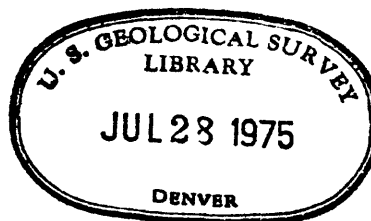


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HYPO71 (REVISED): A COMPUTER PROGRAM FOR DETERMINING HYPOCENTER,
MAGNITUDE, AND FIRST MOTION PATTERN OF LOCAL EARTHQUAKES

by



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1. INTRODUCTION

HYP071 is a computer program for determining hypocenter, magnitude, and first motion pattern of local earthquakes. The original program was dated December 21, 1971, and a user's manual was released as an open-file report of the U.S. Geological Survey on March 30, 1972 (Lee and Lahr, 1972). In order to generalize HYP071 for worldwide usage and to correct a few programming "bugs", the program HYP071 was revised on November 25, 1973, and a note on "Revisions of HYP071" was released on January 30, 1974. Now that all reprints of the original HYP071 manual have been exhausted, we take this opportunity to release a revised and updated HYP071 manual. For simplicity, HYP071 (Revised) will be referred to as HYP071.

Because this report is intended as a manual for HYP071 users, emphasis has been placed upon how to use the program. Our experience indicates that locating local earthquakes accurately requires considerable efforts. One must have accurate station coordinates (better than ± 0.1 km if possible), a reasonable crustal structure model (from controlled explosions), and reliable P and S arrivals. Naturally no computer program will give correct answers if the input data contain errors, so careful checking is essential before HYP071 is run. One should also remember that small residuals and standard errors are NOT sufficient to guarantee accurate hypocenter solution.

HYP071 is designed to catch some common mistakes in the input data, but this should not be counted on to find all of the errors. HYP071 also provides an assessment of the quality of the hypocenter solution

(see p.26) and much other information. Users are urged to study the output carefully. We wish to emphasize that values for "TEST VARIABLES" (see p. 7) must be carefully chosen for a given application because they influence 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 usually less than 10 kilometers).

HYP071 differs from HYPOLAYR (Eaton, 1969) and its revised version HYPOMAG in its scope and design, except that a similar subroutine is used to calculate traveltimes and their derivatives. Although major results of HYPOLAYR (or HYPOMAG) could be reproduced with HYP071, several additional features are available in HYP071 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 traveltimes are now available.

Comments and criticisms of HYP071 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 HYP071.

2. HOW TO USE HYP071

The HYP071 program is available in two versions: one for the IBM 360 or 370 computer in EBCDIC punched code, and the other for the CDC 6600 or 7600 computer in BCD punched code. It is written in FORTRAN IV language and has been successfully executed under the FORTRAN H compiler for IBM computers or under the MNF (University of Minnesota FORTRAN) compiler for CDC computers. The program requires approximately 150,000 bytes (or 37,500 words) of core storage for execution. Section 2.4 will describe how to adapt HYP071 to your computer, especially when the available core storage is less than what is required. A listing of HYP071 is given in Appendix 1 (p.45-86).

If HYP071 is to be used routinely, a load module should be created and stored on disk. Since compilation and link-editing are not needed to execute a load module, considerable savings in computer time is achieved (about 2 minutes per run on an IBM 360/65 computer). In the following two sections, a step-by-step description of how to use the load module of HYP071 is presented. A listing of a test run for IBM 360 or 370 computers is illustrated in Appendix 2 (p.87-89).

2.1 Input Card Deck Setup.

To execute the load module of HYP071 the following input card deck setup is required:

- (1) Job card
- (2) Job control cards
- (3) Input data cards
- (4) End card

Because "Input Data Cards" are independent of the computer facility, they will be treated in detail in Section 2.2. For NCER users, a load module of HYP071 has been stored on (1) USGS Computer Center at Reston, (2) Stanford Computation Center at Stanford University, and (3) Computing Facility at Lawrence Berkeley Laboratory. The input card deck setup for the Reston computer is illustrated in Appendix 2 (p.87-89). The deck setup for the Stanford computer is as follows:

```

- - - - - JOB CARD FOR STANFORD IBM 360/67 COMPUTER - - - - -
//HYP0 EXEC PGM=HYP071
//STEPLIB DD DSN=C896.LEE,UNIT=2314,DISP=OLD,VOL=SER=SYS10
//FT06F001 DD SYSOUT=A
//FT07F001 DD SYSOUT=B
//FT05F001 DD *
- - - - - INPUT DATA CARDS FOR HYP071 - - - - -
/*

```

The deck setup for the LBL computer (BKY) is as follows:

```

- - - - - JOB CARD FOR BKY CDC 7600 COMPUTER - - - - -
LIBCOPY(UPGEO,BIN/BR,RHP71)
LINK,B,F=BIN.
LGOB,LC=20000.      (NOTE: LC=MAXIMUM NUMBER OF OUTPUT LINES)
EXIT.
7/8/9 CARD      (NOTE: MULTIPLE PUNCH OF 7,8,& 9 AT COLUMN 1)
- - - - - INPUT DATA CARDS FOR HYP071 - - - - -
6/7/8/9 CARD      (NOTE: THIS IS THE BKY END OF JOB CARD)

```

2.1-1. Job Card. This card must be prepared according to the computer facility used. One should normally allow 1 second computer time (IBM 360/65) and 100 lines printout for each earthquake. In addition, 5 seconds and 500 lines should be allowed for overhead. The actual computer time and printout depend, of course, on the options chosen and on the amount of data for each earthquake.

2.1-2. Job Control Cards. These cards depend on the computer facility used and how the load module is stored. Examples for IBM and CDC computers are shown in Section 2.1 above.

2.2. Input Data Cards.

These cards contain the input data for HYP071, and are set up as described below. A quick reference guide for variable names and formats of the input data is given in Figure 1. To denote a blank punch in the text, we use Δ .

<u>Item</u>	<u>Maximum Number of cards</u>	<u>Remarks</u>	<u>Page</u>
(1) Heading card	1	optional	5
(2) Reset list	13	optional	7
(3) Selection card	1		9
(4) Station list	150		9
(5) Blank card	1	to signal end of (4)	12
(6) Crustal model list	20		12
(7) Blank card	1	to signal end of (6)	12
(8) Control card	1		12
(9) Phase list	100	} repeated for each quake	15
(10) Instruction card	1		17
(11) Additional instruction list		optional	17
(12) Recycle card		optional	18

2.2-1 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.

2.2-2 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 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:

<u>Test Variable</u>	<u>Standard Value</u>	<u>Definition</u>
TEST(01)	0.1 sec	TEST(01) is the cutoff value for RMS below which Jeffreys' weighting of residuals is not used. It should be set to a value approximately equal to the overall timing accuracy of P-arrivals in seconds.*
TEST(02)	10 km	For each iteration step, if the epicentral adjustment \geq TEST(02), this step is recalculated without focal-depth adjustment. TEST(02) should be set to a value approximately equal to station spacing in kilometers.
TEST(03)	2.	Critical F-value for the stepwise multiple regression (Draper and Smith, 1966). TEST(03) should be set according to the number and quality of P- and S-arrivals. A value between 0.5 and 2 is recommended. If TEST(03) \leq 0., a simple multiple regression is performed regardless of whether the matrix is ill-conditioned (p.32-33).

* Jeffreys' weighting is designed to catch large arrival-time errors. Therefore, it is useful to use it on preliminary runs. After arrival-time errors have been corrected, Jeffreys' weighting is not recommended. (i.e. Reset TEST(01) to a large value, such as 0.5, on your final run).

<u>Test Variable</u>	<u>Standard Value</u>	<u>Definition</u>
		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.
TEST(04)	0.05 km	If the hypocentral adjustment is less than TEST(04), Geiger's iteration 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 $K = DZ / \text{TEST}(05)$. 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. 12), and $\text{TEST}(05) = 5 \text{ km}$.
TEST(06)	4.	If no significant variable is found in the stepwise multiple regression, the critical F-value, TEST(03), is reduced to $\text{TEST}(03)/\text{TEST}(06)$, and the regression is repeated. If $\text{TEST}(06) \leq 1$, then the regression is repeated to find one variable, and the adjustment is made only if it is greater than $\text{TEST}(06) \times \text{standard error}$. If TEST(03) is set to be less than 2, then TEST(06) should be set to 1.
TEST(07)	-0.87	{ Coefficients for calculating the duration magnitude (FMAG) (<u>Lee, Bennett and Meagher, 1972</u>): $\text{FMAG} = -0.87 + 2 \log(T) + 0.0035 D$ 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 $J = D/\text{TEST}(10)$, D being the larger of DX or DY.

<u>Test Variable</u>	<u>Standard Value</u>	<u>Definition</u>
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 $\sqrt{3} * TEST(13)$ centered on the final solution. Eight of the ten points fall on the corners of a cube, with sides equal to $2 * TEST(13)$. If the solution converged to a minimum of RMS, then all nearby values of RMS will be greater. TEST(13) should be set to a value approximately equal to the standard error of hypocenter in kilometers. (See p. 30 for details).

2.2-3 Selection Card. In HYP071, travel time from a trial hypocenter to a station is calculated from a given crustal 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.

2.2-4 Station List. 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. A maximum of 150 station cards is allowed in the program.

Station Format No. 1 (for Station Delay Model)

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
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 Δ MOB
7-8	LAT1	I2	Degree portion of latitude	37
9-13	LAT2	F5.2	Minute portion of latitude	15.72
14	INS *	A1	Punch N or leave this column blank for stations in northern hemisphere. Punch S for stations in southern hemisphere.	N or S
15-17	LON1	I3	Degree portion of longitude	121
18-22	LON2	F5.2	Minute portion of longitude	30.45
23	IEW *	A1	Punch E for eastern longitude. Punch W or leave this column blank for western longitude	E or W
24-27	IELV	I4	Elevation in meters. This data is not used in the program	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 10-day recorders

* INS and IEW must be the same for all stations.

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
53-56	PRR	F4.2	Standard period for XMAG	0.15 or blank
58-63	CALR	F6.2	Standard calibration for XMAG	Δ 10.50 or blank
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
<u>Station Format No. 2 (for Variable First-Layer Model)</u>				
1-4	NSTA	A4	Station name	SBSM or Δ MOB
5	IW	A1	If IW=*, then this station has zero weight assigned to its P &/ S readings	normally blank
6-7	LAT1	I2	Degree portion of latitude	37
9-13	LAT2	F5.2	Minute portion of latitude	15.72
14	INS*	A1	Punch N or leave this column blank for stations in northern hemisphere. Punch S for stations in southern hemisphere	N or S
15-17	LON1	I3	Degree portion of longitude	121
19-23	LON2	F5.2	Minute portion of longitude	30.45
24	IEW*	A1	Punch E for eastern longitude. Punch W or leave this column blank for western longitude	E or W
25-28	IELV	I4	Elevation in meters. This data is not used in the program.	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 seconds	+0.20 or -0.08
42-46	DLY2	F5.2	Station delay for model 2 in seconds	+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

* INS and IEW must be the same for all stations.

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

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
60	KLAS	I2	System number (see explanation in Station Format No. 1).	
61-66	CALR	F6.2	Standard calibration for XMAG	10.50 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

2.2-5 Blank Card. Signals end of station list.

2.2-6 Crustal Model List. For each flat layer, a crustal model list card must be punched as follows:

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
1-7	V	F7.3	P-velocity in km/sec in a given layer	$\Delta\Delta^{3.5}\Delta\Delta$
8-14	D	F7.3	Depth in km to the top of a given layer	$\Delta\Delta^{0.00}\Delta$ for the first layer

2.2-7 Blank Card. Signals end of crustal model.

2.2-8 Control Card. This card selects some of the options in HYPO71 and must be punched as follows:

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
1-5	ZTR	F5.0	Trial focal depth in km	$\Delta\Delta\Delta^5.$
6-10	XNEAR	F5.0	Distance in km from epicenter where the distance weighting is 1	$\Delta\Delta^{50}.$
11-15	XFAR	F5.0	Distance in km from epicenter beyond which the distance weighting is 0	$\Delta^{200}.$

2.2-8 Control Card -- Continued

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
16-20	POS	F5.2	Ratio of P-velocity to S-velocity	Δ 1.78 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 p. 57 (555-560), and p. 85-86.	blank

2.2-8 Control Card -- Continued

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>	
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	C O D E	KTEST	I1	If KTEST = 1, then auxiliary RMS values are calculated at ten points on a sphere centered at the hypocenter. (See p.9). This option will help to determine if the solution is at the RMS minimum. (See p.30).	1 or blank
58		KAZ	I1	If KAZ = 1, then azimuthal weighting of stations is applied. See page 29.	1 or blank
59		KSORT	I1	If KSORT = 1, then the stations are sorted by distance in the output	1 or blank
60		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).

2.2-9 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. Examples of data forms for punching phase cards are shown in Appendix 5 (p. 111-113).

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
1-4	MSTA	A4	Station name	SBSM or Δ MOB
5	PRMK	A1	Description of onset of P-arrival	I denotes impulsive or sharp E denotes emergent or gradual
6		A1	"P" to denote P-arrival	P or blank
7		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		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

* 'KDATE' and 'KHR' must have the same values for P and S arrivals for a given earthquake. For arrival times where 'KHR' changes, the extra hour MUST be carried into 'KMIN'.

** For arrival times where 'KMIN' changes, 'KMIN' may be punched as it is, or if the same 'KMIN' is punched, carry the extra minute into 'SEC' & 'S'.

2.2-9 Phase list. -- Continued

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
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	Δ^{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 μ v 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

2.2-9 Phase list. -- Continued

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
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.	$\Delta\Delta^{15}$.

2.2-10 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.

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

2.2-11 Additional Instruction List. Additional instruction cards may be optionally added to obtain other solutions for the same earthquake data. They are punched as follows:

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>
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 2.3-10 (p. 17).
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

2.3-12 Recycle Card. Previous items may be repeated by using a recycle card to be punched on columns 2 to 4

<u>Columns (2 to 4)</u>	<u>Remarks</u>
***	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 Additional Options.

Several additional options are available in HYP071, as follows:

2.3-1. 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:

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
1-5	ORG1	F5.0	Minute portion of origin time	$\Delta\Delta$ 15.
6-10	ORG2	F5.2	Second portion of origin time	10.05
11-15	LAT1	I5	Degree portion of latitude of hypocenter	$\Delta\Delta\Delta$ 37
16-20	LAT2	F5.2	Minute portion of latitude of hypocenter.	15.50
21-25	LON1	I5	Degree portion of longitude of hypocenter	$\Delta\Delta$ 121
26-30	LON2	F5.2	Minute portion of longitude of hypocenter	32.45
31-35	Z	F5.2	Focal depth of hypocenter in km	Δ 0.00

2.3-2 Use of S-Arrivals. Whether or not S-arrivals are used in the hypocenter solution, they will appear on the output if they are punched on phase cards. To use S-arrivals in the solution, set KNST = 1 on the instruction card (p. 17 & 18).

2.3-3 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.15). 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.

2.3-4 Calibration Changes. 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. In this case, the phase list and instruction card are replaced by one card punched as follows:

<u>Column</u>	<u>Name</u>	<u>Format</u>	<u>Explanation</u>	<u>Examples</u>
1-4	MSTA	A4	Station name	SBSM or Δ 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
22	KLAS	I1	New system number	1
59-62	CALX	F4.1	New station calibration value (10 μ v signal in mm)	13.2
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.

2.4 Adapting HYP071 for Your Computer. The EBCDIC punched code of the HYP071 program is written for an IBM 360 or 370 computer. A listing is given in Appendix 1 (p.45-86), where the number in the right hand side is the FORTRAN card sequence number. If you have an IBM 360 or 370 computer, adapting HYP071 for your computer will be easy, except perhaps the error handling facility of your FORTRAN compiler and the amount of core storage available. If your FORTRAN compiler does not have ERRSET subroutines, you must delete HYP071 cards numbered from 22 to 27 (see p.⁴⁶). If the amount of core storage available to you is less than 150,000 bytes, you may reduce the dimension of the arrays and/or delete some non-critical subroutines.

The length of various HYP071 components as compiled by FORTH on an IBM 360/65 computer is as follows:

2.4 Adapting HYP071 for Your Computer. (continued)

<u>HYP071 Components</u>	<u>Card Sequence Number</u>	<u>Length (bytes)</u>
MAIN	1 - 98	1,588
ANSWER	99 - 133	1,520
AZWTS	134 - 211	1,836
BLOCK DATA	212 - 248	7,676
FMPLOT	249 - 361	13,568
INPUT1	362 - 562	5,766
INPUT2	563 - 676	2,574
MISING	677 - 737	1,218
OUTPUT	738 - 1021	7,604
SINGLE	1022 - 1499	9,028
SORT	1500 - 1526	560
SUMOUT	1527 - 1652	9,048
SWMREG	1653 - 1857	5,730
TRVDRV	1858 - 2024	4,344
XFMAGS	2025 - 2123	2,502
COMMON BLOCKS		47,318
FORTTRAN LIBRARY		<u>24,096</u>
Total		145,976 bytes

To execute HYP071, however, one must add several thousand bytes to this total for buffers (this depends on the computer facility). Therefore, we suggest a core storage requirement of 150,000 bytes, although the program length is less than 146,000 bytes.

HYP071 is dimensioned for a maximum of 150 station cards (NMAX = 151), and 100 phase cards (MMAX = 101). If not needed, the core storage may be reduced by redimensioning arrays that have been dimensioned for NMAX = 151

and MMAX = 101. In addition the statement (card number 245) which defines the values of NMAX and MMAX must be modified to the new values chosen. Savings of up to about 25,000 bytes may be realized.

Another way to reduce the core storage requirement is to remove non-critical subroutines and statements that call them:

<u>Subroutine</u>	<u>Card Sequence Number</u>	<u>Cards Calling the Subroutine</u>
ANSWER	99 - 133	1793, 1821
AZWTOS	134 - 211	1174
FMPLLOT	249 - 361	1451
MISING	677 - 737	1450
SUMOUT	1527 - 1652	91

Up to about 30,000 bytes may be saved in this manner.

The BCD punched code for HYP071 is a modification of the IBM version for CDC computers. It is essentially identical except for the following:

- (1) Because CDC allows 131 characters per line (vs 132 characters for IBM), "SDFM" reads "SDF", and only one '*' follows large S-residuals instead of two '*'. This difference has no effect on your result.
- (2) Because CDC only recognizes BCD punched codes, please avoid using characters such as "+", "#", "ç", "%".
- (3) You can use "+" for your first P-motion, but not elsewhere. This restriction is not damaging, because you do not need to use "+" anywhere else.
- (4) "ç" in the IBM version (and HYP071 manual) has been replaced by "=" in the CDC version.

If you do not have either an IBM or CDC computer, adapting HYP071 for your computer will depend on how similar your computer is to the IBM 360 or 370 computers. We suggest that you consult your computer center staff before undertaking this work.

Finally, to facilitate your adaption, a deck of test data (see p.87-89) always accompanies a request for the HYP071 program. You should reproduce the results (within 1 or 2 counts of the last significant figures) shown on p. 90-96.

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 (p. 90-96).

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.

<u>Heading</u>	<u>Explanation</u>
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 LONG Depth	} Hypocenter location at Step I. See Section 3.2 for details.
DM	
DM	
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 skipped 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 skipped, 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

<u>Heading</u>	<u>Explanation</u>
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.

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>
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	37-48.64	Latitude of epicenter in degrees and minutes: 37° 48.64'.
LONG	121-57.59	Longitude of epicenter in degrees and minutes: 121° 57.59'
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.

3.2 Hypocenter Output. -- Continued

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>															
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. $RMS = \sqrt{\sum R_i^2 / NO}$, 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:															
<table> <tr> <th><u>Q</u></th><th><u>Epicenter</u></th><th><u>Focal Depth</u></th></tr> <tr> <td>A</td><td>Excellent</td><td>good</td></tr> <tr> <td>B</td><td>good</td><td>fair</td></tr> <tr> <td>C</td><td>fair</td><td>poor</td></tr> <tr> <td>D</td><td>poor</td><td>poor</td></tr> </table>			<u>Q</u>	<u>Epicenter</u>	<u>Focal Depth</u>	A	Excellent	good	B	good	fair	C	fair	poor	D	poor	poor
<u>Q</u>	<u>Epicenter</u>	<u>Focal Depth</u>															
A	Excellent	good															
B	good	fair															
C	fair	poor															
D	poor	poor															
<p>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.</p>																	
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.

3.2 Hypocenter Output. -- Continued

<u>QS</u>	<u>RMS (sec)</u>	<u>ERH (km)</u>	<u>ERZ (km)</u>
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:

<u>QD</u>	<u>NO</u>	<u>GAP</u>	<u>DMIN</u>
A	> 6	< 90°	< DEPTH or 5 km
B	> 6	< 135°	< 2x DEPTH or 10 km
C	> 6	< 180°	< 50 km
D	Others		

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>
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. $AAR \equiv \sum_i R_i / NO.$
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.

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>
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. $TPOBS \equiv T + DT - ORG$ 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 $P-RES \equiv TPOBS - (TPCAL + DLY)$. 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 $P-RES \equiv TPOBS - TPCAL$.

* The punch format is given on p.61 (773-775) & is used on p.64 (934-935).

3.3 Station Output. -- Continued

<u>Heading</u>	<u>Example</u>	<u>Explanation</u>
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 NO. 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 _Δ 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.

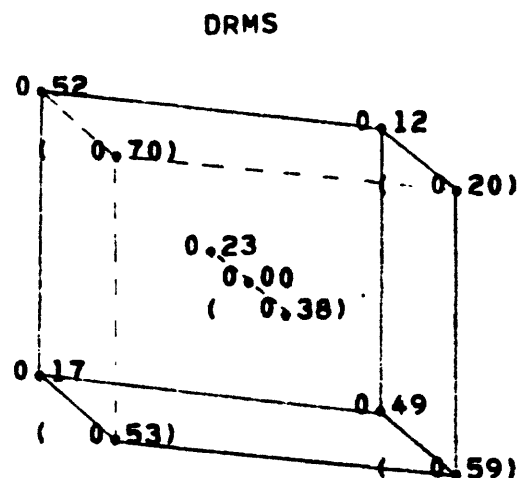
If S-P interval data are used, the meanings of some of the above headings are changed as follows.

<u>Heading</u>	<u>Explanation</u>
P-RES	S-P residual in sec. It is defined by $P-RES \equiv TSOBS - TPOBS - (POS - 1) (DLY + TPCAL)$ 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 Map of Auxiliary RMS Values.

This is an optional output for which KTEST is set to 1 on the Control Card (see p. 14). 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 value minus the final hypocenter RMS value is printed (DRMS). An example is shown below; the view is looking down to the northwest. It is necessary by NOT sufficient for all DRMS values to be positive for a good solution. If any DRMS value is negative, then the solution has not converged to a minimum. It is important to set the radius of the sphere appropriately for a given application (see p.9, TEST(13)).

LAT	LON	Z	AVRPS	RMS
8.17	14.76	0.0	-0.39	0.63
8.17	8.02	0.0	-1.42	0.23
8.17	14.76	9.62	-0.31	0.81
8.17	8.02	9.62	-1.19	0.30
5.47	11.39	0.0	-0.26	0.34
5.47	11.39	13.28	-0.56	0.48
2.77	14.76	0.0	0.50	0.27
2.77	8.02	0.0	-0.88	0.60
2.77	14.76	9.62	0.37	0.63
2.77	8.02	9.62	-0.74	0.70



4. COMPUTATIONAL PROCEDURES IN HYPO71

The program HYPO71 consists of a main program and 14 subroutines: ANSWER, AZWTOS, BLOCK DATA, FMPLLOT, 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

$$R_i \equiv \tau_i - t_i \quad (1)$$

is small, Taylor expansion of it will give:

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

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:

$$\sum e_i^2 = \text{a minimum} \quad (3)$$

where \sum 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):

$$ndt + \sum a_i dx + \sum b_i dy + \sum c_i dz = \sum R_i$$

$$\sum a_i dt + \sum a_i^2 dx + \sum a_i b_i dy + \sum a_i c_i dz = \sum a_i R_i$$

(4)

$$\sum b_i dt + \sum a_i b_i dx + \sum b_i^2 dy + \sum b_i c_i dz = \sum b_i R_i$$

$$\sum c_i dt + \sum a_i c_i dx + \sum b_i c_i dy + \sum c_i^2 dz = \sum c_i R_i$$

where

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

The improved origin time and hypocenter then becomes:

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

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 dependence on the origin time, equation (2) becomes

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

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 HYP071 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_1 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 HYP071, 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) FMPLLOT: 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 $0^\circ \leq \alpha \leq 360^\circ$, $0^\circ \leq \beta \leq 180^\circ$, and SYM = C (or +) for compression, or D (or -) for dilatation.

