GL00120

Preliminary documentation for a FORTRAN program to compute gravity terrain corrections based on topography digitized on a geographic grid

by

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

INTRODUCTION

The FORTRAN computer program listed in Table 1 has been used by the U.S. Geological Survey since 1972 to obtain terrain corrections to a distance as far as 167 km from gravity stations. This program evolved from earlier versions of the program that were first announced and distributed in 1966 (Plouff, 1966). The digitization for a previous terrain correction program of the U.S. Geological Survey (Kane, 1962) adopted the one-kilometer square grid of the Universal Transverse Mercator (UTM) coordinates that are marked on most topographic maps. J. H. Healy (oral communication, 1965) suggested to me that a system based on geographic latitude and longitude coordinates could be more general, more efficient (for storing digital elevations) and more flexible than the one-km UTM grid system. Healy suggested that only one quadrangle map of digitized average elevations needs to be retained in the computer memory at a given time.

I wrote a FORTRAN program in 1965 that implemented Healy's suggestions. That program and its later revisions primarily were used with 15-minute maps digitized in one-minute compartments and with one-by-two degree maps digitized in 3-minute compartments. The version of the program released as a preprint associated with the presentation at the 36th Annual Meeting of the Society of Exploration Geophysicists (Plouff, 1966) included all the basic improvements over previous terrain correction programs. These improvements are the digitization and gravity station locations in a latitude-longitude reference system, the assembly of digitization in quadrangle map units, a tie to an inner circular boundary that permits an exact join to conventional hand terrain corrections, a listing of maps needed but not found in the digital map-input, correction for the effect of the earth's curvature, and use of a gravity formula that is more accurate for those compartments that are closest to the location of the gravity station.

The last improvement was made because the formula used in the previous program was fairly accurate but was based on the assumption that the ground surface is horizontal within every compartment (fig. 1). To a first approximation, however, the ground surface near any point tends to slope through that point, in order to account for the observed difference of elevation

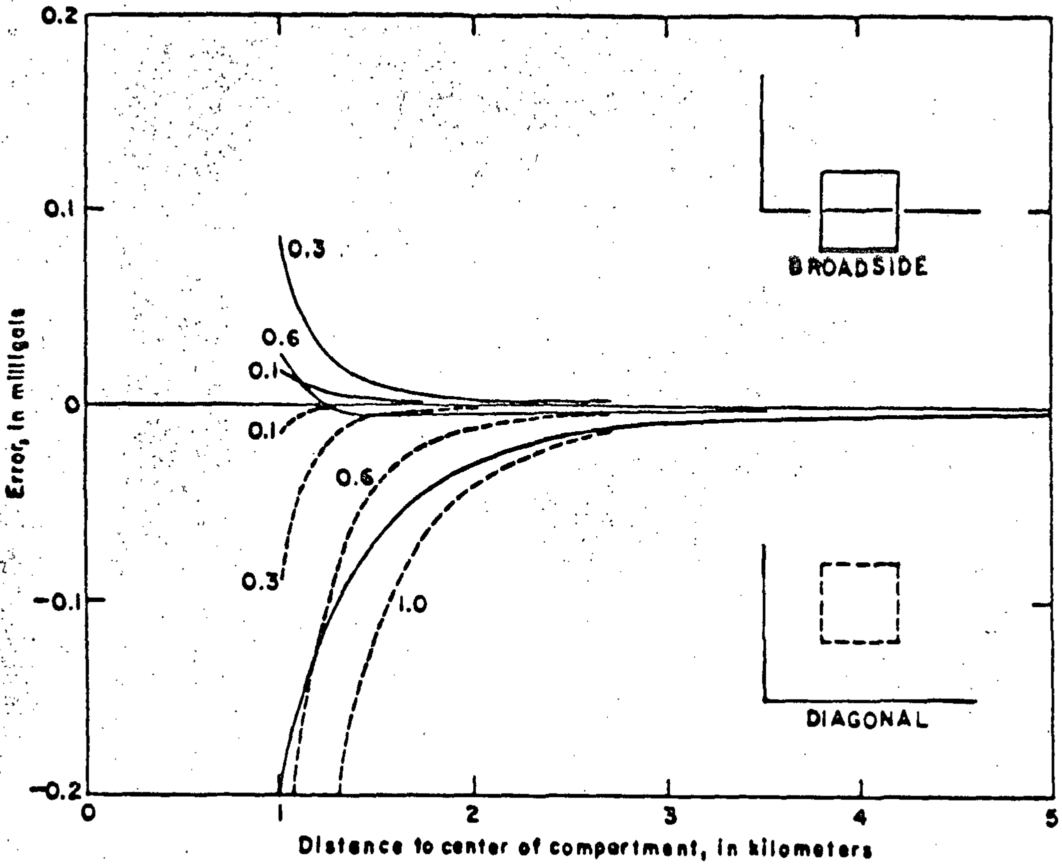

Figure 1.--Comparison of Kane's approximation to gravity effect of flat-topped rectangular prism. Solid lines indicate broadside orientation; dashed lines indicate diagonal orientation. Compartments are one-km squares. Constant height of compartment is distance to center of the compartment times number indicated near curve. Density is 2.67 gm/cm^3.

between that point and nearby locations. A simple formula, in which it is assumed that all the mass within a compartment is concentrated along a vertical line mass at the center of the compartment, was found to provide a close approximation to the gravity effect of a ground surface that slopes through a nearby station location (fig. 2). At farther distances from the gravity station-- distances that exceed about 4 compartment widths from the station--the gravity value calculated by using the two formulas are nearly identical.

Further modifications between the time of the 1966 program and the accompanying listed program improved the distance formulas, removed some minor discrepancies, protected the program user against making mistakes, and were in response to a need for a more self sufficient "final" program in terms of punch card and printer output. A program later was written to convert previous one-km digitization to one-minute (about 1.85 by 1.5 km) digitization, so that previous elevation digitization could be adopted for use with the present program. That program (Robbins, and others, 1973) enabled a substantial block of gridded topographic data in southern California to be absorbed into one-minute and three-minute digitization that entirely covers the state of California.

Though the program listed in Table 1 has been extensively tested, no surety should be implied concerning proper execution of the program. I would welcome receiving the results of independent tests. The program is by no means "final". Only positive values of latitude and longitude have been tested. The terrain corrections for land below sea level and for ocean compartments underlain by rock that does not have a density of 2.67 g/cc are incorrect in the accompanying program. There is no provision of the nearby terrain corrections for gravity observations at or below the surface of the ocean. The effect of water in large inland lakes or seas is not accounted for. An option for using the 1967 Geodetic Reference System for calculating the theoretical value of gravity at sea level has not been provided. None of the advantages of interactive computer usage, such as prompting and storage on disk or tape, are implemented. There is no option to reduce the bulk

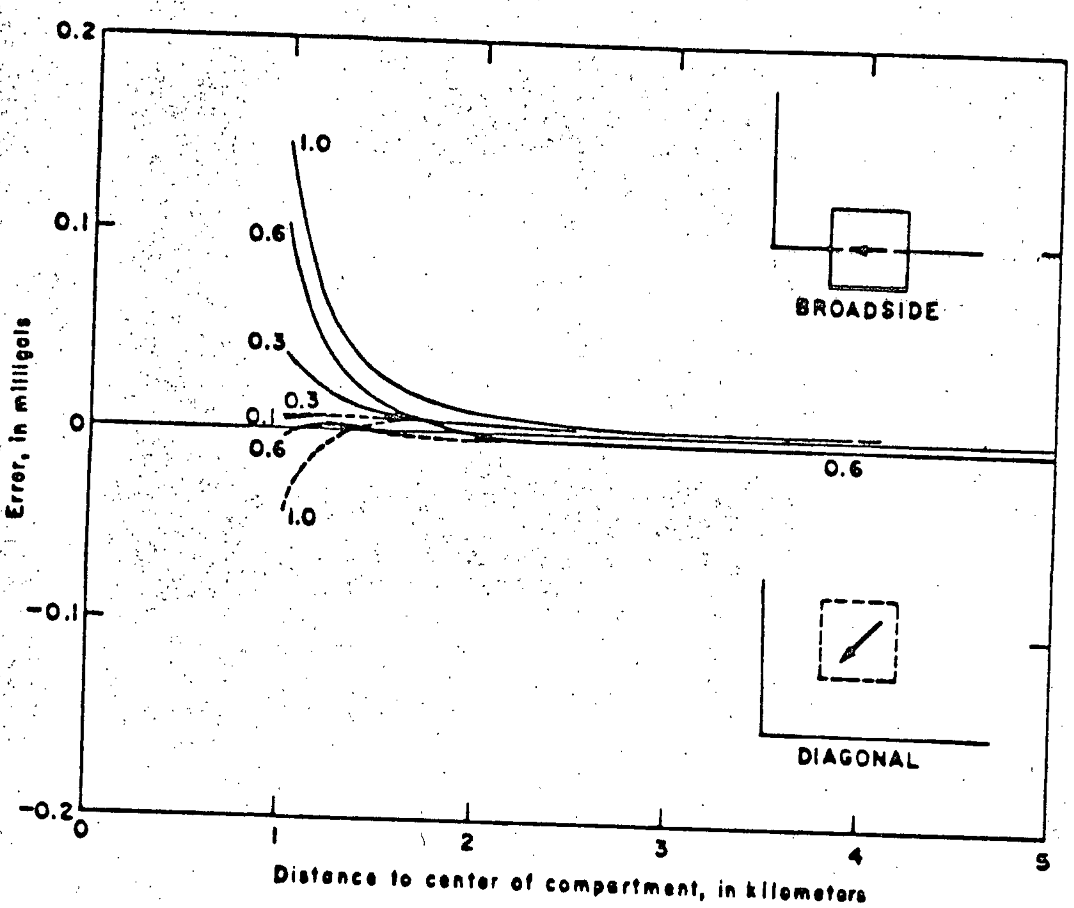

Figure 2.--Comparison of line element approximation to gravity effect of rectangular prism bounded on the top by an inclined plane that passes through the station. Solid lines indicate broadside orientation; dashed lines indicate diagonal orientation. Compartments are one-km squares. Direction of dip indicated by arrow. Numbers indicate slope of inclined plane. Density is 2.67 gm/cm^3.

of the printed output and the associated specialized input and output formats. The accompanying program, however, is useful for the majority of cases and can be adopted with little or no modification for use on most digital computers.

DIGITAL GRAVITY TERRAIN CORRECTION PROGRAM

General

A generalized program flow chart is shown in Figure 3. The arrangement of the card input to the gravity terrain correction program is shown in Figure 4. "Computer cards" on the illustration for example indicate positions for Job Control Language cards of the IBM system. The accompanying program (Table 1) was written in standard FORTRAN IV language and has been used on an IBM-370 computer system. The program designation, M0400, serves to distinguish this program from all other versions of the program. The "99-cards" shown on Figure 4 are cards with nines punched in all 80 columns. These cards serve as delimiters that indicate the end of the sets of station cards or map cards. The formats of other specific types of cards are described later. Examples of typical punch cards are shown in Figure 5 and punch cards for a test case are listed in Table 2.

Limitations

The total number of gravity stations may not exceed 500. The total number of "map sets" may not exceed 10, but 4 is the expected practical limit. The total number of digital maps within a set may not exceed 80. No more than 13 maps from a given map set can be used to provide the specified map coverage for any gravity station. Map parameter cards may not specify compartment and map sizes such that there are more than 30 compartments along the north-south dimension of a map and no more than 40 compartments along the east-west dimension of a map. There must be an integer number of compartments in a map. Similarly, there must be an integer number--not over 15 in either the north-south or east-west direction--of "blocks" in a map. A block is grouping of compartments that is intermediate in size

Read location of area, number of sets of maps

Read station data

Calculations for first/next set of maps

Read variables needed for this set of maps

Establish indexing and distance test parameters

Establish rectangular boundary of maps needed for each station

Calculations for first/next map

Read identification and location of map

Read elevations of compartments

Assemble compartments of map into blocks

Designate indices for map

Calculations for first/next station

Test if map is needed; if not, go to next station

Test each block of map

Calculate terrain correction of block or compartment, if needed

Add to previous total for block

Add to previous total for map

Write name of area and list of variables used for this set of maps

Assemble information for each station

List maps needed

Write name and terrain correction of map

Write total terrain correction; list coordinates of maps needed but not found

Summarize correction, including close-in values

Figure 3.--Flow chart of program.

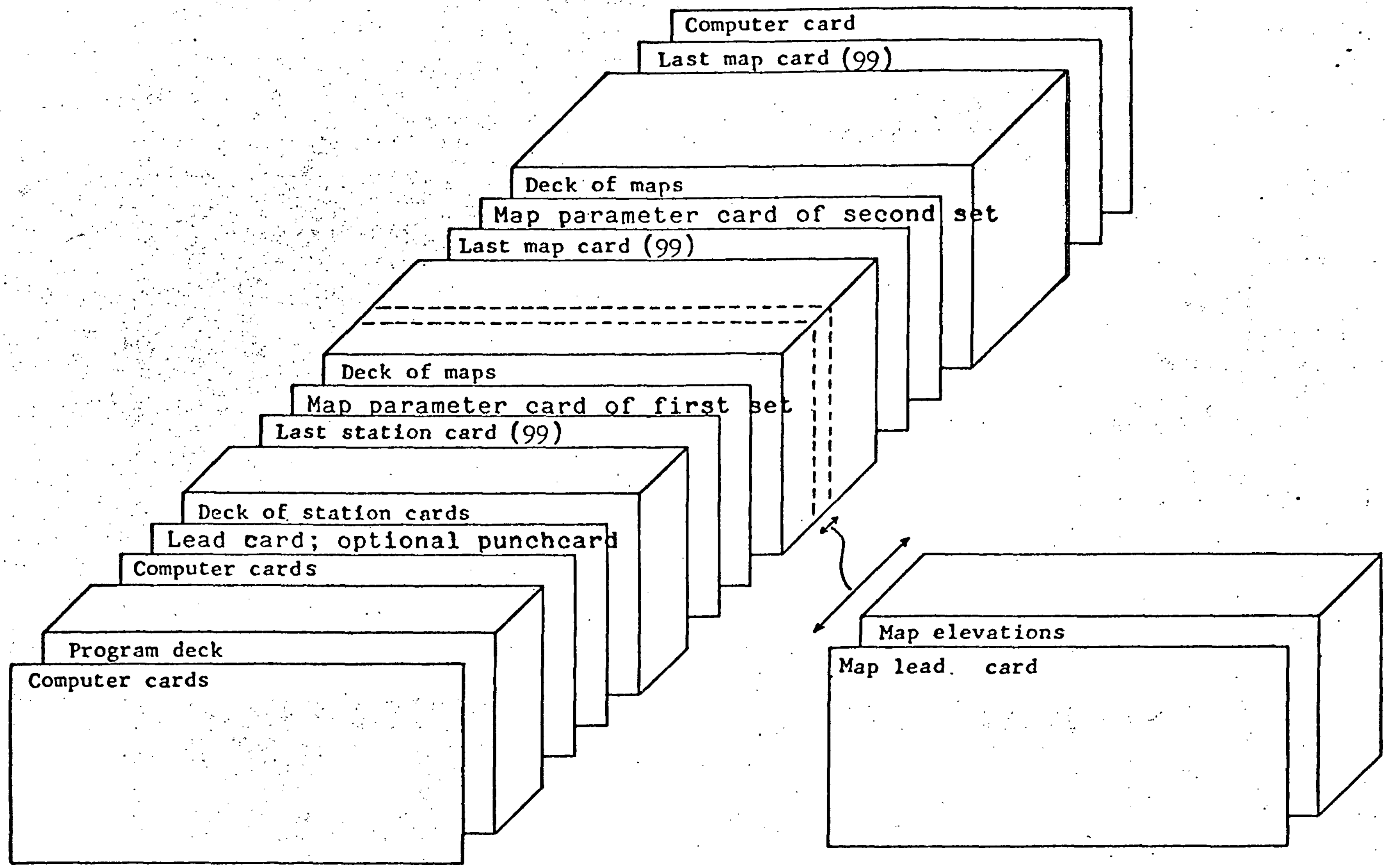

Figure 4.--Assembly of program for input to computer.

