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NOTES ON BEROQ85 AND ASSOCIATED PROGRAMS

(Hypocenter Location Program for Use on HP85)

by

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Introduction

BERQ85 is a hypocenter location program designed for use on the Hewlett-Packard HP 85 desktop calculator. The capabilities and modes of operation of BERQ85 are described in the following pages, along with appropriate comments about the three programs (VMMAK2, STAMAK2, and ATMAK2) used for making data files for BERQ85. The program can accept any local velocity model (none, one or two constant velocity layers over a constant velocity half-space) while also accommodating teleseismic P traveltimes (HERRIN curve)

The programs are written in the simple BASIC of the HP 85. BERQ85 is based on BERQLY, a FORTRAN program written by Lane Johnson at University of California, Berkeley. It may be of interest to some that another BASIC version of BERQLY exists which uses the full capability of the BASIC language of the HP 9845 (true sub-programs, string arrays, etc., etc.). This latter program is nearly a line-by-line translation of BERQLY and contains a variety of niceties not contained in BERQ85. The HP 9845 version of BERQLY does contain the capability to use teleseismic data, a feature not included in BERQLY itself. The version of BERQLY useable on the HP 9845 is available upon request to the author of these notes (JFE).

All explanatory material available for BERQ85 is in the following pages, the 30.7K core capacity of the HP 85 preventing insertion of explanatory notes in the listing of BERQ85.

Notes for BERQ85

This program is designed for the HP 85, uses the BASIC language of the HP 85, and requires 30.4K of programmable memory. All variables are 12 digit (DIM) precision. The program can analyze data of deep and shallow, local and teleseismic events (P phase to 100°).

Array Dimensions

S = number of permissable stations in Station Library File .

P = number of permissable phases in Arrival Time File .

Arrays are dimensioned as follows (those not listed never change):

W(30+2*P),X5(P),B5(P),X7(P),T8(P),X8(P),Y8(P),W7(30+2*P),B7(30+2*P) X(11,P),S(4,S),X6(30+2*P),K(P),S1(S),S2(P),B(P).

All of these are set in the first few lines of the program.

At DIM precision, each new phase requires 224 bytes of memory while each new station requires 40 bytes.

As presently dimensioned, the station library can hold data of 40 stations, while a maximum of 25 arrival times can be used for any event.

Parameters input from keyboard

max # iter = maximum number of iterations

conv.para. = convergence parameter. Adjust as appropriate (.1 to .001 according to L. Johnson).

print option = 0,1,2, or 3. See following pages for output associated with each value.

Restrained depth of focus

If calculated value of depth (beginning from initial estimate in arrival time file) is unacceptable (less than zero or below layer for shallow-focus events, for example), you can rerun and restrain depth to any value you wish:

(a) Answer "Y" at "Change initial depth?", and then give changed depth at next request.

(b) Answer "Y" at "Change weights on init. ests.?", and then enter "1,1,1,0" at next request.

If you do not wish to change initial estimate of depth, enter "N" when queried "Change initial depth?".

Weights on initial estimates of event coordinates

A weight of "1" means the initial estimate is subject to maximum change during calculations. A weight of "0" means the initial estimate will not be allowed to change during calculations. Weights are entered in order of

origin time
latitude
longitude
depth

All of these are initially entered into the program from the arrival time file (see section re ATMAK2). If no changes from these values are

PRINT OPTION = 0

```
DATE-79/08/09  124927

 first guess
time = 26.95  lat =   36.980
long = -121.400  depth =  5.0

   estimate weight stder1 stder2
time  26.950  0.00  0.00  0.00
lat   36.979  1.00   .02   .00
long-121.453  1.00   .02   .00
depth 16.383  1.00  2.04   .29

ale=-45.0  am1=  2.0  am2=  2.5
```

PRINT OPTION = 1

```
DATE-79/08/09  124927

 first guess
time = 26.95  lat =   36.980
long = -121.400  depth =  5.0

st ray dist azi toa time     res
 1  1     4  84  18  28.70 -1.09
 2  1     6 334  24  29.37  -.52
 3  1     9 218  32  29.10  -.95
 4  1    12 261  41  29.78  -.55
 5  1    14 359  47  30.27  -.27
 6  1    16  60  53  30.69  -.14
 6  2    16  60  53  33.27  -.39
 7  1    18 283  56  31.04   .02
 8  1    26 128  69  32.46   .37
 8  2    26 128  69  36.72   .86
 9  1    26 289  70  32.20   .07
10  1    26 306  70  32.32   .20
11  1    37 328  79  34.69  1.04

icv =  0 ier =  0 ndt = 10
str =   .7000  ste =   .1000

   estimate weight stder1 stder2
time  26.950  0.00  0.00  0.00
lat   36.979  1.00   .02   .00
long-121.453  1.00   .02   .00
depth 16.383  1.00  2.04   .29

ale=-45.0  am1=  2.0  am2=  2.5
```

PRINT OPTION = 2

```
DATE-79/08/09  124927

 first guess
time = 26.95  lat =   36.980
long = -121.400  depth =  5.0

st ray dist azi toa time     res
 1  1     4  84  18  28.70 -1.09
 2  1     6 334  24  29.37  -.52
 3  1     9 218  32  29.10  -.95
 4  1    12 261  41  29.78  -.55
 5  1    14 359  47  30.27  -.27
 6  1    16  60  53  30.69  -.14
 6  2    16  60  53  33.27  -.39
 7  1    18 283  56  31.04   .02
 8  1    26 128  69  32.46   .37
 8  2    26 128  69  36.72   .86
 9  1    26 289  70  32.20   .07
10  1    26 306  70  32.32   .20
11  1    37 328  79  34.69  1.04

icv =  0 ier =  0 ndf = 10
str =   .7000  ste =   .1000

iter =  1  fssr=4.899E+000
flmp=2.500E-003  fcon=3.003E+001

   estimate weight stderl stder2
time  26.950  0.00   0.00  0.00
lat   36.979  1.00    .02   .00
long-121.453  1.00    .02   .00
dpth  16.383  1.00   2.04   .29

ale=-45.0  am1=  2.0  am2=  2.5
```

PRINT OPTION = 3

```
DATE-79/08/09  124927

st   lat    long   time   wt ray
 1  36.98 -121.40  28.7 1.0   1
 2  37.03 -121.48  29.4 1.0   1
 3  36.92 -121.51  29.1 1.0   1
 4  36.96 -121.58  29.8 1.0   1
 5  37.10 -121.46  30.3 1.0   1
 6  37.05 -121.29  30.7 1.0   1
 6  37.05 -121.29  33.3 1.0   2
 7  37.02 -121.65  31.0 1.0   1
 8  36.83 -121.22  32.5 1.0   1
 8  36.83 -121.22  36.7 1.0   2
 9  37.06 -121.73  32.2 1.0   1
10  37.12 -121.69  32.3 1.0   1
11  37.26 -121.68  34.7 1.0   1

 first guess
time = 26.95  lat =   36.980
long = -121.400  depth =  5.0

st ray dist azi toa time     res
 1  1     4  84  18  28.70 -1.09
 2  1     6 334  24  29.37  -.52
 3  1     9 218  32  29.10  -.95
 4  1    12 261  41  29.78  -.55
 5  1    14 359  47  30.27  -.27
 6  1    16  60  53  30.69  -.14
 6  2    16  60  53  33.27  -.39
 7  1    18 283  56  31.04   .02
 8  1    26 128  69  32.46   .37
 8  2    26 128  69  36.72   .86
 9  1    26 289  70  32.20   .07
10  1    26 306  70  32.32   .20
11  1    37 328  79  34.69  1.04

icv =  0 ier =  0 ndf = 10
str =   .7000  ste =   .1000

iter =  1  fssr=4.899E+000
flmp=2.500E-003  fcon=3.003E+001

   estimate weight stderl stder2
time  26.950  0.00   0.00  0.00
lat   36.979  1.00    .02   00
long-121.453  1.00    .02   .00
dpth  16.383  1.00   2.04   .29

ale=-45.0  am1=  2.0  am2=  2.5
```

to be made, enter "N" when queried "Change weights on init. ests.?". If you want to change any of these values (i.e., restrain origin time or depth because you have other definitive data on these parameters), enter "Y" when queried "Change weights on init. ests.?",and enter new set of four weights on next request. You must enter all four values even if you are changing only one of them.

Error Ellipse Calculations

The only error ellipse calculations given in BERQ85 are as in E. Flinn. See citation of appropriate reference in section "To Run Program".

Station File

Program STMAK2 is used for generating the file containing station coordinates, station elevations and station travel-time corrections. See attached appendix. An important point to note is that there is allowance for entry of only one travel-time correction for each station. This correction is presumed to apply to all P phases from that station while the appropriate travel-time correction for all S phases at that station is assumed to be $3^{\frac{1}{2}}$ times that for P phases. Station corrections are algebraically added to observed travel times.

Another important point to remember is that if you are using two separate velocity models (say, one for either side of the San Andreas Fault), the station file made with STAMAK2 does not contain any information about which velocity model is associated with each station. This information is inserted via ATMAK2, i.e., in the arrival time data of each event. Each individual phase requires a model designation attached to it in the data file of each event. This may not be ideal but this is the way the files are written at present.

<u>Velocity Model for Local Earthquakes</u>

The parameters of the crustal model(s) is (are) entered by calling for a file. See section re VMMAK2.