If $\beta > 90^\circ$, we let $\alpha = 180^\circ + \alpha$ and $\beta = 180^\circ - \beta$ 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 $\text{SYM} = \text{C}$, 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 $\text{SYM} = \text{D}$, 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 $\text{SYM} = +$ or $-$, it is plotted only if the position (r, θ) is not occupied.

(6) INPUT1: 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) INPUT2: 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 $25 \cdot (\text{MAG})^2$ 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 TEST(11) (p.9) 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 Appendix 4, p.97ff. 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 , $i = 1, \dots, N$ by increasing value.

(12) SUMOUT: This subroutine prints a table of the number and percentage of earthquakes in each quality class, Q, (see P. 26). 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

$$e_i = Y_i - B_0 - \sum_{j=1}^3 B_j X_{j,i} \quad \text{for } i=1, \dots, n$$

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

$$e_i = Y_i - X_{0,i} B_0 - \sum_{j=1}^3 B_j X_{j,i} \quad \text{for } i = 1, \dots, n$$

where $Y_i = R_i$

$$B_0 = dt; B_1 = dx; B_2 = dy; B_3 = dz$$

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

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

$$\text{let } Q = \sum_{i=1}^n e_i^2 = \sum_{i=1}^n \left(Y_i - X_{0,i} B_0 - \sum_{j=1}^3 B_j X_{j,i} \right)^2$$

By minimizing the sum of the squares, Q , the maximum likelihood estimates of B_0, 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 $i = 1, \dots, n$.

$$X_{0,i} X_{0,i} B_0 + \sum_{j=1}^3 B_j X_{0,i} X_{j,i} = X_{0,i} Y_i$$

$$X_{1,i} X_{0,i} B_0 + \sum_{j=1}^3 B_j X_{1,i} X_{j,i} = X_{1,i} Y_i$$

$$X_{2,i} X_{0,i} B_0 + \sum_{j=1}^3 B_j X_{2,i} X_{j,i} = X_{2,i} Y_i$$

$$X_{3,i} X_{0,i} B_0 + \sum_{j=1}^3 B_j X_{3,i} X_{j,i} = X_{3,i} Y_i$$

We can solve the first of these four equations for B_0 .

Of the n original equations let q be the number based upon S-P interval data.

Then set $m = n - q$.

$$X_{0,i} X_{0,i} = m$$

$$\text{Define } \tilde{V}_j = \frac{1}{m} \sum_{i=1}^n X_{0,i} V_{j,i}$$

Then:

$$B_0 = \tilde{Y} - \sum_{j=1}^3 B_j \tilde{X}_j$$

Use this value of B_0 in the other three equations. K th equation (k may equal 1, 2, or 3) becomes

$$X_{k,i} X_{0,i} \tilde{Y} + \sum_{j=1}^3 (B_j X_{k,i} X_{j,i} - B_j X_{k,i} X_{0,i} \tilde{X}_j) = X_{k,i} Y_i,$$

$$\text{or} \quad \sum_{j=1}^3 X_{k,i} (X_{j,i} - X_{0,i} \tilde{X}_j) B_j = X_{k,i} (Y_i - X_{0,i} \tilde{Y}).$$

But note that:

$$\begin{aligned}
 (X_{k,i} - X_{o,i} \bar{X}_k) (X_{j,i} - X_{o,i} \bar{X}_j) &= X_{k,i} (X_{j,i} - X_{o,i} \bar{X}_j) + \\
 &\quad X_{o,i} X_{o,i} \bar{X}_j \bar{X}_k - X_{o,i} X_{j,i} \bar{X}_k \\
 &= X_{k,i} (X_{j,i} - X_{o,i} \bar{X}_j) + m \bar{X}_j \bar{X}_k - m \bar{X}_j \bar{X}_k
 \end{aligned}$$

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

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

for $k = 1, 2, \text{ or } 3$

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

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

with the understanding that

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

In the program, we use

$$\begin{aligned} S_{jk} &= \sum_{i=1}^n (X_{j,i} - X_{0,i} \tilde{X}_j) (X_{k,i} - X_{0,i} \tilde{X}_k) \\ &= X_{j,i} X_{k,i} - X_{0,i} X_{j,i} \tilde{X}_k + m \tilde{X}_j \tilde{X}_k - X_{0,i} X_{k,i} \tilde{X}_j \\ &= X_{j,i} X_{k,i} - \frac{(X_{0,i} X_{j,i}) (X_{0,i} X_{k,i})}{m} + m \tilde{X}_j \tilde{X}_k - m \tilde{X}_k \tilde{X}_j \end{aligned}$$

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

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

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

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

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

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

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

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

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

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

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

$$E_j = \sqrt{S_{44}A_{44}^2/\phi} \quad \sqrt{A_{j+4,j+4}/S_{jj}}$$

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

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

The regression constant is then obtained by

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

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. Please see Appendix 4 (p.97ff.) for details.

(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:

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

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.)

$$\left. \begin{array}{l} B_1 = 0.15 \\ B_2 = 0.80 \end{array} \right\} \text{ for } 1 \text{ km} \leq D \leq 200 \text{ km}$$

$$\left. \begin{array}{l} B_1 = 3.38 \\ B_2 = 1.50 \end{array} \right\} \text{ for } 200 \text{ km} \leq D \leq 600 \text{ km}$$

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

G = station XMAG correction.

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

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

where

$$C_1 = -0.87, \text{ or TEST(07)}$$

$$C_2 = 2.0, \text{ or TEST(08)}$$

$$C_3 = 0.0035, \text{ or TEST(09)}$$

$$F = \text{F-P time in sec.}$$

$$\Delta = \text{epicentral distance in km.}$$

$$\gamma = \text{station FMAG correction.}$$

ACKNOWLEDGEMENTS

We wish to thank Jerry Eaton for permission to include a section of his report (Eaton, 1969, p.26-38) as Appendix 4 of this manual. We are grateful to Ray Buland of University of California at San Diego for pointing out two errors in the original HYP071 program concerning the azimuthal weighting.

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APPENDIX 1

A Listing of HYP071

The following listing of HYP071 is given in the EBCDIC (029) punched code for an IBM 360 or 370 computer. Each subroutine starts at a new page, and the number to the right of each FORTRAN statement is the card sequence number. A brief index for the HYP071 program is as follows:

	<u>FUNCTION</u>	<u>PAGE</u>
MAIN	Main Program	46
ANSWER	Print results of regression analysis	48
AZWTOS	Azimuthal weighting of stations	49
BLOCK DATA	Initialize constants	51
FMPL0T	First-Motion Plot	52
INPUT1	Input station list, crustal model, & control card	54
INPUT2	Input phase list	58
MISING	Check Missing stations	60
OUTPUT	Output hypocenter solution	61
SINGLE	Hypocenter solution for a single earthquake	66
SORT	Sort an array of numbers	74
SUMOUT	Output summary of time and magnitude residuals	75
SWMREG	Compute Geiger adjustments	78
TRVDRV	Compute traveltimes and derivatives	82
XFMAGS	Compute amplitude and duration magnitudes	85

A copy of HYP071 in either EBCDIC (029) punched code or BCD (026) punched code in the form of punched cards may be obtained by writing to the authors.


```

C----- PROGRAM: HYP071 (DEC. 21, 1971; REVISED NOV. 25, 1973) ----- 1.
  INTEGER*2 SYM 2.
  REAL*8 TIME1,TIME2 3.
  REAL LAT,LON,LAT2,LON2,LATFP,LONEP,MAG,LATR,LONR 4.
  COMMON /A3/ NRES(2,151),NXM(151),NFM(151),SR(2,151),SRSQ(2,151), 5.
1  SRWT(2,151),SXM(151),SXMSQ(151),SFM(151),SFMSQ(151),QNO(4) 6.
  COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40) 7.
  COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101) 8.
  COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180) 9.
  COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM, 10.
1  SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101) 11.
  COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101), 12.
1  RMK(101),WRK(101),TP(101),DT(101),COSL(701) 13.
  COMMON /A14/ MRK,MDOL,HLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR 14.
  COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDX,S,LATEP,LONEP 15.
  COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSEL,XFN 16.
  COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151) 17.
  COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,IEXIT 18.
  COMMON /A23/ AIN(101),RMS,ADJ,SYM(101) 19.
  COMMON /A25/ INS(151),IFW(151),JPH 20.
C----- 21.
C----- RESET SOME LIMITS OF ERROR HANDLING FACILITY OF IBM FORTH ----- 22.
  CALL ERRSET(207,256,1,0) 23.
  CALL ERRSET(208,256,1,0) 24.
  CALL ERRSET(209,256,1,0) 25.
  CALL ERRSET(251,256,1,0) 26.
  CALL ERRSET(255,256,1,0) 27.
C----- SET UP SINE & COSINE TABLES FOR CALCULATING DISTANCES ----- 28.
  DO 10 I=1,180 29.
  PI=I*.0349066 30.
  CP(I)=COS(PI) 31.
10 SP(I)=SIN(PI) 32.
  DO 20 I=1,701 33.
20 COSL(I)=COS((I-1)*.0017453) 34.
30 M=0 35.
C----- INPUT STATION LIST, CRUSTAL MODEL, & CONTROL CARD ----- 36.
40 CALL INPUT1 37.
  IF(IPUN.EQ.0) GO TO 44 38.
  WRITE(7,41) INS(1),IFW(1) 39.
41 FORMAT(' DATE ORIGIN LAT ',A1,' LONG ',A1,' DEPTH M 40.
  1AG NO GAP DMIN RMS ERH ERZ QM') 41.
C----- INITIALIZE SUMMARY OF RESIDUALS ----- 42.
44 DO 48 L=1,NS 43.
  NRES(1,L)=0 44.
  NRES(2,L)=0 45.
  NXM(L)=0 46.
  NFM(L)=0 47.
  SR(1,L)=0. 48.
  SR(2,L)=0. 49.
  SRSQ(1,L)=0. 50.
  SRSQ(2,L)=0. 51.
  SRWT(1,L)=0. 52.
  SRWT(2,L)=0. 53.
  SXM(L)=0. 54.
  SXMSQ(L)=0. 55.
  SFM(L)=0. 56.
  SFMSQ(L)=0. 57.
48 CONTINUE 58.
  DO 49 I=1,4 59.
49 QNO(I)=0. 60.
  XFN=XFAR-XNEAR*0.000001 61.

```

TIME1=0.0+00	62.
50 CALL INPUT2	63.
C----- TO PROCESS ONE EARTHQUAKE -----	64.
IF (M .EQ. 1) GO TO 900	65.
IF (NR .GE. 1) GO TO 100	66.
WRITE(6,55)	67.
55 FORMAT(///, ' ***** EXTRA BLANK CARD ENCOUNTERED *****')	68.
GO TO 50	69.
100 CALL SINGLE	70.
IF (IFXIT .EQ. 1) GO TO 50	71.
C----- COMPUTE SUMMARY OF MAGNITUDE RESIDUALS -----	72.
110 IF (JAV .GT. IQ) GO TO 50	73.
DO 150 I=1,NRP	74.
IF (XMAG(I) .EQ. BLANK) GO TO 120	75.
JI=KDX(I)	76.
DXMAG=XMAG(I)-AVXM	77.
NXM(JI)=NXM(JI)+1	78.
SXM(JI)=SXM(JI)+DXMAG	79.
SXMSQ(JI)=SXMSQ(JI)+DXMAG**2	80.
120 IF (FMAG(I) .EQ. BLANK) GO TO 150	81.
JI=KDX(I)	82.
DFMAG=FMAG(I)-AVFM	83.
NFM(JI)=NFM(JI)+1	84.
SFM(JI)=SFM(JI)+DFMAG	85.
SFMSQ(JI)=SFMSQ(JI)+DFMAG**2	86.
150 CONTINUE	87.
GO TO 50	88.
900 CONTINUE	89.
C----- END OF ONE DATA SET: PRINT SUMMARY OF RESIDUALS & RETURN -----	90.
CALL SUMOUT	91.
IF (MSTA(NR+1) .EQ. MSTAR) GO TO 30	92.
M=1	93.
IF (MSTA(NR+1) .EQ. MDOL) GO TO 40	94.
M=2	95.
IF (MSTA(NR+1) .EQ. MCENT) GO TO 40	96.
STOP	97.
END	98.

	SUBROUTINE ANSWER(A,S,XMEAN,SIGMA,IDX,PHI,L,M,MM,PF,NDX,ADX)	99.
C-----	PRINT INTERMEDIATE RESULTS OF REGRESSION ANALYSIS (SWMREG) ---	100.
	REAL*8 ADX	101.
	DIMENSION A(7,7),S(4,4)	102.
	DIMENSION XMEAN(1),SIGMA(1),IDX(1),B(4),BSE(4),PF(1)	103.
C-----		104.
	DO 410 I=1,MM	105.
	WRITE(6,400) (A(I,J),J=1,MM)	106.
400	FORMAT(7E18.8)	107.
410	CONTINUE	108.
	FVE=1.-A(M,M)	109.
	B0=XMEAN(M)	110.
450	YSE=77.7	111.
	IF (PHI .GE. 1) YSE=SIGMA(M)*SQRT(ABS(A(M,M)/PHI))	112.
	DO 5 I=1,L	113.
	IF (IDX(I).EQ.0) GO TO 5	114.
	B(I)=A(I,M)* SQRT(ABS(S(M,M)/S(I,I)))	115.
	BSE(I)=YSE* SQRT(ABS(A(I+M,I+M)/S(I,I)))	116.
	B0=B0-B(I)*XMEAN(I)	117.
5	CONTINUE	118.
	WRITE(6,10) ADX,NDX,FVE,YSE,B0	119.
10	FORMAT(/,' VARIABLE ',A8,'',I5	120.
2,	/' FRACTION OF VARIATION EXPLAINED..',E18.8	121.
3,	/' STANDARD ERROR OF Y.....',E18.8	122.
4,	/' CONSTANT IN REGRESSION EQUATION..',E18.8)	123.
	WRITE(6,20)	124.
20	FORMAT(/,' VARIABLE COEFFICIENT STANDARD ERROR'	125.
1,'	PARTIAL F-VALUE')	126.
	DO 40 I=1,L	127.
	IF (IDX(I).EQ.0) GO TO 40	128.
	WRITE(6,30) I,B(I),BSE(I),PF(I)	129.
30	FORMAT(I5,3E20.6)	130.
40	CONTINUE	131.
	RETURN	132.
	END	133.

	SUBROUTINE AZWTOS	134.
C-----	--- AZIMUTHAL WEIGHTING OF STATIONS BY QUADRANTS -----	135.
	COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101)	136.
	COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)	137.
	COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180)	138.
	COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,	139.
1	SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)	140.
	COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)	141.
	COMMON /A13/ JUX(151),LDX(101),KEY(101),CLASS(4)	142.
	COMMON /A25/ INS(151),IEW(151),JPH	143.
	DIMENSION TX(4),TXN(4),KTX(4),KEMP(101)	144.
	DATA KS1,KW1/'S','W'/'	145.
C-----	-----	146.
	J=0	147.
	DO 10 I=1,NR	148.
	IF (WT(I) .EQ. 0.) GO TO 10	149.
	DXI=DX(I)	150.
	DYI=DY(I)	151.
	IF ((DXI.EQ.0.).AND.(DYI.EQ.0.)) GO TO 6	152.
	J1=KDX(I)	153.
	IF (INS(J1) .EQ. KS1) DYI=-DYI	154.
	IF (IEW(J1) .EQ. KW1) DXI=-DXI	155.
	AZ(I)=AMOD(ATAN2(DXI,DYI)*57.29578 + 360., 360.)	156.
	GO TO 7	157.
6	AZ(I)=999.	158.
7	J=J+1	159.
	TEMP(J)=AZ(I)	160.
10	CONTINUE	161.
	CALL SORT(TEMP,KEY,J)	162.
	GAP=TEMP(1)+360.-TEMP(J)	163.
	IG=1	164.
	DO 20 I=2,J	165.
	DTEMP=TEMP(I)-TEMP(I-1)	166.
	IF (DTEMP .LE. GAP) GO TO 20	167.
	GAP=DTEMP	168.
	IG=I	169.
20	CONTINUE	170.
	TX(1)=TEMP(IG)-0.5*GAP	171.
	TX(2)=TX(1)+90.	172.
	TX(3)=TX(1)+180.	173.
	TX(4)=TX(1)+270.	174.
	DO 124 I=1,4	175.
	TXN(I)=0.	176.
	IF (TX(I) .LT. 0.) TX(I)=TX(I)+360.	177.
	IF (TX(I) .GT. 360.) TX(I)=TX(I)-360.	178.
124	CONTINUE	179.
	CALL SORT(TX,KTX,4)	180.
	DO 130 I=1,NR	181.
	IF (WT(I) .EQ. 0.) GO TO 130	182.
	IF (A7(I) .GT. TX(1)) GO TO 126	183.
125	TXN(1)=TXN(1)+1.	184.
	KEMP(I)=1	185.
	GO TO 130	186.
126	IF (AZ(I) .GT. TX(2)) GO TO 127	187.
	TXN(2)=TXN(2)+1.	188.
	KEMP(I)=2	189.
	GO TO 130	190.
127	IF (AZ(I) .GT. TX(3)) GO TO 128	191.
	TXN(3)=TXN(3)+1.	192.
	KEMP(I)=3	193.
	GO TO 130	194.

128 IF (AZ(I) .GT. TX(4)) GO TO 125	195.
TXN(4)=TXN(4)+1.	196.
KEMP(I)=4	197.
130 CONTINUE	198.
XN=4	199.
IF (TXN(1).EQ.0.) XN=XN-1	200.
IF (TXN(2).EQ.0.) XN=XN-1	201.
IF (TXN(3).EQ.0.) XN=XN-1	202.
IF (TXN(4).EQ.0.) XN=XN-1	203.
FJ=J/XN	204.
DO 150 I=1,NR	205.
IF (WT(I) .EQ. 0.) GO TO 150	206.
KI=KEMP(I)	207.
WT(I)=WT(I)*FJ/TXN(KI)	208.
150 CONTINUE	209.
RETURN	210.
END	211.

BLOCK DATA		212.
C----- INITIALIZE CONSTANTS IN COMMON STATEMENTS -----		213.
COMMON /A6/ NMAX,LMAX,NS,NL,MMAx,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101)		214.
COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CB(71)		215.
COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)		216.
COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR		217.
COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),IONE		218.
COMMON /A24/ FLTEP,IPRO,ISTIT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC		219.
DATA CA/ 1.855365,1.855369,1.855374,1.855383,1.855396,1.855414,		220.
1 1.855434,1.855458,1.855487,1.855520,1.855555,1.855595,1.855638,		221.
2 1.855683,1.855733,1.855786,1.855842,1.855902,1.855966,1.856031,		222.
3 1.856100,1.856173,1.856248,1.856325,1.856404,1.856488,1.856573,		223.
4 1.856661,1.856750,1.856843,1.856937,1.857033,1.857132,1.857231,		224.
5 1.857371,1.857435,1.857539,1.857643,1.857750,1.857858,1.857964,		225.
6 1.858074,1.858184,1.858294,1.858403,1.858512,1.858623,1.858734,		226.
7 1.858842,1.858951,1.859061,1.859170,1.859276,1.859384,1.859488,		227.
8 1.859592,1.859695,1.859798,1.859896,1.859995,1.860094,1.860187,		228.
9 1.860279,1.860369,1.860459,1.860544,1.860627,1.860709,1.860787,		229.
A 1.860861,1.860934/		230.
DATA CB/ 1.842808,1.842813,1.842830,1.842858,1.842898,1.842950,		231.
1 1.843011,1.843085,1.843170,1.843265,1.843372,1.843488,1.843617,		232.
2 1.843755,1.843903,1.844062,1.844230,1.844408,1.844595,1.844792,		233.
3 1.844998,1.845213,1.845437,1.845668,1.845907,1.846153,1.846408,		234.
4 1.846670,1.846938,1.847213,1.847495,1.847781,1.848073,1.848372,		235.
5 1.848673,1.848980,1.849290,1.849605,1.849922,1.850242,1.850565,		236.
6 1.850890,1.851217,1.851543,1.851873,1.852202,1.852531,1.852860,		237.
7 1.853188,1.853515,1.853842,1.854165,1.854487,1.854805,1.855122,		238.
8 1.855433,1.855742,1.856045,1.856345,1.856640,1.856928,1.857212,		239.
9 1.857490,1.857762,1.858025,1.858283,1.858533,1.858775,1.859008,		240.
A 1.859235,1.859452/		241.
DATA MBK,DOT,MSTAR,MDOL,MCENT/' ,,' ,,' ***,,' \$\$\$,' ,' /		242.
DATA ISITT/' **, /		243.
DATA BLANK,STAR4,CLASS/' ,,'****','A','B','C','D'/,QUES/'?'/		244.
DATA LMAX,MMAx,NMAX/21,101,151/,CRMK,ISTAR,IONE/'CAL','*',',1' /		245.
DATA AHEAD/' ,,' ,,' ,,' ,,' ,,' ,,' ,,' ,'		246.
1 ' ,,' ,,' ,,' ,,' ,,' ,'		247.
END		248.

SUBROUTINE FMPL0T	249.
C----- PLOT FIRST-MOTION DIRECTIONS OF THE LOWER FOCAL HEMISPHERE	250.
C----- IN EQUAL AREA PROJECTION, WHERE C DENOTES COMPRESSION AND	251.
C----- D DENOTES DILATATION -----	252.
INTEGER*2 GRAPH(95,59),SYM,TEMP	253.
INTEGER*2 BORD,BLANK,PL,CR,DOT,SI,A,B,C,D,E,F,CO,SN,UP	254.
REAL LAT2,LON2,MAG	255.
COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40)	256.
COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,G(4,101),ZSQ,NRP,DF(101)	257.
COMMON /A7/ KP,KZ,KOUT,WT(101),O(4),SE(4),XMEAN(4),CP(180),SP(180)	258.
COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM,	259.
1 SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101)	260.
COMMON /A10/ ANIN(101),AZ(101),O000(101),CA(71),CR(71)	261.
COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,	262.
1 IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR	263.
COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151)	264.
COMMON /A23/ AIN(101),RMS,ADJ,SYM(101)	265.
COMMON /A25/ INS(151),IFW(151),JPH	266.
DATA HORD,BLANK,PL,CR,DOT,SI/' ',' ',' ',' ',' ',' ',' ',' ',' '	267.
DATA A,B,C,D,E,F,CO,SN,UP/'A','B','C','D','E','F','X','N','U'/'	268.
DATA NOX,NOY,IX,IY,NOY1,NOX2,NOY2/95,59,39,24,57,48,30/	269.
DATA RMAX,XSCALE,YSCALE,ADD/3.937008,0.101064,0.169643,4.75/	270.
C-----	271.
NFMR=0	272.
NO=FNO	273.
DO 1 I=1,NRP	274.
IF (SYM(I) .EQ. SN) SYM(I)=BLANK	275.
IF (SYM(I) .EQ. BLANK) GO TO 1	276.
IF (SYM(I) .EQ. UP) SYM(I)=C	277.
NFMR=NFMR+1	278.
1 CONTINUE	279.
IF (NFMR .LT. KFM) RETURN	280.
WRITE(6,2) INS(1),IEW(1)	281.
2 FORMAT(1H1,' DATE ORIGIN LAT ',A1,' LONG ',A1,' DEPTH	282.
1 MAG NO GAP DMIN RMS ERH ERZ Q M')	283.
WRITE(6,5) KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,Z,RMK2	284.
1,MAG,NO,IGAP,DMIN,RMS,ERH,SE(3),Q,KNO	285.
5 FORMAT(2X,I6,1X,2I2,F6.2,I3,'-',F5.2,I4,'-',F5.2,A1,F6.2,A1	286.
1,F6.2,I3,I4,F5.1,F5.2,2F5.1,1X,A1,1X,I1)	287.
DO 10 I=1,NOX	288.
DO 10 J=1,NOY	289.
10 GRAPH(I,J)=BLANK	290.
DO 20 I=1,180	291.
X=RMAX*CP(I)+ADD	292.
Y=RMAX*SP(I)+ADD	293.
JX=X/XSCALE+.5	294.
JY=Y/YSCALE+.5	295.
JY=NOY-JY-1	296.
20 GRAPH(JX,JY)=BORD	297.
IT=NOX2-IX-1	298.
GRAPH(IT,NOY2)=CR	299.
IT=NOX2+IX+1	300.
GRAPH(IT,NOY2)=CR	301.
IT=NOY2-IY-1	302.
GRAPH(NOX2,IT)=SI	303.
IT=NOY2+IY+1	304.
GRAPH(NOX2,IT)=SI	305.
DO 50 I=1,NRP	306.
IF (SYM(I) .EQ. BLANK) GO TO 50	307.
IF (AIN(I) .GT. 90.) GO TO 31	308.
ANN=AIN(I)	309.