Lead card

SAN JUAN MTS., COLORADO -2 0 3 2.5

Special card

SJM

Station card

1857375508106504513718 0 1188UD5347884138 KXFIS

Map parameter cards

5 53030 60 60 4.1 0.8949 4.0 15.0 160 5 MIN

15 15 1 1 3 3 21. 4.1 14. 14. 0 1 15 MIN

60120 3 3 12 12 166.7 21. 60. 14. 0 1 1-2 DEG

Map lead card

SJM VIIB7 37 20 107 50

Map elevation card

9990 9200 9900 10200 10040 9200 8560 8300 7660 7050DURANGO 7

Output card

SJM 1857 375508 1065045137180788413 8D534 13357-33431 1188 1406U-32019-29130KXFIS

Figure 5.-- Examples of punchcards.

between a "compartment" and a "map". The block size for one-minute digitization (one-by-one minute compartments), for example, usually is three-by-three minutes in anticipation of coarser three-minute digitization provided in another map set.

Definitions

The numbers near the left margin in the following paragraphs refer to inclusive card column numbers. The term "default" is the value or condition assumed if card columns for the specific parameter are left blank or are zero. The term "alpha" refers to any keyboard character. "Integer" is any right justified number without a decimal point. "Decimal" is a number in which a decimal point may be punched or the location of the decimal point is assumed to be located as indicated in the associated description.

Lead card

1-24 Alpha. Name of area or a title.

25-26 Integer. Indicates format of station cards. The code number minus-2 should be punched if punch card output is desired. The code numbers minus-1, zero, and one also are permitted. A detailed description is given in the next section.

27-28 Integer. The number zero indicates that the station elevations are expressed in feet. The number 3 indicates that station elevations are in meters.

29-30 Integer. The total number of digital map sets (or types) to follow the station data. The number 2 would indicate that 2 map sets will follow (for example, one-minute and three-minute digitization).

31-36 Decimal. Optional second density. The terrain corrections always are calculated for an assumed average rock density of 2.67 g/cm^3. The terrain correction and corresponding Bouguer anomaly also will be calculated for the optional second average density punched in these columns. The default is a density of 2.50 g/cm^3.

Station card formats for code numbers in columns 25-26 of the Lead Card

Minus-2 or minus-1 code (Burch format)

The present program produces punch card output only if this code is minus-2 (see description of "special card for punch output" for details of the format of the output card). If this code is minus-1, no output card is produced and alpha columns except 1-5 are ignored.

1-5 Alpha. Five-digit station name.

6-7	Integer. Latitude degrees (assumed North and positive). Negative numbers would give incorrect results.
8-11	Decimal. Latitude minutes with decimal point assumed between columns 9 and 10.
12-14	Integer. Longitude degrees (assumed West and positive). Negative numbers would give incorrect results.
15-18	Decimal. Longitude minutes with decimal point assumed between columns 16 and 17.
19-24	Decimal. Elevation with decimal point assumed between columns 23 and 24.
35-39	Decimal. Hand terrain correction in milligals or total terrain correction exclusive of that determined within this program. submittal. The assumed density is 2.67 g/ The decimal point is assumed between columns 37 and 38. The default implies a hand correction has not been done. Therefore, it is suggested that the number 1 punched in column 39 (0.01 milligal) rather than zero should be used to indicate that a hand correction has been determined for hand corrections that are less than 0.005 milligal.
40	Alpha. An optional code letter that indicates, for example, the distance to which the hand terrain calculation has been determined. The letter "F" may indicate that the hand correction has been done through Hayford's F-ring.
41-44	Alpha. An optional code grouping that indicates, for example, a 4-digit accuracy code.
45-51	Decimal. The observed gravity in milligals without the leading 9. The decimal point is assumed between columns 49 and 50; therefore, 0.01 milligal units are provided.
52-57	Decimal. The free-air an maly in milligals, with the assumed decimal point between columns 55 and 56. The default condition (or anomalies that are zero) signifies that the program will calculate the free-air anomaly using the International Formula of 1930 to calculate the theoretical value of gravity at sea level and the formula used by Swick (1942) to calculate the free-air correction.
69-73	Alpha, Optional information to be passed to the punch output card.

Zero or one codes

1-4 Alpha. Four-digit station name.

5-23 The same information related to location and elevation as appears in columns 6-24 of the Burch format.

24-29 Decimal. Relative observed gravity in milligals with the decimal point assumed between columns 27 and 28. The value is relative to 978,000 milligals if the code number is zero. If the code number is one, then the leading two digits (97 or 98, to cover the range of 975 to 985 gals) have been dropped from the absolute value of observed gravity.

71-74 Decimal. Hand terrain correction in milligals with the assumed decimal point between columns 72 and 73.

Special parameter card for punch output

This additional card must be placed between the Lead Card and the first Station Card if the format code is minus-2 in columns 25-26 on the Lead Card. The entire card may be blank or may provide the following supplementary data. The column structure of this card is identical to that of the punch output cards (see later section), but the card lacks numerical values.

1-3 Alpha. Three-digit prefix (area or project identifier) that is to precede the 5-digit station name on the output cards.

9 Alpha. Prefix, such as "N" or "+", that is to precede the latitude on output cards.

16 Alpha. Prefix, such as "W" or "-" or "+" that is to precede the longitude on output cards.

63 Alpha. Unless column 63 is left blank, this symbol will replace the symbol punched in column 40 of all station input cards. This symbol signifies the closest distance to which the computer terrain correction is carried.

76-80 Alpha. Unless left blank, this group of symbols will replace the data in columns 69-73 of the station input card. This option would rarely be used.

Map parameter card

One of these cards precedes each set of digital maps. The number of such cards therefore is prescribed in columns 29-30 of the Lead Card. See Figure 3 for the position of this type of card and see Figure 5 for an example of a combination of three of these cards.

1-3 Integer. North-south dimension of digital "map" in minutes. For example, 15 minutes is convenient for maps of one-minute digitization and 60 minutes for three-minute digitization.

4-6 Integer. East-west dimension of digital "map" in minutes. For example, 120 minutes is convenient for maps of three-minute digitization.

The geographic units of measurement (minutes or seconds) of the following four numbers are defined in columns 63-64 of this card. The program execution stops if there is not an integer number of "compartments" in a "block" or if there is not an integer number of "blocks" in a "map".

7-8 Integer. North-south dimension of the smallest cell--a "compartment"--of the gridded elevations.

9-10 Integer. East-width dimension of a compartment in minutes or seconds.

11-13 Integer. North-south dimension of a block of compartments. If the compartment size is one minute, for example, the block size would be three minutes, in order to make an exact join with three-minute gridded topography in another map set.

14-16 Integer. East-west dimension of a block in minutes or seconds.

17-24 Decimal. Maximum distance in kilometers to which a digital terrain correction is to be calculated by using this set of maps. The contribution to the terrain correction of all blocks of compartments whose centers occur at or beyond this distance are ignored.

25-32 Decimal. Minimum distance in kilometers to which a terrain correction is to be calculated by using this set of maps. Note that the minimum distance for the 3-minute set of digital maps should be identical to the maximum distance of the 1-minute set of digital maps, for example. This distance must exceed half the diagonal length of a compartment. The minimum distance selected for the map set with the smallest compartment size usually is equal to the farthest distance to which hand terrain corrections are carried. For example, 0.895 km (Hammer F-ring) is used for half-minute digitization and 2.29 km (Hayford F-ring) or 2.615 km (Hammer H-ring) are used for one-minute digitization.

33-40 Decimal. The distance in kilometers beyond which groups of compartments are lumped to form blocks for purposes of calculation of the terrain correction. This distance must be less than the value in columns 17-24 and probably should be greater than twice the maximum dimension of a block.

41-48 Decimal. Distance in kilometers beyond which a correction for the earth's curvature will be made. Values less than the default of 14 km produce a warning message, because the assumption of maximum slope upon which the curved-earth approximations are based would not necessarily be valid at shorter distances.

61-62 Integer. The number zero (or blank) signifies that the terrain corrections for only those compartments whose centers occur at or beyond the distance given in columns 25-32 are calculated. The number one signifies that an exact join to cylindrical rings of conventional hand terrain corrections will be made by excluding all parts of compartments that are closer to the station than the distance specified in columns 25-32 and including in the terrain calculation all parts of compartments that are farther from the station than that distance. The latter option may be selected for only one Map Parameter Card of the terrain model.

63-64 Integer. The number 60 signifies that the units of compartment and block dimensions given in columns 7-16 are expressed in seconds. The units are expressed in minutes if this number is one.

Map Lead Card

1-12 Alpha. Name of map.

The following four numbers specify the geographic coordinates of the northwest corner of the map. Negative numbers should not be used. The purpose of the extra space in each field is to improve readability.

13-15 Integer. Latitude degrees.

16-18 Integer. Latitude minutes.

19-22 Integer. Longitude degrees.

23-25 Integer. Longitude minutes.

26-27 Integer. Number that defines the units of compartment elevations.
0 or 1. All elevations are expressed in feet.
6 Positive elevations are in feet and negative elevations are in fathoms.
31 Positive elevations are in meters and negative elevations are in feet.
33 All elevations are expressed in meters.
36 Positive elevations are in meters and negative elevations are in fathoms.

Map elevation card

Ten average elevations are punched on each elevation card. Each elevation occupies 7 columns and the decimal point need not be punched if the elevation is a right-adjusted, integer number. In practice the elevations are estimated no closer than the nearest 10 elevation units, so that drum-card control is used to punch the final zero digits. Columns 71-80 often are used to indiate an abbreviated map name and a sequence number.

A blank or a zero elevation indicates that an elevation estimate has not been made and a terrain correction will not be calculated for that compartment. Therefore, a -1 or a +1 should be punched for compartments whose average elevation is near sea level. Negative compartment elevations refer to ocean bottom depths, so that water rather than rock beneath sea level is accounted for. Unfortunately, a small error occurs for land compartments that are beneath sea level, because sea water rather than air is assumed to be present.

The sequence of compartment numbering begins with the compartment in the northwest corner of the map and continues eastward along the northernmost row of compartments. Then, the compartmencs of the next row to the south and each successive row farther to the south similarly are arranged in west-to-east progression. A total of 23 elevation cards are needed, for example, to digitize 15-minute maps into one-minute compartments.

Format of output cards

1-3	Prefix from columns 1-3 on the "Special card".
4-8	Station name (from 1-5 of Station card).
9	From Special Card.
10-15	Latitude in degrees and minutes carried to hundredths, without a decimal point (from 6-11 of Station Card).
16	From Special Card.
17-23	Longitude in degrees and minutes carried to hundredths, without a decimal point (from 12-18 of Station card).
24-29	Elevation to nearest 0.1 foot or meter, without a decimal point from 19-24 of Station card.
30-36	Observed gravity in milligals to nearest hundredth without decimal point (from 45-51 of Station card). *No leading nine.*
37-40	Alpha data from 41-44 of Station card.
41-46	Free-air anomaly in 52-57 of Station card or as calculated during program execution.
47-52	Simple Bouguer anomaly at a reduction density of 2.67 g/cm^3.
53-57	Hand terrain correction in milligals in 71-74, expressed to 0.01 milligal.
58-62	Total terrain correction, including hand and digital computer correction at a density of 2.67 g/cm^3.
63	Single character from column 40 of the station input card or from the Special Card.
64-69	Complete Bouguer anomaly expressed to 0.01 milligal at a reduction density of 2.67 g/cm^3. It is the Simple Bouguer anomaly (47-52) plus the total terrain (58-62) plus a correction for the earth's curvature to 166.7 km.
70-75	Complete Bouguer anomaly expressed to 0.01 milligal at the reduction density specified in columns 31-36 of the Lead Card. That density is assumed instead of 2.67 g/cm^3 in making the mass, terrain, and curvature corrections. Note that a simple formula, ($T_2 = D_2 T_1 / 2.67$), is used to convert the total terrain correction (58-62), T_1, from a density of 2.67 g/cm^3 to the equivalent terrain correction, T_2, at the second density, D_2. The contribution of sea water compartments to the terrain correction is not correctly obtained for the second density when using this simple formula.
76-80	Optional data from 69-73 of the station input card or 76-80 of the Special Card.

Printout from terrain correction program (Table 3)

An example is attached. The first page includes a listing of the information about the punch card input and the calculated values of the theoretical gravity and free-air anomaly. When the free-air anomaly is provided on the station input card, the value 900,000 is printed for the theoretical gravity. Next, the names and location of maps of the first set are listed. A summary of the terrain corrections is printed, a station at a time. A similar list then is printed for each successive set of maps.

For each station the terrain correction of each map within the indicated range of distances is listed. Where maps are needed but not found in the set of maps, a list of the coordinates of the northwest corner of these maps is printed. Rarely, the coordinates of a map located near the maximum distance may be listed, though the map is included in the set, owing to a slightly abbreviated formula used for relating geographic to rectangular coordinates used in the map indexing part of the program. Later when the omitted maps are found or become available another computation can be made by using these maps and adding the terrain correction to the earlier printed total for each station.

The last pages of printout include a summary of the free-air anomaly and the simple and complete Bouguer anomalies at the two densities. The column labelled "(NEAR)" refers to that part of the computer terrain correction which represents the contribution of compartments that intersect the inner circular radius. If an exceptionally high value is printed, the average elevations in map compartments near the station should be checked. If no error is found, an outward shift of the selected inner circular radius may be considered.

The time of execution for a typical set of 60 stations using 4 sets of maps for terrain corrections in the distance interval 0.068 to 166.7 km is 48 seconds on the IBM-370 Computer. The maximum execution time for 2 sets of maps (1' and 3' digitization) that cover the distance interval 2.3 to 166.7 km is about 0.6 second per station and the length of printout is about 16 lines per station.

Input/output requirements

The program requires a region size of 160,000 bytes on the IBM-370 system. Logical unit 5 is used for reading data cards, unit 6 is used to print the results, and unit 8 is used for punch card output. The time of execution for a typical set of 60 stations using 4 sets of maps for terrain corrections in the distance interval 0.068 to 166.7 km is 48 seconds on the IBM-370 Computer. The maximum execution time for 2 sets of maps (1' and 3' digitization) that cover the distance interval 2.3 to 166.7 km is about 0.6 second per station and the length of printout is about 16 lines per station.

REFERENCES

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Plouff, Donald, 1966, Digital terrain corrections based on geographic coordinates [abs.]: Geophysics, v. 31, no. 6, p. 1208.

Robbins, S. L., Oliver, H. W., and Plouff, Donald, 1973, Description of magnetic tape containing average elevations of topography in California and adjacent regions for areas of 1x1 minute and 3x3 minutes in size: Nat'l. Tech. Inf. Service, No. PB-219-795 (magnetic tape is PB-219-794), U.S. Dept. Commerce, Springfield, Va., 31 p.

Swick, C.H., 1942, Pendulum gravity measurements and isostatic reductions: U.S. Coast and Geod. Survey, Spec. Publ. no. 232, 82 p.