Permissable models for local earthquakes, shallow or deep, are half-space, one layer over a half-space, and two layers over a half-space. Distances are calculated for a round earth but travel times for local earthquakes are calculated for a flat earth. When using a two-layer model for local shallow-focus earthquakes, you can only enter times for direct rays and refractions along the top of the half-space. You cannot enter times for an intermediate refractor, i.e., you cannot enter times for refractions along the top of the second layer. However, you can model one or two layers above an intermediate refractor ("Conrad Discontinuity") and use sub-Conrad velocities as those of the half-space in the model. The second layer is included only to allow a better modeling of crustal velocity structure.

Both layers and the half-space are assumed to have constant velocities (when using BERQ85 for teleseismic events, the HERRIN curve has an implied velocity structure in it).

A few details on making the velocity model file may be useful here. Three important rules to follow in so far as possible are:

-- Do not use a model that is more complex than required for your investigation.

-- Try to avoid having layer boundaries near focal depths

-- Try to eliminate iterations across layer boundaries by making accurate estimates of origin time and depth, making particular effort to place the initial estimate of depth in the correct medium.

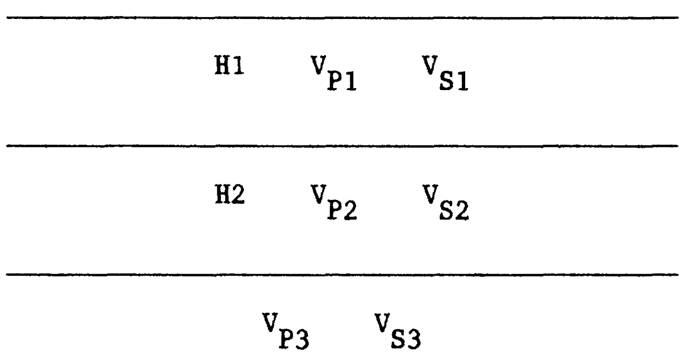
The HP 85 does not have a compiler so that it runs line-by-line, i.e., it takes a long time to make a run relative to regular computers with compilers. All of the above three conditions influence run-time, of particular significance being elimination of iterations across and very near layer boundaries. Since models are somewhat arbitrary anyway, I would suggest juggling of model parameters a bit if calculated depths are frequently near a layer boundary with resultant unavoidable extra and long iterations. Minor adjustments can eliminate iterations across the boundary, hardly change the calculated depth, and decrease run-time by a factor of 3 to 7. Raypaths for direct rays crossing two or more media must be found iteratively and run-time consequently will increase. As presently programmed, this iteration for definition of the raypath ceases when the calculated epicentral distance for a test ray path is within 0.2 kilometers of the epicentral distance calculated between the station and the estimated location of the event. In most cases, this condition is fulfilled by the first estimate of the raypath. If you deem an even closer fit is necessary, change 0.2 in lines 7100 and 7110 of BERQ85 to whatever you wish.

In order to shorten run times, the program checks all S arrivals to see if there is an associated P arrival just before an S datum. If there is, range and azimuth calculations for the S phase are aborted and the values for the P phase are used for the S phase. Also, the calculated travel-time for S is found by multiplying the P travel-time by $3^{\frac{1}{2}}$. If there are a significant number of paired P and S phases, this program element markedly decreases run time. An unassociated S phase follows normal calculations. If there are Pn and Sn phases at the same station as Pg and Sg, range and azimuth are done once for Pg and are copied for all other phases. Time for Sg will be $3^{1/2}$ times that for Pg while time for Sn will be $3^{1/2}$ times that for Pn. When there are associated P and S phases, the data for the P phase must immediately precede that for the S phase. Pg and Sg should precede Pn and Sn in the file. In addition, the ratio of P and S velocities must always be $3^{1/2}$.

If you do not like the rigidity imposed by the above conditions, you can make the following changes in the program:

(a) to change velocity ratios (all of them): put in proper velocity model and change "SQR(3)" in line 7155 to whatever you wish.

(b) to be able to use different velocity ratios in different media: put in proper velocity model and place exclamation marks after the number of lines 6740,6741,6775,6776,6985, and 6986. DO NOT DELETE THESE LINES!!!



Data are entered in the following order:

V_{P1}, V_{S1}, V_{P2}, V_{S2}, V_{P3}, V_{S3}, H1, and H2.

Various simplifications of this model are easily done:

For one-layer over half-space, layer velocities are first and second entries, half-space velocities are fifth and sixth entries, layer thickness is seventh entry, all others are zero.

For a half-space, the half-space velocities are the first and second entries in the file, use a large number like 400 for the seventh entry while all other entries should be zero (can actually be anything).

Two totally different layer models can be used (for example, to model different velocity structures on either side of the San Andreas Fault). In the velocity model file, the first eight values describe one model as indicated above, while the second eight values can be used to describe another model. You <u>must always enter a full complement of sixteen values</u> when making up a velocity model file. Enter eight zeros separated by commas for the second set of values if there is to be only one model.

<u>Arrival Time Data</u>

Each arrival time must be labeled by ray type ("ray") in the arrival time file (see section re ATMAK2) .Labels are as follows:

Direct P Ray "1" ("9" for second model)

Direct S Ray "2" ("10" for second model)

Interface P Ray "3" ("11" for second model)

Interface S Ray "4" ("12" for second model)

Local data and teleseismic data can be mixed. I suspect that, in order to do so, you will have to perform a calibration so that the two travel-time models (local and teleseismic) are synchronized at one depth. One way to perform this calibration is by use of events for which you are certain of the depths or origin times by either local or teleseismic data and for which you have both local and teleseismic data. Evaluate the difference in origin time or depth by each set of data when restraining depth or origin time. Enter this value as a fixed adjustment to teleseismic calculated times in the first B7(L) line of teleseismic travel-time calculations (line number 6930 of BERQ85).

Weights can be attached to each travel time datum in the event data file. A weight of "1" results in maximum impact on the solution, while a weight of "0" results in zero impact on the solution. Weights should have only one significant figure to the right of the decimal point so that the correct value appears in the printout. As the program is presently written, assignment of a weight of zero (0) to a phase means there will be no printout of data for this phase, i.e., there will be no indication of the residual for this phase against the calculated solution based on data of the phases of nonzero weight. If you want an output of residuals of zero-weight phases, assign a nonzero but very low weight (say, .001) to the zero-weight phases. The output will now include data for these phases.

Teleseismic Calculations

In order to use the teleseismic portion of BERQ85, the exclamation marks at the beginnings of lines 130 and 140 of the program (as listed following these notes) must be removed.

At present, the depth range for teleseismic travel time curves in the program is 0 to 100 kilometers while the distance range is 2100 kilometers (adjustable by you) to 11,000 kilometers (100°, limit of data in HERRIN travel time curve file). The phase or ray label is unimportant for teleseismic travel time data as all phases with an epicentral distance of greater than 2100 kilometers are treated as P. However, you must enter a phase or ray label in the file for each teleseismic datum so that the program will read correctly other parts of the file.

The depth range capability of the teleseismic portion of the program can be extended with no increase in the size of the program. Using Herrin's tables, set up a set of simultaneous equations in powers of distance and depth at a grid of distance vs. depth points, the equations being for (travel-time (depth = 0) minus travel-time (depth = d_i)). I used five depths and five distances and the final equations agreed with the Herrin curve at intermediate points in nearly all cases. I solved for depth coefficients at mid-range (60°) and then for range coefficients. You will just have to experiment with required number of grid points and powers of depth and distance (using cross terms). See the relevant equations in the program for the format used by me. These equations are those for Q1 through Q6 (the equations with the eleven or twelve digit constants) in the teleseismic portion of the program (just above the B7(L) equation mentioned above).

The file HERRIN contains P travel-times for each half-degree of epicentral distance from 0° to 100° for an event of zero depth. These travel-times and associated distances are listed in the last section of this paper.

IMPORTANT NOTE

Three conventions used in this program are different from those frequently used in location programs. All have been noted elsewhere in these notes but they are restated here for emphasis:

(1) Station travel-time corrections

The station corrections entered in STMAK2 will be algebraically added to observed travel-times.

(2) Weights to be attached to travel-times

Weights range from 1 to 0 with 1 signifying maximum impact on the solution and 0 signifying zero impact on the solution. Where HYPO 70 would use a weight of 5, BERQ85 uses a weight of 0.2.

(3) Take-off angle

In this program, the reference direction for measurement of take-off angles is vertically upwards.

To Run Program

(1) LOAD program BERQ85.

(2) Press RUN.

(3) Enter name of station library file when so requested.

(4) Enter name of velocity model file when so requested.

(5) Enter values for maximum number of iterations, convergence parameter, and print option.

(6) Enter name of arrival time file when so requested.

(7) Enter either "Y" or "N" when queried "Change initial depth?". If you answered "Y", enter new value of initial depth when so requested.

(8) Enter either "Y" or "N" when queried "Change weights on init. ests.?". If you answered "Y", enter new set of weights when so requested, remembering that all four values must be entered even if changing only one of them.

(9) Wait patiently.

The estimated event parameters are

"time" -- origin time in seconds relative to hours and minutes of initial origin time.

"lat" -- latitude in fractional degrees (+ north)

"long" -- longitude in fractional degrees (+ east)

"dpth" -- depth in kilometers.