AZZ=AZ(I)*.0174533	310.
GO TO 32	311.
31 ANN=180.-AIN(I)	312.
AZZ=(180.+AZ(I))*0.0174533	313.
32 R=RMAX*1.414214*SIN(ANN*.0087266)	314.
X=R*SIN(AZZ)+ADD	315.
Y=R*COS(AZZ)+ADD	316.
JX=X/XSCALE+1.5	317.
JY=Y/YSCALE+.5	318.
JY=NOY-JY-1	319.
TEMP=GRAPH(JX,JY)	320.
C-----OVER-WRITE TEMP IF IT IS EQUAL TO BLANK, DOT, *, +, OR -	321.
IF ((TEMP.EQ.BLANK).OR.(TEMP.EQ.BORD).OR.(TEMP.EQ.PL)	322.
1.OR.(TEMP.EQ.CR).OR.(TEMP.EQ.DOT)) GO TO 47	323.
C-----TEMP IS OCCUPIED SO IF SYS(I)=+ OR - SKIP THIS STATION	324.
IF ((SYM(I).EQ.PL).OR.(SYM(I).EQ.CR)) GO TO 50	325.
IF (SYM(I).EQ.C) GO TO 40	326.
IF (GRAPH(JX,JY).NE.D) GO TO 35	327.
GRAPH(JX,JY)=E	328.
GO TO 50	329.
35 IF (GRAPH(JX,JY).NE.E) GO TO 37	330.
GRAPH(JX,JY)=F	331.
GO TO 50	332.
37 IF (GRAPH(JX,JY).EQ.F) GO TO 50	333.
GRAPH(JX,JY)=CD	334.
GO TO 50	335.
40 IF (GRAPH(JX,JY).NE.C) GO TO 43	336.
GRAPH(JX,JY)=B	337.
GO TO 50	338.
43 IF (GRAPH(JX,JY).NE.B) GO TO 45	339.
GRAPH(JX,JY)=A	340.
GO TO 50	341.
45 IF (GRAPH(JX,JY).EQ.A) GO TO 50	342.
GRAPH(JX,JY)=CD	343.
GO TO 50	344.
47 GRAPH(JX,JY)=SYM(I)	345.
50 CONTINUE	346.
GRAPH(NOX2,NOY2)=BORD	347.
WRITE(6,61)	348.
61 FORMAT(1H0,67X,'0')	349.
DO 80 I=3,NOY1	350.
IF (I.EQ.NOY2) GO TO 70	351.
WRITE(6,65) (GRAPH(J,I),J=1,NOX)	352.
65 FORMAT(1H ,20X,95A1)	353.
GO TO 80	354.
70 WRITE(6,75) (GRAPH(J,I),J=1,NOX)	355.
75 FORMAT(1H ,16X,'270 ',95A1,' 90')	356.
80 CONTINUE	357.
WRITE(6,85)	358.
85 FORMAT(67X,'180')	359.
RETURN	360.
END	361.


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SUBROUTINE INPUT1                                     362.
C----- INPUT STATION LIST, CRUSTAL MODEL, AND CONTROL CARD ----- 363.
  INTEGER HEAD/'HEAD'/                                364.
  REAL*8 TIME1, TIME2                                  365.
  REAL LAT, LON, LAT2, LON2, LATR, LONR               366.
  COMMON /A1/ NSTA(151), DLY(2,151), FMGC(151), XMGC(151), KLAS(151), 367.
1    PHR(151), CALR(151), ICAL(151), IS(151), NDATE(151), NHRMN(151) 368.
  COMMON /A2/ LAT(151), LON(151), DELTA(101), DX(101), DY(101), T(101) 369.
  COMMON /A5/ ZTR, XNEAR, XFAR, POS, IO, KMS, KFM, IPUN, IMAG, IR, QSPA(9,40) 370.
  COMMON /A6/ NMAX, LMAX, NS, NL, MMAX, NR, FNO, Z, X(4,101), ZSQ, NRP, DF(101) 371.
  COMMON /A14/ MBK, MDOL, BLANK, MSTAR, DOT, STAR4, QUES, CRMK, MCENT, ISTAR 372.
  COMMON /A15/ M, L, J, ORG, JAV, PMIN, AZRES(101), NEAR, INXS, LATEP, LONEP 373.
  COMMON /A16/ KLSS(151), CALS(151), MDATE(151), MHRMN(151), IPRN, ISW 374.
  COMMON /A17/ TIME1, TIME2, LATR, LONR, KTEST, KAZ, KSORT, KSEL, XFN 375.
  COMMON /A19/ KNO, IELV(151), TEST(15), FLT(2,151), MNO(151), IW(151) 376.
  COMMON /A20/ V(21), D(21), VSQ(21), THK(21), TID(21,21), DID(21,21) 377.
  COMMON /A22/ F(21,21), G(4,21), H(21), DEPTH(21), IONE 378.
  COMMON /A24/ FLTEP, IPRO, ISTIT, ISKP(4), AHEAD(12), FLIM, AF(3), NDEC 379.
  COMMON /A25/ INS(151), IFW(151), JPH 380.
  DIMENSION BHEAD(12), ATEST(15) 381.
  DATA IB1, KN1, KW1/' ', 'N', 'W'/ 382.
C----- 383.
  DO 350 I=1,15 384.
    ATEST(I) = 1.23456 385.
350 CONTINUE 386.
  WRITE(6,300) 387.
300 FORMAT(1H1) 388.
  IF (M-1) 1,100,200 389.
C----- INITIALIZE TEST VARIABLES ----- 390.
1 TEST(1)=0.10 391.
  TEST(2)=10. 392.
  TEST(3)=2. 393.
  TEST(4)=0.05 394.
  TEST(5)=5. 395.
  TEST(6)=4. 396.
  TEST(7)=-0.87 397.
  TEST(8)=+2.00 398.
  TEST(9)=+0.0035 399.
  TEST(10)=100. 400.
  TEST(11)=8.0 401.
  TEST(12)=0.5 402.
  TEST(13)=1. 403.
  IFLAG=0 404.
C----- INPUT RESET TEST-VARIABLE CARDS AND SELECTION CARD ----- 405.
  DO 5 I=1,16 406.
    READ(5,4) ISW,J, TESTJ,BHEAD 407.
4 FORMAT(A4,T12, I2,T16,F9.4,12A4) 408.
11 IF ((ISW.EQ.MBK).OR.(ISW.EQ.IONE)) GO TO 6 409.
  IF (ISW.NE.HEAD) GO TO 12 410.
  DO 13 II=1,12 411.
    AHEAD(II)=BHEAD(II) 412.
13 CONTINUE 413.
  GO TO 5 414.
12 IFLAG=1 415.
  ATEST(J)=TESTJ 416.
5 CONTINUE 417.
6 WRITE(6,14) AHEAD 418.
14 FORMAT(40X,12A4) 419.
  WRITE(6,2) 420.
2 FORMAT(///, ' ***** PROGRAM: HYP071 REVISED (11/25/73) ***** 421.
1', ///,13X,'TEST(1) TEST(2) TEST(3) TEST(4) TEST(5) TEST(6 422.

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2) TEST(7) TEST(8) TEST(9) TEST(10) TEST(11) TEST(12) TEST(13)) 423.
WRITE(6,3) (TEST(I),I=1,13) 424.
3 FORMAT(' STANDARD ',13F9.4) 425.
IF (IFLAG .EQ. 0) GO TO 8 426.
DO 16 I = 1,15 427.
IF (ATEST(I) .NE. 1,23456) TEST(I)=ATEST(I) 428.
16 CONTINUE 429.
WRITE(6,7) (TEST(I),I=1,13) 430.
7 FORMAT(' RESET TO ',13F9.4) 431.
C----- SQUARE SOME TEST-VARIABLES FOR LATER USE ----- 432.
8 TEST(1)=TEST(1)**2 433.
TEST(2)=TEST(2)**2 434.
TEST(4)=TEST(4)**2 435.
C----- INPUT STATION LIST ----- 436.
IF (ISW .EQ. 10NE) GO TO 10 437.
KNO=1 438.
WRITE(6,9) 439.
9 FORMAT(/,4X,'L STN LAT LONG ', ' ELV DELAY',5X 440.
1,'FMGC XMGC KL PRK CALR IC DATE HRMN') 441.
GO TO 20 442.
10 WRITE(6,15) 443.
15 FORMAT(/,4X,'L STN LAT LONG ELV M DLY1 DLY2', 444.
1' XMGC FMGC KL CALR IC DATE HRMN') 445.
20 DO 50 L=1,NMAX 446.
IF (ISW .EQ. 10NE) GO TO 30 447.
READ(5,25) IW(L),NSTA(L),LAT1,LAT2,INS(L),LON1,LON2,IEW(L),IELV(L) 448.
1,DLY(1,L),FMGC(L),XMGC(L),KLAS(L),PRR(L),CALR(L),ICAL(L),NDATE(L) 449.
2,NHRMN(L) 450.
25 FORMAT(1X,A1,A4,I2,F5.2,A1,I3,F5.2,A1,I4,F6.2,4X,F5.2,2X,F5.2,1X 451.
1,I1,F5.2,F7.2,1X,I1,5X,I6,I4) 452.
IF (NSTA(L) .EQ. MBK) GO TO 60 453.
IF (INS(L) .EQ. IB1) INS(L)=KN1 454.
IF (IFW(L) .EQ. IB1) IEW(L)=KW1 455.
WRITE(6,26) L,IW(L),NSTA(L),LAT1,LAT2,INS(L),LON1,LON2,IEW(L) 456.
1,IELV(L),DLY(1,L),FMGC(L),XMGC(L),KLAS(L),PRR(L),CALR(L),ICAL(L) 457.
2,NDATE(L),NHRMN(L) 458.
26 FORMAT(15,3X,A1,A4,I3,F5.2,A1,I4,F5.2,A1,I5,F6.2,4X,F5.2,2X,F5.2 459.
1,1X,I1,F5.2,F7.2,1X,I1,5X,I6,I4) 460.
GO TO 40 461.
30 READ(5,35) NSTA(L),IW(L),LAT1,LAT2,INS(L),LON1,LON2,IEW(L),IELV(L) 462.
1,MNO(L),DLY(1,L),DLY(2,L),XMGC(L),FMGC(L),KLAS(L),CALR(L),ICAL(L) 463.
2,NDATE(L),NHRMN(L) 464.
35 FORMAT(A4,A1,I2,1X,F5.2,A1,I3,1X,F5.2,A1,I4,5X,I1 465.
1,4F6.2,1X,I1,F6.2,1X,I1,2X,I6,I4) 466.
IF (NSTA(L) .EQ. MBK) GO TO 60 467.
IF (INS(L) .EQ. IB1) INS(L)=KN1 468.
IF (IFW(L) .EQ. IB1) IEW(L)=KW1 469.
WRITE(6,36) L,NSTA(L),IW(L),LAT1,LAT2,INS(L),LON1,LON2,IEW(L) 470.
1,IELV(L),MNO(L),DLY(1,L),DLY(2,L),XMGC(L),FMGC(L),KLAS(L),CALR(L) 471.
2,ICAL(L),NDATE(L),NHRMN(L) 472.
36 FORMAT(15,2X,A4,A1,I2,1X,F5.2,A1,I4,1X,F5.2,A1,I5,5X,I1 473.
1,4F6.2,1X,I1,F6.2,1X,I1,2X,I6,I4) 474.
PRR(L)=0. 475.
40 LAT(L)=60.*LAT1+LAT2 476.
LON(L)=60.*LON1+LON2 477.
MDATE(L)=NDATE(L) 478.
MHRMN(L)=NHRMN(L) 479.
KLSS(L)=KLAS(L) 480.
CALS(L)=CALR(L) 481.
50 CONTINUE 482.
WRITE(6,55) 483.

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55	FORMAT(///, ' ***** ERROR: STATION LIST EXCEEDS ARRAY DIMENSION')	484.
	STOP	485.
60	NS=L-1	486.
C-----	INPUT CRUSTAL MODEL -----	487.
100	WRITE(6,105)	488.
105	FORMAT(///, 7X, 'CRUSTAL MODEL 1', /, 5X, 'VELOCITY DEPTH')	489.
	DO 130 L=1, LMAX	490.
	READ(5,115) V(L), D(L)	491.
115	FORMAT(2F7.3)	492.
	IF (V(L) .LT. 0.01) GO TO 140	493.
	WRITE(6,125) V(L), D(L)	494.
125	FORMAT(3X, 2F10.3)	495.
	DEPTH(L)=D(L)	496.
	VSQ(L)=V(L)**2	497.
130	CONTINUE	498.
	WRITE(6,135)	499.
135	FORMAT(///, ' ***** ERROR: CRUSTAL MODEL EXCEEDS ARRAY DIMENSION')	500.
	STOP	501.
140	NL=L-1	502.
	N1=NL-1	503.
C-----	LAYER THICKNESS THK, F & G TERMS	504.
	DO 145 L=1, N1	505.
	THK(L)=D(L+1)-D(L)	506.
145	H(L)=THK(L)	507.
C-----	COMPUTE TID AND DID	508.
	DO 150 J=1, NL	509.
	G(1,J)=SQRT(ABS(VSQ(J)-VSQ(1)))/(V(1)*V(J))	510.
	G(2,J)=SQRT(ABS(VSQ(J)-VSQ(2)))/(V(2)*V(J))	511.
	G(3,J)=V(1)/SQRT(ABS(VSQ(J)-VSQ(1))+0.000001)	512.
	G(4,J)=V(2)/SQRT(ABS(VSQ(J)-VSQ(2))+0.000001)	513.
	IF (J .LE. 1) G(1,J)=0.	514.
	IF (J .LE. 2) G(2,J)=0.	515.
	IF (J .LE. 1) G(3,J)=0.	516.
	IF (J .LE. 2) G(4,J)=0.	517.
	DO 150 L=1, NL	518.
	F(L,J)=1.	519.
	IF (L .GE. J) F(L,J)=2.	520.
150	CONTINUE	521.
	DO 165 J=1, NL	522.
	DO 165 M=1, NL	523.
	TID(J,M)=0.	524.
165	DID(J,M)=0.	525.
	DO 170 J=1, NL	526.
	DO 170 M=J, NL	527.
	IF (M .EQ. 1) GO TO 170	528.
	M1=M-1	529.
	DO 160 L=1, M1	530.
	SQT=SQRT(VSQ(M)-VSQ(L))	531.
	TIM=THK(L)*SQT/(V(L)*V(M))	532.
	DIM=THK(L)*V(L)/SQT	533.
	TID(J,M)=TID(J,M)+F(L,J)*TIM	534.
160	DID(J,M)=DID(J,M)+F(L,J)*DIM	535.
170	CONTINUE	536.
	IF (ISW .NE. 10NE) GO TO 200	537.
C-----	VARIABLE FIRST LAYER	538.
	VC=V(1)*V(2)/SQRT(VSQ(2)-VSQ(1))	539.
	DO 180 I=1, NS	540.
	FLT(1,I)=DLY(1,I)*VC*D(2)	541.
180	FLT(2,I)=DLY(2,I)*VC*D(2)	542.
C-----	INPUT CONTROL CARD -----	543.
200	WRITE(6,205)	544.