TABLE 1.--List of gravity terrain correction program (M0400)

```
      DOUBLE PRECISION DENTS,GOBS,THG,DENTST,DENTSK                        1
      DOUBLE PRECISION DATID,DATNM,BLANKN,OBSGR                            2
      INTEGER*2 NUMS                                                       3
      DIMENSION BREA(6),DENTS(500),SLATM(500),SLONM(500),ELS(500),         4
     1NUMS(500,13),GRAV(500,13),BOUG(500),TERM(500),AS(500),BS(500),
     2 GV(500),GCEN(500),LTM(500),LNM(500)
      DIMENSION ACCUR(501),ALPHA(501),DATID(501),OBSGR(501)                5
      COMMON /STATN/ DENTS                                                 6
      COMMON RMIN,RMIN2,RMAX2,BL2K,BL2L,QB2B,QA2B,AQM,BQM,ST,SN,           7
     1 A,B,    GCEN,GRAV,GV,NUMS
      COMMON /BLK2/ SLATM,SLONM,AS,BS,ELS,BREA,LTM,LNM                     8
      DATA BLANK/'    '/                                                   9
      DATA BLANKN/'        '/                                              10
C 500 STATIONS. 80 MAPS. 1200 (30 NORTH BY 40 WEST) COMPARTMENTS
C PER MAP.  BREA-NAME OF AREA.
C LC=0 IS CARD OUTPUT FORMAT OF GRAVITY REDUCTION PROGRAM FIRST USED
C  ON WASHINGTON COMPUTER (EXCEPT HAND TERRAIN CORRECTION PUNCHED IN
C COLUMNS 71-74). OBSERVED GRAVITY IN COLUMNS 33-38. OBSERVED GRAVITY
C CARRIED TO 0.01 MGAL. 6 DIGITS RELATIVE TO 978,000. LC=1 FOR FIRST TWO
C SIGNIFICANT FIGURES DROPPED FROM OBSERVED GRAVITY. LC=-1 FOR 7 DIGITS
C           RELATIVE TO 900,000. LD=3 FOR STATION ELEVATIONS IN METERS.
C      LD=0 FOR FEET. D2-SECOND CHOICE OF DENSITY (FIRST IS 2.67).
C NTYPE-NUMBER OF DISTINCT MAP SETS TO FOLLOW STATION DATA (0 IS 1).
C      (PROBABLY FIRST RMAX=2ND RMIN, FIRST COMPOSITE BLOCK=2ND COMPART)
C LC=-2 SIMILAR TO LC=-1 FORMAT EXCEPT PROVIDES PUNCH OUTPUT WITH
C ADDITIONAL INFORMATION READ IN AND PUNCHED OUT.
       NCIRC=0                                                             11
       RAD1=10000.0                                                        12
       RAD2=0.0                                                            13
       ASMAX=0.0                                                           14
       READ  (5,100)BREA,LC,LD,NTYPE,D2                                    15
  100  FORMAT (6A4,3I2,F6.3)
C INFORMATION FOR CORRESPONDING COLUMNS OF OUTPUT CARD.
       ALFA=BLANK                                                          16
       DATNM=BLANKN                                                        17
       STDENT=BLANK                                                        18
       SIGNLT=BLANK                                                        19
       SIGNLN=BLANK                                                        20
       IF (LC .EQ. -2) READ (5,106) STDENT,SIGNLT,SIGNLN,ALFA,DATNM        21
  106  FORMAT (A3,5X,A1,6X,A1,46X,A1,12X,A5)
       IF (NTYPE .LE. 0) NTYPE=1                                           22
       DEGR=  1.7453292E-2                                                 23
       WRITE (6,206)BREA,NTYPE                                             24
  206  FORMAT ('1TERRAIN CORRECTION PROGRAM D. PLOUFF  9-1972',/,
     1          35HOSUMMARY OF PRELIMINARY VALUES FOR ,6A4,19H TERRAIN COR
     2RECTION/,18H WILL BE MADE FOR ,I2,13H SETS OF MAPS/,31HO STA  LATI
     3TUDE LONGITUDE  ELEV,4X,40HOBS GRAV  THEO GRAV  FREE AIR  HAND TER
     4 )
C READ IN STATION DATA
C DENTQ- IDENTIFICATION. LATSD,SLATM- LATITUDE IN DEGREES, MINUTES.
C LONSD,SLONM- LONGITUDE IN DEGREES, MINUTES.  ELS- ELEVATION IN FEET.
       DO 6  K=1,502                                                       25
       NS=K                                                                26
       IF (NS-501) 77,76,91                                                27
```

Read on unit 5
Print on unit 6
Punch on unit 8

TABLE 1--CONTINUED

```
   76 WRITE (6,216)DENTS(500)
  216 FORMAT (9H STATION , A5,20H IS CARD NUMBER 500.)
      GO TO 4
   77 THG=0.0
      ALPHA(K)=BLANK
      ACCUR(K)=BLANK
      DATID(K)=BLANK
      IF (LC .NE. -1 .AND. LC .NE. -2) GO TO 3
C BURCH FORMAT. TC-TERRAIN CORRECTION DONE BY HAND (IN MGALS FOR 2.67).
C FA-PREVIOUSLY CALCULATED FREE AIR ANOMALY. 5-DIGIT STATION NAME.
      IF (LC .EQ. -1) GO TO 4
C LC=-2 OPTION (PUNCH OUTPUT)
      READ  (5,107)DENTST,LT,QT,LN,QN,ELSIS,TC,ALPHA(K),ACCUR(K),GOBS,
     1 FA,DATID(K)
  107 FORMAT (A5,I2,F4.2,I3,F4.2,F6.1,10X,F5.2,A1,A4,F7.2,F6.2,11X,A5)
      IF (ALFA .NE. BLANK) ALPHA(K)=ALFA
      IF (DATNM .NE. BLANKN) DATID(K)=DATNM
      GO TO 52
    4 READ  (5,102)DENTST,LT,QT,LN,QN,ELSIS,TC,GOBS,FA
  102 FORMAT (A5,I2,F4.2,I3,F4.2,F6.1,10X,F5.2,5X,F7.2,F6.2)
   52 IF (LT-90) 5,7,7
    5 DEGS=LT+QT/60.0
      PHI=DEGR*DEGS
      IF (LD .EQ. 0) GO TO 42
      IF (LD .EQ. 3) GO TO 41
      WRITE (6,201)
  201 FORMAT (30H1STATION ELEVATION UNITS WRONG)
      STOP
   41 ELKM=ELSIS/1000.0
      GO TO 43
   42 ELKM=3.048006E-4*ELSIS
   43 IF (FA) 56,55,56
C LONG USED FORMAT (EXCEPT TC PLACED IN COLUMNS 71-74)
    3 READ  (5,101)DENTST,LT,QT,LN,QN,ELSIS,GOBS,TC
  101 FORMAT (A4,I2,F4.2,I3,F4.2,F6.1,F6.2,41X,F4.2)
      IF (LT-90) 8,7,7
    8 IF (LD .EQ. 0) GO TO 70
      IF (LD .EQ. 3) GO TO 68
      WRITE (6,201)
      STOP
   68 ELKM=ELSIS/1000.0
      GO TO 75
   70 ELKM=3.048006E-4*ELSIS
   75 IF (LC .EQ. 0) GO TO 58
      IF (LC .EQ. 1) GO TO 57
      WRITE (6,209)
  209 FORMAT (39H1OBSERVED GRAVITY FORMAT NOT RECOGNIZED)
      STOP
   58 GOBS=GOBS+7.8D4
      GO TO 59
   57 KGB=GOBS/1000.0D0
      IF (KGB-4) 60,60,61
   60 GOBS=GOBS+8.0D4
      GO TO 59
   61 GOBS=GOBS+7.0D4
```

TABLE 1--CONTINUED

```
   59 DEGS=LT+QT/60.0                                                     72
      PHI=DEGR*DEGS                                                       73
   55 S=SIN(PHI)                                                          74
      S2=S*S                                                              75
      E2=ELKM*ELKM                                                        76
C THG-THEORETICAL GRAVITY RELATIVE TO 900,000 MGALS
      THG=7.8049D4+S2*(5149.232+23.082*S2)                                77
C SWICK FORMULA
      FA=(GOBS-THG) +ELKM*(308.77  -0.44   *S2)-0.072 *E2                 78
   56 BOUG(K)=FA                                                          79
C STATION LATITUDE AND LONGITUDE IN MINUTES
      JT=QT                                                               80
      JN=QN                                                               81
      SLATM(K)=QT-JT                                                      82
      SLONM(K)=QN-JN                                                      83
      LTM(K)=60*LT+JT                                                     84
      LNM(K)=60*LN+JN                                                     85
      ELS(K)=ELKM                                                         86
C AS,BS -EW AND NS CONSTANTS FOR CONVERSION BETWEEN GEOGRAPHIC AND
C RECTANGULAR COORDINATES (UNITS ARE KM/MINUTE).
      C=COS(PHI)                                                          87
      C2=C*C                                                              88
      AS(K)=C*(1.861656-0.006343*C2)                                      89
      BS(K)= 1.861656+C2*(0.000160*C2-0.019028)                           90
      IF (AS(K) .LT. ASMAX) GO TO 83                                      91
      ASMAX=AS(K)                                                         92
      BSMAX=BS(K)                                                         93
   83 GV(K)=0.0                                                           94
      GCEN(K)=0.0                                                         95
      DENTS(K)=DENTST                                                     96
      OBSGR(K)=GOBS                                                       97
      GOBS=GOBS+9.0D5                                                     98
      THG=THG+9.0D5                                                       99
      WRITE (6,214)DENTST, LT,QT,LN,QN,ELSIS,GOBS,THG, FA,TC             100
  214 FORMAT (1X,A5,I3,F6.2,I4,F6.2,F7.0,2F11.2,2F10.2)
    6 TERH(K)=TC                                                         101
C TOTAL NUMBER OF STATIONS, NS. CARD WITH 99 IN LOCATION FOR LATITUDE
C DEGREES PLACED BEHIND LAST STATION CARD.
    7 NS=NS-1                                                            102
      CALL ARRNG(NTYPE,RAD1,RAD2,NCIRC,ASMAX,BSMAX,NS)                   103
      IF (NCIRC) 63,62,63                                                104
   62 WRITE (6,215)NS,BREA,RAD1                                          105
  215 FORMAT (13H1SUMMARY FOR , I4,13H STATIONS IN , 6A4/,73H  COMPUTER
     1TERRAIN CORRECTIONS CARRIED FROM NON-CIRCULAR INNER RADIUS OF  ,
     2F8.3)
      GO TO 69                                                           106
   63 WRITE (6,218)NS,BREA,RAD1                                          107
  218 FORMAT (13H1SUMMARY FOR , I4,13H STATIONS IN , 6A4/,73H  COMPUTER
     1TERRAIN CORRECTIONS CARRIED FROM     CIRCULAR INNER RADIUS OF  ,
     2F8.3)
   69 WRITE (6,219)       RAD2,D2                                        108
  219 FORMAT (4H  TO,F8.3,37H KILOMETERS.  DENSITIES ARE 2.67 AND ,F5.2,
     1 30H   DENSITY OF 2.67 IS USED FOR/,    '  VALUES IN COLUMNS LABEL
     2LED CC, TC, TER, (NEAR), AND TOT. TC-HAND CORRECTION'/,'  TER-TOTA
     3L COMPUTER CORRECTION. (NEAR)-PART OF TOTAL THAT REPRESENTS CONTRI
```

TABLE 1--CONTINUED

```
     4BUTION'/, '    OF COMPARTMENTS THAT INTERSECT INNER CIRCULAR RADIUS
     5. TOT-HAND PLUS COMPUTER TERRAIN.'/,  'O STATION LATITUDE LONGITUD
     6E    ELEV    OBS GRAV',  4X,'F.A.',5X,'S.B.1    S.B.2    CC    TC',
     7 4X,'TER (NEAR)  TOT',4X,'C.B.1    C.B.2  ACC    STA')
      D2Q=D2/2.67
      D2P=0.012774*D2
      DO 53 KS=1,NS
      ELSIS=3280.833*ELS(KS)
      JT=LTM(KS)
      JN=LNM(KS)
      LT=JT/60
      LN=JN/60
      JT=JT-60*LT
      JN=JN-60*LN
      QT=JT+SLATM(KS)
      QN=JN+SLONM(KS)
      FA=BOUG(KS)
      SBA1=FA-3.410658E-2*ELSIS
      SBA2=FA-D2P*ELSIS
      E2=ELSIS*ELSIS
      TC=TERH(KS)
      TER=GV(KS)
      CC=ELSIS*(446200.0-32.82*ELSIS+1.27E-6*E2)*1.0E-9
      TERCOR=TC+TER
      A=TERCOR-CC
      CBA1=SBA1+A
      CBA2=SBA2+A*D2Q
      GOBS=OBSGR(KS)+9.0D5
      IF (LD .EQ. 0) GO TO 67
   66 ELSIS=0.3048006*ELSIS
   67 DENTSK=DENTS(KS)
      IF (LC .NE. -2) GO TO 53
      JT=100.0*QT+0.5
      JN=100.0*QN+0.5
      LEL=10.0*ELSIS+0.5
      IFA=100.0*FA+0.5
      ISB=100.0*SBA1+0.5
      ITC=100.0*TC+0.5
      ITER=100.0*TERCOR+0.5
      ICB1=100.0*CBA1+0.5
      ICB2=100.0*CBA2+0.5
      LOBGR=1.0D2*OBSGR(KS)+5.0D-1
      IF (IFA .LT. 0) IFA=IFA-1
      IF (ISB .LT. 0) ISB=ISB-1
      IF (ICB1 .LT. 0) ICB1=ICB1-1
      IF (ICB2 .LT. 0) ICB2=ICB2-1
      WRITE (8,400) STDENT,DENTSK,SIGNLT,LT,JT,SIGNLN,LN,JN,LEL,LOBGR,
     1 ACCUR(KS),IFA,ISB,ITC,ITER,ALPHA(KS),ICB1,ICB2,DATID(KS)
  400 FORMAT (A3,A5,A1,I2,I4,A1,I3,I4,I6,I7,A4,2I6,2I5,A1,2I6,A5)
   53 WRITE (6,211) STDENT,DENTSK, LT,QT,LN,QN,ELSIS,GOBS, FA,SBA1,
     1 SBA2,CC, TC,TER,GCEN(KS),TERCOR,CBA1,CBA2,ACCUR(KS),DENTSK
  211 FORMAT (1X,A3,A5, I3,F6.2,I4,F6.2,F8.1,F10.2,3F9.2,F5.2,4F6.2,
     1 2F8.2,1X,A4,1X,A5)
  799 CONTINUE
   91 STOP
```