In addition to the obvious run parameters, the following are on one or more print options:

"toa" = take-off angle of ray from focus, measured from vertically upwards.

"ale" = azimuth of axis 1 of ellipse (deg E of N); "am1" = length of axis 1 of ellipse (km); "am2" = length of axis 2 of ellipse. Note that both am1 and am2 must be multiplied by the factor c_k of eq. 15, p. 160, E. Flinn (Rev. Geophys., 3, 157-185,1965) to obtain the size of confidence ellipse at any confidence level.

"stder1" -- standard error of estimate using variance of data derived from final sum of squares of residuals.

"stder2" -- standard error of estimate using "ste" of input.

"icv" -- convergence criterion :0 = convergence failed, see "ier"; 2 = convergence because relative difference of sum of squares of residuals is less than conv. para.;4 = convergence because squared length of gradient vector is less than conv. para.

"ier" = error criterion:0 = no error;1 = Jacobian is singular and recovery failed;2 = after recovery, solution has returned to singular Jacobian; 3 = Levenberg-Marquardt parameter has exceeded upper limit (100); 4 = max# iters. exceeded; 5 = Jacobian is zero and solution is stationary point.

"ndf" = number of degrees of freedom for solution.

"str" = standard error of readings estimated from residuals; "ste" = standard error of readings provided in input data.

"iter" = number of iterations completed; "fssr" = final sum of squares of residuals; "flmp" = final value of Levenberg-Marquardt parameter;

"fcon" = final condition number.

