.6 285 100 IP-1  612  9.52  5.29  5.26  0.04 -0.00 0.81   0  0  0.0  8
 SR06  29.1  26  99 IPD0  612  9.75  5.52  5.69 -0.19  0.02 1.08   0  0  0.0  8                 ES 2 13.94  9.71 -0.08  0.0
 SR03  30.4 210  99 IP-1  612 10.13  5.90  5.92  0.12 -0.14 0.81   0  0  0.0  8


***** SR04IPU0 691005120649.66       54.03IS 0                                 8      ***** DELETED: WRONG TIME


***** INSUFFICIENT DATA FOR LOCATING THIS QUAKE:
    SR01EP 2 691005111259.78         0.0
    SR02IPU0 691005111259.42         0.0
```

***** CLASS:	A	B	C	D	TOTAL *****
NUMBER:	2.0	1.0	0.0	0.0	3.0
%:	66.7	33.3	0.0	0.0	

	TRAVELTIME RESIDUALS (MODEL=1)				TRAVELTIME RESIDUALS (MODEL=2)				X-MAGNITUDE RESIDUALS			F-MAGNITUDE RESIDUALS		
STATION	NRES	SRWT	AVRES	SDRES	NRES	SRWT	AVRES	SDRES	NXM	AVXM	SDXM	NFM	AVFM	SDFM
SR01	2	1.52	0.05	0.11	0	0.0	0.0	0.0	0	0.0	0.0	1	0.00	0.00
SR02	2	2.10	0.04	0.02	0	0.0	0.0	0.0	0	0.0	0.0	1	-0.16	0.00
SR03	3	2.49	-0.14	0.18	0	0.0	0.0	0.0	1	-0.02	0.00	0	0.0	0.0
SR04	2	2.10	-0.06	0.03	0	0.0	0.0	0.0	1	0.02	0.00	1	-0.02	0.00
SR05	3	2.89	0.01	0.08	0	0.0	0.0	0.0	0	0.0	0.0	2	0.01	0.15
SR06	3	3.16	0.04	0.06	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR07	3	3.14	-0.03	0.11	0	0.0	0.0	0.0	0	0.0	0.0	2	-0.01	0.03
SR8A	2	1.82	0.02	0.00	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR08	0	0.0	0.0	0.0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR09	3	3.17	-0.01	0.02	0	0.0	0.0	0.0	0	0.0	0.0	1	-0.07	0.00
SR10	3	3.14	-0.06	0.09	0	0.0	0.0	0.0	0	0.0	0.0	1	-0.13	0.00
SR11	3	3.17	-0.01	0.06	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR12	3	2.90	-0.04	0.02	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR13	3	2.87	0.10	0.17	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR14	0	0.0	0.0	0.0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR15	3	3.17	-0.02	0.05	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR16	3	2.87	0.05	0.09	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR17	0	0.0	0.0	0.0	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR18	3	3.17	0.06	0.09	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0
SR19	3	3.17	-0.01	0.03	0	0.0	0.0	0.0	0	0.0	0.0	1	0.37	0.00