Balgol Program for Trend-Surface Mapping Using an IBM 7090 Computer

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PREFACE

This special publication describes a computer program that will be useful to geologists in Kansas and elsewhere; it is the first of a series of publications of the Kansas Geological Survey in which the objective is to present details of computer programs that should be of general usefulness to geologists and petroleum engineers. The computer revolution is fast sweeping through the petroleum industry, but many small companies and independent operators do not have employees on their staffs who are skilled in computer applications. It is the intention of the Kansas Geological Survey to provide some assistance in computer applications in solving geological and petroleum engineering problems.

INTRODUCTION

The program described here is for trend-surface mapping of geological data, such as geologic structure, and for smoothing geophysical data. A trend surface is a plane or smoothly curving surface that is fitted so that it passes above some data points and below others. The difference between the trend-surface value and the actual data point value is called the deviation or residual value. Trend surfaces are generally fitted so that the sum of the squared deviations is the least possible and may be termed least-squares trend surfaces. A more complete discussion of the applications of least-squares trend surfaces is given by Forgotson (1963) and Merriam and Harbaugh (in press), and the principles have been discussed by Krumbein (1959) and Harbaugh (in press).

The program for fitting first-, second-, and third-degree trend surfaces is written in BALGOL and may be used on any IBM 7090/1401 computer system for which a 7090 BALGOL compiler tape is available. The program was developed at the Computation Center at Stanford University. Peter Carah wrote that part of the program dealing with plotting of residual values, and procedure SOLV was written by the Stanford Computation Center staff.

The Kansas Geological Survey will distribute the program in punched card form for a limited time at a cost of \$10. The 7090 BALGOL compiler tape may be obtained by sending a magnetic tape to the Computation Center, Stanford University, Stanford, California.

The trend-surface program is fast and efficient, compiling in 18 seconds from the BALGOL source deck, requiring about 30 seconds to execute for a data set consisting of about 200 data points, and producing printed maps of about 60 square inches each. The data points may be irregularly spaced. The program prints contoured trend-surface maps and plots original and residual values on maps that are ready to be contoured manually. The program may be used with any number of sets of data. Many of the steps in the program are similar or identical to a four-variable trend-surface program described by Harbaugh (in press).

A manual describing BALGOL and entitled "Burroughs Algebraic Compiler, Revised Edition" (1963) may be obtained from the Burroughs Corporation, Detroit 32, Michigan. "An Introduction to BALGOL" (1961) by R. V. Oakford and J. M. Gere is available through the Stanford University Bookstore.

STEPS IN TREND-SURFACE PROGRAM

Steps in the trend-surface program are outlined in the flow chart (Fig. 1) and are listed in detail in Table 1. Each line (card) of the program is numbered, permitting parts of the program to be referred to by the line numbers. Steps in the program are tabulated below:

(1) Integer declarations: lines 7-8.

(2) Dimensions of arrays: lines 9-12.

(3) Assign characters to alphanumeric arrays used for headings and for contoured maps: lines 13-21.

(4) Format statements: lines 22, 24, 225-230, 232-241, 245, 246, 251-260, 262, 264, 266, 292-299, 308-313, 326.

(5) Input statements: lines 26, 28, 31-41.

(6) Clear arrays reserved for matrices to zero: lines 42-43.

(7) Generate matrix and column vector for solution of normal equations (for discussion see Harbaugh, in press): lines 46-113.

(8) Assign linear, linear plus quadratic, and linear plus quadratic plus cubic matrices and column vectors to new matrices and column vectors before inversion: lines 114-122.

(9) Declare external procedure INPROD (used in matrix inversion procedure): line 124.

(10) Declare procedure SOLV (for inversion of matrix): lines 125-173.

(11) Call and execute procedure SOLV for inverting matrices of first-, second-, and third-degree surfaces: lines 174-178.

(12) Calculate trend and residual values for all data points: lines 180-194.

(13) Calculate error measure: lines 197-206.

(14) Calculate sum of squares of trend values and residuals: lines 207-218.

(15) Calculate percent of total sum of squares: lines 219-223.

(16) Output statements: lines 224, 231, 243, 244, 247-250, 263, 267, 291, 307, 390, 399.

(17) Calculate arithmetic mean: line 242.

(18) Write statements: lines 261, 265, 268, 269, 300-302, 321, 323, 324, 334, 336, 337, 353, 356, 357, 392, 407, 448.

(19) Calculate volume beneath first-, second-, and third-degree trend surfaces by double integration: lines 273-287.

(20) Calculate spatially weighted averages by dividing trend-surface volumes by area beneath trend surface: lines 288-290

(21) Calculate horizontal and vertical increment values for printing of maps: lines 305-306.