As presently written, the program will analyse <u>all</u> events included in the arrival time file without any required interaction with you. This means that your initial estimates of event coordinates for each event cannot be changed and the initial weights attached to these estimates cannot be changed unless you intend the change to apply to all events. Of course, you can easily change this arrangement but that is the way the program presently operates.

```
 10 ! PROGRAM BERQ85. USE ON HP
    85. USE STMAK2, ATMAK2, AND
    VMMAK2 FOR PREPARING FILES.
 50 OPTION BASE 1
 60 DIM D(25,4),B(25),B1(4,4),W(
    80),W1(4,4),X5(25),B5(25),X7
    (25),T8(25),X8(25),Y8(25)
 70 DIM X(11,25),A2(201),S(4,40)
    ,D1(100),X6(80),W7(80),W2(4)
    ,B7(80),Z(1,16),Z9(70)
 80 DIM P(3,4),I$[32]
 90 INTEGER K(25),A1,L,N3,K2,Z7,
    S1(40),S2(25),N7,T5,T6,T7,A2
    ,C1(1)
100 INTEGER A4,A5,I,J,A7,K,N,A9,
    B,B1,B2,M,B4,B5,B6,B7,W9,M3,
    M4,N4,N5,N6,W8
110 DATA 57.29577951,111.1949267
    ,50
120 READ B8,B9
121 FOR I=1 TO 25
122 FOR J=1 TO 4
123 D(I,J)=0
124 NEXT J
125 NEXT I
126 A2=0
127 V5=0
130 ! ASSIGN# 1 TO "HERRIN"
140 ! READ #1;A2(*)
160 DISP "station library";
161 INPUT I$
170 ASSIGN# 1 TO I$
171 READ# 1 ; A5
172 FOR J=1 TO A5
173 FOR I=1 TO 4
174 READ# 1 ; S(I,J)
175 NEXT I
176 READ# 1 ; S1(J)
177 NEXT J
230 P(3,1)=1
240 P(3,2)=10
250 P(3,3)=10
260 P(3,4)=.1
261 DISP "model file";
262 INPUT I$
263 ASSIGN# 1 TO I$
264 READ# 1 ; M$
265 FOR I=1 TO 16
266 READ# 1 ; Z(1,I)
267 NEXT I
270 DISP " max # iter,conv. para
    .,print option";
271 INPUT A4,D9,A1
272 C1(1)=0
345 DISP "arrival file";
346 INPUT I$
347 ASSIGN# 1 TO I$
350 READ# 1 ; I$
360 IF I$="NOMORE" THEN 1890
379 READ# 1 ; A7
381 W9=30+2*A7
382 FOR I=1 TO W9
383 W(I)=0
384 NEXT I
390 READ# 1 ; B,C
400 FOR I=1 TO 4
410 READ# 1 ; P(2,I)
420 NEXT I
430 FOR I=1 TO 4
440 READ# 1 ; P(1,I)
450 NEXT I
451 IF C1(1)<>0 THEN 475
460 DISP "Change initial depth (
    Y or N)";
461 INPUT Y$
462 IF Y$="N" THEN 470
463 DISP "New initial depth";
464 INPUT P(1,4)
470 DISP "Change weights on init
    . ests.(Y/N)";
471 INPUT Y$
472 IF Y$="N" THEN 475
473 DISP "New weights (all four)
    ";
474 INPUT P(2,1),P(2,2),P(2,3),P
    (2,4)
475 PRINT I$
480 IF A1>=3 THEN PRINT USING 49
    0
490 IMAGE /,"st",3X"lat",4X"long
    ",2X"time",3X"wt",X"ray"
500 K=0
510 C1=0
520 FOR N=1 TO A7
530 READ# 1 ; Z7,C2,C3,C4
540 FOR J=1 TO A5
550 IF Z7=S1(J) THEN 590
560 NEXT J
570 PRINT "unknown station   ";Z
    7
580 GOTO 710
590 K=K+1
600 X(8,K)=S(1,J)
610 X(7,K)=S(2,J)
620 X(6,K)=S(3,J)
630 S2(K)=S1(J)
640 X(2,K)=S(4,J)+C3
645 IF C2 MOD 2=0 THEN X(2,K)=S(
    4,J)*SQR(3)+C3
650 X(1,K)=C4
660 C1=C1+C4
670 K(K)=C2
680 IF A1<3 THEN 710
690 PRINT USING 700 ; S2(K),X(8,
    K),X(7,K),X(2,K),C4,C2
700 IMAGE 2D,X,3D.2D,X,4D.2D,X,3
    D.D,X,D.D,2X,DD
710 NEXT N
720 C4=C1/K
730 M=K
```

```
740 N=4
750 PRINT USING 760 ; P(1,1),P(1
    ,2),P(1,3),P(1,4)
760 IMAGE /,X"first guess"/,"tim
    e =",3D.2D,2X"lat =",5D.3D/,
    "long =",5D.3D,2X"depth =",3
    D.D
761 Z5=P(1,4)
770 B5=0
780 FOR I=1 TO N
790 IF P(2,I)<>0 THEN B5=B5+1
800 P(1,I)=P(3,I)*P(1,I)
810 NEXT I
820 B7=0
830 FOR J=1 TO 4
840 FOR I=1 TO A7
850 B7=B7+1
852 D1(B7)=D(I,J)
870 NEXT I
880 NEXT J
890 GOSUB 3570
900 B7=0
910 FOR J=1 TO 4
920 FOR I=1 TO A7
930 B7=B7+1
940 D(I,J)=D1(B7)
950 NEXT I
960 NEXT J
970 B5=M-B5
980 C6=W(2)/C4
990 IF B5>0 THEN C6=C6/B5
1000 C6=SQR(ABS(C6))
1010 IF A1<1 THEN 1250
1050 FOR I=1 TO 4
1060 Q(I)=P(1,I)
1070 NEXT I
1080 GOSUB 6550
1120 PRINT USING 1130
1130 IMAGE /"st",X"ray",X"dist",
     X"azi",X"toa",X"time",5X"re
     s"
1140 FOR I=1 TO M
1150 A9=K(I)
1160 C5=B8*X(5,I)
1170 IF C5<0 THEN C5=C5+180
1180 C1=-B7(I)
1190 IF X(1,I)<>0 THEN C1=C1/X(1
     ,I)
1200 PRINT USING 1210 ; S2(I),K(
     I),X(10,I),X(9,I),C5,X(2,I)
     ,C1
1210 IMAGE 2D,X,2D,2X,4D,X,3D,X,
     3D,X,3D.2D,MDD.DD
1220 NEXT I
1230 PRINT USING 1240 ; B4,B2,B5
     ,C6,C
1240 IMAGE /"icv =",3D," ier =",
     3D," ndf =",3D/,"str =",3D.
     4D,"  ste =",3D.4D
1250 IF A1<2 THEN 1290
1260 A9=INT(W(1))
1270 PRINT USING 1280 ; A9,W(2),
     W(3),W(4)
1280 IMAGE /"iter =",3D,"  fssr=
     ",D.3DE/,"flmr=",D.3DE,"  f
     con=",D.3DE
1290 FOR I=1 TO N
1300 B6=1
1310 FOR J=1 TO N
1320 C1=0
1330 B6=B6+J-1
1340 FOR K=1 TO J
1350 A9=B6+K-1
1360 C1=C1+B1(I,K)*B(A9)
1370 NEXT K
1380 B1=J+1
1390 IF B1>N THEN 1440
1400 FOR K=B1 TO N
1410 A9=A9+K-1
1420 C1=C1+B1(I,K)*B(A9)
1430 NEXT K
1440 W1(I,J)=C1
1450 NEXT J
1460 NEXT I
1470 FOR I=1 TO N
1480 FOR J=1 TO N
1490 C1=0
1500 FOR K=1 TO N
1510 C1=C1+W1(I,K)*B1(K,J)
1520 NEXT K
1530 D(I,J)=C1
1540 NEXT J
1550 NEXT I
1560 FOR I=1 TO N
1570 B(I)=P(1,I)/P(3,I)
1580 C5=SQR(ABS(D(I,I)))/P(3,I)
1590 IF P(2,I)<=0 THEN C5=0
1600 X(8,I)=C5*C6
1610 X(7,I)=C5*C
1620 NEXT I
1630 PRINT USING 1640
1640 IMAGE /3X"estimate",X"weigh
     t",X"stder1",X"stder2"
1650 PRINT USING "4A,4D.3D,3(3D.
     2D)" ; "time",B(1),P(2,1),X
     (8,1),X(7,1)
1651 PRINT USING "4A,4D.3D,3(3D.
     2D)" ; "lat ",B(2),P(2,2),X
     (8,2),X(7,2)
1652 PRINT USING "4A,4D.3D,3(3D.
     2D)" ; "long",B(3),P(2,3),X
     (8,3),X(7,3)
1653 PRINT USING "4A,4D.3D,3(3D.
     2D)" ; "dpth",B(4),P(2,4),X
     (8,4),X(7,4)
1670 C7=PI/2
1680 C8=0
1690 C9=0
1700 C1=B9/P(3,2)
1710 C5=B9/P(3,3)*COS(P(1,2)/P(3
     ,2)/B8)
```

```
1720 D=C1*C1*D(2,2)
1730 D1=C5*C5*D(3,3)
1740 D2=C1*C5*D(2,3)
1750 C1=D-D1
1760 IF C1<>0 THEN C7=ATN(-2*D2/
     C1)
1770 D3=SIN(C7)
1780 D4=COS(C7)
1790 C1=D*D1-D2*D2
1800 C5=D1*D4*D4-2*D2*D3*D4+D*D3
     *D3
1810 IF C5<>0 THEN C8=SQR(C1/C5)
1820 C5=D1*D3*D3+2*D2*D3*D4+D*D4
     *D4
1830 IF C5<>0 THEN C9=SQR(C1/C5)
1840 C7=B8*C7
1850 PRINT USING 1860 ; C7,C8,C9
1860 IMAGE /"ale=",3D.D,"  am1="
     ,3D.D,"  am2=",3D.D,5/
1870 C1(1)=C1(1)+1
1880 GOTO 350
1890 STOP
1900 END
1910 DATA 6378.388,.99327733,.00
     672267002,1.0067679
1920 RESTORE 1910
1940 READ Q2,Q3,Q4,Q5
1950 Q6=E/B8
1960 Q7=E1/B8
1970 Q8=TAN(Q6)
1980 Q9=SIN(Q6)
1990 D=ATN(Q3*Q8)
2000 D1=SIN(Q7)
2010 D2=-COS(Q7)
2020 D3=-COS(D)
2030 D4=D3*D2
2040 D5=-D1*D3
2050 D6=SIN(D)
2060 FOR I=1 TO M