205	FORMAT(///,' ZTR XNEAR XFAR POS IO KMS KFM IPUN IMAG IR'	545.
	1,' IPRN CODE LATR LONR')	546.
	READ(5,215) ZTR,XNEAR,XFAR,POS,IO,KMS,KFM,IPUN,IMAG,IR,IPRN	547.
	1,KTEST,KAZ,KSORT,KSEL,LAT1,LAT2,LON1,LON2	548.
215	FORMAT(3F5.0,F5.2,7I5,1X,4I1,2(I4,F6.2))	549.
	WRITE(6,215) ZTR,XNEAR,XFAR,POS,IO,KMS,KFM,IPUN,IMAG,IR,IPRN	550.
	1,KTEST,KAZ,KSORT,KSEL,LAT1,LAT2,LON1,LON2	551.
	LATR=60.*LAT1+LAT2	552.
	LONR=60.*LON1+LON2	553.
	IF (IR .EQ. 0) RETURN	554.
	DO 240 I=1,IR	555.
	READ(5,225) (QSPA(I,J),J=1,40)	556.
225	FORMAT(20F4.2)	557.
	WRITE(6,235) I,(QSPA(I,J),J=1,40)	558.
235	FORMAT(/,' QSPA(',I1,'): ',20F5.2,/,10X,20F5.2)	559.
240	CONTINUE	560.
	RETURN	561.
	END	562.

```

SUBROUTINE INPUT2
C----- INPUT PHASE LIST -----
INTEGER*2 SYM
REAL*8 TIME1,TIME2
REAL LAT2,LON2,LATEP,LONEP,MAG
COMMON /A1/ NSTA(151),OLY(2,151),FMGC(151),XMGC(151),KLAS(151),
1 PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151)
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 /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,
1 IGAP,DMIN,RMSQ,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),WHK(101),TP(101),DT(101),COSL(701)
COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4)
COMMON /A14/ MRK,MDOL,RLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR
COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDX,S,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 /A23/ AIN(101),RMS,ADJ,SYM(101)
COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
DIMENSION ICARD(20)
C-----
10 PMIN=9999,
   IDXS=0
   DO 20 I=1,NS
     KSMP(I)=0
20 JDX(I)=0
25 L=1
30 READ(5,35,END=300) MSTA(L),PRMK(L),W(L),JTIME,JMIN(L),P(L),S(L)
   1,SRMK(L),WS(L),AMX(L),PRX(L),CALP,CALX(L),RMK(L),DT(L),FMP(L)
   2,AZRES(L),SYM(L),AS,ICARD,QRMK(L),IPRO
35 FORMAT(2A4,T8,F1.0,T10,I8,I2,F5.2,T32,F5.2,A4,T40,F1.0,T44,F4.0
   1,F3.2,F4.1,T59,F4.1,A3,F5.2,F5.0,T21,A4,T7,A1,T32,A4,T1,20A4
   2,T63,A1,T5,A4)
   IF ((MSTA(L).EQ.MSTAR).OR.(MSTA(L).EQ.MDOL).OR.(MSTA(L).EQ.MCENT))
160 TO 300
   IF (MSTA(L).EQ.MRK) GO TO 350
   IF (CALX(L).LT.0.01) CALX(L)=CALP
   DO 40 I=1,NS
     IF (MSTA(L).EQ.NSTA(I)) GO TO 50
40 CONTINUE
   WRITE(6,45) ICARD,MSTA(L)
45 FORMAT(///,1 ***** ',20A4,1 ***** DELETED: ',A4,1 NOT ON STATION L
1IST)
   GO TO 30
50 KDX(L)=I
   LDX(L)=0
   JDX(I)=1
   IF (FMP(L).LE.0.) FMP(L)=BLANK
   IF (L.GT.1) GO TO 60
   KTIME=JTIME
   KDATE=KTIME/100
   KHR=KTIME-KDATE*100
60 IF (JTIME.EQ.KTIME) GO TO 70
   WRITE(6,65) ICARD
65 FORMAT(///,1 ***** ',20A4,1 ***** DELETED: WRONG TIME')

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GO TO 30	624.
70 IF (RMK(L) .EQ. CRMK) GO TO 200	625.
80 W(L)=(4.-W(L))/4.	626.
IF (IW(I) .EQ. ISTAR) W(L)=0.	627.
TP(L)=60.*JMIN(L)+P(L)+DT(L)	628.
WRK(L)=BLANK	629.
IF (W(L) .EQ. 0.) GO TO 90	630.
IF (W(L) .GT. 0.) GO TO 89	631.
C----- SMP DATA: RESET WEIGHT -----	632.
W(L)=(4.-WS(L))/4.	633.
KSMP(L)=1	634.
IF (TP(L) .GE. PMIN) GO TO 95	635.
PMIN=TP(L)	636.
NEAR=L	637.
GO TO 95	638.
89 IF (TP(L) .GE. PMIN) GO TO 90	639.
PMIN=TP(L)	640.
NEAR=L	641.
90 IF (AS .EQ. BLANK) GO TO 100	642.
C----- S DATA -----	643.
IDXS=1	644.
LDX(L)=1	645.
WS(L)=(4.-WS(L))/4.	646.
IF (IW(I) .EQ. ISTAR) WS(L)=0.	647.
95 TS(L)=60.*JMIN(L)+S(L)+DT(L)	648.
100 L=L+1	649.
IF (L .LT. MMAX) GO TO 30	650.
WRITE(6,105)	651.
105 FORMAT(///,' ***** ERROR: PHASE LIST EXCEEDS ARRAY DIMENSION; EXTR	652.
1A DATA TREATED AS NEXT EARTHQUAKE')	653.
GO TO 350	654.
C----- CALIBRATION CHANGE IN STATION LIST -----	655.
200 IF (P(L) .NE. 0.) KLAS(I)=P(L)	656.
CALR(I)=CALX(L)	657.
TIME2=1.0+06*KDATE+1.0+04*KHR+1.0+02*JMIN(L)	658.
IF (TIME2 .GE. TIME1) GO TO 250	659.
WRITE(6,205)	660.
205 FORMAT(///,' ***** THE FOLLOWING EVENT IS OUT OF CHRONOLOGICA	661.
1L ORDER *****')	662.
250 WRITE(6,255) KDATE,KHR,JMIN(L),MSTA(L),KLAS(I),CALR(I)	663.
255 FORMAT(///,' ***** ',I6,1X,2I2,' ***** CALIBRATION CHANGE FOR ',A4	664.
1,'; KLAS = ',I1,'; CALR = ',F4.1)	665.
KDATE(I)=KDATE	666.
MHRMN(I)=100*KHR+JMIN(L)	667.
TIME1=TIME2	668.
GO TO 10	669.
300 M=1	670.
NR=L-1	671.
RETURN	672.
350 M=0	673.
400 NR=L-1	674.
RETURN	675.
END	676.

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SUBROUTINE MISSING 677.
C----- CHECK MISSING STATIONS ----- 678.
REAL*8 TIME1,TIME2 679.
REAL LAT,LON,LAT2,LON2,LATEP,LONEP,MAG 680.
COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151), 681.
1 PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMM(151) 682.
COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101) 683.
COMMON /A5/ ZTR,XNEAR,XFAR,POS,IQ,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40) 684.
COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101) 685.
COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180) 686.
COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM, 687.
1 SUFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101) 688.
COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CR(71) 689.
COMMON /A11/ KDATE,KHR,KMIN,SFC,LAT1,LAT2,LON1,LON2,RMK1,RMK2, 690.
1 IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR 691.
COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101), 692.
1 RMK(101),WRK(101),TP(101),DT(101),COSL(701) 693.
COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4) 694.
COMMON /A14/ MBK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR 695.
COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,INXS,LATEP,LONEP 696.
COMMON /A25/ INS(151),IEW(151),JPH 697.
DATA KS1,KW1/'S','W'/' 698.
C----- 699.
IHD=0 700.
NJ=J+1 701.
TEMP(NJ)=TEMP(1)+360. 702.
TDEL=25.*MAG**2 703.
IF (MAG .EQ. BLANK) TDEL=100. 704.
DO 30 I=1,NS 705.
IF (JDX(I) .EQ. 1) GO TO 30 706.
AVL=(LAT(I)+LATEP)/120. 707.
M1=AVL*.5 708.
M2=AVL*10.*1.5 709.
DXI=(LON(I)-LONEP)*CA(M1)*COSL(M2) 710.
DYI=(LAT(I)-LATEP)*CR(M1) 711.
DELI=SQRT(DXI**2+DYI**2)*0.000001 712.
IF (DELI .GT. TDEL) GO TO 30 713.
C CHECK LATITUDE AND LONGITUDE 714.
IF (INS(I) .EQ. KS1) DYI=-DYI 715.
IF (IFW(I) .EQ. KW1) DXI=-DXI 716.
AZI=AMOD(ATAN2(DXI,DYI)*57.29578 + 360., 360.) 717.
IF (AZI .LE. TEMP(1)) AZI=Azi+360. 718.
DO 10 J=2,NJ 719.
IF (AZI .LT. TEMP(J)) GO TO 20 720.
10 CONTINUE 721.
J=NJ 722.
20 EXGAP=TEMP(J)-TEMP(J-1) 723.
RDGAP=TEMP(J)-AZI 724.
TGAP=Azi-TEMP(J-1) 725.
IF (TGAP .LT. RDGAP) RDGAP=TGAP 726.
IF ((DELI.GT.DMIN).AND.(RDGAP.LT.30.)) GO TO 30 727.
IF (AZI .GE. 360.) AZI=Azi-360. 728.
IF (IHD .EQ. 1) GO TO 22 729.
WRITE(6,5) 730.
5 FORMAT(/,10X,'MISSING STATION DELTA AZIM EX-GAP RD-GAP') 731.
IHD=1 732.
22 WRITE(6,25) NSTA(I),DELI,AZI,EXGAP,RDGAP 733.
25 FORMAT(21X,A4,2F7.1,2F8.1) 734.
30 CONTINUE 735.
RETURN 736.
END 737.

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SUBROUTINE OUTPUT 738.
C----- OUTPUT HYPOCENTER ----- 739.
INTEGER*2 SYM 740.
REAL*8 TIME1,TIME2 741.
REAL LAT,LON,LAT2,LON2,LATEP,LONEP,MAG 742.
COMMON /A1/ NSTA(151),DLY(2,151),FMGC(151),XMGC(151),KLAS(151), 743.
1 PRR(151),CALR(151),ICAL(151),IS(151),NDATE(151),NHRMN(151) 744.
COMMON /A2/ LAT(151),LON(151),DELTA(101),DX(101),DY(101),T(101) 745.
COMMON /A5/ ZTH,XNEAR,XFAR,POS,IO,KMS,KFM,IPUN,IMAG,IR,QSPA(9,40) 746.
COMMON /A6/ NMAX,LMAX,NS,IIL,MMAX,NR,FNO,Z,X(4,101),ZSQ,NRP,DF(101) 747.
COMMON /A7/ KP,KZ,KOUT,WT(101),Y(4),SE(4),XMEAN(4),CP(180),SP(180) 748.
COMMON /A8/ CAL(101),XMAG(101),FMAG(101),NM,AVXM,SDXM,NF,AVFM, 749.
1 SDFM,MAG,KDX(101),AMX(101),PRX(101),CALX(101),FMP(101) 750.
COMMON /A10/ ANIN(101),AZ(101),TEMP(101),CA(71),CH(71) 751.
COMMON /A11/ KDATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2, 752.
1 IGAP,DMIN,RMSSQ,FRH,Q,QS,QD,ADJSQ,INST,AVR,AAR,NI,KNST,JHR 753.
COMMON /A12/ MSTA(101),PRMK(101),W(101),JMIN(101),P(101), 754.
1 RMK(101),WRK(101),TP(101),DT(101),COSL(701) 755.
COMMON /A13/ JDX(151),LDX(101),KEY(101),CLASS(4) 756.
COMMON /A14/ MHK,MDOL,BLANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR 757.
COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,IDX,S,LATEP,LONEP 758.
COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW 759.
COMMON /A17/ TIME1,TIME2,LATR,LONR,KTEST,KAZ,KSORT,KSFL,XFN 760.
COMMON /A18/ S(101),SRMK(101),WS(101),TS(101),NOS,QRMK(101) 761.
COMMON /A19/ KNO,IELV(151),TEST(151),FLT(2,151),MNO(151),IW(151) 762.
COMMON /A21/ KSMP(151),FMO,ONF,8(4),IPH,KF,AV,PS,EXIT 763.
COMMON /A22/ F(21,21),G(4,21),H(21),DEPTH(21),TONE 764.
COMMON /A23/ AIN(101),RMS,ADJ,SYM(101) 765.
COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC 766.
COMMON /A25/ INS(151),IEW(151),JPH 767.
DIMENSION FMT1(32),FMT2(24),FMT3(32),FMT4(16),DEMP(101),SYMBOL(5) 768.
DATA FMT1/'(1X,','I6,A','1,2I','2,F6','2,I','3,A','','F5','2,I4', 769.
1 ',A','','F5.2','',A','','F6.2','',A','','F6.2','',2I3','',I4,' 770.
2 'I2,F','5.2','','F5.1','',',','F5.1','',2(1','X,A',''),2A', 771.
3 '1,F5','2,2','I3,2','F5.2','',2(I','3,2F','5.1)','',I2)' / 772.
DATA FMT2/'(I6','1X,2','I2,F','6.2','',I3,A','1,F5','2,I','4,A', 773.
1 ',F5','2,A1','',F6.1','2,A1','',',','F6.2','',I3','I4,F', 774.
2 '5.1','F5.2','',',','F5.1','',',','F5.1','',3A1','') / 775.
DATA FMT3/'(1X','A4,F','6.1','2I4','1X,A','4,1X','2I2','4F6', 776.
1 '2,','F6.2','',A2','F4.2','',I4','I3,F','6.2','I2,' 777.
2 'F4.1','A1','1X,A','3,','I4,','F4.1','A1','1X,A', 778.
3 '4,3','F6.2','A2','F4.2','',',','F6.2','T6','A1)' / 779.
DATA FMT4/'(A4','3F6.1','1,1X','A4','2F6.1','2,F5','1,','F6.2', 780.
1 '1X','A3,','F6.2','',I7','2','I2,2','I4,A','1)' / 781.
DATA SYM1,SYM2,F1,F2,G1,G2/'-','1','F6.2','F5.1','A6','A5' / 782.
DATA F4,F5,F6,G3,G4/'F4.1','I4,','F4.2','A4','A4, / 783.
DATA SYMBOL/' ','1','2','Q','*','ZDOT'/'0. ','KS1,KW1','S','W' / 784.
C----- 785.
IF ((IPRN.GE.2).OR.(KP.EQ.1)) CALL XFMAGS 786.
LAT1=LATEP/60. 787.
LAT2=LATEP-60.*LAT1 788.
LON1=LONEP/60. 789.
LON2=LONEP-60.*LON1 790.
ADJ=SQRT(ADJSQ) 791.
RMS=SQRT(RMSSQ) 792.
JHR=KHR 793.
OSAVE = ORG 794.
IF (ORG .GE. 0.) GO TO 5 795.
ORG=ORG+3600. 796.
KHR=KHR-1 797.
5 KMIN=ORG/60.0 798.

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SEC=ORG-60.0*KMIN	799.
ERH=SQRT(SE(1)**2+SE(2)**2)	800.
NO=FNO	801.
RMK1=RLANK	802.
RMK2=RLANK	803.
RMK0=RLANK	804.
C----- KZ=1 FOR FIXED DEPTH; ONF=0 FOR ORIGIN TIME BASED ON SMP'S	805.
IF (ONF .EQ. 0.) RMK0=STAR4	806.
IF (KZ .EQ. 1) RMK2=STAR4	807.
J=0	808.
DO 10 I=1,NRP	809.
DXI=DX(I)	810.
DYI=DY(I)	811.
IF ((DXI.EQ.0.).AND.(DYI.EQ.0.)) GO TO 6	812.
J1=KDX(I)	813.
IF (INS(J1) .EQ. KS1) DYI=-DYI	814.
IF (IEW(J1) .EQ. KW1) DXI=-DXI	815.
AZ(I)=AMOD(ATAN2(DXI,DYI)*57.29578 + 360., 360.)	816.
GO TO 7	817.
6 AZ(I)= 999.	818.
7 CONTINUE	819.
AIN(I)=AR SIN(ANIN(I))*57.29578	820.
IF (AIN(I) .LT. 0.) AIN(I)=180.+AIN(I)	821.
AIN(I)=180.-AIN(I)	822.
SWT=0.	823.
IF (LDX(I) .EQ. 0.) GO TO 8	824.
KK=LDX(I)	825.
SWT=WT(KK)	826.
8 IF ((WT(I).EQ.0.).AND.(SWT.EQ.0.)) GO TO 10	827.
J=J+1	828.
TEMP(J)=AZ(I)	829.
10 CONTINUE	830.
CALL SORT(TEMP,KEY,J)	831.
GAP=TEMP(1)+360.-TEMP(J)	832.
DO 20 I=2,J	833.
DTEMP=TEMP(I)-TEMP(I-1)	834.
IF (DTEMP .GT. GAP) GAP=DTEMP	835.
20 CONTINUE	836.
IGAP=GAP+0.5	837.
DO 25 I=1,NRP	838.
25 DEMP(I)=DELTA(I)	839.
CALL SORT(DEMP,KEY,NRP)	840.
DO 27 I=1,NRP	841.
K=KEY(I)	842.
SWT=0.	843.
IF (LDX(K) .EQ. 0.) GO TO 26	844.
KK=LDX(K)	845.
SWT=WT(KK)	846.
26 IF ((WT(K).GT.0.).OR.(SWT.GT.0.)) GO TO 28	847.
27 CONTINUE	848.
28 DMIN=DEMP(I)	849.
IDMIN=DMIN+0.5	850.
OFD=Z	851.
TFD=2.*Z	852.
IF (OFD .LT. 5.) OFD=5.	853.
IF (TFD .LT. 10.) TFD=10.	854.
JS=4	855.
IF ((RMS.LT.0.50).AND.(ERH.LE.5.0)) JS=3	856.
IF ((RMS.LT.0.30).AND.(ERH.LE.2.5).AND.(SE(3).LE.5.0)) JS=2	857.
IF ((RMS.LT.0.15).AND.(ERH.LE.1.0).AND.(SE(3).LE.2.0)) JS=1	858.
JD=4	859.

IF (NO .LT. 6) GO TO 30	860.
IF ((GAP.LE.180.).AND.(DMIN.LE.50.)) JD=3	861.
IF ((GAP.LE.135.).AND.(DMIN.LE.TFD)) JD=2	862.
IF ((GAP.LE. 90.).AND.(DMIN.LE.0FD)) JD=1	863.
30 JAV=(JS+JD+1)/2	864.
Q=CLASS(JAV)	865.
QS=CLASS(JS)	866.
QD=CLASS(JD)	867.
50 TIME2=SEC+1.D+02*KMIN+1.D+04*KHR+1.D+06*KDATE	868.
IF(IPRN .EQ. 0) GO TO 52	869.
IF(NI .NE. 1) GO TO 60	870.
IF(INDEC .GE. 1) GO TO 60	871.
IF (JPH .EQ. 1) GO TO 60	872.
52 KKYR=KDATE/10000	873.
KKMO=(KDATE-KKYR*10000)/100	874.
KKDAY=(KDATE-KKYR*10000-KKMO*100)	875.
JPH=1	876.
IF(KSEL) 501,501,505	877.
501 WRITE(6,502)	878.
502 FORMAT(///)	879.
GO TO 535	880.
505 WRITE(6,506)	881.
506 FORMAT(1H1)	882.
51 WRITE(6,53) AHEAD,KKYR,KKMO,KKDAY,KHR,KMIN	883.
53 FORMAT(/,30X,12A4,T112,I2,'/',I2,'/',I2,4X,I2,':',I2)	884.
535 IF(TIME2 - TIME1 .GT. -20.)GO TO 60	885.
WRITE(6,54)	886.
54 FORMAT(' ***** FOLLOWING EVENT IS OUT OF ORDER *****')	887.
60 IF ((KP.EQ.1) .AND. (IPRN.EQ.0)) GO TO 67	888.
IF (IPH .EQ. 1) GO TO 62	889.
WRITE(6,61) INS(1),IFW(1)	890.
61 FORMAT(/,59X,' ADJUSTMENTS (KM) PARTIAL F-VALUES STANDARD ERROR	891.
1S ADJUSTMENTS TAKEN',/, ' I ORIG LAT ',A1	892.
2,' LONG ',A1, ' DEPTH DM RMS AVRPS SKD CF DLA	893.
3T DLON DZ DLAT DLON DZ DLAT ULON DZ DLAT ULON D	894.
4Z)	895.
IF (IPRN .EQ. 1) IPH=1	896.
62 WRITE(6,63) NI,SEC,LAT1,LAT2,LON1,LON2,Z,RMK2,DMIN,RMS,AVRPS,	897.
1 QS,KF,DD,FLIM,B(2),R(1),R(3),AF(2),AF(1),AF(3),SE(2),SE(1),	898.
2 SE(3),Y(2),Y(1),Y(3)	899.
63 FORMAT(I3,F6.2,I3,'-',F5.2,I4,'-',F5.2,F6.2,A1,I3,F5.2,F6.2,	900.
1 1X,A1,I1,A1,13F6.2)	901.
IF (KP .EQ. 0) GO TO 100	902.
67 JNST=KNST*10+INST	903.
IF (NM .EQ. 0) AVXM=0.	904.
IF (NF .EQ. 0) AVFM=0.	905.
FMT1(14)=F1	906.
FMT1(19)=F2	907.
FMT1(21)=F2	908.
FMT2(14)=F1	909.
FMT2(20)=F2	910.
FMT2(22)=F2	911.
IF (MAG .NE. BLANK) GO TO 68	912.
FMT1(14)=G1	913.
FMT2(14)=G1	914.
68 IF (SE(3) .NE. 0.) GO TO 70	915.
SE(3)=BLANK	916.
FMT1(21)=G2	917.
FMT2(22)=G2	918.
70 IF (ERH .NE. 0.) GO TO 72	919.
ERH=BLANK	920.

FMT1(19)=G2	921.
FMT2(20)=G2	922.
72 WRITE(6,75) INS(1),IEW(1)	923.
75 FORMAT(/, ' DATE ORIGIN LAT ',A1,' LONG ',A1,' DEPTH	924.
1 MAG NO DM GAP M RMS ERH ERZ Q SOU ADJ IN NR AVR AAR NM A	925.
2VXM SDXM NF AVFM SDFM I)	926.
80 WRITE(6,FMT1)KDATE,RMKO,KHR,KMIN,SEC,LAT1,SYM1,LAT2,LON1,SYM1,LON2	927.
1,RMK1,Z,RMK2,MAG,NO,DMIN,IGAP,KNO,RMS,ERH,SE(3),Q,QS,SYM2,QD,ADJ	928.
2,JNST,NR,AVR,AAR,NM,AVXM,SDXM,NF,AVFM,SDFM,NI	929.
IF (IPUN .EQ. 0) GO TO 100	930.
IF ((ORMK(1).NE.SYMBOL(4)).AND.(ORMK(1).NE.SYMBOL(5)))	931.
1ORMK(1)=SYMBOL(1)	932.
SYM3=SYMBOL(KNO+1)	933.
WRITE(7,FMT2) KDATE,KHR,KMIN,SEC,LAT1,SYM1,LAT2,LON1,SYM1,LON2	934.
1,RMK1,Z,RMK2,MAG,NO,IGAP,DMIN,RMS,ERH,SE(3),ORMK(1),Q,SYM3	935.
100 IF (KP .EQ. 1) GO TO 105	936.
IF (IPPN .LE. 1) GO TO 300	937.
105 WRITE(6,110)	938.
110 FORMAT(/, ' STN DIST AZM AIN PRMK HRMN P-SEC TPOBS TPCAL DLY/H1 P	939.
1-RES P-WT AMX PRX CALX K XMAG RMK FMP FMAG SRMK S-SEC TSOBS S-RES	940.
2 S-WT DT)	941.
DO 200 I=1,NRP	942.
K=I	943.
IF (KSORT .EQ. 1) K=KEY(I)	944.
KJI=KDX(K)	945.
TPK=TP(K)-ORG	946.
IF (TPK .LT. 0.) TPK=TPK+3600.	947.
FMT3(10)=F1	948.
IF ((AZRES(K).NE.DOT).AND.(AZRES(K).NE.BLANK).AND.	949.
1(AZRES(K).NE.ZDOT)) GO TO 114	950.
X(4,K)=BLANK	951.
FMT3(10)=G1	952.
114 RMK3=BLANK	953.
IF (XMAG(K) .EQ. BLANK) GO TO 115	954.
IF (ABS(XMAG(K)-AVXM) .GE. 0.5) RMK3=STAR4	955.
115 RMK4=BLANK	956.
IF (FMAG(K) .EQ. BLANK) GO TO 130	957.
IF (ABS(FMAG(K)-AVFM) .GE. 0.5) RMK4=STAR4	958.
130 FMT3(17)=F4	959.
FMT3(21)=F5	960.
FMT3(22)=F4	961.
FMT4(R)=F1	962.
FMT4(11)=F1	963.
IF (XMAG(K) .NE. BLANK) GO TO 160	964.
FMT3(17)=G3	965.
FMT4(R)=G1	966.
160 IF (FMAG(K) .NE. BLANK) GO TO 162	967.
FMT3(21)=G4	968.
FMT3(22)=G3	969.
FMT4(11)=G1	970.
162 FMT3(26)=F1	971.
FMT3(28)=F6	972.
IAZ=AZ(K)+0.5	973.
IAIN=AIN(K)+0.5	974.
IAMX=AMX(K)	975.
IPRX=100.*PRX(K)+0.5	976.
IFMP=FMP(K)	977.
IF (LDX(K) .NE. 0) GO TO 153	978.
C-----CHECK FOR SMP DATA	979.
IF (KSMP(K) .EQ. 0) GO TO 165	980.
SRES=X(4,K)	981.

RMK5=RLANK	982.
SWT=11111.	983.
TSK=S(K)-P(K)	984.
GO TO 168	985.
163 KK=LDX(K)	986.
SRES=X(4,KK)	987.
RMK5=WRK(KK)	988.
SWT=WT(KK)	989.
164 TSK=TS(K)-ORG	990.
GO TO 168	991.
165 S(K)=RLANK	992.
TSK=HLANK	993.
SRES=RLANK	994.
RMK5=HLANK	995.
SWT=RLANK	996.
FMT3(26)=G1	997.
FMT3(28)=G3	998.
168 FMT3(30)=F1	999.
DLYK=DLY(KNO,KJI)	1000.
IF (ISW .EQ. IONE) DLYK=FLT(KNO,KJI)	1001.
DTK=DT(K)	1002.
IF (DTK .NE. 0.) GO TO 170	1003.
DTK=HLANK	1004.
FMT3(30)=G1	1005.
170 WRITE(6,FMT3) MSTA(K),DELTA(K),IAZ,IAIN,PRMK(K),JHR,JMIN(K),P(K)	1006.
1,TPK,T(K),DLYK,X(4,K),WRK(K),WT(K),IAM,IPRX,CAL(K)	1007.
2,KLAS(KJI),XMAG(K),RMK3,RMK(K),IFMP,FMAG(K),RMK4,SRMK(K),S(K)	1008.
3,TSK,SRES,RMK5,SWT,DTK,IW(KJI)	1009.
IF (IPUN .NE. 2) GO TO 200	1010.
ISEC = 100.*SEC	1011.
WRITE(7,FMT4) MSTA(K),DELTA(K),AZ(K),AIN(K),PRMK(K),TPK,X(4,K)	1012.
1,WT(K),XMAG(K),RMK(K),FMAG(K),KDATE,KHR,KMIN,ISEC,KJI,SYM3	1013.
200 CONTINUE	1014.
IF (IPUN .NE. 2) GO TO 300	1015.
WRITE(7,205)	1016.
205 FORMAT(' \$\$\$')	1017.
300 KHR = JHR	1018.
ORG = OSAVE	1019.
RETURN	1020.
END	1021.

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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),CR(71)
COMMON /A11/ KUATE,KHR,KMIN,SEC,LAT1,LAT2,LON1,LON2,RMK1,RMK2,
1 IGAP,DMIN,RMSSQ,ERH,Q,QS,QD,ADJSU,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),LX(101),KEY(101),CLASS(4)
COMMON /A14/ MBK,MDOL,E,ANK,MSTAR,DOT,STAR4,QUES,CRMK,MCENT,ISTAR
COMMON /A15/ M,L,J,ORG,JAV,PMIN,AZRES(101),NEAR,INDX,LATEP,LONEP
COMMON /A16/ KLSS(151),ALS(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),KMS,ADJ,SYM(101)
COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
COMMON /A25/ INS(151),IFW(151),JPH
DIMENSION SUM(5),YSAVE(4),WF(41),ALZ(10),LA(10),LO(10)
DATA WF/.95,0.95,0.95,0.95,0.95,0.95,0.95,0.94,0.94,0.94,0.93,
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 (INDX.EQ. 0) GO TO 80
C----- TREAT S DATA BY AUGMENTING P DATA -----
NOS=0
DO 65 I=1,NRP
IF (LOX(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.

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KDX(NRS)=KDX(I)	1083.
LDX(I)=NRS	1084.
WRK(NRS)=BLANK	1085.
65 CONTINUE	1086.
NR=NRP+NOS	1087.
C----- INITIALIZE TRIAL HYPOCENTER -----	1088.
80 K=KDX(NEAR)	1089.
SVY1 = 0.0	1090.
SVY2 = 0.0	1091.
SVY3 = 0.0	1092.
ERLMT = 0.	1093.
DO 25 I = 1,3	1094.
ISKP(I)=0	1095.
25 CONTINUE	1096.
IF (INST .NE. 9) GO TO 90	1097.
READ(5,85) ORG1,ORG2,LAT1,LAT2,LON1,LON2,Z	1098.
85 FORMAT(F5.0,F5.2,I5,F5.2,I5,2F5.2)	1099.
ORG=60.*ORG1+ORG2	1100.
LATEP=60.*LAT1+LAT2	1101.
LONEP=60.*LON1+LON2	1102.
GO TO 105	1103.
90 IF (NR .GE. 3) GO TO 100	1104.
96 WRITE(6,97)	1105.
97 FORMAT(///,' ***** INSUFFICIENT DATA FOR LOCATING THIS QUAKE:')	1106.
IF(NRP .EQ. 0) NRP = 1	1107.
DO 98 L=1,NRP	1108.
98 WRITE(6,99) MST(L),PRMK(L),KDATE,KHR,JMIN(L),P(L),S(L)	1109.
99 FORMAT(5X,2A4,1X,I6,2I2,F5.2,7X,F5.2)	1110.
IEXIT=1	1111.
IF (NRP .EQ. 1) RETURN	1112.
GO TO 575	1113.
100 Z=ZTR	1114.
IF (AZRES(NRP+1).NF. BLANK) Z=ZRES	1115.
ORG=PMIN-7/5.-1.	1116.
IF (LATRT.EQ.0.) GO TO 102	1117.
LATEP=LATRT	1118.
LONEP=LONRT	1119.
GO TO 105	1120.
102 IF (LATR .EQ. 0.) GO TO 104	1121.
LATEP=LATR	1122.
LONEP=LONR	1123.
GO TO 105	1124.
104 LATEP=LAT(K)+0.1	1125.
LONEP=LON(K)+0.1	1126.
105 ADJSQ=0.	1127.
IPH=0	1128.
NDEC=0	1129.
PRMSSQ=100000.	1130.
IF (ISW .EQ. IONE) KNO=MNO(K)	1131.
IF (ISW .EQ. IONE) FLTEP=FLT(KNO,K)	1132.
NIMAX=TEST(11)+.0001	1133.
C----- GEIGER'S ITERATION TO FIND HYPOCENTRAL ADJUSTMENTS -----	1134.
109 NI = 1	1135.
IF (INST .EQ. 9) NI=NIMAX	1136.
111 IF(ERLMT .EQ. 0.) GO TO 110	1137.
LATEP = LATSV + LA(NA)*DELAT	1138.
LONEP = LONSV + LO(NA)*DELON	1139.
Z = ZSV + ALZ(NA)*DEZ	1140.
IF(Z .LT. 0.) Z=0.	1141.
110 FMO=0.	1142.
FNO=0.	1143.

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      DO 112 I=1,NR                                     1144.
112 SUM(I)=0.                                           1145.
C----- CALCULATE EPICENTRAL DISTANCE BY RICHTER'S METHOD ----- 1146.
      DO 120 I=1,NR                                     1147.
      JI=KDX(I)                                         1148.