(22) Contour first-, second-, and third-degree trend-surface maps by successively evaluating X and Y coordinate values: lines 314-379.

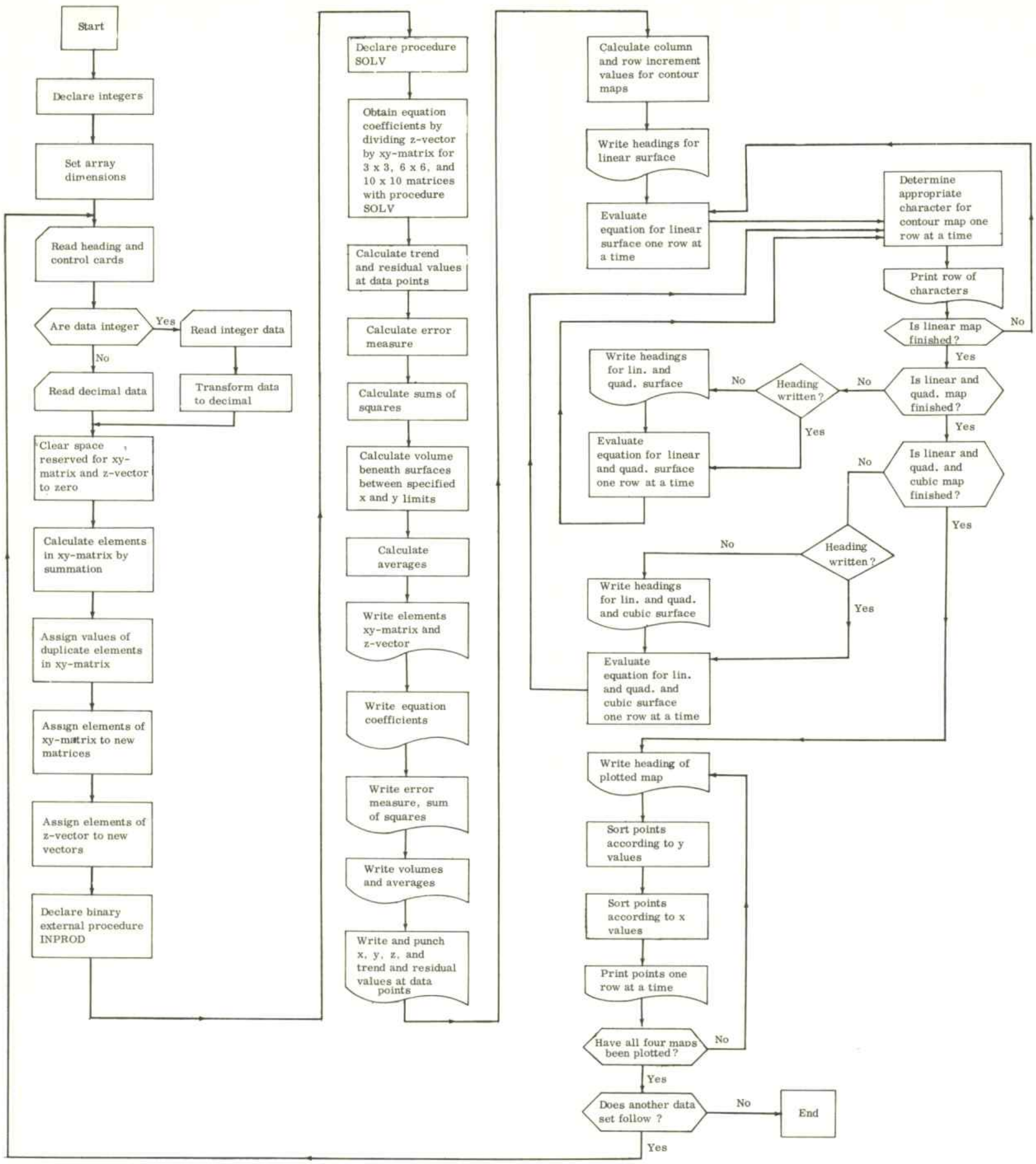

Figure 1. Simplified flow chart of major steps in trend-surface program.

Table 1.--Listing of BALGOL statements in trend-surface program. Each line represents one punched card of program. Numbers in left column are for reference purposes and in practice must be placed in columns 73-80 on punched cards. Each program card must have the number 2 punched in column 1.