2065 IF I=1 THEN 2070
2066 IF S2(I)=S2(I-1) THEN 2355
2070 D7=X(8,I)/B8
2080 D8=X(7,I)/B8
2090 F9=TAN(D7)
2100 G=F9/(Q5*Q8)+Q4*SQR((Q5+F9*
     F9)/(Q5+Q8*Q8))
2110 G1=D8-Q7
2120 D1=SIN(G1)
2130 D2=(G-COS(G1))*Q9
2140 G2=ATN(D1/D2)
2150 IF SGN(D1)=-1 AND SGN(D2)=-
     1 THEN G2=G2-PI
2160 IF SGN(D1)=1 AND SGN(D2)=-1
      THEN G2=G2+PI
2170 G2=B8*G2
2180 IF G2<0 THEN G2=G2+360
2190 X(9,I)=G2
2200 D=ATN(Q3*F9)
2210 D1=SIN(D8)
2220 D2=-COS(D8)
2230 D3=-COS(D)
2240 G3=SIN(D)
2250 G=D3*D2
2260 G5=-D1*D3
2270 G6=D4*G+D5*G5+D6*G3
2280 G7=.25*((D4-G)*(D4-G)+(D5-G
     5)*(D5-G5)+(D6-G3)*(D6-G3))
2281 G7=SQR(G7*((D4+G)*(D4+G)+(D
     5+G5)*(D5+G5)+(D6+G3)*(D6+G
     3)))
2290 D2=ATN(G7/G6)
2300 IF SGN(G7)=-1 AND SGN(G6)=-
     1 THEN D2=D2-PI
2310 IF SGN(G7)=1 AND SGN(G6)=-1
      THEN D2=D2+PI
2320 X(3,I)=B8*D2
2330 D1=SIN(.5*(Q6+D7))
2340 G8=Q2*SQR(1-Q4)/(1-Q4*D1*D1
     )
2350 X(10,I)=G8*D2
2354 GOTO 2360
2355 X(9,I)=X(9,I-1)
2356 X(10,I)=X(10,I-1)
2360 NEXT I
2370 RETURN
2380 FOR I=1 TO W9
2392 X6(I)=W(I)
2393 NEXT I
2400 N1=M1
2410 N2=M2
2420 N3=M4
2430 K2=A2
2440 GOSUB 2750
2450 FOR I=1 TO W9
2452 W(I)=X6(I)
2453 NEXT I
2460 A2=K2
2470 M4=N3
2480 M1=N1
2490 M2=N2
2500 IF A2<>0 THEN 2740
2620 FOR I=1 TO W9
2622 W7(I)=W(I)
2623 NEXT I
2630 W8=1-M7
2640 GOSUB 7170
2650 FOR I=1 TO W9
2662 B7(I)=W7(I)
2663 X6(I)=W7(I)
2664 NEXT I
2670 J1=M4
2680 GOSUB 3220
2690 M4=J1
2700 FOR I=1 TO W9
2702 W7(I)=X6(I)
2703 NEXT I
2710 W8=M7-1
2720 GOSUB 7170
2730 FOR I=1 TO W9
2732 W(I)=W7(I)
```

```
2733 NEXT I
2740 RETURN
2750 N1=1
2770 N2=0
2780 K1=1/40/N3
2790 N4=1
2800 K2=0
2810 FOR I=1 TO N3
2820 N5=N4
2830 N6=1
2840 FOR J=1 TO I
2850 K5=W(N4)
2860 IF J=1 THEN 2910
2870 FOR K=N5 TO N7
2880 K5=K5-X6(K)*X6(N6)
2890 N6=N6+1
2900 NEXT K
2910 IF I<>J THEN 3040
2920 N1=N1*K5
2930 IF W(N4)+K5*K1<=W(N4) THEN
     3110
2940 IF ABS(N1)<=1 THEN 2980
2950 N1=N1/50
2960 N2=N2+4
2970 GOTO 2940
2980 IF 50*ABS(N1)>=1 THEN 3020
2990 N1=N1*50
3000 N2=N2-4
3010 GOTO 2980
3020 X6(N4)=1/SQR(K5)
3030 GOTO 3050
3040 X6(N4)=K5*X6(N6)
3050 N7=N4
3060 N4=N4+1
3070 N6=N6+1
3080 NEXT J
3090 NEXT I
3100 GOTO 3120
3110 K2=1
3120 RETURN
3130 FOR I=1 TO W9
3142 B7(I)=W(I)
3143 NEXT I
3150 FOR I=1 TO W9
3160 L=I+W8
3170 IF L>W9 THEN L=L-W9
3180 IF L<1 THEN L=L+W9
3190 W(L)=B7(I)
3200 NEXT I
3210 RETURN
3220 Q2=1
3240 Q3=0
3250 FOR L=1 TO J1
3260 L8=B7(L)
3270 Q4=L-1
3280 IF Q3=0 THEN 3350
3290 Q2=Q2+Q3-1
3300 FOR K=Q3 TO Q4
3310 L8=L8-W(Q2)*X6(K)
3320 Q2=Q2+1
3330 NEXT K
3340 GOTO 3370
3350 IF L8<>0 THEN Q3=L
3360 Q2=Q2+Q4
3370 X6(L)=L8*W(Q2)
3380 Q2=Q2+1
3390 NEXT L
3400 Q5=J1+1
3410 FOR L=1 TO J1
3420 Q6=Q5-L
3430 Q2=Q2-1
3440 Q7=Q2
3450 Q8=Q6+1
3460 L8=X6(Q6)
3470 IF J1<Q8 THEN 3540
3480 Q9=J1
3490 FOR K=Q8 TO J1
3500 L8=L8-W(Q7)*X6(Q9)
3510 Q9=Q9-1
3520 Q7=Q7-Q9
3530 NEXT K
3540 X6(Q6)=L8*W(Q7)
3550 NEXT L
3560 RETURN
3570 INTEGER R,R1,R2,R3,R4,R5,R6
     ,R7,R8,R9,S,S1,S2,S3,S4,S5,
     S6,S7,S8,S9,T,T1,T2,T3,T4
3590 DATA 12,.1,100,.1,2
3600 RESTORE 3590
3610 READ T8,T9,U,U1,U2
3620 B2=0
3630 U3=10^(-T8-1)
3640 U4=10^(-.5*T8)
3650 R=(N+1)*N/2
3660 R1=R+1
3670 R2=R+N
3680 R3=R2
3690 R4=R3+1
3700 R5=R3+N
3710 R6=R5
3720 R7=R6+1
3730 R8=R6+N
3740 R9=R8
3750 S=R9+1
3760 S1=R9+N
3770 S2=S1+N
3780 S3=S2+1
3790 S4=S2+M
3800 S5=S4
3810 S6=S5+1
3820 U5=D9/2
3830 U6=.01
3840 U7=1/U2
3850 U8=U2*U2
3860 U9=U8^4
3870 V=U6
3880 V1=10000000000
3890 S7=-99
3900 S8=1
3910 S9=-1
```

```
3920 B4=0
3930 B2=0
3940 FOR J=R4 TO R5
3950 W(J)=0
3960 NEXT J
3970 GOTO 5300
3980 V2=V3
3990 IF B4>0 OR T>=N OR T5>0 THE
     N 4210
4000 T=T+1
4010 V4=0
4020 FOR J=R4 TO R5
4030 V4=V4+W(J)*W(J)
4040 NEXT J
4050 IF V4<=0 THEN 4210
4060 FOR I=1 TO M
4070 V5=X(11,I)-W(S5+I)
4080 K=I
4090 FOR J=R4 TO R5
4100 V5=V5+D1(K)*W(J)
4110 K=K+M
4120 NEXT J
4130 V5=V5/V4
4140 K=I
4150 FOR J=R4 TO R5
4160 D1(K)=D1(K)-V5*W(J)
4170 K=K+M
4180 NEXT J
4190 NEXT I
4200 GOTO 4630
4210 T=0
4220 K=0
4230 FOR J=1 TO N
4240 V6=ABS(P(1,J))
4250 V7=U4*MAX(V6,T9)
4260 V8=P(1,J)
4270 P(1,J)=P(1,J)+V7
4280 W8=1-S3
4290 GOSUB 3130
4300 FOR I=1 TO 4
4310 Q(I)=P(1,I)
4320 NEXT I
4330 GOSUB 6550
4340 FOR I=1 TO M
4350 W(I)=B7(I)
4360 NEXT I
4370 W8=S3-1
4380 GOSUB 3130
4390 P(1,J)=V8
4400 IF S8=1 THEN 4570
4410 P(1,J)=V8-V7
4420 W8=1-S6
4430 GOSUB 3130
4440 GOSUB 6550
4450 FOR I=1 TO M
4460 W(I)=B7(I)
4470 NEXT I
4480 W8=S6-1
4490 GOSUB 3130
4500 P(1,J)=V8
4510 V9=.5/V7*P(2,J)
4520 FOR I=S3 TO S4
4530 K=K+1
4540 D1(K)=V9*(W(I)-W(I+M))
4550 NEXT I
4560 GOTO 4620
4570 V9=1/V7*P(2,J)
4580 FOR I=1 TO M
4590 K=K+1
4600 D1(K)=V9*(W(S2+I)-X(11,I))
4610 NEXT I
4620 NEXT J
4630 W=V1
4640 V1=0
4650 K=0
4660 FOR J=R1 TO R2
4670 W1=0
4680 FOR I=1 TO M
4690 K=K+1
4700 W1=W1+D1(K)*X(11,I)
4710 NEXT I
4720 W(J)=W1
4730 V1=V1+W1*W1
4740 NEXT J
4750 V1=SQR(V1)
4760 IF T>0 THEN 4790
4770 IF V1<=U5 THEN B4=B4+4
4780 IF V1<=U1 THEN S8=2
4790 T1=0
4800 T2=-M
4810 FOR I=1 TO N
4820 T2=T2+M
4830 T3=0
4840 FOR J=1 TO I
4850 T1=T1+1
4860 W1=0
4870 FOR K=1 TO M
4880 T4=T2+K
4890 T3=T3+1
4900 W1=W1+D1(T4)*D1(T3)
4910 NEXT K
4920 B(T1)=W1
4930 NEXT J
4940 NEXT I
4950 K=0
4960 FOR J=1 TO N
4970 K=K+J
4980 W(R6+J)=B(K)
4990 NEXT J
5000 T5=0
5010 K=0
5020 IF B4>0 OR B2>0 THEN U6=V
5030 FOR I=1 TO N
5040 FOR J=1 TO I
5050 K=K+1
5060 W(K)=B(K)
5070 NEXT J
5080 W(K)=W(K)+U6*W(R6+I)
5090 IF W(K)<=0 THEN W(K)=1
5100 W(R3+I)=W(R+I)
```

```
5110 NEXT I
5120 IF B4>0 OR B2>0 THEN 6100
5130 IF S9>=A4 THEN 6060
5140 FOR I=1 TO 16 ! !!!!!
5142 B7(I)=W(I)
5143 NEXT I
5150 M1=V5
5160 M2=V8
5170 M3=N
5180 M4=N
5190 M5=1
5200 M6=1
5210 M7=R4
5220 GOSUB 2380
5230 IF B2=0 THEN 5290
5240 B2=0
5250 IF T>0 THEN 4210
5260 IF S7<=0 THEN 5880
5270 IF S7>=2 THEN 6090
5280 GOTO 5590
5290 IF S7<>-99 THEN S7=0
5300 FOR J=1 TO N
5310 W(R9+J)=P(1,J)-W(R3+J)
5320 NEXT J
5330 FOR J=1 TO 4
5340 W2(J)=W(S+J-1)
5350 NEXT J
5360 W8=1-S3
5370 GOSUB 3130
5380 FOR I=1 TO 4
5390 Q(I)=W2(I)
5400 NEXT I
5410 GOSUB 6550
5420 FOR I=1 TO M
5430 W(I)=B7(I)
5440 NEXT I
5450 W8=S3-1
5460 GOSUB 3130
5470 V3=0
5480 FOR I=S3 TO S4
5490 V3=V3+W(I)*W(I)
5500 NEXT I
5510 IF S9>=0 THEN 5580
5520 S9=0
5530 V2=V3
5540 FOR I=1 TO M