      AVL=(LAT(JI)+LATEP)/120.                         1149.
      M1=AVL*1.5                                         1150.
      M2=AVL*10.+1.5                                    1151.
      DX(I)=(LON(JI)-LONEP)*CA(M1)*COSL(M2)            1152.
      DY(I)=(LAT(JI)-LATEP)*CB(M1)                     1153.
      DELTA(I)=SQRT(DX(I)**2+DY(I)**2)+0.000001         1154.
      WT(I)=W(I)                                         1155.
      IF (NI .LE. 1) GO TO 115                          1156.
C----- DISTANCE WEIGHTING ----- 1157.
      IF (DELTA(I) .LE. XNEAR) GO TO 115                1158.
      WT(I)=W(I)*(XFAH-DELTA(I))/XFN                    1159.
      IF (WT(I) .LT. 0.005) WT(I)=0.                   1160.
115 IF (WT(I) .EQ. 0.) GO TO 120                        1161.
      IF (KSMP(I) .EQ. 1) FMO=FMO+1.                   1162.
      FNO=FNO+1.                                         1163.
      SUM(4)=SUM(4)+WT(I)                               1164.
120 CONTINUE                                             1165.
      IF (FNO .LT. 3.) GO TO 116                        1166.
      AVWT=SUM(4)/FNO                                    1167.
C----- NORMALIZE DISTANCE WEIGHTS ----- 1168.
      SUM(4)=0.0                                         1169.
      DO 122 I=1,NR                                     1170.
122 WT(I)=WT(I)/AVWT                                    1171.
      IF ((NI.LE.2).OR.(KAZ.EQ.0)) GO TO 130            1172.
C----- AZIMUTHAL WEIGHTING ----- 1173.
      CALL AZWTOS                                         1174.
C----- COMPUTE TRAVEL TIMES & DERIVATIVES ----- 1175.
130 ZSQ=Z**2                                             1176.
      CALL TRVDRV                                         1177.
      FDLY=1.                                             1178.
      IF (ISW .EQ. IONE) FDLY=0.                        1179.
C----- CALCULATE TRAVEL TIME RESIDUALS X(4,I) & MODIFY THE DERIV'S --- 1180.
140 DO 150 I=1,NR                                       1181.
      JI=KDX(I)                                         1182.
      IF (I .LE. NRP) GO TO 145                         1183.
C----- S PHASE DATA ----- 1184.
      T(I)=POS*T(I)                                     1185.
      X(1,I)=POS*X(1,I)                                 1186.
      X(2,I)=POS*X(2,I)                                 1187.
      X(3,I)=POS*X(3,I)                                 1188.
      X(4,I)=TP(I)-T(I)-ORG-POS*DLY(KNO,JI)*FDLY       1189.
      GO TO 150                                         1190.
145 IF (KSMP(I) .EQ. 0) GO TO 146                       1191.
C----- S-P DATA ----- 1192.
      X(1,I)=(POS-1.)*X(1,I)                           1193.
      X(2,I)=(POS-1.)*X(2,I)                           1194.
      X(3,I)=(POS-1.)*X(3,I)                           1195.
      X(4,I)=TS(I)-TP(I)-(POS-1.)*(DLY(KNO,JI)*FDLY+T(I)) 1196.
      GO TO 150                                         1197.
C----- P TRAVEL TIME RESIDUAL ----- 1198.
146 X(4,I)=TP(I)-T(I)-ORG-DLY(KNO,JI)*FDLY            1199.
150 CONTINUE                                             1200.
C----- COMPUTE AVR, AAR, RMSSQ, & SDR ----- 1201.
      ONF=0.0                                            1202.
      DO 152 I=1,NR                                     1203.
      ONF = ONF + WT(I)*(1-KSMP(I))                    1204.

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XWT = X(4,I)*WT(I)	1205.
SUM(1)=SUM(1)+XWT	1206.
SUM(2)=SUM(2)+ABS(XWT)	1207.
SUM(3)=SUM(3)+X(4,I)*XWT	1208.
SUM(5)=SUM(5)+XWT*(1-KSMP(I))	1209.
152 CONTINUE	1210.
IF(FNO .GT. FMO) AVRPS=SUM(5)/(ONF)	1211.
AVR=SUM(1)/FNO	1212.
AAR=SUM(2)/FNO	1213.
RMSSQ=SUM(3)/FNO	1214.
SDR=SQRT(ABS(RMSSQ-AVR**2))	1215.
DO 153 I=1,5	1216.
SUM(1)= 0.0	1217.
153 CONTINUE	1218.
IF (RMSSQ .GE. TEST(1)) GO TO 154	1219.
IF(ERLMT .EQ. 1.) GO TO 167	1220.
IF(INST.EQ.9) GO TO 501	1221.
IF(NI .GE. 2) GO TO 167	1222.
GO TO 165	1223.
C----- JEFFREYS' WEIGHTING -----	1224.
154 FMO=0.	1225.
FNO=0.	1226.
DO 160 I=1,NR	1227.
WRK(I)=BLANK	1228.
IF (WT(I) .EQ. 0.) GO TO 160	1229.
K=10.*ABS(X(4,I)-AVR)/SDR+1.5	1230.
IF (K .GT. 41) K=41	1231.
WT(I)=WT(I)*WF(K)	1232.
IF (K .GT. 30) WRK(I)=STAR4	1233.
IF (WT(I) .LT. 0.005) WT(I)=0.	1234.
IF (WT(I) .EQ. 0.) GO TO 160	1235.
IF (KSMP(I) .EQ. 1) FMO=FMO+1.	1236.
FNO=FNO+1.	1237.
SUM(4)=SUM(4)+WT(I)	1238.
160 CONTINUE	1239.
IF (FNO .LT. 3.) GO TO 96	1240.
AVWT=SUM(4)/FNO	1241.
SUM(4)=0.0	1242.
ONF=0.0	1243.
DO 164 I=1,NR	1244.
WT(I)=WT(I)/AVWT	1245.
ONF = ONF + WT(I)*(1-KSMP(I))	1246.
XWT=X(4,I)*WT(I)	1247.
SUM(5)=SUM(5)+XWT*(1-KSMP(I))	1248.
164 CONTINUE	1249.
C----- RECALCULATE AVRPS -----	1250.
IF(FRLMT .EQ. 1.) GO TO 163	1251.
IF(INST .NE. 9) GO TO 163	1252.
AVRPS = 0.0	1253.
IF(FNO .NE. FMO) AVRPS = SUM(5)/ONF	1254.
GO TO 501	1255.
163 IF(FNO.EQ.FMO) AVRPS=0.0	1256.
IF(FNO.EQ.FMO) GO TO 167	1257.
AVRPS=SUM(5)/(ONF)	1258.
SUM(5)=0.0	1259.
IF(ERLMT .EQ. 1.) GO TO 167	1260.
C----- RESET FIRST ORIGIN TIME -----	1261.
IF(NI.GE. 2) GO TO 167	1262.
165 ORG=ORG+AVRPS	1263.
DO 166 I=1,NR	1264.
IF(KSMP(I) .EQ. 0) X(4,I)=X(4,I)-AVRPS	1265.

XWT=WT(I)*X(4,I)	1266.
SUM(5)=SUM(5)+XWT*(1 - KSMP(I))	1267.
SUM(2)=SUM(2)+ABS(XWT)	1268.
SUM(3)=SUM(3)+X(4,I)*XWT	1269.
166 CONTINUE	1270.
IF(FNO .GT. FMO) AVRPS=SUM(5)/(ONF)	1271.
AAR=SUM(2)/FNO	1272.
RMSSQ = SUM(3)/FNO	1273.
GO TO 169	1274.
C----- FOR NI>1, COMPUTE AAR, & RMSSQ AS IF AVRPS=0. -----	1275.
167 DO 168 I=1,NR	1276.
XWT=WT(I)*(X(4,I)-AVRPS*(1-KSMP(I)))	1277.
SUM(2)=SUM(2)+ABS(XWT)	1278.
SUM(3)=SUM(3)+(X(4,I)-AVRPS*(1-KSMP(I)))*XWT	1279.
168 CONTINUE	1280.
AAR=SUM(2)/FNO	1281.
RMSSQ=SUM(3)/FNO	1282.
IF(ERLMT .EQ. 0.) GO TO 169	1283.
C----- OUTPUT RMS ERROR OF AUXILIARY POINTS -----	1284.
L = LATEP/60.	1285.
ALA = LATEP - 60.*L	1286.
L = LONEP/60.	1287.
ALO = LONEP - 60.*L	1288.
RMSX= SORT(RMSSQ)	1289.
DRMS = RMSX - RMSSV	1290.
GO TO (1,2,3,4,5,6,1,2,3,4), NA	1291.
1 WRITE(6,801) ALA,ALO,Z,AVRPS,RMSX,DRMS	1292.
801 FORMAT(5F10.2,10X,F6.2)	1293.
GO TO 174	1294.
2 WRITE(6,802) ALA,ALO,Z,AVRPS,RMSX,DRMS	1295.
802 FORMAT(5F10.2,28X,F6.2)	1296.
GO TO 174	1297.
3 WRITE(6,803) ALA,ALO,Z,AVRPS,RMSX,DRMS	1298.
803 FORMAT(5F10.2,13X,'(F6.2,')')	1299.
GO TO 174	1300.
4 WRITE(6,804) ALA,ALO,Z,AVRPS,RMSX,DRMS	1301.
804 FORMAT(5F10.2,31X,'(F6.2,')')	1302.
IF(NA .EQ. 10) GO TO 550	1303.
GO TO 174	1304.
5 WRITE(6,805) ALA,ALO,Z,AVRPS,RMSX,DRMS	1305.
805 FORMAT(5F10.2,19X,F6.2)	1306.
WRITE(6,807) RMSSV	1307.
807 FORMAT(40X,F10.2,23X,'0.00')	1308.
GO TO 174	1309.
6 WRITE(6,806) ALA,ALO,Z,AVRPS,RMSX,DRMS	1310.
806 FORMAT(5F10.2,22X,'(F6.2,')/')	1311.
174 NA = NA + 1	1312.
GO TO 111	1313.
C----- CHECK IF SOLUTION IS BETTER THAN PREVIOUS ONE -----	1314.
169 IF((NI .EQ. 1) .AND. (NDEC .EQ. 0)) GO TO 170	1315.
IF(PRMSSQ.GE.RMSSQ) GO TO 170	1316.
NDEC = NDEC +1	1317.
IF(NDEC .GT. 1) GO TO 175	1318.
DO 177 I= 1,3	1319.
B(I) = 0.0	1320.
AF(I)=-1.0	1321.
SE(I) = 0.0	1322.
177 CONTINUE	1323.
NI = NI -1	1324.
BM1=Y(1)	1325.
BM2=Y(2)	1326.

BM3=Y(3)	1327.
BMAX = ABS(Y(1))	1328.
IIMAX = 1	1329.
DO 176 I = 2,3	1330.
IF(ABS(Y(I)).LE.BMAX) GO TO 176	1331.
BMAX = ABS(Y(I))	1332.
IIMAX = I	1333.
176 CONTINUE	1334.
ISKP(IIMAX)=1	1335.
Y(1)=-BM1/5.	1336.
Y(2)=-BM2/5.	1337.
Y(3)=-BM3/5.	1338.
Y(4)=-Y(1)*XMEAN(1)-Y(2)*XMEAN(2)-Y(3)*XMEAN(3)	1339.
XADJSQ=Y(1)**2+Y(2)**2+Y(3)**2	1340.
KP=0	1341.
IF(XADJSQ.LT. 4.*TEST(4)/25.) GO TO 170	1342.
175 IF(NDEC.EQ. 5) GO TO 170	1343.
GO TO 325	1344.
C----- STEPWISE MULTIPLE REGRESSION ANALYSIS OF TRAVEL TIME RESIDUALS-----	1345.
170 IF(NDEC.GE. 1) NI = NI + 1	1346.
IF (INST.FQ.1) GO TO 250	1347.
IF(ISKP(3).EQ. 1) GO TO 250	1348.
IF (INST.EQ. 9) GO TO 501	1349.
IF ((FNO.EQ.3) .AND. (FNO.LT.3)) GO TO 250	1350.
C---- FREE SOLUTION	1351.
200 KZ=0	1352.
KF=0	1353.
CALL SWMREG	1354.
C----- AVOID CORRECTING DEPTH IF HORIZONTAL CHANGE IS LARGE -----	1355.
IF (Y(1)**2+Y(2)**2.LT. TEST(2)) GO TO 300	1356.
C---- FIXED DEPTH SOLUTION	1357.
250 KZ=1	1358.
KF=0	1359.
CALL SWMREG	1360.
C----- LIMIT FOCAL DEPTH CHANGE & AVOID HYPOCENTER IN THE AIR -----	1361.
300 DO 275 I= 1,3	1362.
ISKP(I)=0	1363.
275 CONTINUE	1364.
OLDY1=Y(1)	1365.
OLDY2=Y(2)	1366.
OLDY3=Y(3)	1367.
ABSY1=ABS(Y(1))	1368.
ABSY2=ABS(Y(2))	1369.
ABSY3=ABS(Y(3))	1370.
IF(ABSY1.GT.ABSY2) GO TO 305	1371.
ABSGR=ABSY2	1372.
GO TO 308	1373.
305 ABSGR=ABSY1	1374.
308 IF(ABSY3.LE.TEST(5)) GO TO 310	1375.
I=ABSY3/TEST(5)	1376.
Y(3)=Y(3)/(I+1)	1377.
310 IF((Z+Y(3)).GT. 0.0) GO TO 315	1378.
Y(3)=-Z*TEST(12)+.000001	1379.
ISKP(3) = 1	1380.
C----- LIMIT HORIZONTAL ADJUSTMENT OF EPICENTER -----	1381.
315 IF(ABSGR.LE.TEST(10)) GO TO 320	1382.
I=ABSGR/TEST(10)	1383.
Y(1)=Y(1)/(I+1)	1384.
Y(2)=Y(2)/(I+1)	1385.
320 Y(4)=Y(4)-(Y(3)-OLDY3)*XMEAN(3)-(Y(1)-OLDY1)*XMEAN(1)	1386.
1 -(Y(2)-OLDY2)*XMEAN(2)	1387.

XADJSQ=Y(1)**2+Y(2)**2+Y(3)**2	1388.
KP=0	1389.
NDEC=0	1390.
JPH=0	1391.
325 IF (IPRN .GE. 1) CALL OUTPUT	1392.
IF(NDEC .GE. 1) GO TO 330	1393.
C----- TERMINATE ITERATION IF HYPOCENTER ADJUSTMENT < TEST(4) -----	1394.
IF (XADJSQ .LT. TEST(4)) GO TO 500	1395.
330 IF(NI .EQ. NIMAX) GO TO 500	1396.
C----- ADJUST HYPOCENTER -----	1397.
350 AVL=LATEP/60.	1398.
375 M1=AVL*1.5	1399.
M2=AVL*10.*1.5	1400.
UY1 =Y(1)/(CA(M1)*COSL(M2))	1401.
DY2 =Y(2)/CH(M1)	1402.
LATEP=LATEP+DY2	1403.
LONEP=LONEP+DY1	1404.
Z=Z+Y(3)	1405.
ORG=ORG+Y(4)	1406.
SVY1 = Y(1)	1407.
SVY2 = Y(2)	1408.
SVY3 = Y(3)	1409.
ADJSQ=XADJSQ	1410.
IF(NDEC .EQ. 0) PRMSSQ=RMSSQ	1411.
IF(NDEC.GE.1) GO TO 110	1412.
400 NI = NI + 1	1413.
IF(NI .LE. NIMAX) GO TO 111	1414.
C----- RESET ORIGIN TIME -----	1415.
500 ORG=ORG+XMEAN(4)	1416.
GO TO 502	1417.
501 XMEAN(4)=0.0	1418.
502 DO 505 I=1,5	1419.
505 SUM(I)=0.0	1420.
SUMM = 0.0	1421.
DO 510 I=1,NR	1422.
IF (KSMP(I) .EQ. 0) X(4,I)=X(4,I)-XMEAN(4)	1423.
IF (WT(I) .EQ. 0.) GO TO 510	1424.
IF (INST .NE. 9) GO TO 509	1425.
XWTS=WT(I)*(X(4,I)**2)	1426.
IF(KSMP(I) .EQ. 0) XWTS=WT(I)*((X(4,I)-AVRPS)**2)	1427.
SUMM = SUMM + XWTS	1428.
509 XWT=X(4,I)*WT(I)	1429.
SUM(1)=SUM(1)+XWT	1430.
SUM(2)=SUM(2)+ABS(XWT)	1431.
SUM(3)=SUM(3)+X(4,I)*XWT	1432.
SUM(5)=SUM(5)+XWT*(1-KSMP(I))	1433.
510 CONTINUE	1434.
RM9SV = SUMM/FNO	1435.
AVR=SUM(1)/FNO	1436.
AVRPS = 0.0	1437.
IF(FNO .GT. FMO) AVRPS=SUM(5)/ONF	1438.
AAR=SUM(2)/FNO	1439.
RMSSQ=SUM(3)/FNO	1440.
C----- COMPUTE ERROR ESTIMATES BY SOLVING FULL NORMAL EQUATION -----	1441.
520 KF=2	1442.
KP=1	1443.
KZ=0	1444.
CALL SWMREG	1445.
DO 521 I =1,3	1446.
521 Y(I)=0.0	1447.
IF(INST.EQ.1) KZ = 1	1448.

CALL OUTPUT	1449.
IF (KMS.EQ. 1) CALL MISING	1450.
IF ((KNST.GE.5) .OR. (KFM.GE.1)) CALL FMPLT	1451.
QNO(JAV)=QNO(JAV)+1.	1452.
IF (JAV.GT. IQ) GO TO 523	1453.
C----- COMPUTE SUMMARY OF TRAVEL TIME RESIDUALS -----	1454.
DO 522 I=1,NRP	1455.
IF ((WT(I).EQ.0.) .OR. (KSMP(I).EQ.1)) GO TO 522	1456.
JI=KDX(I)	1457.
NRES(KNO,JI)=NRES(KNO,JI)+1	1458.
SR(KNO,JI)=SR(KNO,JI)+X(4,I)*WT(I)	1459.
SRSQ(KNO,JI)=SRSQ(KNO,JI)+X(4,I)**2*WT(I)	1460.
SRWT(KNO,JI)=SRWT(KNO,JI)+WT(I)	1461.
522 CONTINUE	1462.
523 IF (KTEST.NE. 1) GO TO 550	1463.
C----- COMPUTE RMS AT AUXILIARY POINTS -----	1464.
RMSSV = SORT(RMSSQ)	1465.
IF (INST.EQ.9) RMSSV = SORT(RM9SV)	1466.
ERLMT = 1.	1467.
LATSV = LATEP	1468.
LONSV = LONEP	1469.
ZSV = Z	1470.
AVL = LATEP/60.	1471.
M1 = AVL + 1.5	1472.
M2 = AVL*10. + 1.5	1473.
DELAT = TFST(13)/CB(M1)	1474.
DELON = TEST(13)/(CA(M1)*COSL(M2))	1475.
DEZ = TEST(13)	1476.
WRITE (6,525)	1477.
525 FORMAT (' LAT LON Z AVRPS RMS	1478.
1 DRMS')	1479.
NA=1	1480.
GO TO 111	1481.
550 TIME1=TIME2	1482.
575 CONTINUE	1483.
C----- CHECK FOR MULTIPLE SOLUTIONS OF THE SAME EARTHQUAKE -----	1484.
IF (IPRO.NE.1STTT) RETURN	1485.
NR=NRP	1486.
NRP1=NR +1	1487.
READ(5,600) CHECK,IPRO,KNST,INST,ZRES,LAT1,LAT2,LON1,LON2.	1488.
1 AZRES(NRP1)	1489.
WRITE(6,601) CHECK,IPRO,KNST,INST,ZRES,LAT1,LAT2,LON1,LON2	1490.
601 FORMAT('//2A4,9X,2I1,F5.2,1X,2(I4,F6.2),'--- RUN AGAIN ---')	1491.
600 FORMAT(2A4,9X,2I1,F5.2,1X,2(I4,F6.2),T21,A4)	1492.
LATRT=60.*LAT1+LAT2	1493.
LONRT=60.*LON1+LON2	1494.
IF (CHECK.EQ.BLANK) GO TO 30	1495.
WRITE(6,610) CHECK	1496.
610 FORMAT(' ERROR ',A4,' SKIPPED. INST. CARD DID NOT FOLLOW ***')	1497.
RETURN	1498.
END	1499.

	SUBROUTINE SORT(X,KEY,NO)	1500.
	DIMENSION X(NO),KEY(NO)	1501.
C	-----	1502.
	DO 1 I=1,NO	1503.
1	KEY(I)=I	1504.
	MO=NO	1505.
2	IF (MO-15) 21,21,23	1506.
21	IF (MO-1) 29,29,22	1507.
22	MO=2*(MO/4)+1	1508.
	GO TO 24	1509.
23	MO=2*(MO/8)+1	1510.
24	KO=NO-MO	1511.
	JO=1	1512.
25	I=JO	1513.
26	IF (X(I)-X(I+MO)) 24,28,27	1514.
27	TEMP=X(I)	1515.
	X(I)=X(I+MO)	1516.
	X(I+MO)=TEMP	1517.
	KEMP=KEY(I)	1518.
	KEY(I)=KEY(I+MO)	1519.
	KEY(I+MO)=KEMP	1520.
	I=I+MO	1521.
	IF (I-1) 28,26,26	1522.
28	JO=JO+1	1523.
	IF (JO-KO) 25,25,2	1524.
29	RETURN	1525.
	END	1526.

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SUBROUTINE SUMOUT
C----- OUTPUT SUMMARY OF TIME AND MAGNITUDE RESIDUALS -----
REAL LAT,LON,LAT2,LON2
COMMON /A1/ NSTA(151),OLY(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 /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 /A22/ F(2,21),G(4,21),H(21),DEPTH(21),IONE
COMMON /A25/ INS(151),IEW(151),JPH
DIMENSION AVRES(4,151),SDRES(4,151)
DATA KS1,KW1/'S','W'/'
C-----
QSUM=QNO(1)+QNO(2)+QNO(3)+QNO(4)
IF (QSUM.EQ. 0.) GO TO 72
WRITE(6,5) (QNO(I),I=1,4),QSUM
5 FORMAT(1H1,' ***** CLASS:      A      B      C      D TOTAL *****'
1,/,7X,'NUMBER:',5F6.1)
DO 10 I=1,4
10 QNO(I)=100.*QNO(I)/QSUM
WRITE(6,15) (QNO(I),I=1,4)
15 FORMAT(/,12X,'%:',4F6.1)
WRITE(6,20)
20 FORMAT(/,10X,'TRAVELTIME RESIDUALS (MODEL=1)',5X
1,'TRAVELTIME RESIDUALS (MODEL=2)',5X,'X-MAGNITUDE RESIDUALS'
2,6X,'F-MAGNITUDE RESIDUALS',/, 'STATION NRES SRWT AVRES S1
3DRES NRES SRWT AVRES SDRES NXM AVXM SDXM1
4 NFM AVFM SDFM')
DO 70 I=1,NS
DO 30 J=1,4
AVRES(J,I)=0.
30 SDRES(J,I)=0.
IF (NRES(1,I).EQ. 0) GO TO 35
AVRES(1,I)=SR(1,I)/SRWT(1,I)
SDRES(1,I)=SQRT(SRSQ(1,I)/SRWT(1,I)-AVRES(1,I)**2+0.000001)
35 IF (NRES(2,I).EQ. 0) GO TO 40
AVRES(2,I)=SR(2,I)/SRWT(2,I)
SDRES(2,I)=SQRT(SRSQ(2,I)/SRWT(2,I)-AVRES(2,I)**2+0.000001)
40 IF (NXM(I).EQ. 0) GO TO 50
AVRES(3,I)=SXM(I)/NXM(I)
SDRES(3,I)=SQRT(SXMSQ(I)/NXM(I)-AVRES(3,I)**2+0.000001)
50 IF (NFM(I).EQ. 0) GO TO 60
AVRES(4,I)=SFM(I)/NFM(I)
SDRES(4,I)=SQRT(SFMSQ(I)/NFM(I)-AVRES(4,I)**2+0.000001)
60 WRITE(6,65) NSTA(I),NRES(1,I),SRWT(1,I),AVRES(1,I),SDRES(1,I)
1,NRES(2,I),SRWT(2,I),AVRES(2,I),SDRES(2,I),NXM(I),AVRES(3,I)
2,SDRES(3,I),NFM(I),AVRES(4,I),SDRES(4,I)
65 FORMAT(4X,A4,2X,I5,3F8.2,6X,I5,3F8.2,2(6X,I5,2F8.2))
70 CONTINUE
72 IF (IPUN.NE. 3) GO TO 200
C----- PUNCH STATION LIST WITH REVISED DELAYS,XMGC,AND FMGC -----
IF (ISW.EQ. IONE) GO TO 80
WRITE(6,75) INS(1),IEW(1)
75 FORMAT(1H1,' ***** NEW STATION LIST *****'
1,/,4X,'I STN LAT ',A1,' LONG ',A1,' ELV DELAY',5X
2,'FMGC XMGC KL PRR CALR IC IS DATE HRMN')
GO TO 90

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80 WRITE(6,85) INS(1),IEW(1)	1588.
85 FORMAT(1H1,' ***** NEW STATION LIST *****	1589.
1,///,4X,'I STN LAT ',A1,' LONG ',A1,' ELV M DLY1	1590.
2DLY2 XMGC FMGC K CALR IC DATE HRMN')	1591.
90 DO 120 I=1,NS	1592.
DLY(1,I)=DLY(1,I)+AVRES(1,I)	1593.
IF (ISW.EQ.IONE) DLY(2,I)=DLY(2,I)+AVRES(2,I)	1594.
XMGC(I)=XMGC(I)+AVRES(3,I)	1595.
FMGC(I)=FMGC(I)+AVRES(4,I)	1596.
LAT1=LAT(I)/60.	1597.
LAT2=LAT(I)-60.*LAT1	1598.
LON1=LON(I)/60.	1599.
LON2=LON(I)-60.*LON1	1600.
IF (ISW.EQ.IONE) GO TO 115	1601.
WRITE(6,105) I,NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1602.
1,DLY(1,I),FMGC(I),XMGC(I),KLSS(I),PRR(I),CALS(I),ICAL(I),NDATE(I)	1603.
2,NHRMN(I)	1604.
105 FORMAT(15,2X,A4,I2,F5.2,A1,I4,F5.2,A1,I5,F6.2,4X,F5.2,2X,F5.2,I2	1605.
1,1X,F4.2,1X,F6.2,I2,5X,I6,I4)	1606.
WRITE(7,110) NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1607.
1,DLY(1,I),FMGC(I),XMGC(I),KLSS(I),PRR(I),CALS(I),ICAL(I),NDATE(I)	1608.
2,NHRMN(I)	1609.
110 FORMAT(2X,A4,I2,F5.2,A1,I3,F5.2,A1,I4,F6.2,T38,F5.2,T45,F5.2	1610.
1,I2,1X,F4.2,1X,F6.2,I2,T71,I6,I4)	1611.
GO TO 120	1612.
115 WRITE(6,116) I,NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1613.
1,MNO(I),DLY(1,I),DLY(2,I),XMGC(I),FMGC(I),KLSS(I),CALS(I),ICAL(I)	1614.
2,NDATE(I),NHRMN(I)	1615.
116 FORMAT(15,2X,A4,I3,'-',F5.2,A1,I4,'-',F5.2,A1,I5,I6,2F6.2	1616.
1,2F6.2,I2,F6.2,I2,2X,I6,I4)	1617.
WRITE(7,117) NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1618.
1,MNO(I),DLY(1,I),DLY(2,I),XMGC(I),FMGC(I),KLSS(I),CALS(I),ICAL(I)	1619.
2,NDATE(I),NHRMN(I)	1620.
117 FORMAT(A4,I3,'-',F5.2,A1,I3,'-',F5.2,A1,I4,I6,2F6.2	1621.
1,2F6.2,I2,F6.2,I2,2X,I6,I4)	1622.
120 CONTINUE	1623.
RETURN	1624.
C----- PUNCH STATION LIST WITH REVISED CALIBRATIONS -----	1625.
200 IF (IPUN.NE.4) RETURN	1626.
IF (ISW.EQ.IONE) GO TO 205	1627.
WRITE(6,75) INS(1),IEW(1)	1628.
GO TO 206	1629.
205 WRITE(6,85) INS(1),IEW(1)	1630.
206 DO 220 I=1,NS	1631.
LAT1=LAT(I)/60.	1632.
LAT2=LAT(I)-60.*LAT1	1633.
LON1=LON(I)/60.	1634.
LON2=LON(I)-60.*LON1	1635.
IF (ISW.EQ.IONE) GO TO 210	1636.
WRITE(6,105) I,NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1637.
1,DLY(1,I),FMGC(I),XMGC(I),KLAS(I),PRR(I),CALR(I),ICAL(I),MDATE(I)	1638.
2,MHRMN(I)	1639.
WRITE(7,110) NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1640.
1,DLY(1,I),FMGC(I),XMGC(I),KLAS(I),PRR(I),CALR(I),ICAL(I),MDATE(I)	1641.
2,MHRMN(I)	1642.
GO TO 220	1643.
210 WRITE(6,116) I,NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1644.
1,MNO(I),DLY(1,I),DLY(2,I),XMGC(I),FMGC(I),KLAS(I),CALR(I),ICAL(I)	1645.
2,MDATE(I),MHRMN(I)	1646.
WRITE(7,117) NSTA(I),LAT1,LAT2,INS(I),LON1,LON2,IEW(I),IELV(I)	1647.
1,MNO(I),DLY(1,I),DLY(2,I),XMGC(I),FMGC(I),KLAS(I),CALR(I),ICAL(I)	1648.

2,MDATE(1),MHRMN(1)
220 CONTINUE
RETURN
END

1649.
1650.
1651.
1652.


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SUBROUTINE SWMREG 1653.
C----- COMPUTE GEIGER ADJUSTMENTS BY STEP-WISE MULTIPLE REGRESSION OF 1654.
C TRAVEL TIME RESIDUALS ----- 1655.
REAL*8 ENT,ELM,FMT 1656.
COMMON /A6/ NMAX,LMAX,NS,NL,MMAX,NR,FNO,Z,X(4,101),ZSQ,RP,OF(101) 1657.
COMMON /A7/ KP,KZ,KOU1,W(101),Y(4),BSE(4),XMEAN(4),CP(180),SP(180) 1658.
COMMON /A16/ KLSS(151),CALS(151),MDATE(151),MHRMN(151),IPRN,ISW 1659.
COMMON /A19/ KNO,IELV(151),TEST(15),FLT(2,151),MNO(151),IW(151) 1660.
COMMON /A21/ KSMP(151),FMO,ONF,B(4),IPH,KF,AVRPS,TEXT 1661.
COMMON /A24/ FLTEP,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC 1662.
DIMENSION XSUM(4),SIGMA(4),IDX(4),V(3),PF(3),A(7,7),T(7,7),S(4,4) 1663.
DATA L,M,MM,M1/3,4,7,5/,ENT,ELM/'ENTERING','LEAVING,.'/ 1664.
C----- 1665.
KFLAG=0 1666.
SVTEST = TEST(3) 1667.
ONF=0.0 1668.
FLIM = TEST(3) 1669.
DO 2 I=1,3 1670.
AF(I)=-1.00 1671.
2 CONTINUE 1672.
DO 5 I=1,NR 1673.
ONF=ONF + W(I)*(1-KSMP(I)) 1674.
5 CONTINUE 1675.
DO 10 I=1,MM 1676.
DO 10 J=1,MM 1677.
10 A(I,J)=0. 1678.
C----- COMPUTE MEANS, STANDARD DEVIATIONS, AND CORRECTED SUMS OF SQUARE 1679.
DO 40 I=1,M 1680.
XSUM(I)=0. 1681.
XMEAN(I)=0. 1682.
DO 40 J=1,M 1683.
40 S(I,J)=0. 1684.
DO 50 K=1,NR 1685.
DO 50 I=1,M 1686.
TEMP=X(I,K)*W(K) 1687.
ETMP=TEMP*(1-KSMP(K)) 1688.
XSUM(I)=XSUM(I)+ETMP 1689.
DO 50 J=I,M 1690.
50 S(I,J)=S(I,J)+TEMP*X(J,K) 1691.
DO 70 I=1,M 1692.
IF (ONF .EQ. 0.) GO TO 65 1693.
XMEAN(I)=XSUM(I)/ONF 1694.
DO 60 J=I,M 1695.
60 S(I,J)=S(I,J)-XSUM(I)*XSUM(J)/ONF 1696.
65 A(I,I)=1. 1697.
IF (S(I,I) .LT. 0.000001) S(I,I)=0.000001 1698.
SIGMA(I)=SQRT(S(I,I)) 1699.
70 CONTINUE 1700.
C----- COMPUTE AND AUGMENT CORRELATION MATRIX A 1701.
DO 80 I=1,L 1702.
I1=I+1 1703.
DO 80 J=I1,M 1704.
A(I,J)=S(I,J)/(SIGMA(I)*SIGMA(J)) 1705.
80 A(J,I)=A(I,J) 1706.
PHI=FNO-1. 1707.
DO 120 I=M1,MM 1708.
A(I-M,I)=1. 1709.
120 A(I,I-M)=-1. 1710.
130 DO 140 I=1,M 1711.
B(I)=0. 1712.
Y(I)=0. 1713.