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 1 COMMENT PROGRAM TO FIT LINEAR, LINEAR + QUADRATIC, AND LINEAR + QUAD-
 2 RATIC + CUBIC TREND SURFACES WHERE X AND Y VALUES ARE IRREGULARLY
 3 SPACED. PROGRAM PRINTS OUT Z VALUES CALCULATED AT THE GIVEN X-Y POINTS
 4 AND ALSO COMPUTES DEVIATIONS OF ACTUAL Z VALUES FROM TREND VALUES.
 5 ERROR MEASURE AND PERCENT TOTAL SUM OF SQUARES ARE CALCULATED. TREND
 6 SURFACES ARE CONTOURED. J. W. HARBAUGH, GEOLOGY DEPT., STANFORD $
 7 INTEGER  XP(), I, J, K, L, OP, N, VERT, HOR,   CV(),      M,W $
 8 INTEGER DIGITS, PLTAR, PRINT, Q, IY, IX, LINE, TEMP, ARMIN, ARPLS $
 9 ARRAY X(500,9), T(10,10), R(10), XP(500,3) , T3(5,5), T6(8,8),
10       T10(12,12), R3(3), R6(6), R10(10), S3(3), S6(6), S10(10) ,
11      Z(132), CV(132) $
12 ARRAY  PRINT(3,50), IY(500), IX(500) , DIGITS(50) $
13  ARRAY PLTAR(12)=('Z VALU','ES ORI','G DATA','1ST OR',
14          'DER RE','SIDUAL','2ND OR','DER RE','SIDUAL','3RD OR',
15          'DER RE','SIDUAL')$
16 ARRAY ARMIN(40) = (' ','A',' ','B',' ','C',' ','D',' ','E',' ','F',
17          ' ','G',' ','H',' ','I',' ','J',' ','K',' ','L',' ','M',' ','N'
18      ,' ','O',' ','P',' ','Q',' ','R',' ','S',' ','T')  $
19 ARRAY ARPLS(40) = ('$',' ','1',' ','2',' ','3',' ','4',' ','5',' ',
20     '6',' ','7',' ','8',' ','9',' ','0',' ','$',' ','*',' ','-',' ',
21     '.',' ','+',' ','=',' ','W',' ','X',' ','Y',' ') $
22 FORMAT FORM($K$(B$PRINT(3,I)$,I$ DIGITS(I)$),W)$
23 OUTPUT PLOT(PLTAR(1.5Q -3.5), PLTAR(1.5Q - 2.5), PLTAR(1.5(Q-1)))$
24 FORMAT PLFT(3A6,W,W) $
25 START..
26 INPUT ALPH(A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12)       $
27 READ ($$ ALPH) $
28 INPUT OPT( OP, N, VERT, HOR,XR, XL, YB, YT, RF, CON)$
29 READ ($$ OPT) $
30 HAR = HOR $
31 IF OP EQL 2222 $
32    BEGIN
33       INPUT DATI(FOR I =(1,1,N) $ FOR J =(1,1,3) $ XP(I,J))$
34       READ ($$ DATI) $
35       FOR I =(1,1,N) $ FOR J =(1,1,3) $ X(I,J) = XP(I,J) $
36    END $
37 IF OP EQL 4444 $
38    BEGIN
39       INPUT DATD(FOR I =(1,1,N) $ FOR J =(1,1,3) $ X(I,J)) $
40       READ ($$ DATD) $
41    END $
42 FOR K =(1,1,10) $ FOR L =(1,1,10) $ T(K,L) = 0.0 $
43 FOR K =(1,1,10) $ R(K) = 0.0 $
44 COMMENT CALCULATE VALUES FOR 10 X 10 T MATRIX ELEMENTS, EXCEPT FOR
45 THOSE VALUES THAT ARE DUPLICATES OF OTHERS,WHICH WILL BE ASSIGNED $
46 FOR I =(1,1,N) $
47    BEGIN
48       T(1,2) =  T(1,2) + X(I,1) $
49       T(1,3) =  T(1,3) + X(I,2) $
50       T(1,4) =  T(1,4) +(X(I,1)*2.0) $
51       T(1,5) =  T(1,5) +(X(I,1).X(I,2))  $
52       T(1,6) =  T(1,6) +(X(I,2)*2.0) $
53       T(1,7) =  T(1,7) +(X(I,1)*3.0) $
54       T(1,8) =  T(1,8) +((X(I,1)*2.0).(X(I,2))) $
55       T(1,9) =  T(1,9) +((X(I,1)).(X(I,2)*2.0)) $
56       T(1,10)=  T(1,10)+(X(I,2)*3.0) $