5550 X(11,I)=W(S2+I)
5560 NEXT I
5570 GOTO 4210
5580 IF V3<=V2 THEN 5690
5590 T5=T5+1
5600 U6=U6*U8
5610 IF T=0 THEN 5630
5620 IF T5>=4 OR U6>U THEN 5670
5630 IF U6<=U THEN 5010
5640 IF S7=1 THEN 6090
5650 B2=3
5660 GOTO 5010
5670 U6=U6/U9
5680 GOTO 4210
5690 IF T5=0 THEN U6=U6/U2
5700 IF W<=0 THEN 5740
5710 V5=V1/W
5720 IF V1<W THEN U6=U6*MAX(U7,V
     5)
5730 IF V1>W THEN U6=U6*MIN(U2,V
     5)
5740 U6=MAX(U6,U3)
5750 S9=S9+1
5760 V=U6
5770 FOR J=1 TO N
5780 P(1,J)=W(R9+J)
5790 NEXT J
5800 FOR I=1 TO M
5810 W(S5+I)=X(11,I)
5820 X(11,I)=W(S2+I)
5830 NEXT I
5840 IF T5>0 OR T>0 THEN 3980
5850 W4=ABS(V3-V2)/MAX(V2,T9)
5860 IF W4<=D9 THEN B4=B4+2
5870 GOTO 3980
5880 ON SGN(S7)+2 GOTO 5940,5890
     ,5980
5890 FOR J=1 TO N
5900 V8=W(S1+J)
5910 IF ABS(P(1,J)-V8)>U4*MAX(T9
     ,ABS(V8)) THEN 5940
5920 NEXT J
5930 GOTO 6080
5940 FOR J=1 TO N
5950 W(S1+J)=P(1,J)
5960 NEXT J
5970 S7=1
5980 T6=0
5990 FOR J=1 TO R7 STEP R8
6000 IF W(J)>0 THEN 6030
6010 T6=T6+1
6020 W(J)=1
6030 NEXT J
6040 IF T6<N THEN 5010
6050 B2=B2+1
6060 B2=B2+1
6070 B2=B2+1
6080 B2=B2+1
6090 B2=B2+1
6100 FOR I=1 TO N
6110 FOR J=1 TO N
6120 B1(I,J)=0
6130 NEXT J
6140 B1(I,I)=1
6150 NEXT I
6160 V7=0
6170 T2=1
6180 FOR J=1 TO N
6190 W1=0
6200 T2=T2+J-1
6210 FOR K=1 TO J
6220 T3=T2+K-1
6230 W1=W1+ABS(W(T3))
6240 NEXT K
```

```
6250 T1=J+1
6260 IF J>N THEN 6310
6270 FOR K=T1 TO N
6280 T3=T3+K-1
6290 W1=W1+ABS(W(T3))
6300 NEXT K
6310 V7=MAX(V7,W1)
6320 NEXT J
6330 M1=V5
6340 M2=V8
6350 M3=4
6360 M4=N
6370 M5=N
6390 M6=0
6395 M7=0
6400 GOSUB 7260
6420 V9=0
6430 FOR I=1 TO N
6440 W1=0
6450 FOR J=1 TO N
6460 W1=W1+ABS(B1(I,J))
6470 NEXT J
6480 V9=MAX(V9,W1)
6490 NEXT I
6500 W(1)=S9
6510 W(2)=V2
6520 W(3)=U6
6530 W(4)=V7*V9
6540 RETURN
6550 X=Q(1)/P(3,1)
6600 X1=Q(2)/P(3,2)
6610 X2=Q(3)/P(3,3)
6620 X3=Q(4)/P(3,4)
6630 E=X1
6640 E1=X2
6670 GOSUB 1910
6680 FOR L=1 TO M
6690 D=K(L)
6700 Z8=X(10,L)
6710 IF X(10,L)>=2100 THEN 6810
6711 IF D<9 THEN 6715
6712 Z4=Z(1,15)
6713 Z6=Z(1,16)
6714 GOTO 6720
6715 Z4=Z(1,7)
6716 Z6=Z(1,8)
6717 IF D>2 AND D<9 THEN 6775
6718 IF D>10 THEN 6775
6720 IF X3>Z4+Z6 THEN 6737
6732 IF Z6>0 AND X3>=Z4 AND X3<Z
     4+Z6 THEN 6734
6733 GOTO 6740
6734 Z6=0
6735 O6=Z(1,D+2)
6736 GOTO 6985
6737 O6=Z(1,D+4)
6738 GOTO 6985
6740 IF L=1 THEN 6742
6741 IF S2(L)=S2(L-1) THEN 7155
6742 B7(L)=SQR(X3*ABS(X3)+Z8^2)/
     Z(1,D)-X(2,L)+X
6743 B7(L)=SQR(X3*ABS(X3)+Z8^2)/
     Z(1,D)-X(2,L)+X
6750 IF X3<=0 THEN X(5,L)=PI/2
6760 IF X3>0 THEN X(5,L)=ATN(Z8/
     X3)
6770 GOTO 7150
6775 IF L=1 THEN 6780
6776 IF S2(L)=S2(L-1) AND D MOD
     2=0 AND D=K(L-1)+1 THEN 715
     5
6780 IF Z6<>0 THEN 6784
6781 B7(L)=Z8/Z(1,D)+(2*Z4-X3)*S
     QR(Z(1,D)^2-Z(1,D-2)^2)/(Z(
     1,D)*Z(1,D-2))-X(2,L)+X
6782 X(5,L)=PI/2+ACS(Z(1,D-2)/Z(
     1,D))
6783 GOTO 7150
6784 Z7=Z4-X3
6785 IF X3<Z4 THEN Z7=0
6786 B7(L)=Z8/Z(1,D+2)+(2*Z4-X3-
     Z7)*SQR(Z(1,D+2)^2-Z(1,D-2)
     ^2)/(Z(1,D+2)*Z(1,D-2))-X(2
     ,L)+X
6787 B7(L)=B7(L)+(2*Z6+Z7)*SQR(Z
     (1,D+2)^2-Z(1,D)^2)/(Z(1,D+
     2)*Z(1,D))
6788 X(5,L)=PI/2+ACS(Z(1,D-2)/Z(
     1,D+2))
6790 IF X3>Z4 THEN X(5,L)=PI/2+A
     CS(Z(1,D)/Z(1,D+2))
6800 GOTO 7150
6810 Y1=Z8/111.12
6820 X(5,L)=0
6830 B7(L)=0
6840 IF Y1<2100/111.12 THEN 7150
6850 IF Y1>100 THEN 7150
6860 Q1=A2(INT(2*Y1+1))
6861 Q1=Q1+(A2(INT(2*Y1)+2)-A2(I
     NT(2*Y1+1)))*(2*Y1-INT(2*Y1
     ))/(INT(2*Y1+1)-INT(2*Y1))
6870 Q2=.145718067221*X3+1.47880
     905697E-3*X3^2-6.8027403214
     E-5*X3^3
6871 Q2=Q2+8.6528478081E-7*X3^4-
     3.5760971074E-9*X3^5
6880 Q3=2.95593487161E-4*X3-6.52
     15899985E-6*X3^2+1.99780616
     797E-7*X3^3
6881 Q3=(Q3-2.06679114896E-9*X3^
     4+7.2346715915E-12*X3^5)*(Y
     1-60)
6890 Q4=-9.3053075417E-6*X
6891 Q4=(Q4+2.38862433757E-10*X3
     ^4-9.83465607815E-13*X3^5)*
     (Y1-60)^2
6900 Q5=8.23660713921E-8*X3-1.58
     92030381E-9*X3^2+9.99818119
     8E-11*X3^3
6901 Q5=(Q5-1.4735449709E-12*X3^
     4+6.6798941686E-15*X3^5)*(Y
     1-60)^3
```

```
6910 Q6=9.0813929833E-10*X3-2.39
     857731243E-10*X3^2+5.978901
     6273E-12*X3^3
6911 Q6=(Q6-6.886476807E-14*X3^4
     +2.8429427292 7E-16*X3^5)*(Y
     1-60)^4
6920 Q1=Q1-Q2-Q3-Q4-Q5-Q6
6930 B7(L)=Q1-X(2,L)+X
6940 GOTO 7150
6950 Q7=2*(A2(INT(2*Y1+2))-A2(IN
     T(2*Y1+1)))
6960 Q8=8.3*Q7/B9 ! "8.3" IS TO
     BE VELOCITY OF P WAVES AT T
     HE DEPTH OF THE EARTHQUAKE.
      MUST PUT IN A V(P) VS. DEP
     TH TABLE AND CALCULATE APPR
     OPRIATE VALUE
6970 X(5,L)=ATN(-Q8/SQR(1-Q8^2))
6980 GOTO 7150
6985 IF L=1 THEN 6990
6986 IF S2(L)=S2(L-1) THEN 7155
6990 Q1=ATN(Z8/X3)
6991 Q7=Z8*(X3-Z4-Z6)/X3
6992 Q8=Z8
7000 Q2=ATN(Z8/(X3-Z4-Z6))
7010 Q3=ASN(SIN(Q1)*Z(1,D)/06)
7020 Q4=ASN(SIN(Q2)*Z(1,D)/06)
7021 O3=ASN(SIN(Q1)*Z(1,D+2)/06)
7022 O4=ASN(SIN(Q2)*Z(1,D+2)/06)
7030 Q5=Q7+Z4*TAN(Q3)+Z6*TAN(O3)
7040 Q6=Q8+Z4*TAN(Q4)+Z6*TAN(O4)
7070 Z1=(Q8-Q7)*((Z8-Q5)/(Q6-Q5)
     )+Q7
7080 Z2=ASN(SIN(ATN(Z1/(X3-Z4-Z6
     )))*(Z(1,D)/06))
7082 O5=ASN(SIN(ATN(Z1/(X3-Z4-Z6
     )))*(Z(1,D+2)/06))
7090 Z3=Z1+Z4*TAN(Z2)+Z6*TAN(O5)
7100 IF ABS(Z8-Z3)>.2 AND Z8-Z3>
     0 THEN 7140
7110 IF ABS(Z8-Z3)>.2 AND Z8-Z3<
     0 THEN 7143
7120 B7(L)=SQR(Z1^2+(X3-Z4-Z6)^2
     )/06+Z4/(COS(Z2)*Z(1,D))-X(
     2,L)+X+Z6/(COS(O5)*Z(1,D+2)
     )
7121 X(5,L)=ATN(Z1/(X3-Z4))
7130 GOTO 7150
7140 Q7=Z1
7141 Q5=Z3
7142 GOTO 7070
7143 Q8=Z1
7144 Q6=Z3
7145 GOTO 7070
7150 B7(L)=X(1,L)*B7(L)
7151 GOTO 7158
7155 B7(L)=((B7(L-1)/X(1,L-1)+X(
     2,L-1)-X)*SQR(3)-X(2,L)+X)*
     X(1,L)
7156 X(5,L)=X(5,L-1)
7158 NEXT L
7160 RETURN
7170 FOR I=1 TO W9
7182 B7(I)=W7(I)
7183 NEXT I
7190 FOR I=1 TO W9
7200 L=I+W8
7210 IF L>W9 THEN L=L-W9
7220 IF L<1 THEN L=L+W9
7230 W7(L)=B7(I)
7240 NEXT I
7250 RETURN
7260 B2=0
7290 FOR I=1 TO W9
7292 X6(I)=W(I)
7293 NEXT I
7300 N1=M1
7310 N2=M2
7320 N3=M4
7330 K2=B2
7340 GOSUB 2750
7350 FOR I=1 TO W9
7352 W(I)=X6(I)
7353 NEXT I
7360 M4=N3
7370 B2=K2
7380 IF B2<>0 THEN 7540
7390 FOR I=1 TO M5
7400 FOR J=1 TO M3
7410 X7(J)=B1(J,I)
7420 NEXT J
7430 FOR L=1 TO M3
7440 B7(L)=X7(L)
7450 X6(L)=X7(L)
7460 NEXT L
7470 J1=M4
7480 GOSUB 3220
7490 M4=J1
7500 FOR J=1 TO M3
7510 B1(J,I)=X6(J)
7520 NEXT J
7530 NEXT I
7540 RETURN
```