TABLE 1--CONTINUED

```
      END

      SUBROUTINE ARRNG(NTYPE,RAD1,RAD2,NCIRC,ASMAX,BSMAX,NS)
      DOUBLE PRECISION DENTS,ASTER,RIF(10),RIL(10)
      INTEGER*2 NUMS
      DIMENSION BREA(6),DENTS(500),LATSD(500),SLATM(500),LONSD(500),
     1SLONM(500),ELS(500),LATNW(500),LONNW(500),LATSE(500),LONSE(500),
     2DENTQ(3,81),NUMS(500,13),GRAV(500,13),E(30,40),
     3LATQ(81),LONQ(81),BEL(15,15),GV(500),DY(4),AS(500),BS(500)
      DIMENSION GCEN(500),LTM(500),LNM(500),MSS(500),LCIRC(10)
      COMMON /STATN/ DENTS
      COMMON /MAP/ DENTQ,LATQ,LONQ
      COMMON RMIN,RMIN2,RMAX2,BL2K,BL2L,QB2Q,QA2B,AQM,BQM,ST,SN,
     1 A,B,   GCEN,GRAV,GV,NUMS
      COMMON /BLK2/ SLATM,SLONM,AS,BS,ELS,BREA,LTM,LNM
      DATA  ASTER/'********'/
      DEGM=  1.666667E-2
      DEGR=  1.745329E-2
      DEGR28=0.125*DEGR*DEGR
      DEGR24=0.25 *DEGR*DEGR
C CONSTANT IN TERRAIN CORRECTION FORMULA.  DISTANCES IN KM.  GRAVITY IN
C MGALS. DENSITY IS 2.67
      GP=2.67*6.670
C LATM,LONM- TOTAL NUMBER OF MINUTES ALONG N-S AND E-W EDGES OF QUAD.
C KCLAT,LCLON- CORRESPONDING SHAPE OF SMALLEST COMPARTMENT IN MIN/SEC.
C MUST BE INTEGRAL NUMBER OF COMPARTMENTS AND BLOCKS ALONG EDGES OF QUAD
C AND EACH ELEMENT MUST DIVIDE BY AN INTEGRAL NUMBER INTO THE LARGER
C ELEMENTS.  KBLOK,LBLOK- CORRESPONDING SHAPE OF COMPOSITE BLOCK IN
C MIN/SEC (=KCLAT,LCLON IF COMPARTMENTS OF ONLY ONE SIZE ARE DESIRED).
C RMAX,RMIN-OUTER AND INNER RADII OF TERRAIN CORRECTION, IN KILOMETERS.
C RMED- INTERMEDIATE RADIUS, FOR CONVERSION TO LARGER BLOCKS, IN KM (=RM
C IF NOT USED).  RGR- DISTANCE FOR CONVERSION OF GRAVITY FORMULA (WITH
C AND WITHOUT CURVATURE CORRECTION).
C                         KCIRC=NON-ZERO, IF RMIN JOINS TRUE CIRCULAR BNDRY.
C SMALLEST PERMISSABLE QUAD IS 1 MINUTE, COMPARTMENT 1 SECOND.
C COMPARTMENT AND BLOCK SIZES EXPRESSED IN MINUTES (KSEC=1) OR SECONDS
C (KSEC=60). MAP EDGES ALWAYS IN MINUTES.
       DO 92 NMAP=1,NTYPE
       READ  (5,103)LATM,LONM,KCLAT,LCLON,KBLOK,LBLOK,RMAX,RMIN,RMED,RGR,
     1            KCIRC,KSEC
  103  FORMAT (2I3,2I2,2I3,4F8.4,12X,2I2)
       IF (LATM .EQ. KBLOK .OR. LONM .EQ. LBLOK) GO TO 99
       IF (KCLAT .EQ. KBLOK .OR. LCLON .EQ. LBLOK) GO TO 99
       IF ( RMIN .LT. RMED .AND. RMIN .LT. RMAX) GO TO 80
       WRITE (6,221) RMIN,RMED,RMAX
  221  FORMAT (' INNER RADIUS',F8.2,' IS NOT LESS THAN INTERMEDIATE OR OU
     1TER RADIUS',2F9.2)
   91  STOP
   80  IF (RGR .EQ. 0.0) RGR=14.0
       IF (RGR .GT. 13.99) GO TO 81
       WRITE (6,222) RGR
  222  FORMAT (///'0WARNING. EARTH CURVATURE EFFECT IS ASSUMED NEGLIGIBLE
     1 FOR DISTANCES LESS THAN 14 KM.'/, ' YOUR SELECTION OF',F9.2,
     2 ' KM MAY LEAD TO INACCURACY IN THE APPROXIMATION USED.')
```

TABLE 1--CONTINUED

```
   81 IF (NMAP .GT. 10) GO TO 2
      RIF(NMAP)=RMIN
      RIL(NMAP)=RMAX
      LCIRC(NMAP)=KCIRC
    2 IF (RMIN-RAD1) 94,95,95
   94 RAD1=RMIN
   95 IF (RMAX .LE. RAD2) GO TO 97
      RAD2=RMAX
   97 NCIRC=NCIRC+KCIRC
      IF (NCIRC .LE. 1) GO TO 96
      WRITE (6,210)
  210 FORMAT (51H1MORE THAN ONE CIRCULAR INNER RADIUS CAN NOT BE RUN)
      STOP
   96 RMAX2=RMAX*RMAX
      RMED2=RMED*RMED
      RMIN2=RMIN*RMIN
      RGR2=RGR*RGR
C ROWS (DIFFERING LATITUDE) AND COLUMNS OF SMALL COMPARTMENTSIN LARGE BL
      MCB=KBLOK/KCLAT
      NCB=LBLOK/LCLON
      LTES=LBLOK-LCLON*NCB
      KTES=KBLOK-KCLAT*MCB
      IF (LTES .NE. 0 .OR. KTES .NE.0) GO TO 99
      CPNUM=MCB*NCB
      MCB1=MCB-1
      NCB1=NCB-1
C NUMBER OF COMPARTMENTS AND  LARGE BLOCKS IN QUAD, BY ROWS AND COLUMNS
      NJN=(60*LONM)/LCLON
      MIT=(60*LATM)/KCLAT
      KBQ=(60*LATM)/KBLOK
      LBQ=(60*LONM)/LBLOK
C EDGES OF QUAD EXPRESSED IN MINUTES AND IN DEGREES
      BQM=LATM
      AQM=LONM
      BQD=BQM/60.0
      AQD=AQM/60.0
      KLCMP=KCLAT*LCLON
      COMP2=KLCMP
      COMP2=COMP2/3600.0
C EDGES AND HALF-EDGES OF LARGE BLOCKS IN MINUTES
      BLOKK=KBLOK
      BLOKL=LBLOK
      BLOKK=BLOKK/60.0
      BLOKL=BLOKL/60.0
      BLOK2=BLOKK*BLOKL
      BL2K=0.5*BLOKK
      BL2L=0.5*BLOKL
C HALF-EDGES OF LARGE BLOCKS IN INDEXING UNITS
      BLK2K=BL2K/BQM
      BLK2L=BL2L/AQM
      HLATM=0.5*BQM
C EDGE OF QUAD MINUS HALF-BLOCK IN MINUTES, FOR TESTING RMAX
      QB2B=BQM-BL2K
      QA2B=AQM-BL2L
C EDGES AND HALF-EDGES OF COMPARTMENTS IN MINUTES OR SECONDS
```

TABLE 1--CONTINUED

```
      COMK=KCLAT
      COML=LCLON
      CMK2=COMK/120.0
      CML2=COML/120.0
      BC2K=BL2K-CMK2
      BC2L=BL2L-CML2
      ARCSB=COMP2/BLOK2
      BQM60=60.0/BQM
      AQM60=60.0/AQM
      RM120=RMAX/120.0
      RMXBQ=RMAX/BQM
      RMXAQ=RMAX/AQM
      IF (KSEC .EQ. 1) GO TO 44
      IF (KSEC .EQ. 60) GO TO 45
      WRITE (6,213)
  213 FORMAT (49H1COMPARTMENT UNITS NOT SPECIFIED IN COLUMNS 63-64)
      STOP
C MINUTES
   44 BLK2K=60.0*BLK2K
      BLK2L=60.0*BLK2L
      NJN=NJN/60
      NIT=NIT/60
      KTES=LONM-NJN*LCLON
      LTES=LATM-NIT*KCLAT
      IF (LTES .NE. 0 .OR. KTES .NE.0) GO TO 99
      KBQ=KBQ/60
      LBQ=LBQ/60
      KTES=LATM-KBQ*KBLOK
      LTES=LONM-LBQ*LBLOK
      IF (LTES .NE. 0 .OR. KTES .NE.0) GO TO 99
      COMP2=3600.0*COMP2
      BLOK2=3600.0*BLOK2
      BL2K=60.0*BL2K
      BL2L=60.0*BL2L
      BLOKK=KBLOK
      BLOKL=LBLOK
      BC2K=60.0*BC2K
      BC2L=60.0*BC2L
      QB2B=BQM-BL2K
      QA2B=AQM-BL2L
      GO TO 46
C SECONDS
   45 COMK=COMK/60.0
      COML=COML/60.0
      KTES=60*LONM-NJN*LCLON
      LTES=60*LATM-NIT*KCLAT
      IF (LTES .NE. 0 .OR. KTES .NE.0) GO TO 99
      KTES=60*LATM-KBQ*KBLOK
      LTES=60*LONM-LBQ*LBLOK
      IF (LTES .NE. 0 .OR. KTES .NE.0) GO TO 99
   46 BL1=KBQ-1
      AC10=0.5*COML*ASMAX
      BC10=0.5*COMK*BSMAX
      TEST=AC10*AC10+BC10*BC10
      IF (RMIN2 .GT. TEST) GO TO 82
```

TABLE 1--CONTINUED

```
      WRITE (6,223) RMIN                                              124
  223 FORMAT (' PROGRAM NOT WRITTEN TO INCLUDE CASE WHERE HALF OF COMPAR
     1TMENT DIAGONAL-LENGTH IS GREATER THAN INNER RADIUS ', F6.2)
      STOP                                                            125
   82 TEST=RMED-RMIN                                                  126
C HALF DIAGONAL OF LARGEST BLOCK
      ADEL=(AC10*NCB)**2+(BC10*MCB)**2                                127
      ADEL=SQRT(ADEL)                                                 128
      IF (TEST .GT. ADEL) GO TO 84                                    129
      WRITE (6,224) RMIN,RMED                                         130
  224 FORMAT (' SELECTED RADII',2F8.2,' DO NOT LEAVE ROOM FOR BLOCKS')
      STOP                                                            131
C ERROR OF 0.001 MINUTE
   84 AC10=ASMAX/1000.0                                               132
      BC10=BSMAX/1000.0                                               133
      DO 9 IS=1,NS                                                    134
C FLOATING POINT NOTATION FOR LOCATION OF STATION IN INDEX SYSTEM (QUAD
C INCREMENTS).
      DO 65 M=1,13                                                    135
      GRAV(IS,M)=0.0                                                  136
   65 NUMS(IS,M)=0                                                    137
      MSS(IS)=0                                                       138
      ST=(SLATM(IS)+LTM(IS))/60.0                                     139
      STIND=BQM60*ST                                                  140
      SNIND=(SLONM(IS)+LNM(IS))/AQM                                   141
C NW CORNER OF QUAD IN WHICH STATION IS LOCATED IN INDEX SYSTEM.
C STATIONS ALONG EAST AND SOUTH EDGES INCLUDED IN QUAD TO NORTHWEST.
      LATSD(IS)=STIND+1.0                                             142
      LONSD(IS)=SNIND+1.0                                             143
C MAX RADIUS IN DEGREES
      RQ2=RM120/BS(IS)                                                144
      CN=COS(DEGR*(ST+RQ2))                                           145
      CS=COS(DEGR*(ST-RQ2))                                           146
      C2N=CN*CN                                                       147
      C2S=CS*CS                                                       148
      RBN=RMXBQ/(1.861656+C2N*(0.000160*C2N-0.019028))-BLK2K          149
      RBS=RMXBQ/(1.861656+C2S*(0.000160*C2S-0.019028))-BLK2K          150
      RAN=RMXAQ/((CN*(1.861656-0.006343*C2N))-BLK2L                   151
C NORTH BOUNDARY OF COVERAGE NEEDED, IN INDEX UNITS- REFERRED TO NW
C CORNER OF BOUNDING QUADS. NUMBERS INCREASE TO NW. THEN  S, E, AND W.
      LATNW(IS)=STIND+RBN +1.0                                        152
      LATSE(IS)=STIND-RBS +1.0                                        153
      LONSE(IS)=SNIND-RAN +1.0                                        154
    9 LONNW(IS)=SNIND+RAN +1.0                                        155
      WRITE (6,208)                                                   156
  208 FORMAT (1H1)
C CALCULATE TERRAIN CORRECTION, ONE QUAD AT A TIME
      DO 10 MQ=1,91                                                   157
C TOTAL NUMBER OF QUADS COUNTED
      NQ=MQ                                                           158
C IDENTIFICATION OF QUAD. COORDINATES OF NW CORNER- DEGREES, MINUTES
C OF LATITUDE AND LONGITUDE IN INTEGERS. KFATH IS 6 IF DEPTHS (NEGATIVE
C ELEVATIONS) IN FATHOMS--FEET OTHERWISE.  33 IS FOR ALL DEPTHS IN
C METERS. 36 FOR ELEVATIONS IN METERS AND DEPTHS IN FATHOMS. 31--M, FT
      READ  (5,104)(DENTQ(ID,MQ),ID=1,3),LTDQ,LTMQ,LNDQ,LNMQ, KFATH   159
```

TABLE 1--CONTINUED

```
  104 FORMAT (3A4,2I3,I4,I3,I2)
      IF (LTDQ-90) 74,12,12
   74 WRITE (6,212)(DENTQ(ID,MQ),ID=1,3),LTDQ,LTMQ,LNDQ,LNMQ
  212 FORMAT (1X,3A4,2I3,I4,I3)
      IF (NQ-81) 11,73,73
   73 WRITE (6,217)(DENTQ(ID,81),ID=1,3)
  217 FORMAT (24H 80 MAPS EXCEEDED.  MAP ,3A4,14H IS NUMBER 81.)
      STOP
C ELEVATIONS OF COMPARTMENTS IN FEET.  ONE WEST-TO-EAST ROW AT A TIME,
C STARTING AT NORTHWEST CORNER.
C CARD WITH 99 IN LOCATION FOR LATITUDE DEGREES PLACED BEHIND ELEVATION
C CARDS OF LAST QUADRANGLE IN DATA--THE FINAL DATA CARD
   11 READ  (5,105)((E(I,J),J=1,NJN),I=1,NIT)
  105 FORMAT ((10F7.0))
  831 DO 307 J=1,NJN
      DO 307 I=1,NIT
  307 E(I,J)=E(I,J)/1000.0
      IF (KFATH-31) 300,306,306
  300 DO 301 J=1,NJN
      DO 301 I=1,NIT
  301 E(I,J)=0.3048006*E(I,J)
      IF (KFATH-6) 305,302,305
  306 IF (KFATH-33) 308,305,309
  302 DO 304 J=1,NJN
      DO 304 I=1,NIT
      EIJ=E(I,J)
      IF (EIJ) 303,304,304
  303 E(I,J)=6.0*EIJ
  304 CONTINUE
      GO TO 305
  308 DO 310 J=1,NJN
      DO 310 I=1,NIT
      EIJ=E(I,J)
      IF (EIJ) 312,310,310
  312 E(I,J)=0.3048006*EIJ
  310 CONTINUE
      GO TO 305
  309 DO 311 J=1,NJN
      DO 311 I=1,NIT
      EIJ=E(I,J)
      IF (EIJ) 313,311,311
  313 E(I,J)=1.8288036*EIJ
  311 CONTINUE
C AVERAGE ELEVATION OF COMPARTMENTS USED FOR ELEVATION OF BLOCKS.
  305 DO 86 K=1,KBQ
      KF=MCB*K
      K1=KF-MCB1
      DO 86 L=1,LBQ
      LF=MCB*L
      L1=LF-MCB1
      ELEV=0.0
      CPDN1=CPNUM
      DO 30 II=K1,KF
      DO 30 JJ=L1,LF
      EIJ=E(II,JJ)
```

TABLE 1--CONTINUED

```
C PROTECTION AGAINST BLANK ELEVATIONS
      IF (EIJ) 54,31,54
   31 CPDN1=CPDN1-1.0
      GO TO 30
   54 ELEV=ELEV+EIJ
   30 CONTINUE
      IF (CPDN1) 32,32,85
   32 BEL(K,L)=0.0
      GO TO 86
   85 BEL(K,L)=ELEV/CPDN1
   86 CONTINUE
C NW CORNER OF QUAD, IN MINUTES
   88 LTNWQ=60*LTDQ+LTMQ
      LNNWQ=60*LNDQ+LNMQ
      QT=LTNWQ
      QN=LNNWQ
C IN INDEX UNITS OF ONE-PER-QUAD
      LATQ(MQ)=LTNWQ/LATM
      LONQ(MQ)=LNNWQ/LONM
      LTQ=LATQ(MQ)
      LNQ=LONQ(MQ)
      LTES=LTNWQ-LTQ*LATM
      KTES=LNNWQ-LNQ*LONM
      IF (LTES .NE. 0 .OR. KTES .NE.0) GO TO 99
      IF (MQ .EQ. 1) GO TO 3
      MINUS=MQ-1
      DO 4 K=1,MINUS
      IF (LTQ .EQ. LATQ(K) .AND. LNQ .EQ. LONQ(K)) GO TO 5
    4 CONTINUE
      GO TO 3
    5 WRITE (6,206)
  206 FORMAT (' THIS MAP WAS SKIPPED. IT ALREADY HAS BEEN USED.')
      GO TO 10
C PARAMETERS FOR NORTH AND SOUTHMOST BLOCK ROWS OF MAP
    3 DEGTOP=DEGM*(QT-BL2K)
      CQS=COS(DEGR*DEGTOP)
      C2=CQS*CQS
      BT=1.861656+C2*(0.000160*C2-0.019028)
      AT=CQS*(1.861656-0.006343*C2)
      DEGBOT=DEGM*(QT-BQM+BL2K)
      CQS=COS(DEGR*DEGBOT)
      C2=CQS*CQS
      BB=1.861656+C2*(0.000160*C2-0.019028)
      AB=CQS*(1.861656-0.006343*C2)
      ADELR=(AB-AT)/BL1
      BDELR=(BB-BT)/BL1
C COMPUTATION OF TERRAIN CORRECTION FOR ONE QUAD, ONE STATION AT A TIME
      DO 13 IS=1,NS
C DETERMINE IF QUAD IS TO BE USED. FIRST OMIT STATIONS WHERE QUAD OCCURS
C OUTSIDE BORDER OF RMAX-RECTANGLE.  SEQUENCE N, S, W, E.
      IF (  LTQ   -LATNW(IS)) 14,14,13
   14 IF (  LTQ   -LATSE(IS)) 13,15,15
   15 IF (  LNQ   -LONNW(IS)) 16,16,13
   16 IF (  LNQ   -LONSE(IS)) 13,17,17
C LATITUDE AND LONGITUDE OF STATION IN MINUTES
```