```

BSE(I)=0.	1714.
140 IDX(I)=0	1715.
IF (IPRN .LT. 3) GO TO 150	1716.
WRITE(6,45)	1717.
45 FORMAT(///, '***** DATA *****', //, 4X, 'K', 8X, 'W'	1718.
1, 14X, 'X1', 14X, 'X2', 14X, 'X3', 14X, 'X4', /)	1719.
DO 47 K=1, NR	1720.
WRITE(6,46) K, W(K), (X(I,K), I=1, M)	1721.
46 FORMAT(15, 8E16.8)	1722.
47 CONTINUE	1723.
WRITE(6,75) (XMEAN(I), I=1, M)	1724.
75 FORMAT(/, ' MEAN', 16X, 8E16.8)	1725.
WRITE(6,76) (SIGMA(I), I=1, M)	1726.
76 FORMAT(/, ' SIGMA', 15X, 7E16.8)	1727.
WRITE(6,77)	1728.
77 FORMAT(///, ' ***** CORRECTED SUMS OF SQUARES MATRIX *****', /)	1729.
DO 78 I=1, M	1730.
78 WRITE(6,95) (S(I,J), J=1, M)	1731.
WRITE(6,85)	1732.
85 FORMAT(///, ' ***** CORRELATION MATRIX R *****', /)	1733.
DO 90 I=1, M	1734.
90 WRITE(6,95) (A(I,J), J=1, M)	1735.
95 FORMAT(7E18.8)	1736.
C-----STEPWISE MULTIPLE REGRESSION	1737.
WRITE(6,125) NR, L, TEST(3)	1738.
125 FORMAT(///, '***** STEPWISE MULTIPLE REGRESSION ANALYSIS'	1739.
1, ' *****', //, ' NUMBER OF DATA.....', I5	1740.
2, ' /, ' NUMBER OF INDEPENDENT VARIABLES... ', I5	1741.
3, ' /, ' CRITICAL F-VALUE.....', F8.2)	1742.
150 DO 300 NSTEP=1, L	1743.
NU=0	1744.
MU=0	1745.
IF (IPRN .LT. 3) GO TO 155	1746.
WRITE(6,154) NSTEP, KZ, KF	1747.
154 FORMAT(//, ' ***** STEP NO., I2, ' *****', 5X, 'KZ =', I2, 5X, 'KF =', I2)	1748.
C-----FIND VARIABLE TO ENTER REGRESSION	1749.
155 VMAX=0.	1750.
MAX=NSTEP	1751.
DO 160 I=1, L	1752.
IF (ISKP(I).EQ.1) GO TO 160	1753.
IF (IDX(I).EQ.1) GO TO 160	1754.
IF ((I.EQ.3).AND.(KZ.EQ.1)) GO TO 160	1755.
V(I)=A(I,M)*A(M,I)/A(I,I)	1756.
IF (V(I).LE. VMAX) GO TO 160	1757.
VMAX=V(I)	1758.
MAX=I	1759.
160 CONTINUE	1760.
F=0.0	1761.
IF (VMAX.EQ.0.0) GO TO 163	1762.
F=(PHI-1.)*VMAX/(A(M,M)-VMAX)	1763.
IF (F .GE. 1000.) F=999.99	1764.
163 AF(MAX)=F	1765.
IF (KF .GE. 2) GO TO 165	1766.
IF (F .LT. TEST(3)) GO TO 400	1767.
165 IF ((MAX.EQ.3).AND.(KZ.EQ.1)) GO TO 300	1768.
166 NU=MAX	1769.
IDX(NU)=1	1770.
PHI=PHI-1.	1771.
C-----COMPUTE MATRIX T FOR THE ENTRANCE OF VARIABLE X(NU)	1772.
DO 170 J=1, MM	1773.
170 T(NU,J)=A(NU,J)/A(NU,NU)	1774.

DO 180 I=1,MM	1775.
IF (I .EQ. NU) GO TO 180	1776.
DO 175 J=1,MM	1777.
175 T(I,J)=A(I,J)-A(I,NU)*A(NU,J)/A(NU,NU)	1778.
180 CONTINUE	1779.
DO 190 I=1,MM	1780.
DO 190 J=1,MM	1781.
190 A(I,J)=T(I,J)	1782.
DO 200 I=1,L	1783.
IF (IDX(I) .EQ. 0) GO TO 200	1784.
IF (ABS(A(M,M)*A(I+M,I+M)) .LT. .000001) GO TO 195	1785.
PF(I)=PHI*A(I,M)**2/(A(M,M)*A(I+M,I+M))	1786.
IF(PF(I) .GE. 1000.0) PF(I)=999.99	1787.
AT(I) = PF(I)	1788.
GO TO 200	1789.
195 PF(I) = 999.99	1790.
200 CONTINUE	1791.
IF (IPRN .LT. 3) GO TO 210	1792.
CALL ANSWER(A,S,XMEAN,SIGMA,IDX,PHI,L,M,MM,PF,NU,ENT)	1793.
210 IF (KF .EQ. 2) GO TO 300	1794.
IF(KF .GE. 3) GO TO 450	1795.
C-----FIND VARIABLE TO LEAVE REGRESSION	1796.
DO 250 K=1,L	1797.
IF (IDX(K) .EQ. 0) GO TO 250	1798.
IF (PF(K) .GE. TEST(3)) GO TO 250	1799.
MU=K	1800.
F=PF(MU)	1801.
IDX(MU)=0	1802.
PHI=PHI+1.	1803.
DO 220 J=1,MM	1804.
220 T(MU,J)=A(MU,J)/A(MU+M,MU+M)	1805.
DO 230 I=1,MM	1806.
IF (I .EQ. MU) GO TO 230	1807.
DO 225 J=1,MM	1808.
IF (J .EQ. MU) GO TO 225	1809.
T(I,J)=A(I,J)-A(I,MU+M)*A(MU+M,J)/A(MU+M,MU+M)	1810.
225 CONTINUE	1811.
230 CONTINUE	1812.
DO 240 I=1,MM	1813.
IF (I .EQ. MU) GO TO 240	1814.
T(I,MU)=A(I,MU)-A(I,MU+M)/A(MU+M,MU+M)	1815.
240 CONTINUE	1816.
DO 245 I=1,MM	1817.
DO 245 J=1,MM	1818.
245 A(I,J)=T(I,J)	1819.
IF (IPRN .LT. 3) GO TO 250	1820.
CALL ANSWER(A,S,XMEAN,SIGMA,IDX,PHI,L,M,MM,PF,MU,ELM)	1821.
250 CONTINUE	1822.
300 CONTINUE	1823.
C-----CHECK TERMINATION CONDITION	1824.
400 KOUT=0	1825.
DO 410 I=1,L	1826.
410 KOUT=KOUT+IDX(I)	1827.
B(4)=XMEAN(M)	1828.
IF (KOUT .NE. 0) GO TO 450	1829.
IF(KF .NE. 1) GO TO 420	1830.
KF = 3	1831.
GO TO 150	1832.
420 TEST(3)= TEST(3)/TEST(6)	1833.
FLIM=TEST(3)	1834.
KF=1	1835.

KFLAG = 0	1836.
IF (TEST(6) .GT. 1.) GO TO 150	1837.
KFLAG = 1	1838.
KF = 4	1839.
GO TO 150	1840.
C-----COMPUTE REGRESSION CONSTANT, COEFFICIENTS, AND STANDARD ERRORS	1841.
450 YSE=77.7	1842.
IF (PHI .GE. 1) YSE=SIGMA(M)*SQRT(ABS(A(M,M)/PHI))	1843.
DO 500 I=1,L	1844.
IF (IDX(I) .EQ. 0) GO TO 500	1845.
B(I)=A(I,M)*SQRT(S(M,M)/S(I,I))	1846.
BSE(I)=YSE*SQRT(ABS(A(I+M,I+M)/S(I,I)))	1847.
IF (KF .NE. 3) Y(I)=B(I)	1848.
IF (KFLAG .EQ. 0) GO TO 480	1849.
IF (ABS(B(I)) .LE. TEST(6)*BSE(I)) Y(I)=0.	1850.
480 IF (PHI .LT. 1.) BSE(I) = 0.	1851.
B(4)=B(4)-Y(I)*XMEAN(I)	1852.
500 CONTINUE	1853.
IF (KF .NE. 3) Y(4)=B(4)	1854.
TEST(3)=SVTEST	1855.
RETURN	1856.
END	1857.

```

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),Z(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,IPRO,ISTTT,ISKP(4),AHEAD(12),FLIM,AF(3),NDEC
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

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TIX=F(1,JL)*DH1*G(1,JL)+F(2,JL)*DH2*G(2,JL)+TID(JL,JL)	1919.
XOVMAX=V(JJ)*V(JL)*(TINJ(JJ)-TIX)/(V(JJ)-V(JL))	1920.
GO TO 50	1921.
45 IF (JL .EQ. NL) GO TO 100	1922.
50 DO 60 M=JJ,NL	1923.
60 TR(M)=TINJ(M)+DELTA(I)/V(M)	1924.
TMIN=999.99	1925.
DO 70 M=JJ,NL	1926.
IF (TR(M) .GT. TMIN) GO TO 70	1927.
IF (DIDJ(M) .GT. DELTA(I)) GO TO 70	1928.
K=M	1929.
TMIN=TR(M)	1930.
70 CONTINUE	1931.
IF (DELTA(I) .LT. XOVMAX) GO TO 90	1932.
C-----TRAVEL TIME & DERIVATIVES FOR REFRACTED WAVE	1933.
80 T(I)=TR(K)	1934.
DTDD=1.0/V(K)	1935.
DTDH=-SQRT(VSQ(K)-VSQ(JL))/(V(K)*V(JL))	1936.
ANIN(I)=-V(JL)/V(K)	1937.
GO TO 260	1938.
C-----CALCULATION FOR DIRECT WAVE -----	1939.
90 IF (JL .NF. 1) GO TO 100	1940.
SQT=SQRT(7SQ+DELTA(I)**2)	1941.
TOJ1=SQT/V(1)	1942.
IF (TOJ1 .GE. TMIN) GO TO 80	1943.
C-----TRAVEL TIME & DERIVATIVES FOR DIRECT WAVE IN FIRST LAYER	1944.
T(I)=TOJ1	1945.
DTDD=DELTA(I)/(V(1)*SQT)	1946.
DTDH=7/(V(1)*SQT)	1947.
ANIN(I)=DELTA(I)/SQT	1948.
GO TO 260	1949.
C-----FIND A DIRECT WAVE THAT WILL EMERGE AT THE STATION	1950.
100 XHIG=DELTA(I)	1951.
XLIT=DELTA(I)*TKJ/Z	1952.
UB=XHIG/SQRT(XHIG**2+TKJSQ)	1953.
UL=XLIT/SQRT(XLIT**2+TKJSQ)	1954.
UBSQ=UB**2	1955.
ULSQ=UL**2	1956.
DELBIG=TKJ*UB/SQRT(1.000001-UBSQ)	1957.
DELLIT=TKJ*UL/SQRT(1.000001-ULSQ)	1958.
J1=JL-1	1959.
DO 110 L=1,J1	1960.
DELBIG=DELBIG+(THK(L)*UB)/SQRT(VSQ(JL)/VSQ(L)-UBSQ)	1961.
110 DELLIT=DELLIT+(THK(L)*UL)/SQRT(VSQ(JL)/VSQ(L)-ULSQ)	1962.
DO 170 LL=1,25	1963.
IF (DELBIG-DELLIT .LT. 0.02) GO TO 180	1964.
XTR=XLIT+(DELTA(I)-DELLIT)*(XHIG-XLIT)/(DELBIG-DELLIT)	1965.
U=XTR/SQRT(XTR**2+TKJSQ)	1966.
USQ=U**2	1967.
DELXTR=TKJ*U/SQRT(1.000001-USQ)	1968.
DO 120 L=1,J1	1969.
120 DELXTR=DELXTR+(THK(L)*U)/SQRT(VSQ(JL)/VSQ(L)-USQ)	1970.
XTEST=DELTA(I)-DELXTR	1971.
IF (ABS(XTEST) .LE. 0.02) GO TO 190	1972.
IF (XTEST) 140,190,150	1973.
140 XHIG=XTR	1974.
DELBIG=DELXTR	1975.
GO TO 160	1976.
150 XLIT=XTR	1977.
DELLIT=DELXTR	1978.
160 IF (LL .LT. 10) GO TO 170	1979.

IF (1.0-U .LT. 0.0002) GO TO 190	1980.
170 CONTINUE	1981.
180 XTR=0.5*(XBIG+XLIT)	1982.
U=XTR/SQRT(XTR**2+TKJSQ)	1983.
USQ=U**2	1984.
190 IF (1.0-U .GT. 0.0002) GO TO 220	1985.
C-----IF U IS TOO NEAR 1, COMPUTE TDIR AS WAVE ALONG THE TOP OF LAYER JL	1986.
IF (ISW .EQ. 10NE) GO TO 195	1987.
TDC=TID(JL,JL)+DELTA(I)/V(JL)	1988.
GO TO 200	1989.
195 TIX=F(1,JL)*DH1*G(1,JL)+F(2,JL)*DH2*G(2,JL)+TID(JL,JL)	1990.
TDC=TIX+DELTA(I)/V(JL)	1991.
200 IF (JL .EQ. NL) GO TO 210	1992.
IF (TDC .GE. TMIN) GO TO 80	1993.
210 T(I)=TDC	1994.
DTDD=1.0/V(JL)	1995.
DTDH=0.0	1996.
ANIN(I)=0.9999999	1997.
GO TO 260	1998.
C-----TRAVEL TIME & DERIVATIVES FOR DIRECT WAVE BELOW FIRST LAYER	1999.
220 TDIR=TKJ/(V(JL)*SQRT(1.0-USQ))	2000.
DO 240 L=1,J1	2001.
240 TDIR=TDIR+(THK(L)*V(JL))/(VSQ(L)*SQRT(VSQ(JL)/VSQ(L)-USQ))	2002.
IF (JL .EQ. NL) GO TO 245	2003.
IF (TDIR .GE. TMIN) GO TO 80	2004.
245 T(I)=TDIR	2005.
SRR=SQRT(1.-USQ)	2006.
SRT=SRR**3	2007.
ALFA=TKJ/SRT	2008.
BETA=TKJ*U/(V(JL)*SRT)	2009.
DO 250 L=1,J1	2010.
STK=(SQRT(VSQ(JL)/VSQ(L)-USQ))**3	2011.
VTK=THK(L)/(VSQ(L)*STK)	2012.
ALFA=ALFA+VTK*VSQ(JL)	2013.
250 BETA=BETA+VTK*V(JL)*U	2014.
DTDD=BETA/ALFA	2015.
DTDH=(1.0-V(JL)*U*DTDD)/(V(JL)*SRR)	2016.
ANIN(I)=U	2017.
C-----SET UP PARTIAL DERIVATIVES FOR REGRESSION ANALYSIS -----	2018.
260 X(1,I)=-DTDD*DX(I)/DELTA(I)	2019.
X(2,I)=-DTDD*DY(I)/DELTA(I)	2020.
X(3,I)=DTDH	2021.
300 CONTINUE	2022.
RETURN	2023.
END	2024.

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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,OF(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(151),FLT(2,151),MNO(151),IW(151)
DIMENSION RSPA(8,20)
DATA 7MC1,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 (IPR.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))

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GO TO 20	2086.
10 IF ((PRXI.GT.3.).OR.(PRXI.LT.0.05)) GO TO 30	2087.
FQ=10.*ALOG10(1./PRXI)+6.	2088.
IFQ=FQ	2089.
XLMR=RSPA(K,IFQ)+(FQ-IFQ)*(RSPA(K,IFQ+1)-RSPA(K,IFQ))	2090.
20 BLAC=ALOG10(AMXI/(2.*CAL(I)))-XLMR	2091.
RLD2=ALOG10(RAD2)	2092.
BLNT=ZMC1-PWC1*RLD2	2093.
IF (RAD2 .GE. 40000.) BLNT=ZMC2-PWC2*RLD2	2094.
XMAG(I)=BLAC-BLNT+XMGC(JI)	2095.
NM=NK+1	2096.
AVXM=AVXM+XMAG(I)	2097.
SDXM=SDXM+XMAG(I)**2	2098.
30 FMAG(I)=BLANK	2099.
IF (FMP(I) .EQ. BLANK) GO TO 40	2100.
FMAG(I)=TEST(7)+TEST(8)*ALOG10(FMP(I))+TEST(9)*DELTA(I)+FMGC(JI)	2101.
NF=NF+1	2102.
AVFM=AVFM+FMAG(I)	2103.
SDFM=SDFM+FMAG(I)**2	2104.
40 CONTINUE	2105.
IF (NM .EQ. 0) GO TO 50	2106.
AVXM=AVXM/NM	2107.
SDXM=SQR(T(SDXM/NM-AVXM**2))	2108.
50 IF (NF .EQ. 0) GO TO 60	2109.
AVFM=AVFM/NF	2110.
SDFM=SQR(T(SDFM/NF-AVFM**2))	2111.
60 IF (NM .EQ. 0) AVXM=BLANK	2112.
IF (NF .EQ. 0) AVFM=BLANK	2113.
IF (IMAG-1) 70,80,90	2114.
70 MAG=AVXM	2115.
RETURN	2116.
80 MAG=AVFM	2117.
RETURN	2118.
90 MAG=0.5*(AVXM+AVFM)	2119.
IF (AVXM .EQ. BLANK) GO TO 80	2120.
IF (AVFM .EQ. BLANK) GO TO 70	2121.
RETURN	2122.
END	2123.

APPENDIX 2

A Listing of a Test Run of HYP071

On the following two pages is a listing of a complete input card deck for running a load module of HYP071. This load module has been stored in the IBM 370/155 system at the USGS Computer Center in Reston. Some mistakes are introduced in the input data so that errors detected by HYP071 may be illustrated (see Appendix 3, p. 90-96). Otherwise, the data used are real.