Notes for VMMAK2

(For use with BERQ85)

This program is for use with BERQ85 and provides the means for entering velocity models into BERQ85. Two separate velocity models can be entered (for modeling either side of the San Andreas Fault simultaneously). The permissable models are half-space, one layer over a half-space, and two layers over a half-space, all media being of uniform velocity. Therefore, eight paramenters characterize each model, leading to a total of sixteen parameters. No matter what model(s) you choose to use, sixteen parameters must be entered into the velocity model file. Phases are assigned to a specific velocity model in ATMAK2 so any numbers can be entered in operationally irrelevant spaces in the velocity model file. However, sixteen entries are required in order for BERQ85 to not get confused when it reads the velocity model file. The name of the velocity model file is assigned in line 320 of VMMAK2 (see listing).

The parameters for each model are entered in the order:

P velocity of upper layer

S velocity of upper layer

P velocity of lower layer

S velocity of lower layer

P velocity of half-space

S velocity of half-space

Thickness (km) of upper layer

Thickness (km) of lower layer

Remember, you must enter sixteen values even if many of them are operationally irrelevant.

See notes for BERQ85 for the mode of entering data for half-space and one layer models.

```
10 ! PROGRAM VMMAK2. FOR USE WI
   TH BERQ85. ALLOWS FOR TWO SE
   PARATE
20 ! P1,S1,P2,S2,P3,S3, MODELS
   WITH DIFFERENT LAYER THICKNE
   SSES H1 AND H2.
30 ! MODELS CAN BE NONE, ONE OR
    TWO LAYERS OVER A HALF-SPAC
   E,-ALL CONSTANT
40 ! VELOCITY. THERE ARE EIGHT
   PARAMETERS FOR EACH MODEL. I
   F YOU WISH TO
50 ! USE A SINGLE LAYER MODEL O
   VER A HALF-SPACE, P3 AND S3
   ARE THE Pn AND Sn
60 ! VELOCITIES AND P2,S2 AND L
   2 ARE SET EQUAL TO ZERO.
70 ! THIS PROGRAM MAKES A SINGL
   E ARRAY OF NUMBERS AS FOLLOW
   S:
80 ! Z(1,1)=P1 OF MODEL 1 (Pg)
90 ! Z(1,2)=S1 OF MODEL 1 (Sg)
100 ! Z(1,3)=P2 OF MODEL 1 (P IN
     2ND LAYER)
110 ! Z(1,4)=S2 OF MODEL 1 (S IN
     2ND LAYER)
120 ! Z(1,5)=P3 OF MODEL 1 (Pn I
    N LAYERED MODEL)
130 ! Z(1,6)=S3 OF MODEL 1 (Sn I
    N LAYERED MODEL)
140 ! Z(1,7)=H1 OF UPPER LAYER O
    R ONLY LAYER
150 ! Z(1,8)=H2 OF LOWER LAYER
160 ! Z(1,9)=P1 OF MODEL 2 (Pg)
170 ! Z(1,10)=S1 OF MODEL 2 (Sg)
180 ! Z(1,11)=P2 OF MODEL 2 (P I
    N 2ND LAYER)
190 ! Z(1,12)=S2 OF MODEL 2 (S I
    N 2ND LAYER)
200 ! Z(1,13)=P3 OF MODEL 2 (Pn
    IN LAYERED MODEL)
210 ! Z(1,14)=S3 OF MODEL 2 (Sn
    IN LAYERED MODEL)
220 ! Z(1,15)=H1 OF UPPER LAYER
    OR ONLY LAYER
230 ! Z(1,16)=H2 OF LOWER LAYER
240 ! YOU MUST ENTER ALL SIXTEEN
     VALUES EVEN IF MANY OR MOST
     OF THEM ARE ZERO
250 OPTION BASE 1
260 SHORT Z(1,16)
270 DATA 5.5,3.18,6.8,3.93,8.1,4
    .68,12,18,0,0,0,0,0,0,0,0
280 FOR I=1 TO 16
290 READ Z(1,I)
310 NEXT I
320 N$="VLGUAT"
330 CREATE N$,1,256
340 ASSIGN# 1 TO N$
350 PRINT N$
360 PRINT# 1 ; N$
370 FOR I=1 TO 16
380 PRINT I,Z(1,I)
390 PRINT# 1 ; Z(1,I)
400 NEXT I
410 END
```

Notes for STMAK2

(For use with BERQ85)

This program is for use with BERQ85 and generates the file containing the station library for the network being used in the locations.

Because of a variety of considerations, stations are designated by numbers, not letters in BERQ85 and STMAK2.

If latitude and longitude of the stations are known in degrees, minutes, and seconds, enter them in this program in the form

ddd.mmsss

i.e., place a decimal point after the degrees and then string the minutes and seconds without punctuation. If station coordinates are known in fractional degrees, enter as such and insert the following line temporarily in STMAK2

365 GOTO 440

The sign convention for latitude and longitude is north and east positive, south and west negative.

"Nos" is number of stations to be included in network.

The data sequence for each station is latitude, longitude, elevation (km), station time correction (for P phases and to be added to observed travel times), and station number identifier.

The name of the station file is assigned in line 260.

```
10 ! program STMAK2. generates
   station library for BERQ85
20 ! if latitude and longitude
   are given in d,m,s, enter in
   form ddd.mmsss,
30 ! i.e.,a decimal point after
   degrees and then string the
   minutes and
40 ! seconds without punctuatio
   n. If coordinates are alread
   y in fractional
50 ! degrees, put in the line "
   365 GOTO 440". The sign
60 ! convention is east and nor
   th positive, west and south
   negative.
70 ! Nos is number of stations
   to be included in network.
80 ! the data sequence for each
   station is latitude,longitu
   de,elevation(km),
90 ! station time correction(se
   c added to observed time), a
   nd station
100 ! number identifier.
110 OPTION BASE 1
120 DIM S(4),S1(2)
130 INTEGER I,N1,N
140 DATA 10
150 DATA 30,-122,0,0,1
160 DATA 30,-120.3,0,0,2
170 DATA 30,-119.45,0,0,3
180 DATA 30,-119.3,0,0,4
190 DATA 30.15,-120,0,0,5
200 DATA 30.3,-120,0,0,6
210 DATA 31,-120,0,0,7
220 DATA 29,-120,0,0,8
230 DATA 29.3,-120,0,0,9
240 DATA 30.01,-120.01,0,0,10
260 N$="TSTSTA"
270 CREATE N$,1,1250
280 ASSIGN# 1 TO N$
290 PRINTER IS 0
300 PRINT N$
310 READ N1
320 PRINT# 1 ; N1
330 PRINT N1
340 FOR I=1 TO N1
350 FOR J=1 TO 2
360 READ S(J)
370 S1(J)=S(J)
380 S(J)=ABS(S(J))
390 A1=S(J)-INT(S(J))
400 A2=100*A1
410 A3=A2-INT(A2)
420 F=(A3*100+60*INT(A2))/3600
430 S(J)=(INT(S(J))+F)*(S1(J)/AB
    S(S1(J)))
440 NEXT J
450 READ S(3),S(4),N
451 FOR J=1 TO 4
452 PRINT# 1 ; S(J)
453 NEXT J
454 PRINT# 1 ; N
470 PRINT USING "4(6D.4D),5X2D"
    ; S(1),S(2),S(3),S(4),N
480 NEXT I
490 PRINTER IS 16
500 STOP
510 END
```

Notes for ATMAK2

(For use with BERQ85)

This program is for use with BERQ85 and generates the arrival time file for events to be located by BERQ85.

The order of data entry is as follows:

I$[32]	Identification of event (DATE--HR/MIN--NAME OR LOCATION)
N1	Number of time readings for event
N2	Always set this number equal to zero
S1	Estimated standard error of the readings (set by you)
Q(1) to Q(4)	Weights for origin time estimate, latitude estimate, longitude estimate, and depth estimate
P(1) to P(4)	Initial estimates of origin time, latitude, longitude, and depth. Estimated origin time is entered in the format HH.MMSSS. Estimated latitude and longitude are entered in fractional degrees, estimated depth is entered in kilometers
T1	Clock correction to be added to all arrival times

Data for each travel time are to be entered in the following order:

N	Station number

X	Number of appropriate phase or ray (see below)
Y	Arrival time (in format HH.MMSSS)
Z	Weight to be attached to this traveltime (see notes for BERQ85 for appropriate scheme for assigning weights)

Data of several events can be entered into the same arrival time file and the events will be sequentially analyzed by BERQ85 without any required interaction with you. You need not enter the number of events into the data file. The last data card must read DATA "NOMORE".

Since only station numbers appear in the output of BERQ85, I suggest you put a table of number-name equivalence into STMAK2 and arrange to print it before each run.

Ray numbers are assigned as follows: (1 or 9) for direct P; (2 or 10) for direct S; (3 or 11) for lower interface P; (4 or 11) for lower interface S. 1,2,3, and 4 apply to the first velocity model in VMMAK2, while 9,10,11, and 12 apply to the second model in VMMAK2. No other crustal phases are permitted even if using a two-layer crust.

Teleseismic P times can be given any phase or ray value as BERQ85 finds these by checking epicentral distance.

When locating local deep-focus earthquakes, use rays 1 and 2 or 9 and 10, not 3 and 4 or 11 and 12.