TABLE 1--CONTINUED

```
   17 ST=SLATM(IS)+LTM(IS)
      SN=SLONM(IS)+LNM(IS)
      DEGS=ST/60.0
      DEGN=SN/60.0
C DIFFERENCE IN LOCATION BETWEEN NW QUAD CORNER AND STATION, IN MINUTES
      QTST=(LTNWQ-LTM(IS))-SLATM(IS)
      QNSN=(LNNWQ-LNM(IS))-SLONM(IS)
      QTS2B=QTST-BL2K
      QNS2B=QNSN-BL2L
      QQNB=QNSN-QA2B
      QQTB=QTST-QB2B
C INDEX UNITS FOR CORNER OF QUAD IN WHICH STATION LOCATED
      LTS=LATSD(IS)
      LNS=LONSD(IS)
C TEST IF QUAD OUTSIDE RMAX RADIUS SQUARED
      IF (LTQ-LTS) 19,22,20
   19 DPHI2=(DEGS-DEGTOP)**2
      AQ2=(0.5*(AT+AS(IS))*(1.0+DEGR28*DPHI2))**2
      BQ2=(0.5*(BT+BS(IS)))**2
      IF (LNQ-LNS) 21,22,23
   20 DPHI2=(DEGS-DEGBOT)**2
      AQ2=(0.5*(AB+AS(IS))*(1.0+DEGR28*DPHI2))**2
      BQ2=(0.5*(BB+BS(IS)))**2
      IF (LNQ-LNS) 24,22,25
C SOUTHEAST
   21 DISQ2=BQ2*QTS2B*QTS2B+AQ2*QNS2B*QNS2B
      GO TO 26
C SOUTHWEST
   23 DISQ2=BQ2*QTS2B*QTS2B+AQ2*QQNB*QQNB
      GO TO 26
C NORTHEAST
   24 DISQ2=BQ2*QQTB*QQTB+AQ2*QNS2B*QNS2B
      GO TO 26
C NORTHWEST
   25 DISQ2=BQ2*QQTB*QQTB+AQ2*QQNB*QQNB
C TEST RMAX
   26 IF (DISQ2-RMAX2) 22,13,13
   22 BCOMK=BS(IS)*COMK
      ACOML=AS(IS)*COML
      ABC5=0.5*SQRT(BCOMK*BCOMK+ACOML*ACOML)
      MS=MSS(IS)+1
      IF (MS-14) 72,71,71
   71 WRITE (6,220)DENTS(IS),DEGS,DEGN,(DENTQ(ID,MQ),ID=1,3)
  220 FORMAT (' STATION ',A5,2F8.3,' (RENAMED *****) NEEDS MORE THAN 13
     1MAPS'/,8X,' MAP ', 3A4,' NEEDED BUT NOT COMPUTED.')
      DENTS(IS)=ASTER
      GO TO 13
   72 MSS(IS)=MS
      NUMS(IS,MS)=MQ
      RC5=RMIN+ABC5
      RC5=RC5*RC5
      ELST=ELS(IS)
      DPHI2=(DEGS-DEGTOP)**2
      ATOP=0.5*(AT+AS(IS) *(1.0+DEGR24*DPHI2))
      BTOP=0.5*(BT+BS(IS))
```

TABLE 1--CONTINUED

```
      DPHI2=(DEGS-DEGBOT)**2                                          297
      ABOT=0.5*(AB+AS(IS) *(1.0+DEGR24*DPHI2))                        298
      BBOT=0.5*(BB+BS(IS))                                            299
      ADEL =(ABOT-ATOP)/BL1                                           300
      BDEL =(BBOT-BTOP)/BL1                                           301
      A=ATOP-ADEL                                                     302
      B=BTOP-BDEL                                                     303
      AROW=AT-ADELR                                                   304
      BROW=BT-BDELR                                                   305
C START LOOP FOR TESTING BLOCKS OF COMPARTMENTS NORTH TO SOUTH
      DO 411 I=1,KBQ                                                  306
      KF=MCB*I                                                        307
      K1=KF-MCB1                                                      308
      FK1=I-1                                                         309
C FOR DISTANCES OF STATION TO BLOCK ROW
      B=B+BDEL                                                        310
      A=A+ADEL                                                        311
C FOR DISTANCES WITHIN BLOCK ROW
      AROW=AROW+ADELR                                                 312
      BROW=BROW+BDELR                                                 313
      DISTN=B*(QTS2B-FK1*BLOKK)                                       314
      IF (DISTN .GE. RMAX) GO TO 411                                  315
C BLOCK AREA IN SQUARE KILOMETERS
      AREAB=AROW*BROW*BLOK2                                           316
      BCOMK=BROW*COMK                                                 317
      ACOML=AROW*COML                                                 318
C CONSTANT IN TERRAIN CORRECTION FORMULA
      GPA=AREAB*GP                                                    319
      AC5=0.5*ACOML                                                   320
      BC5=0.5*BCOMK                                                   321
C EAST TO WEST
      DO 40 L=1,LBQ                                                   322
      LF=NCB*L                                                        323
      L1=LF-NCB1                                                      324
      FL1=L-1                                                         325
   79 DISTW=A*(QNS2B-FL1*BLOKL)                                       326
      R2B=DISTN*DISTN+DISTW*DISTW                                     327
      IF (R2B-RMAX2) 28,40,40                                         328
   28 IF (R2B-RMED2) 34,29,29                                         329
C USE LARGE BLOCKS. AVERAGE THE ELEVATIONS OF COMPARTMENTS.
   29 ELEV=BEL(I,L)                                                   330
      IF (ELEV .NE. 0.0) GO TO 87                                     331
      WRITE (6,211)  I, L,DENTS(IS)                                   332
  211 FORMAT (' WARNING. BLOCK',       I3,'S,',I3,'E HAS ZERO ELEVATION.'
     1,' TC NEEDED BUT NOT CALCULATED FOR STATION ',A5)
      GO TO 40                                                        333
   87 GB=G(ELEV,ELST,R2B,RGR2)                                        334
      GO TO 39                                                        335
C USE SMALL COMPARTMENTS.  DISTANCES RELATIVE TO CENTER OF COMPARTMENT
C IN NW CORNER OF BLOCK.
   34 DISNC=DISTN+BROW*BC2K                                           336
      DISWC=DISTW+AROW*BC2L                                           337
      FJI=0.0                                                         338
      GB=0.0                                                          339
      DO 35 II=K1,KF                                                  340
```

TABLE 1--CONTINUED

```
      FIJ=0.0
      YC=DISNC-FJI*BCOMK
      YC2=YC*YC
C DISTANCE, IN KM, FROM STATION  TO NORTH AND S EDGES OF COMPARTMENT
      DYN=YC+BC5
      DYS=YC-BC5
      IF (ABS(DYN) .LT. BC10) DYN=0.0
      IF (ABS(DYS) .LT. BC10) DYS=0.0
      YN=DYN*DYN
      YS=DYS*DYS
      DY(1)=DYN
      DY(2)=DYN
      DY(3)=DYS
      DY(4)=DYS
      DO 78 JJ=L1,LF
      ELEV=E(II,JJ)
      IF (ELEV .NE. 0.0) GO TO 38
      WRITE (6,214) II,JJ,DENTS(IS)
  214 FORMAT (' WARNING. COMPARTMENT',I3,'S,',I3,'E HAS ZERO ELEVATION.'
     1,' TC NEEDED BUT NOT CALCULATED FOR STATION ',A5)
      GO TO 78
   38 XC=DISWC-FIJ*ACOML
      XC2=XC*XC
      RC=XC2+YC2
C RC5 IS RMIN PLUS 0.5* SLANT LENGTH OF COMPARTMENT
C TEST IF THIS MAP GROUP REQUIRES INNER TIE TO CIRCLE
      IF (KCIRC) 49,51,49
   49 IF (RC-RC5) 64,51,51
   51 IF (RC-RMIN2) 78,37,37
   37 GC=G(ELEV,ELST,RC,RGR2)*ARCSB
      GB=GB+GC
      GO TO 78
   64 CALL GINNER(XC,YC,AC5,YS,YN,DY,    ELEV,ELST,RC,AREAB,GPA,GB,
     1     RGR2,ARCSB,IS,AC10)
   78 FIJ=FIJ+1.0
      FJI=FJI+1.0
   35 CONTINUE
   39 GRAV(IS,MS)=GRAV(IS,MS)+GB*AREAB
   40 CONTINUE
  411 CONTINUE
      GRAV(IS,MS)=GRAV(IS,MS)+GP
C END STATION LOOP
   13 CONTINUE
C END MAP LOOP
   10 CONTINUE
      GO TO 12
   99 WRITE (6,229)KCLAT,LCLON,KBLOK,LBLOK,LATM,LONM,LTDQ,LTMQ,LNDQ,LNMQ
  229 FORMAT (1X,2I3,3X,2I4,3X,2I4,4X,2I3,I5,I3/, 4X, 'STOP. ABOVE LISTE
     1D COMPARTMENT, BLOCK, MAP SIZES OR NORTHWEST CORNER OF MAP DO NOT
     2PROGRESS BY INTEGER MULTIPLICATION (EXCLUDING 1).')
      STOP
   12 NQ=NQ-1
C PRINTOUT
      IF(KCIRC    .EQ. 0) GO TO 52
      WRITE (6,200)RMIN,RMAX,BREA
```

TABLE 1--CONTINUED

```
  200 FORMAT ('0MAP COVERAGE FOR ',F8.3,' TO ',F8.3,' KILOMETERS ',
     1 '(CIRCULAR INNER JOIN) OF ',6A4)
      GO TO 53                                                          384
   52 WRITE (6,209)RMIN,RMAX,BREA                                       385
  209 FORMAT ('0MAP COVERAGE FOR ',F8.3,' TO ',F8.3,' KILOMETERS ',
     1 '(PIECEMEAL INNER JOIN) OF ',6A4)
   53 IF (KSEC .EQ. 60) GO TO 48                                        386
   47 WRITE (6,204)KCLAT,LCLON,KBLOK,LBLOK                              387
  204 FORMAT (36H SMALLEST COMPARTMENT DIGITIZED ARE ,I2, 4H BY ,I2,
     1 33H AND LARGEST COMPOSITE BLOCKS ARE,I3,3H BY,I3,8H MINUTES)
      GO TO 50                                                          388
   48 WRITE (6,205)KCLAT,LCLON,KBLOK,LBLOK                              389
  205 FORMAT (36H SMALLEST COMPARTMENT DIGITIZED ARE ,I2, 4H BY ,I2,
     1 33H AND LARGEST COMPOSITE BLOCKS ARE,I3,3H BY,I3,8H SECONDS)
   50 WRITE (6,207)LATM,LONM,RMED,RGR                                   390
  207 FORMAT(49H IN LATITUDE AND LONGITUDE. QUADRANGLES USED ARE , I3,
     24H BY , I3,9H MINUTES.,26H  CONVERSION TO BLOCKS AT ,F7.2,4H KM./,
     3  25H CURVATURE CORRECTION AT ,F4.0,' KM.',//)
C BEGIN INDEXING LOOP FOR EACH STATION
      DO 90 IS=1,NS                                                     391
      ST=SLATM(IS)+LTM(IS)                                              392
      SN=SLONM(IS)+LNM(IS)                                              393
      DEGS=ST/60.0                                                      394
      DEGN=SN/60.0                                                      395
      WRITE (6,202)DENTS(IS),DEGS,DEGN                                  396
  202 FORMAT(9H STATION ,A5,' AT',F7.3,1H,,F8.3,' DEGREES')
      WRITE (6,203)                                                     397
  203 FORMAT (6X, 2(3HMAP,9X,'NW CORNER (D,M)',7X,'MGLS',11X))
      A=AS(IS)                                                          398
      B=BS(IS)                                                          399
      CALL DEXQD(IS,LATNW(IS),LONNW(IS),DQD,AQD,LATSE(IS),LONSE(IS),    400
     1 LATSD(IS),LONSD(IS),NQ,      MSS(IS),                  LATM,LONM)
   90 CONTINUE                                                          401
   92 CONTINUE                                                          402
      JN=NTYPE                                                          403
      IF (JN .GT. 10) JN=10                                             404
      WRITE (6,201)                                                     405
  201 FORMAT (///,'0LIST OF RADIAL COVERAGE FOR SUCCESSIVE MAP SETS',/,
     1 '   INNER BOUNDARY IS PIECEMEAL UNLESS CIRCULAR IS INDICATED. ',
     2 'ALL OUTER BOUNDARIES ARE PIECEMEAL')
      DO 6 J=1,JN                                                       406
      IF(LCIRC(J) .EQ. 0) GO TO 7                                       407
      WRITE (6,215)  RIF(J),RIL(J)                                      408
  215 FORMAT (1X,F10.5,' TO ',F10.5,' KM (CIRCULAR INNER JOIN)')
      GO TO 6                                                           409
    7 WRITE (6,216)  RIF(J),RIL(J)                                      410
  216 FORMAT (1X,F10.5,' TO ',F10.5,' KM')
    6 CONTINUE                                                          411
      RETURN                                                            412
      END                                                               413


      SUBROUTINE GINNER(XC,YC,ACS,YS,YN,DY,ELEV,ELST,RC,AREAB,GPA,GB,
     1 RGR2,ARCSB,IS,AC10)        Circular inner join
      DOUBLE PRECISION DENTS                                            1
```

TABLE 1--CONTINUED

```
      INTEGER*2 NUMS
      DIMENSION DX(4),DY(4),R2(4),         GCEN(500),DENTS(500)
      DIMENSION GRAV(500,13),NUMS(500,13),GV(500)
      COMMON /STATN/ DENTS
      COMMON RMIN,RMIN2,RMAX2,BL2K,BL2L,QB2B,QA2B,AQM,BQM,ST,SN,
     1 A,B,    GCEN,GRAV,GV,NUMS
   66 DXW=XC+AC5
      DXE=XC-AC5
      IF (ABS(DXW) .LT. AC10) DXW=0.0
      IF (ABS(DXE) .LT. AC10) DXE=0.0
      XW=DXW*DXW
      XE=DXE*DXE
      DX(1)=DXW
      DX(2)=DXE
      DX(3)=DXE
      DX(4)=DXW
      R2(1)=XW+YN
      R2(2)=XE+YN
      R2(3)=XE+YS
      R2(4)=XW+YS
      BIG=0.0
C           NPT-NUMBER OF CORNERS OF COMPARTMENT THAT ARE LOCATED
C OUTSIDE RMIN CIRCLE
      NPT=0
      DO 320 K=1,4
      IF (RMIN2 .GE. R2(K)) GO TO 320
      NPT=NPT+1
      IF (BIG   .GE. R2(K)) GO TO 320
      KBIG=K
      BIG=R2(K)
  320 CONTINUE
      IF (NPT .EQ. 0) RETURN
C ASSIGN COORDINATES (X2,Y2) TO CORNER FARTHEST FROM STATION
      Y2=DY(KBIG)
      X2=DX(KBIG)
      I1=1
      I2=1
      IF (X2 .LT. 0.0) I1=-1
      IF (Y2 .LT. 0.0) I2=-1
      KTEST=0
      S1=DXW*DXE
      IF (S1 .GE. 0.0) GO TO 337
      S1=DY(1)*DY(4)
      IF (S1 .LT. 0.0) KTEST=1
  337 S1=I1
      S2=I2
C COORDINATES OF CORNER CLOSEST TO STATION (OPPOSITE FARTHEST CORNER)
      KSML=KBIG+2
      IF (KSML .GT. 4) KSML=KBIG-2
      X1=DX(KSML)
      Y1=DY(KSML)
C CALCULATE ACCORDING TO HOW MANY CORNERS ARE OUTSIDE CIRCLE
      GO TO (322,323,324,325), NPT
C ONE CORNER OUTSIDE CIRCLE
  322 CALL CENTD(0.0,X2,0.0,Y2,S1, S2,AREA,YM,XM,1)
```