```
//MG992601 JOB (993001173,E230,3,10,900),'LEE - 800',CLASS=D
//GO EXEC PGM=E230,REGION=160K,TIME=1
//STEPLIB DD DSNAME=A993001.AZ173.MG9E230.HYP071,UNIT=ONLINE,
// VOL=SER=SYS011,DISP=SHR
//FT06F001 DD SYSOUT=A
//FT07F001 DD SYSOUT=B
//FT05F001 DD *
```

```
HEAD SOME SANTA ROSA QUAKES FOR TESTING HYP071
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
SR083835.50	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	0.19	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									
SR08AIP+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		18
SR07IPD0 691005120646.38			
SR08AIPU0 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?	25
SR05IP-1 691005061209.04			
SR06IPD0 691005061209.75	13.94ES 2		30
SR07IPD0 691005061206.45			28
SR09IPU0 691005061207.29			27
SR10IPU0 691005061206.10			
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			10
SR02IPU0 691005111259.42			9
SR04IPU0 691005120649.66	54.03IS 0		

/*

APPENDIX 3

Printed Results of the HYP071 Test Run

The following six pages are actual output printed by HYP071 using the test data shown in Appendix 2 (p. 87-88). Users adapting HYP071 for their computers should reproduce these results to + 1 or 2 counts of the last significant figures. Please note that the error messages shown are for the purpose of illustrating some common mistakes in the input data.

SOME SANTA ROSA QUAKES FOR TESTING HYP071

***** PROGRAM HYP071 REVISED (11/25/73) *****

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	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			
L	STN	LAT	LONG	ELV	DELAY	FMGC	FMGC	KL	PRR	CALR	IC	DATE	MM	HH	MM
1	SR01	3442.55N	12259.17W	0	-0.15	0.40	0.25	A	0.0	0.0	0	0	0	0	0
2	SR02	3427.28N	123 4.80W	0	0.09	0.40	0.25	A	0.0	0.0	0	0	0	0	0
3	SR03	3414.15N	12251.29W	0	0.12	0.40	0.25	A	0.0	0.0	0	0	0	0	0
4	SR04	3417.20N	12231.92W	0	0.14	0.40	0.25	A	0.0	0.0	0	0	0	0	0
5	SR05	3429.55N	12224.33W	0	0.07	0.40	0.25	A	0.0	0.0	0	0	0	0	0
6	SR06	3442.58N	12212.22W	0	-0.19	0.40	0.25	A	0.0	0.0	0	0	0	0	0
7	SR07	3432.20N	12242.74W	0	0.03	0.40	0.25	A	0.0	0.0	0	0	0	0	0
8	SR08	3435.50N	12249.38W	0	0.06	0.40	0.25	A	0.0	0.0	0	0	0	0	0
9	SR09	3435.92N	12244.25W	0	0.07	0.40	0.25	A	0.0	0.0	0	0	0	0	0
10	SR10	3429.42N	12251.00W	0	-0.19	0.40	0.25	A	0.0	0.0	0	0	0	0	0
11	SR10	3425.00N	12231.75W	0	-0.16	0.40	0.25	A	0.0	0.0	0	0	0	0	0
12	SR11	3413.58N	12239.44W	0	0.02	0.40	0.25	A	0.0	0.0	0	0	0	0	0
13	SR12	3433.95N	12246.20W	0	0.19	0.40	0.25	A	0.0	0.0	0	0	0	0	0
14	SR13	3428.50N	12241.10W	0	-0.01	0.40	0.25	A	0.0	0.0	0	0	0	0	0
15	SR14	3423.08N	12249.39W	0	0.01	0.40	0.25	A	0.0	0.0	0	0	0	0	0
16	SR15	3429.40N	12235.95W	0	0.07	0.40	0.25	A	0.0	0.0	0	0	0	0	0
17	SR16	3432.02N	12254.55W	0	0.06	0.40	0.25	A	0.0	0.0	0	0	0	0	0
18	SR17	3445.95N	12244.35W	0	0.0	0.40	0.25	A	0.0	0.0	0	0	0	0	0
19	SR18	3417.75N	12244.44W	0	-0.11	0.40	0.25	A	0.0	0.0	0	0	0	0	0
20	SR19	3440.25N	12240.04W	0	-0.05	0.40	0.25	A	0.0	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 XWEAR AFAM PUS TU RMS KFM IPUN IMAG IR IPRN CODE LATR LONR
S. 50. 100. 1.78 2 0 18 0 1 0 1 0011 0 0.0 0 0.0

69/10/ 5 11:12

SOME SANTA ROSA QUAKES FOR TESTING HYPOT1

I	ORIG	LAT N	LONG W	DEPTH	DM	RMS	AVRPS	SKD	CF	ADJUSTMENTS (KM)			PARTIAL F-VALUES			STANDARD ERRORS			ADJUSTMENTS TAKEN		
										DLAT	DLOM	DZ	DLAT	DLOM	DZ	DLAT	DLOM	DZ	DLAT	DLOM	DZ
1	52.57	38-25.10	122-30.65	5.00	0	0.97	-0.00	00A	2.00	5.00	4.50	6.82	126.34	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	80A	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	52.42	38-28.59	122-41.94	0.41	1	0.16	0.01	84A	2.00	0.15	0.0	0.27	-1.00	-1.00	0.29	0.0	0.0	0.0	0.0	0.0	0.0
3	52.03	38-28.59	122-41.94	0.51	1	0.16	-0.00	82A	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 ERM ERZ Q SOD ADJ IN NR AVR AAR NM AVXIM SORX NF AVFM SOFM I
 691005 1112 52.83 38-28.59 122-41.94 0.41 1.81 19 1 59 1 0.16 0.5 1.1 B B1A 0.67 10 19-0.00 0.13 2 1.7 0.0 3 1.0 0.1 3

STN	DIST	AZM	AIN	PRMK	HRMN	P-SEC	TPBS	TPCAL	DLT/M1	P-RES	P-WT	AMX	PRX	CALK	K	XMAG	RMK	FMP	FMAG	SRMK	S-SEC	TSOBS	S-RES	S-WT	DT
SR13	1.2	94	171	IP00	1112	54.09	2.06	1.69	-0.01	0.38	0.80	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR07	6.0	350	137	IP00	1112	54.01	1.98	2.14	0.03	-0.10	1.06	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR10	0.1	145	131	IP00	1112	54.00	1.97	2.30	-0.16	-0.17	1.06	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR15	8.8	80	129	IP00	1112	55.21	2.38	2.40	0.07	-0.09	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR11	9.9	21	125	IP00	1112	55.32	2.49	2.55	0.02	-0.08	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR12	11.7	324	120	IP00	1112	55.77	2.94	2.82	0.19	-0.06	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR09	13.3	277	116	IP00	1112	55.66	2.03	3.06	-0.19	-0.04	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR0A	16.7	320	111	IP01	1112	56.51	3.68	3.62	0.04	0.02	0.02	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR18	20.4	190	106	IP00	1112	56.94	4.11	4.23	-0.11	-0.01	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR19	21.7	7	105	IP00	1112	57.26	4.43	4.45	-0.05	0.03	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR16	25.0	205	103	IP00	1112	58.04	5.21	5.00	0.04	0.17	1.06	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR04	25.6	145	102	IP00	1112	58.05	5.22	5.12	0.14	-0.04	1.10	29	20	0.78	1.7	15	2.0	15	0	62.45	9.62	0.26	1.00	0	0
SR05	25.7	84	102	IP00	1112	58.12	5.29	5.12	0.07	0.10	1.08	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR06	29.5	29	101	IP00	1112	58.53	5.70	5.78	-0.19	0.11	1.08	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR03	30.0	207	100	IP00	1112	58.41	5.58	5.87	0.12	-0.08	0.68	23	15	0.65	0	1.7	CLP	15	0	62.59	9.76	-0.19	1.06	0	0
SR02	33.3	264	99	IP00	1112	59.42	6.59	6.44	0.09	0.06	1.10	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0
SR01	36.0	314	98	EP-2	1112	59.70	6.95	6.90	-0.15	0.20	0.52	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0	0	0

***** SR201PD0 A91005120644.0A

***** DELETED! SR20 NOT ON STATION LIST

SOME SANTA ROSA QUAKES FOR TESTING HYPOT1

69/10/ 5 12: 6

I	ORIG	LAT N	LONG W	DEPTH	OM	RMS	AVRPS	SKD	CF	ADJUSTMENTS (KM)			PARTIAL F-VALUES			STANDARD ERRORS			ADJUSTMENTS TAKEN		
										DZ	DLAT	DLOM	DZ	DLAT	DLOM	DZ	DLAT	DLOM	DZ	DLAT	DLOM
1	44.52	38-24.60	122-41.20	5.00	0	0.15	0.00	A0A	2.00	-0.13	1.29	-0.78	0.64	0.09	0.10	0.26	-0.13	1.29	-0.78	0.09	0.10
2	44.58	38-24.53	122-42.08	4.22	1	0.04	-0.01	A0A	2.00	0.0	0.0	-0.47	-1.00	0.06	4.61	0.0	0.22	0.0	0.0	0.0	0.0
2	44.57	38-24.53	122-42.08	3.75	1	0.04	-0.02	A0A	2.00	0.0	0.0	0.0	-1.00	-1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.09
3	44.57	38-24.53	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	38-24.53	122-42.08	3.45	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

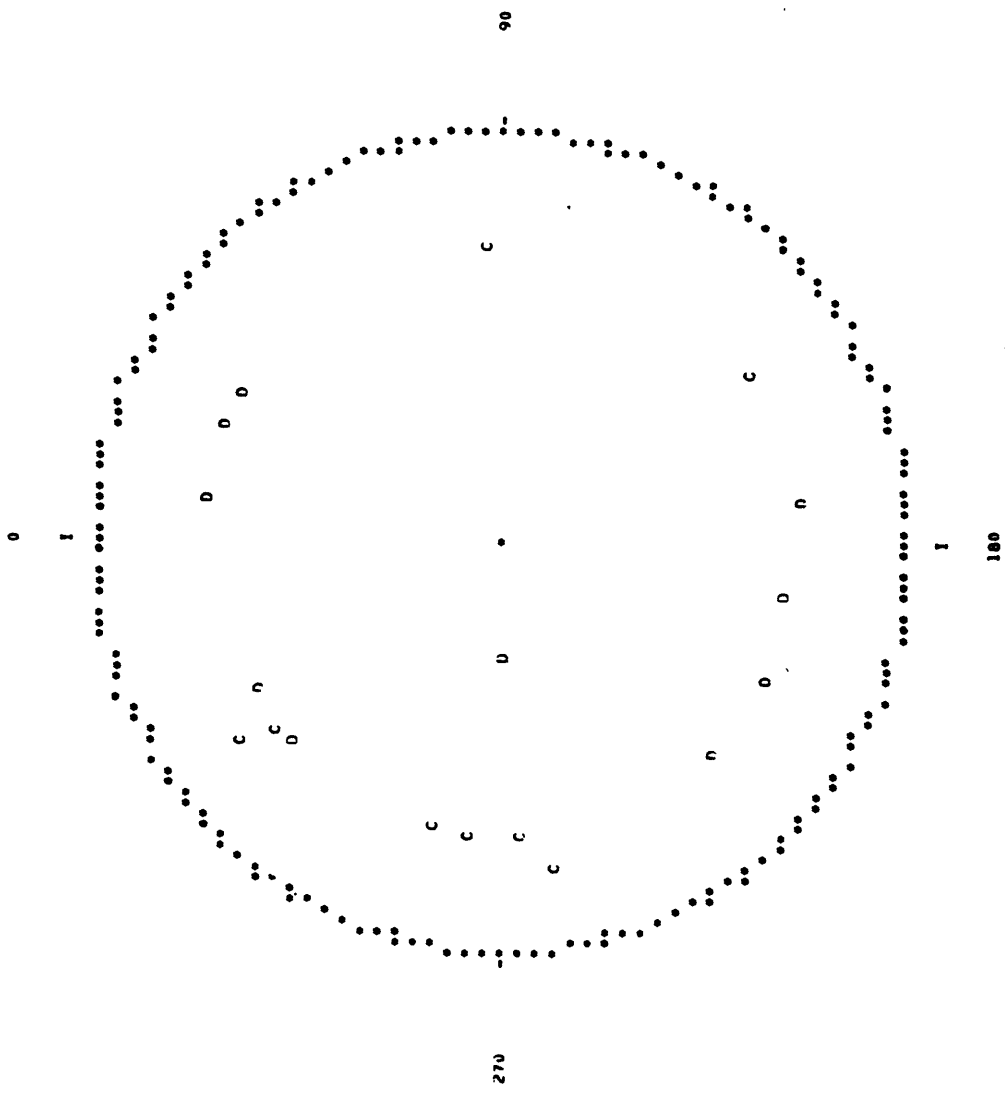
DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	OM	GAP	M	RMS	ERM	ENZ	Q	SOD	ADJ	IN	NR	AVN	AAR	NM	AVIM	SDXM	NF	AVFM	SDFM	I		
691005	12	6	44.56	38-24.53	122-42.08	3.05	2.05	17	1	59	1	0.03	0.1	0.1	A	A	0.09	0	20	-0.00	0.03	0	0.0	0.0	2	2.0	0.0	3

STN	U1ST	A2N	AIN	PHWK	HHNN	P-SEC	TP08S	TPCAL	DLY/MI	P-RES	P-WT	AMX	PRX	CALX	K	XMAG	RHK	FMP	FMAG	SRMK	S-SEC	TSOBS	S-RES	S-WT	DT
SRI3	1.4	92	158	IP00	12	6	45.46	0.90	0.93	-0.01	-0.02	1.00	0	0	0.0	8									
SRI7	6.9	357	115	IP00	12	6	46.18	1.82	1.73	0.03	0.06	1.00	0	0	0.0	8									
SRI0	8.1	143	111	IP00	12	6	46.40	1.84	1.96	-0.16	0.04	1.00	0	0	0.0	8									
SRI5	9.1	84	109	IP00	12	6	46.80	2.24	2.14	0.07	0.04	1.00	0	0	0.0	8									
SW11	10.1	27	61	IP00	12	6	46.89	2.33	2.32	0.02	-0.01	1.00	0	0	0.0	8									
SW12	11.7	324	61	IP00	12	6	47.32	2.76	2.60	0.19	-0.03	1.00	0	0	0.0	8									
SR09	13.1	277	61	IP00	12	6	47.23	2.67	2.04	-0.19	0.02	1.00	0	0	0.0	8									
SW14	14.6	224	61	IP00	12	6	57.78	13.22	3.12	0.01	10.09	-0.0	0	0	0.0	8									
SR44	16.7	321	61	IP00	12	6	48.09	3.53	3.48	0.04	0.01	1.00	0	0	0.0	8									
SW18	20.2	190	61	IP00	12	6	48.55	3.99	4.10	-0.11	0.00	1.00	0	0	0.0	8									
SW19	21.9	8	61	IP00	12	6	48.88	4.32	4.39	-0.05	-0.02	1.00	0	0	0.0	8									
SR16	24.8	285	61	IP00	12	6	49.47	4.91	4.90	0.04	-0.03	1.00	0	0	0.0	8									
SR04	25.7	145	61	IP00	12	6	49.66	5.10	5.05	0.14	-0.09	1.00	0	0	0.0	8									
SW05	25.9	86	61	IP00	12	6	49.72	5.16	5.04	0.07	0.00	1.00	0	0	0.0	8									
SR04	29.7	29	61	IP00	12	6	50.10	5.54	5.76	-0.19	-0.02	1.00	0	0	0.0	8									
SR03	29.8	207	61	IP00	12	6	50.49	5.93	5.78	0.12	0.04	1.00	0	0	0.0	8									
SW02	33.1	266	61	IP00	12	6	51.02	6.44	6.36	0.09	0.02	1.00	0	0	0.0	8									
SW01	35.9	316	61	IP00	12	6	51.72	6.64	6.85	-0.15	-0.03	1.00	0	0	0.0	8									

ES 2 53.70 9.14 -0.04 0.0
ES44 54.20 9.64 -0.27 0.0

16 2.0

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



69/10/ 5 6112

SOME SANTA ROSA QUAKES FOR TESTING HYPOT1

***** FOLLOWING EVENT IS OUT OF ORDER *****

1	ORIG	LAT N	LONG W	DEPTH M	RMS	AVMPS SKD	CF	ADJUSTMENTS (KM)	PARTIAL F-VALUES	STANDARD ERRORS	ADJUSTMENTS TAKEN	
								OLAT OLON	OZ OLAT OLON	OZ OLAT OLON	OZ OLAT OLON	
1	4.41	38-28.40	122-40.44	7.42	0.07	0.00	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	4.24	38-28.40	122-40.44	7.42	0.07	0.00	2.00	-0.10 0.0	-1.00 0.0	0.20 -1.00	0.0 0.22	0.0 0.0 0.0 0.0
2	4.23	38-28.40	122-40.44	7.42	0.07	0.00	2.00	-0.02 -0.11	0.11 0.01	0.20 0.05	0.20 0.24	0.52 0.0 0.0 0.0

DATE	ORIG	LAT N	LONG W	DEPTH M	RMS	ERM	ERZ	Q	SOD	ADJ IN	NR	AVN	AAR	NM	AVM	SDM	MF	AVFM	SDFM	I						
691005	612	4.23	38-28.40	122-40.44	7.42	2.55	14	0	67	1	0.07	0.3	0.5	A	AIA	2.88	0	16-0.00	0.05	0	0.0	0.0	5	2.5	0.2	2

ST	4	DIST	AZ	AW	PMK	MMN	P-SEC	TPDMS	TPCAL	OLY/MI	P-RES	P-WT	ANX	PRX	CALX	K	RMAG	RHK	FMP	FMAG	SHMK	S-SEC	TSORS	S-RES	S-WT	OT
SRI1	0.4	300	177	1P00	612	5.79	1.56	1.57	-0.01	-0.00	1.04	0	0	0.0	8	0	0.0	8	27	2.4						
SRI0	7.0	134	133	1P00	612	6.10	1.87	2.09	-0.16	-0.06	1.04	0	0	0.0	8	0	0.0	8	30	2.5						
SRI5	7.4	134	132	1P00	612	6.44	2.21	2.14	0.07	0.00	1.04	0	0	0.0	8	0	0.0	8								
SM07	7.4	334	131	1P00	612	6.45	2.22	2.16	0.03	0.03	1.04	0	0	0.0	8	0	0.0	8								
SRI1	7.4	17	123	1P00	612	6.78	2.55	2.48	0.02	0.06	1.04	0	0	0.0	8	0	0.0	8								
SRI2	12.9	323	115	1P-1	612	7.35	3.12	2.95	0.19	-0.02	0.81	0	0	0.0	8	0	0.0	8	28	2.5						
SR09	14.8	277	111	1P00	612	7.29	3.06	3.27	-0.19	-0.02	1.08	0	0	0.0	8	0	0.0	8								
SRI4	20.4	195	104	1P00	612	8.50	4.27	4.20	-0.11	0.19	1.08	0	0	0.0	8	0	0.0	8								
SRI4	22.0	3	103	1P00	612	8.61	4.38	4.47	-0.05	-0.03	1.04	0	0	0.0	8	0	0.0	8	45	2.9	15	0	12.00	7.77	-0.09	0.0
SM05	24.2	45	102	1P-1	612	9.04	4.81	4.84	0.07	-0.10	0.81	0	0	0.0	8	0	0.0	8	25	2.4						
SM06	24.5	144	102	1P09	612	10.40	6.17	6.90	0.14	-0.03	1.04	0	0	0.0	8	0	0.0	8								
SRI6	24.6	244	100	1P-1	612	8.52	5.29	5.26	0.04	-0.00	0.81	0	0	0.0	8	0	0.0	8	1500	14.30	3.90	-0.03	****			
SM06	24.1	24	99	1P00	612	9.75	5.52	5.69	-0.19	0.02	1.08	0	0	0.0	8	0	0.0	8	ES	2	13.94	9.71	-0.08	0.0		
SM03	30.4	210	99	1P-1	612	10.13	5.90	5.92	0.12	-0.14	0.81	0	0	0.0	8	0	0.0	8								

***** DELETED! WRONG TIME

54.0315 0

***** SP041P00 691005120654.56

***** INSUFFICIENT DATA FOR LOCATING THIS QUAKE!
SM01EP 2 691005111259.78 0.0
SM021P00 691005111259.42 0.0

```

***** CLASS1      A      B      C      D TOTAL *****
NUMBERS      2.0      1.0      0.0      0.0      3.0
81  66.7  33.3      0.0      0.0

```

STATION	TMAVFLTIME RESIDUALS (MODEL#1)				TMAVFLTIME RESIDUALS (MODEL#2)				X-MAGNITUDE RESIDUALS				F-MAGNITUDE RESIDUALS			
	NRES	SRWT	AVRES	SDRES	NRES	SRWT	AVRES	SDRES	NRM	AVRM	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	2	2.49	-0.14	0.14	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	2.49	0.01	0.04	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	3.16	-0.03	0.11	0	0.0	0.0	0.0	0	0.0	0.0	2	-0.01	0.03		
SR08	2	1.82	0.02	0.00	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	0	0.0	0.0		
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	2.47	0.10	0.17	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0		
SR14	3	2.47	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	2.47	0.05	0.09	0	0.0	0.0	0.0	0	0.0	0.0	0	0.0	0.0		
SR17	3	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	0.04	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		

APPENDIX 4

Calculation of Traveltimes, Derivatives, and Angle of Incidence

(by J. P. Eaton)

This section is taken from Eaton (1969, p. 26-38), and explains how traveltimes, derivatives, and angles of incidence are calculated in HYP071.

Calculation of Traveltimes, Derivatives, and

Angles of Incidence

(Subroutines TPAR and TRVDRV)

Program TRVDRV, on which these subroutines are based, was designed to calculate traveltimes and derivatives of traveltimes with respect to epicentral distance and focal depth for events in an "earth" consisting of N-1 flat layers above a homogeneous half space. The earth model is described by the depth to the top of layer L and the P-velocity in layer L; i.e., by $D(L)$, $V(L)$, $L = 1, N$, where the index N refers to the half space.

The course of the program can be outlined as follows:

1. Determine the layer, J; that contains the focus at depth, H.
2. Determine which of the several possible waves (direct, and refractions from successively lower horizons) is the first arrival at distance DELTA.

3. Calculate the traveltime and derivatives by an appropriate method: for refracted waves these calculations are straightforward, but for the direct waves a numerical solution must be employed.

Because the traveltime, derivative, and angle of incidence calculations are a critical central part of the hypocenter determination, these subroutines are treated more thoroughly than other subroutines in the program. This writeup describes a somewhat more elaborate version of the subroutine that constitutes a self-contained program as well as a test of the program on an actual earth model (the 3-layer "Hawaii B" structure). It is supplemented by an independent flow chart and a FORTRAN listing of the TRVDRV program. The variables used in the program

and flow chart are identified in the accompanying list. The same notation will be used, generally, in the following section of the writeup, which outlines the mathematical formulation of the program and discusses some of the principal problems that must be solved. The notation used in this section is nearly identical (but not exactly) to that used in HYPOLAYR and its subroutines.