IMPORTANT Paired P and S phases must always be entered with the P data preceding the S data.

```
10 ! program ATMAK2, generates
   arrival time file for BERQ85
20 ! The order of data entry is
    as follows:
30 ! I$[32]             Identificat
   ion of event (DATE--HR/MIN--
   NAME or LOCATION)
40 ! N1                  Number of
   time readings for event
50 ! N2                  Always set
    this number equal to zero!!
   !!!
90 ! S1                  Estimated
   standard  error of the readi
   ngs (set by you).
100 ! Q(1) TO Q(4)    Weight for
   origin time estimate,latitud
   e estimate, longitude estima
   te, and
110 ! depth estimate.
120 ! P(1) TO P(4)     Initial es
   timate of origin time.latitu
   de, longitude, and depth.
130 ! Estimated origin time is e
   ntered in the format,
140 !        HH.MMSSSS
150 !                    Estimated
   latitude and longitude are e
   ntered in FRACTIONAL DEGREES

170 !                    Estimated
   depth is entered in KILOMETE
   RS.
180 ! T1                 Clock corr
   ection to be ADDED to ALL ar
   rival times.
181 ! Data for each arrival time
    are entered in the followin
   g order:
182 ! N    Station number (see b
   elow)
183 ! X    Number of appropriate
    phase or ray(see below)
184 ! Y    Arrival time (see lin
   e 200 below for proper forma
   t)
185 ! Z    Weight to be attached
   to this arrival time. Z=1 me
   ans phase used,Z=0 means not
    used.
190 ! Arrival times are to be en
   tered in the following forma
   t:
200 !       HH.MMSSSS
210 ! This program converts arri
   vals times so entered into o
   rigin time in seconds re HH.
   MM of
220 ! estimated origin time (P1)
   , and stores these calculate
   d times in the event data fi
   le.
230 ! Clock corrections(i.e.,Tc)
   are applied before storage.
240 ! Data of several events can
   be entered into the same arr
   ival time file.
250 ! This program is so written
   that you need not enter numb
   er  of events in the file.
260 ! The last DATA card must re
   ad   DATA "NOMORE"
261 ! Station name -- Since the
   HP85 will not handle string
   arrays, each station must ha
   ve a
262 ! number designation in the
   program.I suggest that you e
   nter here in this program a
   table of
263 ! equivalence between your n
   ames of each station and the
    numbers assigned to them.
265 ! Ray numbers -- (1,9) direc
   t P,(2,10) direct S,(3,11) i
   nterface Pn,(4,12) interface
    Sn.
266 ! No other crustal phases ar
   e permitted even if using a
   two-layer crust.
267 ! Teleseismic P times can be
    given any phase or ray valu
   e as the program finds these
    by
268 ! epicentral distance. When
   locating local deep-focus ea
   rthquakes, use (1) and (2)
269 ! for P and S phases. Do not
    use (3) and (4)!!
270 ! Ray numbers 9,10,11,12 are
   to be used when two velocity
     models are used (2 sides o
   f SAF)
290 !  !!!!!!IMPORTANT!!!!!!!!!
291 !  PAIRED P AND S PHASES  !
292 !  MUST ALWAYS BE ENTERED!
293 !  WITH P DATA PRECEDING  !
294 !         S DATA           !
295 !  !!!!!!IMPORTANT!!!!!!!!!
300 OPTION BASE 1
310 DIM I$[32]
320 SHORT Q(4),T1,X,Z,S(4)
321 INTEGER N
330 DIM P(4)
340 INTEGER I,N1,N2
350 DATA "DATE-80/02/04  112438"
360 DATA 12,0,.1,1,1,1,1,11 2438
   ,35.83,-120.35,10,0
365 DATA 1,1,11.244185,1,1,2,11.
   2445,.2
370 DATA 2,1,11.244272,1
375 DATA 3,9,11.244045,.5,3,10,1
   1 24431,.2
```

```
380 DATA 4,1,11.244264,1
385 DATA 5,9,11.244025,.8
390 DATA 6,9,11.244188,.5
395 DATA 7,9,11.24405,1,7,10,11.
    244247,.8
400 DATA 8,9,11.244083,1,9,1,11.
    244107,.8
1560 DATA "NOMORE"
1565 PURGE "ATCAL1",0
1571 N$="ATCAL1"
1590 CREATE N$,1,512
1600 ASSIGN# 1 TO N$
1620 PRINT N$
1640 READ I$
1670 PRINT I$
1680 PRINT# 1 ; I$
1685 IF I$="NOMORE" THEN 1990
1690 READ N1
1700 PRINT N1
1710 PRINT# 1 ; N1
1720 READ N2,S1
1721 FOR I=1 TO 4
1722 READ Q(I)
1723 NEXT I
1724 FOR I=1 TO 4
1725 READ P(I)
1726 NEXT I
1727 READ T1
1730 S(1)=100*FP(100*P(1))
1740 S(2)=P(2)
1750 S(3)=P(3)
1760 S(4)=P(4)
1770 PRINT USING "4D,5(2D.2D)" ;
      N2,S1,Q(1),Q(2),Q(3),Q(4)
1771 PRINT USING "4(4D.4D),MDD.D
     " ; S(1),S(2),S(3),S(4),T1
1780 PRINT# 1 ; N2,S1
1781 FOR I=1 TO 4
1782 PRINT# 1 ; Q(I)
1783 NEXT I
1784 FOR I=1 TO 4
1785 PRINT# 1 ; S(I)
1786 NEXT I
1790 FOR I=1 TO N1
1800 READ N,X,Y,Z
1810 O1=INT(P(1))
1820 O2=INT(100*(P(1)-INT(P(1)))
     )
1830 O3=100*(100*(P(1)-INT(P(1))
     )-O2)
1840 A1=INT(Y)
1850 A2=INT(100*(Y-INT(Y)))
1860 A3=100*(100*(Y-INT(Y))-A2)
1870 Y=3600*(A1-O1)+60*(A2-O2)+(
     A3-O3)+T1
1920 Y=Y+O3
1940 PRINT USING "2D,5D,5D.3D,3D
     .D" ; N,X,Y,Z
1950 PRINT# 1 ; N,X,Y,Z
1960 NEXT I
1970 GOTO 1640
1990 STOP
2000 END
```

HERRIN P Travel-Time Curve

(Surface Focus)

HERRI[illegible] TIME CURVE
SURF[illegible]S

DIST(DEG)	T.TIME(SEC)
0	0
.5	9.27
1	18.53
1.5	26.95
2	34.86
2.5	41.72
3	48.58
3.5	55.44
4	62.29
4.5	69.14
5	75.99
5.5	82.83
6	89.67
6.5	96.5
7	103.33
7.5	110.16
8	116.98
8.5	123.79
9	130.6
9.5	137.4
10	144.19
10.5	150.97
11	157.75
11.5	164.52
12	171.28
12.5	178.03
13	184.77
13.5	191.5
14	198.19
14.5	204.86
15	211.48
15.5	218.04
16	224.55
16.5	230.98
17	237.34
17.5	243.61
18	249.78
18.5	255.84
19	261.79
19.5	267.61
20	273.32
20.5	278.9
21	284.37
21.5	289.72
22	294.95
22.5	300.08
23	305.11
23.5	310.05
24	314.91
24.5	319.68
25	324.39
25.5	329.03
26	333.63
26.5	338.18
27	342.71
27.5	347.2
28	351.68
28.5	356.15
29	360.6
29.5	365.06
30	369.51
30.5	373.95
31	378.38
31.5	382.79
32	387.19
32.5	391.58
33	395.96
33.5	400.33
34	404.68
34.5	409.02
35	413.34
35.5	417.65
36	421.95
36.5	426.23
37	430.4[illegible]
37.5	434.[illegible]
38	438.96
38.5	443.17
39	447.37
39.5	451.54
40	455.7
40.5	459.84
41	463.97
41.5	468.08
42	472.17
42.5	476.25
43	480.31
43.5	484.35
44	488.37
44.5	492.37
45	496.36
45.5	500.33
46	504.28
46.5	508.21
47	512.12
47.5	516.02
48	519.89
48.5	523.75
49	527.58
49.5	531.58
50	535.2

DIST(DEG)	T.TIME(SEC)
50.5	538.98
51	542 74
51.5	546.49
52	550.22
52.5	553.93
53	557.62
53.5	561.29
54	564.95
54 5	568.59
55	572.21
55.5	575.81
56	579.4
56.5	582.97
57	586.51
57.5	590.04
58	593.55
58.5	597.05
59	600.52
59.5	603.98
60	607.42
60 5	610.84
61	614.24
61 5	617.63
62	621.01
62.5	624.37
63	627.71
63.5	631.04
64	634.35
64.5	637.64
65	640.91
65.5	644.17
66	647.41
66.5	650.64
67	653.85
67.5	657.04
68	660.22
68.5	663.37
69	666.51
69.5	669.64
70	672.74
70.5	675.82
71	678.88
71.5	681.92
72	684 94
72.5	687.93
73	690.91
73.5	693.87
74	696.81
74.5	699.73
75	702.63
75.5	705.52
76	708.38
76.5	711.23
77	714.07
77.5	716.88
78	719.67
78.5	722.44
79	725.19
79.5	727.92
80	730.63
80.5	733.33
81	736
81.5	738.65
82	741.29
82.5	743.9
83	746.49
83.5	749.06
84	751.61
84.5	754.13
85	756.63
85.5	759.1
86	761.56
86.5	764.01
87	766.43
87.5	768.85
88	771.25
88.5	773.63
89	776.01
89.5	778.37
90	780.72
90.5	783.07
91	785.4
91.5	787.74
92	790.06
92.5	792.38
93	794.68
93.5	797
94	799.3
94.5	801.59
95	803.89
95.5	806.18
96	808.47
96 5	810.75
97	813.04
97.5	815.32
98	817 6
98.5	819.88
99	822.17
99 5	824 45
100	826.73