TABLE 1--CONTINUED

```
C ASSUME 0.002-MINUTE LOCATION ACCURACY
      ABAR=ABS(AREA)
      IF(ABAR .LT. 1.0E-5) RETURN
      RBAR2=(YM*YM+XM*XM)/(ABAR*ABAR)
      IF (RBAR2 .LT. R2(KBIG)) GO TO 406
      RBAR2=R2(KBIG)
      H=ELST+SQRT(RBAR2/RC)*(ELEV-ELST)
      GO TO 405
C TWO POINTS OUTSIDE CIRCLE.
C FIND COORDINATES OF SECOND CORNER OUTSIDE CIRCLE-ADJACENT FARTHEST
  323 LBIG=KBIG+1
      IF (LBIG .EQ. 5) LBIG=1
      IF (R2(LBIG) .GT. RMIN2) GO TO 65
      LBIG=KBIG-1
      IF (LBIG .EQ. 0) LBIG=4
   65 IF (DY(KBIG) .EQ. DY(LBIG)) GO TO 342
C REVERSED ROLES
      IF (Y1) 376,343,377
  376 LY1=-1
      GO TO 367
  377 LY1=1
  367 L3=I2+LY1
      IF (L3 .EQ. 0) GO TO 368
  343 CALL CENTD(Y1,Y2,0.0,X2,S2, S1,AREA,XM,YM,2)
      GO TO 403
  342 IF (X1) 346,344,347
  346 LX1=-1
      GO TO 351
  347 LX1=1
  351 L4=I1+LX1
      IF (L4 .EQ. 0) GO TO 349
  344 CALL CENTD(X1,X2,0.0,Y2,S1, S2,AREA,YM,XM,2)
      GO TO 403
C X1 AND X2 ARE OF OPPOSITE SIGN  (368 FOR OPP. Y1, Y2)
  349 IF (RMIN-ABS(Y2)) 344,344,330
  368 IF (RMIN-ABS(X2)) 343,343,330
C 3 CORNERS OUTSIDE CIRCLE
  324 IF (R2(KSML) .EQ. RMIN2) GO TO 37
      IF (Y1) 51,52,53
   51 LY1=-1
      GO TO 354
   52 LY1= 0
      GO TO 354
   53 LY1= 1
  354 L3=I2+LY1+3
      IF (X1) 5,6,7
    5 LX1=-1
      GO TO 8
    6 LX1= 0
      GO TO 8
    7 LX1= 1
    8 L4=I1+LX1+3
      GO TO (101,102,103,102,101), L3
  101 GO TO (355,121,104,121,355), L4
  355 CALL CENTD(X1,0.0,Y1,0.0,S1,S2,AREA,YM,XM,3)
```

```
      GO TO 400
  121 CALL CENTD(Y1,0.0,0.0,0.0,S2,S1,AREA,XM,YM,6)
      GO TO 400
  122 CALL CENTD(X1,0.0,0.0,0.0,S1,S2,AREA,YM,XM,6)
      GO TO 400
  104 IF (ABS(Y2) .GE. RMIN) GO TO 355
   15 LBIG=KBIG+1
      IF (LBIG .EQ. 5) LBIG=1
      IF (DX(LBIG) .EQ. DX(KBIG)) GO TO 108
      LBIG=KBIG-1
      IF (LBIG .EQ. 0) LBIG=4
  108 CALL CENTD(Y1,Y2,0.0,X2,S2, S1,AREA,XM,YM,2)
      GO TO 114
  102 GO TO (122,105,106,105,122), L4
  105 AREA=0.7853982*RMIN2
      BIG=RMIN*RMIN2/3.0
      YM=S1*BIG
      XM=S2*BIG
      GO TO 400
  106 IF (ABS(Y2) .LT. RMIN) GO TO 15
      GO TO 122
  103 GO TO (111,112,113,112,111), L4
  111 IF (ABS(X2) .LT. RMIN) GO TO 12
  356 CALL CENTD(Y1,0.0,X1,0.0,S2,S1,AREA,XM,YM,3)
      GO TO 400
  112 IF (ABS(X2) .GE. RMIN) GO TO 121
   12 LBIG=KBIG+1
      IF (LBIG .EQ. 5) LBIG=1
      IF (DY(LBIG) .EQ. DY(KBIG)) GO TO 109
      LBIG=KBIG-1
      IF (LBIG .EQ. 0) LBIG=4
  109 CALL CENTD(X1,X2,0.0,Y2,S1, S2,AREA,YM,XM,2)
  114 LR=10-(KBIG+LBIG+KSML)
      CALL CENTD (0.0,DX(LR),0.0,DY(LR),0.0,0.0,AREAR,XE,XW,1)
      GO TO 115
  113 IF (ABS(X2) .LT. RMIN) GO TO 107
      IF (ABS(Y2) .LT. RMIN) GO TO 15
      CALL CENTD(X1,X2,Y1,Y2,S1, S2,AREA,YM,XM,5)
      AREAR=AREA
      GO TO 115
  107 IF (ABS(Y2) .GE. RMIN) GO TO 12
   14 LBIG=KBIG+1
      IF (LBIG .EQ. 5) LBIG=1
      LR=10-(KBIG+LBIG+KSML)
      CALL CENTD (0.0,DX(LR),0.0,DY(LR),0.0,0.0,AREAR,XE,XW,1)
      GO TO 110
  330 AREAR=0.0
  110 CALL CENTD (0.0,DX(LBIG),0.0,DY(LBIG),0.0,0.0,AREA,XE,XW,1)
      AREAR=AREAR+AREA
      CALL CENTD (0.0,X2,0.0,Y2,S1,S2,AREA,YM,XM,1)
  115 AREAR=AREAR+AREA
      ABAR=ABS(AREAR)
      RBAR2=(XM*XM+YM*YM)/(AREA*AREA)
      H=ELEV
      GO TO 405
```

TABLE 1--CONTINUED

```
C 4 CORNERS OUTSIDE CIRCLE
  325 IF (X1) 54,37,55
   54 LX1=-1
      GO TO 56
   55 LX1= 1
   56 L3=I1+LX1
      IF (L3 .NE. 0) GO TO 366
  360 IF (Y1) 57,37,58
   57 LY1=-1
      GO TO 59
   58 LY1= 1
   59 L4=I2+LY1
      IF (L4 .EQ. 0) RETURN
  378 IF (ABS(Y1) .GE. RMIN) GO TO 37
  361 CALL CENTD(0.0,0.0,Y1,0.0,0.0,S2,AREA,YM,XM,4)
      GO TO 400
  366 IF (Y1) 16,37,17
   16 LY1=-1
      GO TO 18
   17 LY1= 1
   18 L4=I2+LY1
      IF (L4 .NE. 0) GO TO 37
C REVERSED ROLES
   19 IF (ABS(X1) .GE. RMIN) GO TO 37
  373 CALL CENTD(0.0,0.0,X1,0.0,0.0,S1,AREA,XM,YM,4)
C MOMENT OF RECTANGULAR COMPARTMENT.
  400 AREAR=ABS((X2-X1)*(Y2-Y1))
      AREA =AREAR-AREA
C MOMENTS ABOUT Y- AND X-AXES FOR REMAINING AREA
      YM=XC*AREAR-YM
      XM=YC*AREAR-XM
  403 ABAR=ABS(AREA)
      RBAR2=(YM*YM+XM*XM)/(ABAR*ABAR)
  406 RBAR=SQRT(RBAR2)
      H=ELST+RBAR*(ELEV-ELST)/SQRT(RC)
  405 GC=ABAR*G(H,ELST,RBAR2,RGR2)/AREAB
      BIG=GC*GPA
      IF (KTEST .EQ. 1) WRITE (6,200) DENTS(IS),BIG
  200 FORMAT (4X,'STATION ',A5,' IS INSIDE CALCULATED COMPARTMENT. ',
     1 'CORRECTION USED IS',F8.3,' MGAL.')
  404 GCEN(IS)=GCEN(IS)+BIG
      GB=GB+GC
      RETURN
   37 GB=GB+ G(ELEV,ELST,RC,RGR2)*ARCSB
   78 RETURN
      END
```

Called by GINNER--circular inner join

```
      SUBROUTINE CENTD(X1,X2,Y1,Y2,S1,S2,AREA,YM,XM,M)
      INTEGER*2 NUMS
      DIMENSION GRAV(500,13),NUMS(500,13),GV(500),GCEN(500)
      COMMON R,AA,      RMAX2,BL2K,BL2L,QB2B,QA2B,AQM,BQM,ST,SN,
     1 A,B,   GCEN,GRAV,GV,NUMS
C NOTE-COMMON STATEMENT NAMES ARE DIFFERENT THAN OTHER SUBROUTINES
C M-NUMBER OF CORNERS OUTSIDE COMPARTMENT (EXCEPT 5=3). ABSOLUTE VALUES
```

TABLE 1--CONTINUED

```
C GIVE PROTECTION AGAINST SQUARE ROOTS OF NEGATIVE NUMBERS MEANT TO BE 0
      GO TO (12,12,35,4,35,6), M
   12 AX2=ABS(X2)
      AY2=ABS(Y2)
      X22=X2*X2
      Y22=Y2*Y2
      AAX2=ABS(AA-X22)
      AAY2=AA-Y22
      SAX2=SQRT(AAX2)
      IF (M .EQ. 2) GO TO 2
C 1 CORNER OUTSIDE
    1 AAY2=ABS(AAY2)
      SAY2=SQRT(AAY2)
C FACTOR TERMS TO MINIMIZE LOSS OF SIGNIFICANT FIGURES
      AREA=AX2*(AY2-0.5*SAX2)-0.5*(AY2*SAY2+AA*(ARSIN(AX2/R)-ARSIN(SAY2/
     1 R)))
      YM=S1*(0.5*AY2*(Y22/3.0-AAX2)+AAX2*SAX2/3.0)
      XM=S2*(0.5*AX2*(X22/3.0-AAY2)+AAY2*SAY2/3.0)
      RETURN
C 2 CORNERS OUTSIDE-CONNECTED AREA
    2 SX=S1*X1
      X11=X1*X1
      AAX1=ABS(AA-X11)
      SAX1=SQRT(AAX1)
      AREA=AY2*(AX2-SX)-0.5*(AX2*SAX2-SX*SAX1+AA*(ARSIN(AX2/R)
     1 -ARSIN(SX/R)))
      YM=S1*(0.5*AY2*(X22-X11)+(AAX2*SAX2-AAX1*SAX1)/3.0)
      XM=0.5*S2*(AX2*(X22/3.0-AAY2)-SX*(X11/3.0-AAY2))
      RETURN
C 4 CORNERS OUTSIDE-CONNECTED INSIDE AREA USED
    4 AAY1=ABS(AA-Y1*Y1)
      SAY1=SQRT(AAY1)
      AREA=AA*ARSIN(SAY1/R)-ABS(Y1)*SAY1
      YM=0.0
      XM=0.6666667*S2*AAY1*SAY1
      RETURN
   35 AY1=ABS(Y1)
      X11=X1*X1
      Y11=Y1*Y1
      AAX1=ABS(AA-X11)
      AAY1=ABS(AA-Y11)
      SAX1=SQRT(AAX1)
      SAY1=SQRT(AAY1)
      IF (M .EQ. 5) GO TO 5
C 3 CORNERS OUTSIDE-1 CORNER INSIDE USED
    3 SX=S1*X1
      IF (SAY1 .EQ. SX) GO TO 10
      AREA=SX*(AY1-0.5*SAX1)-0.5*(AY1*SAY1-AA*(ARSIN(SAY1/R)-ARSIN(SX/R)
     1 ))
      YM=S1*(AAX1*SAX1/3.0+0.5*AY1*(Y11/3.0-AAX1))
      XM=S2*(AAY1*SAY1/3.0+0.5*SX*(X11/3.0-AAY1))
      RETURN
C CASE WHERE A CORNER IS ON CIRCLE AND WHOLE COMPARTMENT IS OUTSIDE
   10 AREA=0.0
      YM=0.0
```

TABLE 1--CONTINUED

```
      XM=0.0
      RETURN
C 3 CORNERS OUTSIDE-OCCUPIES 3 QUADRANTS (CLOSE-IN)
    5 AX1=ABS(X1)
      AX2=ABS(X2)
      AY2=ABS(Y2)
      X22=X2*X2
      Y22=Y2*Y2
      AREA=AX2*(AY1+AY2)+AX1*AY2-0.5*(AX1*SAX1+AY1*SAY1
     1 +AA*(1.570796+ARSIN(AX1/R)+ARSIN(AY1/R)))
      YM=S1*(0.5*(AY1*(Y11/3.0-AA+X22)+AY2*(X22-X11))-AAX1*SAX1/3.0)
      XM=S2*(0.5*(AX1*(X11/3.0-AA+Y22)+AX2*(Y22-Y11))-AAY1*SAY1/3.0)
      RETURN
C 3 CORNERS OUT, Y1=0.0
    6 SX=S1*X1
      X11=X1*X1
      AAX1=ABS(AA-X11)
      SAX1=SQRT(AAX1)
      AREA=0.5*(AA*(1.570796-ARSIN(SX/R))-SX*SAX1)
      YM=S1*AAX1*SAX1/3.0
      XM=S2*(AA*R/3.0+0.5*SX*(X11/3.0-AA))
      RETURN
      END


      SUBROUTINE DEXQD(IS,LT,LN,BQD,AQD,LTSE,LNSE,LTS,LNS,NQ,      MS,
     1                          LATM,LONM)
      INTEGER*2 NUMS
      DIMENSION IQ(5,7),GCEN(500),GRAV(500,13),GV(500),DENTM(3,13),
     1 DENTQ(3,81),NUMS(500,13),         LATQ(81),LONQ(81),
     2 LTDQ(13),LTMQ(13),LNDQ(13),LNMQ(13)
      COMMON /MAP/ DENTQ,LATQ,LONQ
      COMMON RMIN,RMIN2,RMAX2,BL2K,BL2L,QB2B,QA2B,AQM,BQM,ST,SN,
     1 A,B,    GCEN,GRAV,GV,NUMS
C PREPARE LIST OF QUADRANGLES NEEDED   Indexing
      DO 41 K=1,5
      DO 41 L=1,7
   41 IQ(K,L)=0
C NW CORNER OF INDEX MAP IN INDEX UNITS,DEGREES, AND MINUTES.
      QTNW=LT
      QNNW=LN
      QTNW=BQD*QTNW
      QNNW=AQD*QNNW
      QB=60.*QTNW
      QA=60.*QNNW
C FIND QUADS NEEDED.  FIRST BY N-S-W-E BOUNDARIES, THEN RADII.
C REFERENCE TO NW CORNER OF QUADS.
      KMAX=LT-LTSE+1
      LMAX=LN-LNSE+1
      KSM1=LT-LTS
      LSM1=LN-LNS
      KSP1=KSM1+2
      LSP1=LSM1+2
      DO 42 K=1,KMAX
      DO 42 L=1,LMAX
```