Traveltime of Refracted Waves

(See Sketch A)

The traveltime, to distance DELTA, of seismic waves from a focus in layer J that are refracted along the top of layer M can be written:

$$T = TINJ(M) + DELTA / V(M)$$

The intercept, $TINJ(M)$, can be written:

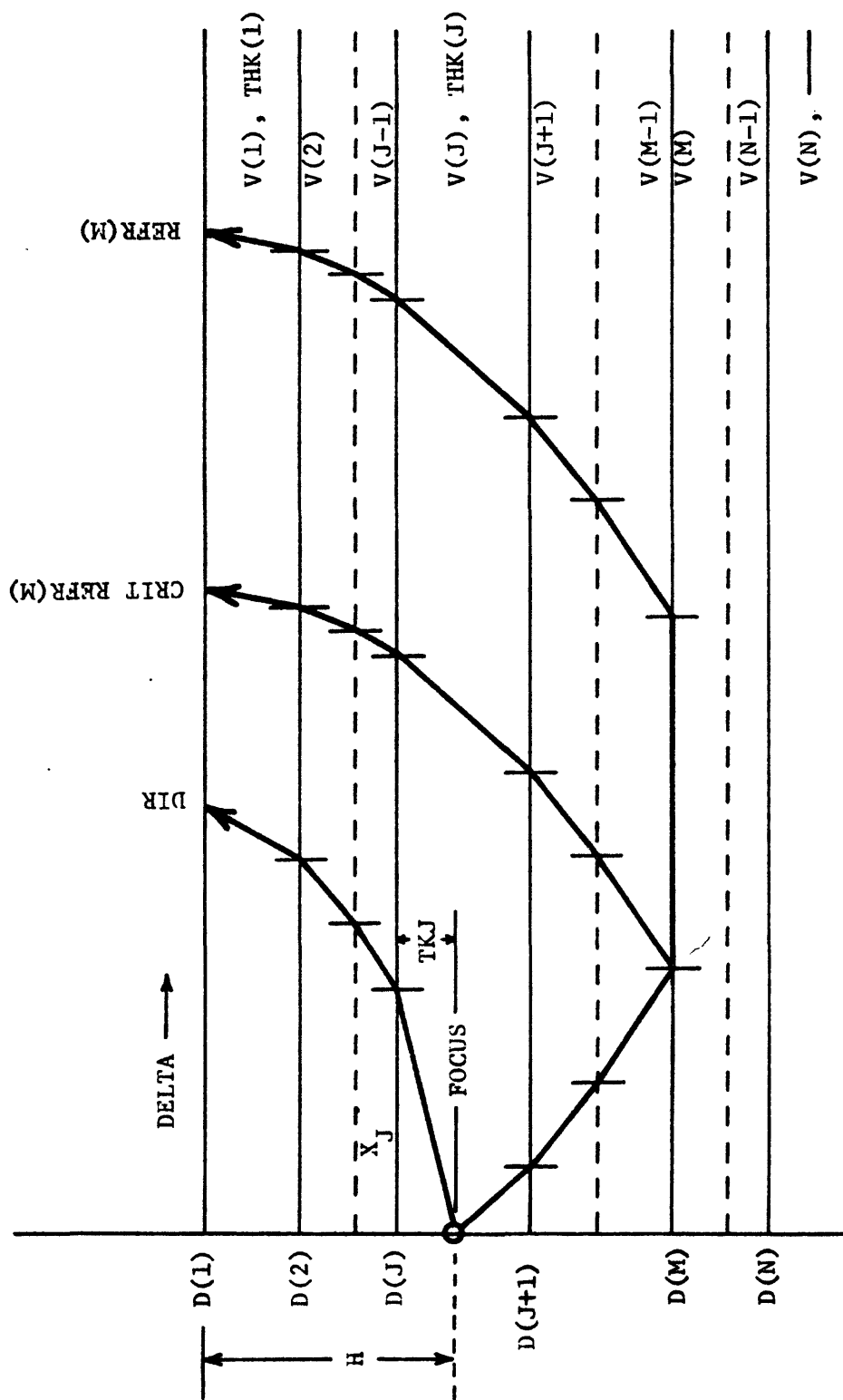
$$TINJ(M) = TID(J,M) - \frac{TKJ * \cos \theta_M^J}{V(J)}$$

where $TID(J,M)$ is the intercept of a wave with its focus at the top of layer J (at depth $D(J)$) that is refracted along the top of layer M (at depth $D(M)$).

Finally,

$$TID(J,M) = \sum_{L=J}^{M-1} \frac{THK(L) * \cos \theta_M^L}{V(L)} + \sum_{L=1}^{M-1} \frac{THK(L) * \cos \theta_M^L}{V(L)}$$

In these equations, θ_M^L is the angle of incidence in layer L of a wave that is refracted horizontally in layer M.



SKETCH A. Notation used to specify crustal model.

Critical Distance (Initial Point) of Refracted Waves

Analogous equations can be written for the distance to the initial point (distance of critical reflection) of the wave from a focus at depth H (in layer J) that is refracted along the top of layer M.

$$DIDJ(M) = DID(J,M) - TKJ * \tan \Theta_M^J, \text{ and}$$

$$DID(J,M) = \sum_{L=J}^{M-1} THK(L) * \tan \Theta_M^J + \sum_{L=1}^{M-1} THK(L) * \tan \Theta_M^J$$

where $DID(J,M)$ is the critical distance for a wave with a focus at the top of layer J (depth $D(J)$) that is reflected from the top of layer M (depth $D(M)$).

For waves that are refracted along or critically reflected from the top of layer M, the angle of incidence in layer M is $\pi/2$.

Critical Distance and Intercept Formulas in Terms of Layer Velocities and Thicknesses

From Snell's law $\sin \Theta_M^L = \frac{V(L)}{V(M)}$. Hence,

$$\cos \Theta_M^L = (1 - \frac{V(L)^2}{V(M)^2})^{1/2} = \frac{\sqrt{V(M)^2 - V(L)^2}}{V(M)}, \text{ and}$$

$$\tan \Theta_M^L = V(L) / \sqrt{V(M)^2 - V(L)^2}.$$

The expressions for $TID(J,M)$, $DID(J,M)$, $TINJ(M)$, and $DIDJ(M)$ can be written:

$$TID(J,M) = \sum_{L=J}^{M-1} \frac{THK(L) * \sqrt{V(M)^2 - V(L)^2}}{V(M) * V(L)} + \sum_{L=1}^{M-1} \frac{THK(L) * \sqrt{V(M)^2 - V(L)^2}}{V(M) * V(L)}$$

$$DID(J,M) = \sum_{L=J}^{M-1} \frac{THK(L) * V(L)}{\sqrt{V(M)^2 - V(L)^2}} + \sum_{L=1}^{M-1} \frac{THK(L) * V(L)}{\sqrt{V(M)^2 - V(L)^2}}$$

$$TINJ(M) = TID(J,M) - TKJ * \frac{\sqrt{V(M)^2 - V(J)^2}}{V(M) * V(J)}$$

$$DIDJ(M) = DID(J,M) - TKJ * \frac{TKJ * V(J)}{\sqrt{V(M)^2 - V(J)^2}}$$

In these equations, TKJ is the depth of the focus below the top of layer J, ie., TKJ = H - D(J).

Traveltime of the Direct Wave

The traveltime of the direct wave to distance DELTA from a focus in the first layer is simply:

$$T = \sqrt{H^2 + DELTA^2} / V(1)$$

For a focus in a deeper layer (J = 2, N) the expression for T as a function of DELTA is too complex to be useful, if it can be obtained at all. However, both T and DELTA are relatively simple functions of $\sin \Theta_J$, where Θ_J is the angle of incidence of the ray at the focus in layer J. In the program "DIRECT", a simple method for determining $\sin \Theta_J$

and then calculating T for any specified DELTA was developed. This routine is employed in the present program to compute the traveltime of the direct ray to distance DELTA for $J > 1$.

Maximum Distance at Which the Direct Wave Can Be a First Arrival.

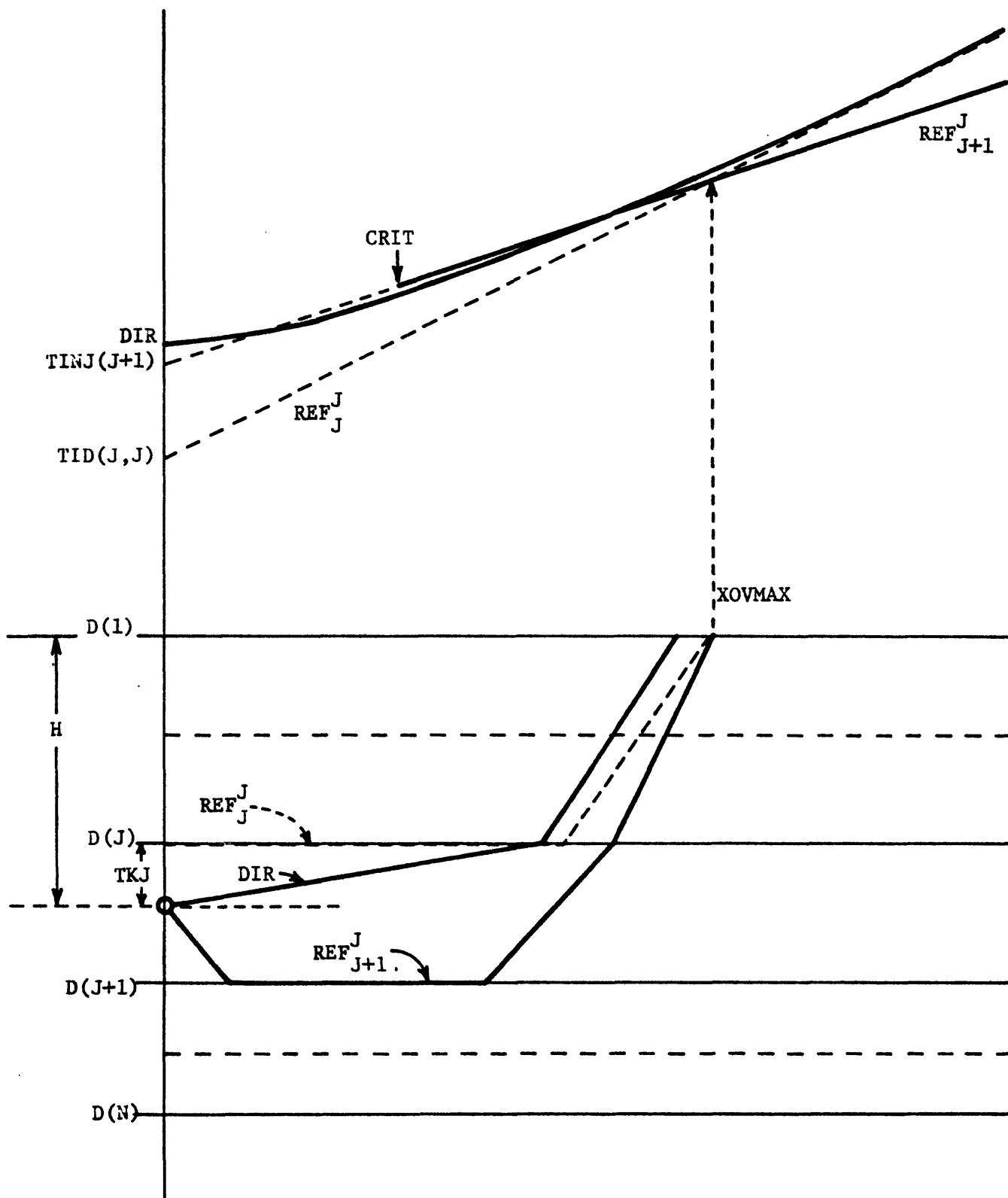
(See Sketch B)

Because the traveltime of the direct wave is more time-consuming to calculate than the traveltimes of refracted waves, a preliminary test is made to determine whether DELTA is beyond the range of possible direct-wave first arrivals. Consider a focus at depth H in layer J. At large DELTA the direct wave is asymptotic to the refraction line for a focus at the very top of layer J; but the direct wave is always later than the asymptote. Let the crossover distance between the wave refracted along the top of J from a focus at the top of J and the wave refracted along the top of J + 1 from a focus at depth H be XOVMAX. Then the crossover between the direct wave and the refracted wave from J + 1 will be smaller than XOVMAX, and the first arrival at DELTA larger than XOVMAX must be a refracted wave, if $J < N$.

Because the initial point of the refraction from layer K + 1 is coincident with the critical reflection from the top of K + 1 (or the bottom of K) and because the reflection from the base of K must be later than the direct wave (if $K = J$) or a refracted wave from the top of K, the initial point of the K + 1 refraction curve must lie above the K-refraction curve (or the direct-wave curve if $K = J$). Hence, for DELTA greater than XOVMAX and $J < N$ the first arrival must be a refracted wave recorded beyond its initial point.

Determination of Which Wave Is the First Arrival at $DELTA < XOVMAX$

For DELTA less than XOVMAX the first arrival may be the direct wave: so the traveltime of the direct wave must be computed and



SKETCH B. Sketch to illustrate discussion of XOVMAX, initial point, and critical distance.

compared with the traveltimes of possible refracted phases to establish which arrival is earliest. In this range of DELTA, however, it must be established that any prospective refracted first arrival actually exists at the specific value of DELTA considered; i.e., is DELTA beyond the initial point of the refracted wave?

Derivatives of Traveltime with Respect to Epicentral Distance and Focal Depth.--When the nature of the first arrival at distance DELTA has been established, the traveltime of that arrival is set equal to T and derivatives of the traveltime with respect to DELTA and H are computed by methods that are appropriate for the first-arrival wave type.

Derivatives of refracted-wave traveltimes with respect to DELTA and H.--For refracted waves, by differentiation of the equation for T as a function of DELTA and H:

$$\frac{\partial T}{\partial \text{DELTA}} = \frac{1}{V(M)}$$

$$\frac{\partial T}{\partial H} = \frac{-\sqrt{V(M)^2 - V(J)^2}}{V(M) * V(J)}$$

Derivatives of first-layer direct arrivals.--For the direct wave through layer 1:

$$\frac{\partial T}{\partial \text{DELTA}} = \frac{\text{DELTA}}{V(1) * \sqrt{H^2 + \text{DELTA}^2}}$$

$$\frac{\partial T}{\partial H} = \frac{H}{V(1) * \sqrt{H^2 + \text{DELTA}^2}}$$

Derivatives of direct-wave traveltimes: $J > 1$.--(See sketch C.)

Because both T and DELTA for the direct wave from layers below the first can be expressed in terms of the parameter $\sin \theta_J$

$$\frac{\partial T}{\partial \text{DELTA}} \quad \text{can be computed as} \quad \frac{\frac{\partial T}{\partial \sin \theta_J}}{\frac{\partial \text{DELTA}}{\partial \sin \theta_J}}$$

$$\frac{\partial T}{\partial \text{DELTA}} = \frac{TKJ \cdot U / (V(J) \cdot (1.0 - U^2)^{3/2}) + \sum_{L=1}^{J-1} THK(L) \cdot V(J) \cdot U / \left(V(L)^2 \cdot \left(\frac{V(J)^2}{V(L)^2} - 1 \right)^{3/2} \right)}{TKJ / (1.0 - U^2)^{3/2} + \sum_{L=1}^{J-1} THK(L) \cdot V(J)^2 / \left(V(L)^2 \cdot \left(\frac{V(J)^2}{V(L)^2} - 1 \right)^{3/2} \right)}$$

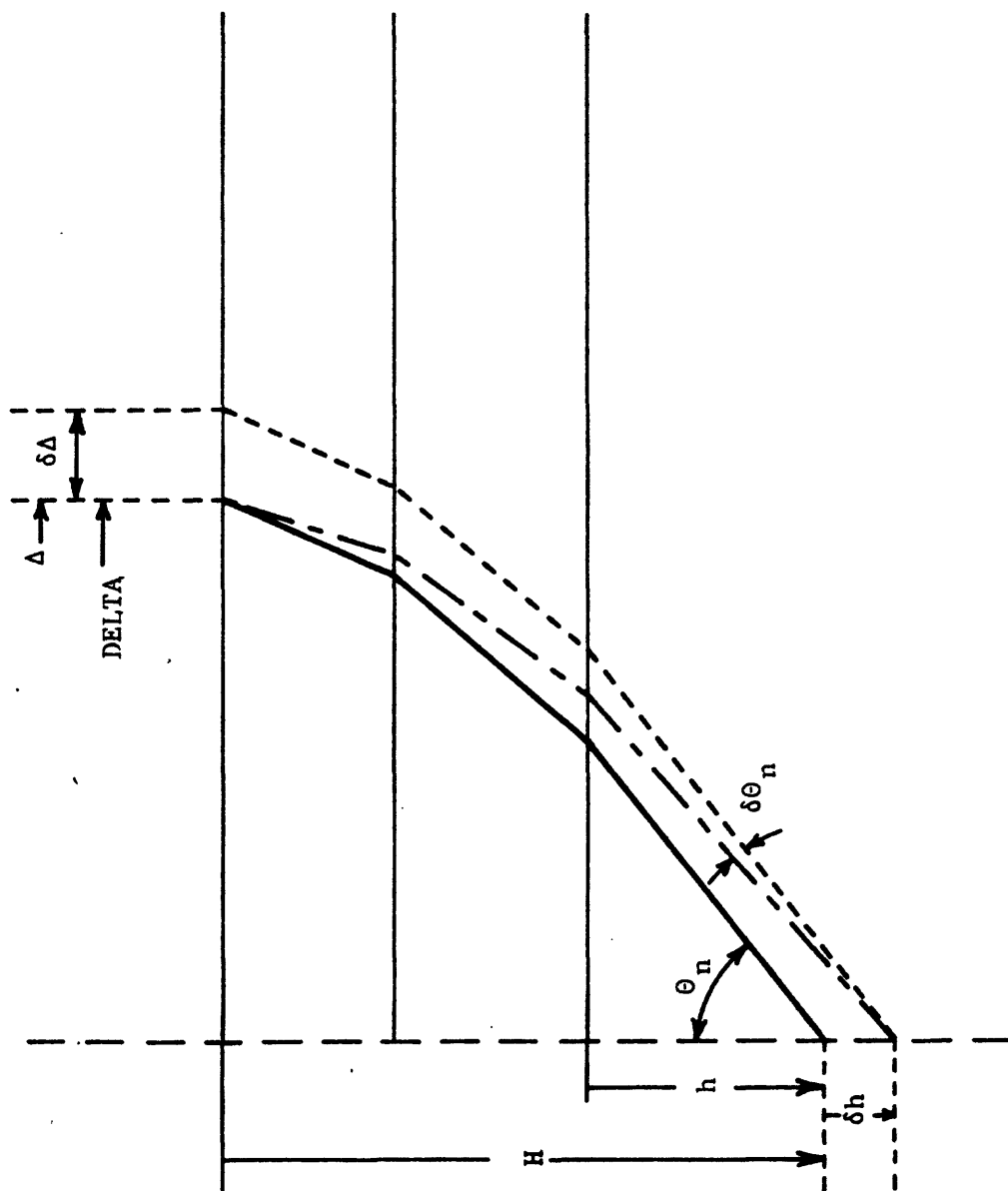
where

$$U = \sin \theta_J$$

Note: $\frac{\partial T}{\partial \text{DELTA}}$ can be calculated more simply from elementary considerations.

$$\frac{\partial T}{\partial \Delta} \Big|_h = \frac{\sin \theta_J}{V_J} = \frac{1}{\bar{V}}, \quad \text{where } \bar{V} \text{ is the apparent surface velocity at distance } \Delta.$$

(Thanks to Rex Allen for catching this point. 6/10/75 JRE)



SKETCH C. Sketch to illustrate derivation of $\left. \frac{\partial T}{\partial h} \right|_{\Delta \text{const}}$.

Next, we must calculate $\frac{\partial T}{\partial h} \Big|_{\text{DELTA}}$ for the direct arrival from layer J.

Letting $U = \sin \theta_J$, and $h = TKJ = H - D(J)$, and $\text{DELTA} = \Delta$,

$$T = \frac{h}{V(J) \times \sqrt{1.0 - U^2}} + \sum_{L=1}^{J-1} \frac{THK(L) * V(J)}{V(L)^2 * \left(\frac{V(J)^2}{V(L)^2} - U^2 \right)^{1/2}}$$

$$\Delta = \frac{h * U}{\sqrt{1.0 - U^2}} + \sum_{L=1}^{J-1} \frac{THK(L) * U}{\left(\frac{V(J)^2}{V(L)^2} - U^2 \right)^{1/2}}$$

Holding $U = \sin \theta_J = \text{const}$, increase h by an amount δh . The corresponding changes in T and Δ are

$$\delta T_1 = \frac{\partial T}{\partial h} \Big|_U * \delta h$$

$$\delta \Delta_1 = \frac{\partial \Delta}{\partial h} \Big|_U * \delta h$$

Next, change U by an amount δU , holding h constant so that the change in Δ , $\delta \Delta_2$, is equal and opposite to that caused by the previous change in h .

$$\delta \Delta_2 = \frac{\partial \Delta}{\partial U} \Big|_h * \delta U = - \frac{\partial \Delta}{\partial U} \Big|_h * \delta h = - \delta \Delta_1$$

Thus, the required δU is:

$$\delta U = - \frac{\frac{\partial \Delta}{\partial h}|_u}{\frac{\partial \Delta}{\partial u}|_h} * \delta h$$

The corresponding change in T is

$$\delta T_2 = \frac{\partial T}{\partial u}|_h \delta U$$

Substituting the previous expression for δU

$$\delta T_2 = - \frac{\partial T}{\partial u}|_h * \frac{\frac{\partial \Delta}{\partial h}|_u}{\frac{\partial \Delta}{\partial u}|_h} * \delta h$$

The total change in Δ , i.e., $\delta \Delta_1 + \delta \Delta_2 = 0$, and the total change in T is

$$\delta T = \delta T_1 + \delta T_2 = \frac{\partial T}{\partial h}|_u * \delta h - \frac{\partial T}{\partial u}|_h * \frac{\frac{\partial \Delta}{\partial h}|_u}{\frac{\partial \Delta}{\partial u}|_h} * \delta h$$

$$\frac{\delta T}{\delta h}|_\Delta = \frac{\partial T}{\partial h}|_u - \frac{\partial T}{\partial u}|_h * \frac{\frac{\partial \Delta}{\partial h}|_u}{\frac{\partial \Delta}{\partial u}|_h}$$

We have previously calculated

$$\frac{\frac{\partial T}{\partial u}|_h}{\frac{\partial \Delta}{\partial u}|_h} = \frac{\partial T}{\partial \Delta}|_h$$

Passing to the limit

$$\frac{\partial T}{\partial h}|_\Delta = \frac{\partial T}{\partial h}|_u - \frac{\partial T}{\partial \Delta}|_h * \frac{\partial \Delta}{\partial h}|_u$$

But $\frac{\partial T}{\partial h}|_u = \frac{1}{v(j)\sqrt{1.0-u^2}}$, $\frac{\partial \Delta}{\partial h}|_u = \frac{u}{\sqrt{1.0-u^2}}$

and

$$\left. \frac{\partial T}{\partial h} \right|_{\Delta} = \frac{1.0}{V(J) * \sqrt{1.0 - u^2}} - \frac{u}{\sqrt{1.0 - u^2}} * \left. \frac{\partial T}{\partial \Delta} \right|_h$$

Thus

$$\left. \frac{\partial T}{\partial h} \right|_{\Delta} = \frac{1.0 - V(J) * u * \left. \frac{\partial T}{\partial \Delta} \right|_h}{V(J) * \sqrt{1.0 - u^2}}$$

In the notation used in the FORTRAN program

$$DTDH = \frac{1.0 - V(J) * u * DTDD}{V(J) * \sqrt{1.0 - u^2}}$$

APPENDIX 5

Examples of Data Forms for Punching Phase Cards

In order to avoid errors in preparing the phase cards, it is useful to write the seismic data on a special form from which it is easily key-punched. Users of HYP071 are urged to prepare their data forms carefully. Examples of data forms used at NCER are given in the following two pages.

Page 112 shows a typical data form used for processing seismic data from a large network of stations. The actual form is 8-1/2 x 13 inches, and only the top two-thirds are shown here. This form has space for data recorded on four develocorder films or nets. Each net has 16 stations, and station names are labelled in the form. Since S-arrivals are difficult to read on develocorder films, they are not routinely processed and are not included in the form. Space for two more nets and space for remarks are not shown here. In the upper left corner of the data form are abbreviations for some commonly used remarks to be punched in column "RK."

Page 113 shows a data form used for a small network where S-arrivals are routinely read and time corrections may be needed. Amplitude data are not processed and are left out in the form. An additional column for rise time is included although it is not used in the HYP071 program. The actual form is 8-1/2 x 11 inches and fits nicely in a loose-leaf binder.

N = NOISY
 Q = QUARRY
 A = A BOMB
 NE = NO ENERGY

CF = CROSS - FEED
 D = DEAD
 E = EMERGENT

REV. APR. 28, 1971

10	11	12	13	14	15	16	17	18	19
Y	R	M	O	O	D	Y	H	R	M

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
STN	i	u	P	W	P	AMX	PRX	RK	FMP										
						(mm)	(sec)		(sec)										

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
STN	i	u	P	W	P	AMX	PRX	RK	FMP										
						(mm)	(sec)		(sec)										

P NET

ANG	P																		
BOL	P																		
PAL	P																		
SAL	P																		
CYH	P																		
WDS	P																		
MOB	P																		
SFT	P																		
BGU	P																		
LTH	P																		
POR	P																		
STV	P																		
STJ	P																		
BCR	P																		
EGR	P																		
PES	P																		

B NET

PMR	P																		
CHR	P																		
CAN	P																		
PCL	P																		
ANZ	P																		
DIL	P																		
OCR	P																		
SJG	P																		
LTR	P																		
PKH	P																		
FRP	P																		
SRS	P																		
PNC	P																		
QSR	P																		
CNR	P																		
MON	P																		

Date

SAN LUIS RESERVOIR

10	11	12	13	14	15	16	17	18	19
Y	R	M	O	D	Y	H	R	M	N

Time by _____

Checked by _____

KP by _____

Feb. 27, 1974

	1	2	3	4	5	6	7	8	20	21	22	23	24	32	33	34	35	36	37	38	39	40	53	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	STN				i	P	u	P	P (sec)					S (sec)					i	S	u	S	RK	DT (sec)					FMP (sec)					RISE TIME (sec)						
					e	d	W																																	
1	SL1				P															S																				
2	SL2				P															S																				
3	SL3				P															S																				
4	SL4				P															S																				
5	SL5				P															S																				
6	SL6				P															S																				
7	SL7				P															S																				
8	SL8				P															S																				
					P															S																				
					P															S																				
9	ARN				P															S																				
10	SLD				P															S																				
11	PCL				P															S																				
12	FEL				P															S																				
13	LTR				P															S																				
14	QSR				P															S																				
15	EMM				P															S																				
16	RBM				P															S																				
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