TABLE 1--CONTINUED

```
   42 IQ(K,L)=IQ(K,L)+2
      B2=B*B
      A2=A*A
C SOUTH CORNERS
      QTS2B=ST+BL2K
C EAST CORNERS
      QNS2B=SN+BL2L
C NORTH CORNERS
      QTST=ST+QB2B
C WEST CORNERS
      QNSN=SN+QA2B
C NW CORNER
      IF (KSM1) 152,152,156
  156 IF (LSM1) 158,158,157
  157 DO 44 K=1,KSM1
      FK=K-1
      QT=QB-FK*BQM-QTST
      DO 44 L=1,LSM1
      FL=L-1
      QN=QA-FL*AQM-QNSN
      DISQ2=B2*QT*QT+A2*QN*QN
      IF (DISQ2-RMAX2) 44,44,43
   43 IQ(K,L)=IQ(K,L)-2
   44 CONTINUE
C NE CORNER
  158 IF (LMAX-LSP1) 152,151,151
  151 DO 46 K=1,KSM1
      FK=K-1
      QT=QB-FK*BQM-QTST
      DO 46 L=LSP1,LMAX
      FL=L-1
      QN=QA-FL*AQM-QNS2B
      DISQ2=B2*QT*QT+A2*QN*QN
      IF (DISQ2-RMAX2) 46,46,45
   45 IQ(K,L)=IQ(K,L)-2
   46 CONTINUE
C SW CORNER
  152 IF (KMAX-KSP1) 155,153,153
  153 IF (LSM1) 159,159,160
  160 DO 48 K=KSP1,KMAX
      FK=K-1
      QT=QB-FK*BQM-QTS2B
      DO 48 L=1,LSM1
      FL=L-1
      QN=QA-FL*AQM-QNSN
      DISQ2=B2*QT*QT+A2*QN*QN
      IF (DISQ2-RMAX2) 48,48,47
   47 IQ(K,L)=IQ(K,L)-2
   48 CONTINUE
C SE CORNER
  159 IF (LMAX-LSP1) 155,154,154
  154 DO 50 K=KSP1,KMAX
      FK=K-1
      QT=QB-FK*BQM-QTS2B
      DO 50 L=LSP1,LMAX
```

TABLE 1--CONTINUED

```
      FL=L-1                                                            69
      QN=QA-FL*AQM-QNS2B                                                70
      DISQ2=B2*QT*QT+A2*QN*QN                                           71
      IF (DISQ2-RMAX2) 50,50,149                                        72
  149 IQ(K,L)=IQ(K,L)-2                                                 73
   50 CONTINUE                                                          74
  155 CONTINUE                                                          75
C QUADS USED
   75 GB=0.                                                             76
      M=0                                                               77
      IF (MS) 53,53,54                                                  78
   54 DO 132 MQ=1,MS                                                    79
      M  =NUMS(IS,MQ)                                                   80
   66 LTQ=LATQ(M)                                                       81
      LNQ=LONQ(M)                                                       82
      LTB=LATM*LTQ                                                      83
      LNA=LONM*LNQ                                                      84
      LTD=LTB/60                                                        85
      LND=LNA/60                                                        86
      LTDQ(MQ)=LTD                                                      87
      LTMQ(MQ)=LTB-60*LTD                                               88
      LNDQ(MQ)=LND                                                      89
      LNMQ(MQ)=LNA-60*LND                                               90
      LTS=LT-LTQ+1                                                      91
      LNS=LN-LNQ+1                                                      92
      IQ(LTS,LNS)=IQ(LTS,LNS)-1                                         93
      DENTM(1,MQ)=DENTQ(1,M)                                            94
      DENTM(2,MQ)=DENTQ(2,M)                                            95
      DENTM(3,MQ)=DENTQ(3,M)                                            96
  132 GB=GB+GRAV(IS,MQ)                                                 97
   68 GV(IS)=GV(IS)+GB                                                  98
      IF (MS-1) 53,134,52                                               99
   52 MS5=MS/2                                                         100
      MS2=2*MS5                                                        101
      MSM=MS-MS2                                                       102
      DO 93 M=2,MS2,2                                                  103
      M1=M-1                                                           104
   93 WRITE (6,204)(DENTM(ID,M1),ID=1,3), LTDQ(M1),LTMQ(M1),LNDQ(M1),  105
     1 LNMQ(M1),GRAV(IS,M1), (DENTM(ID,M),ID=1,3),LTDQ(M),LTMQ(M),
     2 LNDQ(M),LNMQ(M),GRAV(IS,M)
  204 FORMAT (2X,2(3A4,I6,I3,I8,I3, F11.3,6X))
      IF (MSM) 134,133,134                                             106
  134 WRITE (6,207)(DENTM(ID,MS),ID=1,3),LTDQ(MS),LTMQ(MS),LNDQ(MS),   107
     1 LNMQ(MS),GRAV(IS,MS)
  207 FORMAT (2X,3A4,I6,I3,I8,I3,F11.3)
  133 WRITE (6,205)GB                                                  108
  205 FORMAT (35X,16HTOTAL CORRECTION,F7.3,10H MILLIGALS)
   53 LTB=LT*LATM                                                      109
      LNA=LN*LONM                                                      110
      DO 136 K=1,5                                                     111
      DO 136 L=1,7                                                     112
      IF (IQ(K,L)-2) 136,137,136                                       113
  137 LTMIN=LTB-LATM*(K-1)                                             114
      LNMIN=LNA-LONM*(L-1)                                             115
      LTDEG=LTMIN/60                                                   116
```

TABLE 1--CONTINUED

```
      LNDEG=LNMIN/60
      LTMIN=LTMIN-60*LTDEG
      LNMIN=LNMIN-60*LNDEG
  138 WRITE (6,209)LTDEG,LTMIN,LNDEG,LNMIN
  209 FORMAT (14H      NOT FOUND,I6,I3,I8,I3)
  136 CONTINUE
      RETURN
      END


      FUNCTION G(H,E,R2,RGR2)
C DETERMINE TERRAIN CORRECTION FOR COMPARTMENT.   H,E- ELEVATION OF
C COMPARTMENT AND STATION IN KM.    R2- SQUARE OF DISTANCE IN KM.  RGR2-
C TEST RADIUS FOR USE OF CURVATURE CORRECTION.
      RP2=1.0/R2
      RP=SQRT(RP2)
      HKM=E-H
      HE2=HKM*HKM
      HR2=HE2*RP2
      IF (H) 14,25,1
    1 IF (RGR2-R2) 2,2,5
C CURVATURE ACCOUNTED FOR.  MODIFIED LINE ELEMENT FORMULA.
    2 EARTH=6371.2
      C2=R2/EARTH
      G=0.5*HKM*RP*RP2
      FG=HKM+C2
      IF (HR2-0.013) 4,4,3
    3 FG=FG-0.75*HKM*HR2
    4 G=G*FG
      RETURN
C NO CURVATURE, LINE ELEMENT FORMULA.
    5 IF (HR2-0.47) 7,6,6
    6 G=RP*(1.0-1.0/SQRT(1.0+HR2))
      RETURN
    7 G=0.5*RP*HR2
      IF (HR2-0.013) 13,13,8
    8 FG=1.0-0.75*HR2
      IF (HR2-0.12) 12,12,9
    9 HR4=HR2*HR2
      FG=FG+0.625*HR4
      IF (HR2-0.26) 12,12,10
   10 FG=FG-0.546875*HR2*HR4
      IF (HR2-0.37) 12,12,11
   11 FG=FG+0.4921875*HR4*HR4
   12 G=G*FG
   13 RETURN
C SEAWATER COMPARTMENTS (NEGATIVE ELEVATIONS)
   14 E2=E*E
      IF (RGR2-R2) 15,15,18
C WITH CURVATURE
   15 EARTH=6371.2
      C=0.5*R2/EARTH
      C2=C*C
      CE=C+E
      CEH=C+HKM
```

TABLE 1--CONTINUED

```
      CE2=CE*CE
      CEH2=CEH*CEH
      C4=C2*C2
      CE4=CE2*CE2
      CEH4=CEH2*CEH2
      RP4=RP2*RP2
      FG=-C2+0.3846*CE2+0.6154*CEH2
     1 -0.75*RP2*(-C4+0.3846*CE4+0.6154*CEH4)+0.625*RP4*(-C2*C4
     2 +0.3846*CE2*CE4+0.6154*CEH2*CEH4)
   17 G=0.5*RP*RP2*FG
      RETURN
C NO CURVATURE
   18 IF (HR2-0.42) 20,20,19
   19 G=RP*(1.0-0.3846/SQRT(1.0+E2/R2)-0.6154/SQRT(1.0+HE2/R2))
      RETURN
   20 FG=0.3846*E2+0.6154*HE2
      IF (HR2-0.02) 24,24,21
   21 E4=E2*E2
      HE4=HE2*HE2
      FG=FG-0.75*RP2*(0.3846*E4+0.6154*HE4)
      IF (HR2-0.16) 24,24,22
   22 RP4=RP2*RP2
      FG=FG+0.625*RP4*(0.3846*E2*E4+0.6154*HE2*HE4)
      IF (HR2-0.30) 24,24,23
   23 FG=FG-0.546875*RP2*RP4*(0.3846*E4*E4+0.6154*HE4*HE4)
   24 G=0.5*RP*RP2*FG
   25 RETURN
      END
```

Table 2. List of punchcards for test case (See Table 3 for printout).

```
SAN JUAN MTS., COLORADO -2 0 3  2.5
SJM
 B2173716471075267 65570                     14      7928477
 1857375508106504513718O                   1188UD5347884138                 KXFIS
99999999999999999999999999999999999999999999999999999999999999999999999999999999
  5  53030 60 60 4.1        0.8949  4.0     15.0                 160             5 MIN
SJM VIIB7     37 20 107 50     Hanover F/G          SJ 30 SECOND
    8040     8350     8340     8310     8200     8080     7950     7780     7700     7540   VIIB7 01
    7700     7800     7800     7780     7750     7650     7600     7400     7340     7600   VIIB7 02
    7080     7310     7300     7360     7420     7380     7340     7300     7650     8050   VIIB7 03
    6920     7380     7290     7400     7460     7260     7230     7560     7680     7800   VIIB7 04
    7320     7640     7430     7280     7240     7250     7480     7640     7880     7880   VIIB7 05
    7480     7470     7490     7300     7100     7260     7680     7750     7700     7570   VIIB7 06
    7600     7680     7450     7260     7080     7260     7360     7400     7410     7320   VIIB7 07
    7500     7440     7250     7200     7140     7040     7120     7250     7220     7190   VIIB7 08
    7320     7160     7160     7180     7140     7080     7000     7070     7030     7060   VIIB7 09
    7130     7000     7030     7130     7070     7060     7010     6950     6970     7000   VIIB7 10
SJM VIIB8     37 20 107 55                          SJ 30 SECOND
    7500     7150     7000     6960     7250     7700     7520     6650     6550     6690   VIIB8 01
    7460     7320     6980     7070     7600     7840     7900     7020     6550     6570   VIIB8 02
    7380     7240     7040     6950     7360     7520     7260     6600     6560     6580   VIIB8 03
    7440     7140     6150     6880     6850     6720     6550     6540     6550     6740   VIIB8 04
    7480     7300     7120     6780     6620     6550     6600     6680     6880     6970   VIIB8 05
    7610     7110     6980     6740     6600     6540     6750     6860     6950     7320   VIIB8 06
    7270     6900     6850     6690     6570     6740     6860     6940     7260     7340   VIIB8 07
    6800     6720     6660     6550     6530     6640     6960     7040     7160     7620   VIIB8 08
    7360     7520     7320     7160     6480     6710     6900     6940     7320     7490   VIIB8 09
    7440     7300     7080     6940     6580     6640     6880     7080     7280     7250   VIIB8 10
SJM VIIC2     37 15 107 55                          SJ 30 SECOND
    7190     7050     6950     6840     6600     6480     6780     6980     7040     7000   VIIC2 01
    6880     6970     7160     7090     6760     6480     6650     6800     6870     6920   VIIC2 02
    6780     6900     7220     7400     7200     6750     6370     6760     6810     6720   VIIC2 03
    6750     6750     6850     6840     6880     6840     6480     6470     6660     6800   VIIC2 04
    7260     7280     7240     6860     6680     6720     6680     6410     6550     6750   VIIC2 05
    7160     7290     6920     6660     6580     6690     6530     6430     6370     6710   VIIC2 06
    6950     6900     6760     6600     6480     6430     6330     6360     6660     6670   VIIC2 07
    6720     6650     6650     6540     6320     6310     6460     6640     6640     6680   VIIC2 08
    6700     6640     6540     6380     6320     6460     6610     6610     6620     6700   VIIC2 09
    6540     6560     6500     6340     6320     6450     6590     6590     6620     6780   VIIC2 10
TRIAL MAP     37 15 107 55                          SJ 30 SECOND
                            } 10 blank cards (duplicate map location)
99999999999999999999999999999999999999999999999999999999999999999999999999999999
 15 15 1 1  3  3 21.       4.1     14.     14.                    0 1          15 MIN
IGNACIO 3     37 15 108 00                          SAN JUAN MTS
    7410     7300     7270     7160     7170     7020     7010     6580     6800     6960IGNACIO3 1
    6840     6970     7020     6960     6850     7280     7160     7030     6930     6840IGNACIO3 2
    6800     7080     6920     6520     6750     6830     6900     6950     6920     6820IGNACIO3 3
    7310     7400     7670     7560     7410     7250     6920     6670     6510     6600IGNACIO3 4
    6860     6870     6880     6870     6820     7770     7620     7400     7230     6970IGNACIO3 5
    6800     6640     6380     6450     6660     6830     6830     6820     6820     6750IGNACIO3 6
    7940     7410     7110     6920     6730     6610     6440     6390     6600     6680IGNACIO3 7
    6790     6780     6760     6770     6700     8020     7420     7160     6920     6770IGNACIO3 8
    6650     6370     6260     6550     6720     6730     6730     6680     6700     6580IGNACIO3 9
    7750     7080     6750     6660     6580     6460     6250     6250     6520     6670IGNACIO310
    6580     6550     6530     6480     6540     7180     7300     6780     6630     6470IGNACIO311
    6340     6180     6280     6480     6370     6430     6530     6460     6530     6580IGNACIO312
    6860     7460     7250     6560     6410     6310     6140     6250     6410     6400IGNACIO313
```

Table 2.--Continued

6650	6720	6670	6640	6660	6680	7340	6920	6690	6620	IGNACIO314
6310	6270	6160	6320	6290	6570	6640	6700	6800	6860	IGNACIO315
6540	6760	7280	6790	6660	6640	6260	6120	6270	6520	IGNACIO316
6550	6690	6980	7320	7370	6480	6660	7180	6760	6540	IGNACIO317
6370	6290	6050	6380	6570	6680	6960	7330	7270	7220	IGNACIO318
6420	6620	7120	6730	6480	6500	6300	6130	6560	6560	IGNACIO319
6850	6690	7100	7200	7070	6460	6640	6560	6550	6470	IGNACIO320
6630	6570	6140	6660	6530	6540	6650	7030	7140	7150	IGNACIO321
6560	6600	6600	6500	6330	6400	6660	6150	6410	6460	IGNACIO322
6680	6800	6950	6990	6900						IGNACIO323
DURANGO	37 30 108 00					SAN JUAN MTS				
9480	8880	8930	8860	8830	8150	7950	8330	9190	9500	DURANGO 1
8700	7470	7400	8000	9050	9520	9420	9450	9000	8690	DURANGO 2
8500	8230	7750	8340	9000	8470	7300	7200	7800	8800	DURANGO 3
10820	10150	9590	9320	9040	9100	8900	8140	7630	8630	DURANGO 4
8640	7300	6870	7760	8720	10550	9820	10120	10320	9630	DURANGO 5
9130	8680	8340	7600	7990	8350	7010	6750	7600	8720	DURANGO 6
9990	9200	9900	10200	10040	9200	8560	8300	7660	7050	DURANGO 7
6980	6650	7040	8170	8930	10300	9260	9050	9300	9740	DURANGO 8
9550	9180	8400	7550	6680	6600	6860	7920	8750	9100	DURANGO 9
10490	9840	8880	8580	9460	9300	8990	8120	7250	6600	DURANGO 10
6840	7800	8480	8830	9250	9100	9200	8980	8200	8760	DURANGO 11
9350	8930	7900	7000	6600	7790	8400	9100	9340	9240	DURANGO 12
8600	8640	8830	8460	7960	8450	8650	8000	6850	6800	DURANGO 13
8100	8860	9460	9240	8800	8350	7950	7920	7730	7560	DURANGO 14
7600	7800	7540	6790	6880	8430	8970	8700	8660	8300	DURANGO 15
7650	7560	7640	7460	7630	7360	7000	7600	7270	6600	DURANGO 16
7970	8060	7900	7700	7520	7900	7420	7900	7380	8100	DURANGO 17
7300	6760	7110	6740	6600	7170	7340	7400	7360	7800	DURANGO 18
7960	7780	7460	7240	7670	7400	6900	6580	6700	7000	DURANGO 19
7480	7370	7200	7640	7760	7610	7400	7300	7310	7000	DURANGO 20
6900	6700	6620	6950	7350	7550	7290	7100	7280	7280	DURANGO 21
7500	7350	7400	7500	7220	7400	7100	6600	6950	7330	DURANGO 22
7150	7100	7100	7000	7000						DURANGO 23
99999999999999999999999999999999999999999999999999999999999999999999999999999999										
60120 3 3 12 12 166.7			21.	60.	14.			0 1		1-2 DEG
DURANGO	AMS 38	108								
8900	9400	10320	11360	12200	11280	10760	11370	12210	12140	38108 1
11770	12480	11580	11080	10070	11440	10670	11710	12030	11480	38108 2
11980	12390	12140	11990	10950	10670	10070	10650	11010	10430	38108 3
10580	9940	9800	10070	8790	8170	7690	7590	7590	7570	38108 4
9300	9010	9440	10000	11120	12280	11020	12260	11960	12480	38108 5
11870	11870	10940	10070	11440	11490	10840	11900	12070	11620	38108 6
11580	11470	12060	12070	11630	11150	10810	11760	11640	11120	38108 7
10000	9420	9460	9310	8480	7890	7640	7580	7580	7560	38108 8
11160	10030	9920	11490	12470	11480	11440	12210	11030	12450	38108 9
12160	11880	11810	12160	11260	10810	10390	10990	11890	11170	38108 10
10380	10170	11040	11050	11550	11640	11750	11740	10930	10680	38108 11
10090	9510	9070	8820	8230	7780	7630	7600	7600	7560	38108 12
11670	10950	10400	11920	11460	10680	10300	10910	11340	12400	38108 13
12090	12470	11810	11440	10770	10760	10170	9900	11260	10840	38108 14
9080	8880	9030	9410	10830	11010	11580	10780	10280	9780	38108 15
9960	9400	8740	8350	7910	7730	7650	7620	7600	7580	38108 16
10210	10540	11890	12070	11580	11740	10660	12200	12170	12040	38108 17
11360	11910	10720	11130	10580	10210	9620	9240	9790	9850	38108 18
9940	10290	10180	9170	9790	10710	10680	10720	9290	8680	38108 19
9310	8740	8450	8160	7850	7720	7670	7650	7610	7600	38108 20
10880	11190	11440	11100	11170	10790	10610	11070	11950	12240	38108 21
11700	11570	11100	10640	10210	10190	10660	10730	9490	8920	38108 22
10180	10990	10380	9200	10270	9030	9420	9410	9340	8400	38108 23

Table 2--Continued

8340	8200	8140	7920	7780	7740	7690	7660	7630	7600	38108	24
10920	10030	10980	10110	9990	11240	10200	11650	12410	11720	38108	25
11990	11480	12180	11030	11460	11320	11530	11640	10380	9640	38108	26
10680	11320	10150	10330	10990	9680	8720	8470	8490	8280	38108	27
8100	8020	8010	7870	7770	7750	7700	7660	7630	7600	38108	28
10110	9370	9990	9700	8970	10000	10060	12040	12470	10940	38108	29
12180	11800	11540	10820	11670	11630	11620	11090	10840	10770	38108	30
11460	11340	10800	11230	10650	9440	8860	9950	10050	9640	38108	31
8870	8380	8420	8360	7980	7750	7690	7660	7630	7600	38108	32
9460	9290	10100	9170	8760	11070	11920	12020	11920	10410	38108	33
11900	11170	10570	10600	9990	11040	10050	10980	11420	11480	38108	34
11920	11380	11640	10900	10020	9470	9650	10310	11280	10350	38108	35
9260	9490	9170	8600	8160	7850	7680	7640	7620	7600	38108	36
9430	8700	9380	8860	8440	10270	11040	11200	11450	9980	38108	37
11270	10090	10840	10770	8770	8760	9690	10210	11090	11650	38108	38
10970	10700	11520	10650	10020	10650	10060	10540	11310	10010	38108	39
10180	10890	10100	9030	8380	7980	7730	7630	7610	7600	38108	40
9580	8830	8270	8330	7960	10300	9680	11240	9640	9280	38108	41
9740	9980	10590	9500	9030	8260	8330	8800	10530	11480	38108	42
11050	9580	10370	10870	10510	10570	10580	11240	11510	11230	38108	43
11230	11910	10860	9710	9110	8400	7790	7650	7620	7600	38108	44
9800	9680	8250	7130	8110	9840	8960	9530	8800	8160	38108	45
9220	10040	9550	9200	8630	8140	7920	8670	10300	10040	38108	46
9600	9040	8840	9340	9260	10260	11310	11580	11450	10880	38108	47
10170	11120	10320	9690	9920	8820	7870	7720	7640	7600	38108	48
9170	8720	7960	7530	9080	8930	8450	8520	8020	8800	38108	49
9500	9200	8450	8280	8430	8500	8080	8280	8740	8400	38108	50
8380	8180	8500	8980	10170	10570	11850	11190	10730	10780	38108	51
11090	9970	9730	9410	8680	8410	8000	7840	7710	7620	38108	52
7810	7570	7180	7560	7930	7880	7990	7580	7950	8010	38108	53
8400	9320	8730	8100	9150	8850	8030	7890	7900	7620	38108	54
7690	7850	9230	10310	10940	11180	11520	11320	10740	10630	38108	55
10310	11260	10100	9860	8780	8390	8080	7910	7750	7630	38108	56
7530	7290	6790	7290	7260	7340	7540	7270	7290	7310	38108	57
7690	8090	8000	7940	8990	7850	7900	7670	7590	7340	38108	58
7310	7760	8420	9570	10170	9910	11680	11080	11870	11440	38108	59
10210	10760	9900	9730	8820	8340	7980	7880	7750	7640	38108	60
7310	7130	6780	6840	6880	6940	7060	6950	6930	7180	38108	61
8040	7650	7280	7090	7260	7090	7200	7490	7490	7220	38108	62
7340	7780	8000	8650	8460	9600	10980	11390	11120	10510	38108	63
9780	10200	9750	9690	9210	8600	8230	8120	7900	7680	38108	64
7540	6840	6450	6750	6720	6680	6710	6740	6760	7200	38108	65
8190	7700	6890	6680	6900	7400	7300	7870	7480	7240	38108	66
7440	7500	7930	8430	9490	10300	9510	11000	11770	11160	38108	67
10700	9900	10150	9760	9360	8770	8740	8250	7960	7760	38108	68
7140	6500	6300	6600	6610	6680	6590	6560	6610	7040	38108	69
8020	7290	6470	7130	7460	7830	7090	7280	7300	6950	38108	70
7280	7670	7840	8890	9930	9840	8730	11310	11100	11380	38108	71
11130	9810	9440	9630	9500	9180	8900	8370	8010	7860	38108	72
6890	6610	6220	6610	7140	7130	6680	6430	6460	6610	38108	73
7110	6720	7080	7470	7340	6880	6820	7000	6900	6980	38108	74
7540	7600	7790	7950	8600	8970	8820	10800	10150	10490	38108	75
11010	10670	10470	9710	9290	8660	9010	8410	8010	7910	38108	76
6620	6510	6450	6660	7110	6970	6920	6450	6390	6370	38108	77
6240	6190	6370	6570	6690	6600	6680	6720	7380	7830	38108	78
8380	7450	7780	7600	7750	8060	8970	10080	9420	9920	38108	79
10290	10000	10230	10150	9870	9100	8540	8400	8170	7960	38108	80

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Table 3. Example of printout from terrain correction program M0400.

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TERRAIN CORRECTION PROGRAM D. Plouff  9-1972

SUMMARY OF PRELIMINARY VALUES FOR SAN JUAN MTS., COLORADO  TERRAIN CORRECTION
WILL BE MADE FOR  3 SETS OF MAPS

 STA  LATITUDE LONGITUDE  ELEV    OBS GRAV   THEO GRAV  FREE AIR  HAND TER
 0217 37 16.47 107 52.67  6557.  979284.77  979940.81    -39.55      0.16
 1857 37 55.08 106 50.45 13718.  978841.38  979996.90    133.57     11.80
                      <- page skipped
SJM VIIB7     37 20 107 50
SJM VIIB8     37 20 107 55
   STATION  0217 IS INSIDE CALCULATED COMPARTMENT. CORRECTION USED IS   0.000 MGAL.
SJM VIIC2     37 15 107 55
TRIAL MAP     37 15 107 55
THIS MAP WAS SKIPPED. IT ALREADY HAS BEEN USED.

MAP COVERAGE FOR    0.895 TO    4.100 KILOMETERS (CIRCULAR INNER JOIN) OF SAN JUAN MTS., COLORADO
SMALLEST COMPARTMENT DIGITIZED ARE 30 BY 30 AND LARGEST COMPOSITE BLOCKS ARE 60 BY 60 SECONDS
IN LATITUDE AND LONGITUDE. QUADRANGLES USED ARE   5 BY   5 MINUTES.  CONVERSION TO BLOCKS AT    4.00 KM.
CURVATURE CORRECTION AT  15. KM.

STATION  0217 AT 37.274, 107.878 DEGREES
     MAP            NW CORNER (D,M)       MGLS           MAP            NW CORNER (D,M)       MGLS
 SJM VIIB8          37 20      107 55     0.478     SJM VIIC2         37 15      107 55      0.010
                                    TOTAL CORRECTION  0.488 MILLIGALS
STATION  1857 AT 37.918, 106.841 DEGREES
     MAP            NW CORNER (D,M)       MGLS           MAP            NW CORNER (D,M)       MGLS
    NOT FOUND       38  0      106 55
    NOT FOUND       38  0      106 50
    NOT FOUND       37 55      106 55
    NOT FOUND       37 55      106 50
                      <- page skipped
IGNACIO 3     37 15 108  0
DURANGO       37 30 108  0

MAP COVERAGE FOR    4.100 TO   21.000 KILOMETERS (PIECEMEAL INNER JOIN) OF SAN JUAN MTS., COLORADO
SMALLEST COMPARTMENT DIGITIZED ARE  1 BY  1 AND LARGEST COMPOSITE BLOCKS ARE  3 BY  3 MINUTES
IN LATITUDE AND LONGITUDE. QUADRANGLES USED ARE  15 BY  15 MINUTES.  CONVERSION TO BLOCKS AT   14.00 KM.
CURVATURE CORRECTION AT  16. KM.

STATION  0217 AT 37.274, 107.878 DEGREES
     MAP            NW CORNER (D,M)       MGLS           MAP            NW CORNER (D,M)       MGLS
 IGNACIO 3          37 15      108  0     0.060     DURANGO           37 30      108  0      0.693
                                    TOTAL CORRECTION  0.753 MILLIGALS
    NOT FOUND       37 30      108 15
    NOT FOUND       37 30      107 45
    NOT FOUND       37 15      108 15
    NOT FOUND       37 15      107 45
STATION  1857 AT 37.918, 106.841 DEGREES
     MAP            NW CORNER (D,M)       MGLS           MAP            NW CORNER (D,M)       MGLS
    NOT FOUND       38 15      107 15
    NOT FOUND       38 15      107  0
    NOT FOUND       38 15      106 45
    NOT FOUND       38  0      107 15
    NOT FOUND       38  0      107  0
    NOT FOUND       38  0      106 45
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Table 3--continued

DURANGO- AMS 38 0 108 0

MAP COVERAGE FOR 21.000 TO 166.700 KILOMETERS (PIECEMEAL INNER JOIN) OF SAN JUAN MTS., COLORADO
SMALLEST COMPARTMENT DIGITIZED ARE 3 BY 3 AND LARGEST COMPOSITE BLOCKS ARE 12 BY 12 MINUTES
IN LATITUDE AND LONGITUDE. QUADRANGLES USED ARE 60 BY 120 MINUTES. CONVERSION TO BLOCKS AT 60.00 KM.
CURVATURE CORRECTION AT 14. KM.

STATION 8217 AT 37.274, 107.878 DEGREES

MAP	NW CORNER (D,M)		MGLS	MAP	NW CORNER (D,M)	MGLS
DURANGO AMS	38 0	108 0	0.371			

TOTAL CORRECTION 0.371 MILLIGALS

NOT FOUND	39 0	110 0
NOT FOUND	39 0	108 0
NOT FOUND	38 0	110 0
NOT FOUND	37 0	110 0
NOT FOUND	37 0	108 0
NOT FOUND	36 0	110 0
NOT FOUND	36 0	108 0

STATION 1857 AT 37.918, 106.841 DEGREES

MAP	NW CORNER (D,M)		MGLS	MAP	NW CORNER (D,M)	MGLS
DURANGO AMS	38 0	108 0	2.183			

TOTAL CORRECTION 2.183 MILLIGALS

NOT FOUND	40 0	108 0
NOT FOUND	40 0	106 0
NOT FOUND	39 0	110 0
NOT FOUND	39 0	108 0
NOT FOUND	39 0	106 0
NOT FOUND	38 0	110 0
NOT FOUND	38 0	106 0
NOT FOUND	37 0	110 0
NOT FOUND	37 0	108 0
NOT FOUND	37 0	106 0

LIST OF RADIAL COVERAGE FOR SUCCESSIVE MAP SETS
INNER BOUNDARY IS PIECEMEAL UNLESS CIRCULAR IS INDICATED. ALL OUTER BOUNDARIES ARE PIECEMEAL
0.09490 TO 4.10000 KM (CIRCULAR INNER JOIN)
4.10000 TO 21.00000 KM
21.00000 TO 166.70000 KM

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SUMMARY FOR 2 STATIONS IN SAN JUAN MTS., COLORADO
COMPUTER TERRAIN CORRECTIONS CARRIED FROM CIRCULAR INNER RADIUS OF 0.895
TO 166.700 KILOMETERS. DENSITIES ARE 2.67 AND 2.50 DENSITY OF 2.67 IS USED FOR
VALUES IN COLUMNS LABELLED CC, TC, TER, (NEAR), AND TOT. TC-HAND CORRECTION
TER-TOTAL COMPUTER CORRECTION. (NEAR)-PART OF TOTAL THAT REPRESENTS CONTRIBUTION
OF COMPARTMENTS THAT INTERSECT INNER CIRCULAR RADIUS. TOT-HAND PLUS COMPUTER TERRAIN.

STATION	LATITUDE	LONGITUDE	ELEV	OBS GRAV	F.A.	S.B.1	S.B.2	CC	TC	TER	(NEAR)	TOT	C.B.1	C.B.2	ACC	STA
SJM 8217	37 16.67	107 52.67	6557.0	979284.77	-39.55	-263.18	-248.94	1.52	0.14	1.61	0.02	1.75	-262.95	-248.72		8217
SJM 1857	37 55.08	106 50.65	13718.0	978841.38	133.57	-334.31	-304.32	-0.05	11.88	2.18	0.00	14.06	-320.19	-291.30	8534	1857