57       T(2,7) =  T(2,7) +(X(I,1)*4.0) $
58       T(2,8) =  T(2,8) +((X(I,1)*3.0).(X(I,2))) $
59       T(2,9) =  T(2,9) +((X(I,1)*2.0).(X(I,2)*2.0)) $
60       T(2,10)=  T(2,10)+((X(I,1)).(X(I,2)*3.0)) $
61       T(3,10)=  T(3,10)+(X(I,2)*4.0) $
62       T(4,7) =  T(4,7) +(X(I,1)*5.0) $
63       T(4,8) =  T(4,8) +((X(I,1)*4.0).(X(I,2))) $
64      T(4,9) =  T(4,9) +((X(I,1)*3.0).(X(I,2)*2.0)) $
65      T(4,10)=  T(4,10)+((X(I,1)*2.0).(X(I,2)*3.0)) $
66      T(5,10)=  T(5,10)+((X(I,1)).(X(I,2)*4.0)) $
67      T(6,10)=  T(6,10)+ (X(I,2)*5.0) $
68      T(7,4) =  T(7,4) + (X(I,1)*5.0) $
69      T(7,7) =  T(7,7) + (X(I,1)*6.0) $
70      T(7,8) =  T(7,8) +((X(I,1)*5.0).(X(I,2))) $
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        T(7,9) =  T(7,9) +((X(I,1)*4.0).(X(I,2)*2.0)) $
        T(7,10)=  T(7,10)+((X(I,1)*3.0).(X(I,2)*3.0)) $
        T(8,10)=  T(8,10)+((X(I,1)*2.0).(X(I,2)*4.0)) $
        T(9,10)=  T(9,10)+((X(I,1)).(X(I,2)*5.0)) $
        T(10,10)= T(10,10) + (X(I,2)*6.0) $
        R(1) = R(1) + X(I,3) $
        R(2) = R(2) +((X(I,1)).(X(I,3))) $
        R(3) = R(3) +((X(I,2)).(X(I,3))) $
        R(4) = R(4) +((X(I,1)*2.0).(X(I,3))) $
        R(5) = R(5) +((X(I,1)).(X(I,2).X(I,3))) $
        R(6) = R(6) +((X(I,2)*2.0).(X(I,3))) $
        R(7) = R(7) +((X(I,1)*3.0).(X(I,3))) $
        R(8) = R(8) +((X(I,1)*2.0).(X(I,2).X(I,3))) $
        R(9) = R(9) + (X(I,1).((X(I,2)*2.0).(X(I,3)))) $
        R(10)= R(10)+((X(I,2)*3.0).(X(I,3))) $
    END $
T(1,1) = N   $
T(2,1) = T(1,2) $ T(5,2) = T(1,8) $
T(3,1) = T(1,3) $ T(5,4) = T(2,8) $ T(7,3) = T(2,8) $
T(4,1) = T(1,4) $ T(2,2) = T(1,4) $ T(5,5) = T(2,9) $ T(6,4) = T(2,9) $
T(5,1) = T(1,5) $ T(2,3) = T(1,5) $ T(3,2) = T(1,5) $ T(8,3) = T(2,9) $
T(6,1) = T(1,6) $ T(3,3) = T(1,6) $ T(6,2) = T(1,9) $
T(7,1) = T(1,7) $ T(2,4) = T(1,7) $ T(4,2) = T(1,7) $
T(8,1) = T(1,8) $ T(2,5) = T(1,8) $ T(3,4) = T(1,8) $ T(4,3) = T(1,8) $
T(9,1) = T(1,9) $ T(2,6) = T(1,9) $ T(3,5) = T(1,9) $ T(5,3) = T(1,9) $
T(10,1)=T(1,10) $ T(3,6) = T(1,10)$ T(6,3) = T(1,10)$
T(7,2) = T(2,7) $ T(4,4) = T(2,7) $ T(9,3) = T(2,10)$
T(8,2) = T(2,8) $ T(5,4) = T(2,8) $ T(3,7) = T(2,8) $ T(4,5) = T(2,8) $
T(9,2) = T(2,9) $ T(5,5) = T(2,9) $ T(3,8) = T(2,9) $ T(4,6) = T(2,9) $
T(10,2)=T(2,10) $ T(3,9) = T(2,10)$ T(5,6) = T(2,10)$ T(6,5) = T(2,10)$
T(5,7) = T(4,8) $ T(7,5) = T(4,8) $ T(8,4) = T(4,8) $
T(5,8) = T(4,9) $ T(7,6) = T(4,9) $ T(8,5) = T(4,9) $ T(9,4) = T(4,9) $
T(5,9) = T(4,10)$ T(8,6) = T(4,10)$ T(9,5) = T(4,10)$ T(10,4)= T(4,10)$
T(6,6) = T(3,10)$ T(10,3)= T(3,10) $
T(6,7) = T(4,9) $
T(6,8) = T(4,10)$
T(6,9) = T(5,10)$ T(9,6) = T(5,10) $ T(10,5) = T(5,10) $
T(8,7) = T(7,8) $
T(8,8) = T(7,9) $ T(9,7) = T(7,9)  $
T(8,9) = T(7,10)$ T(9,8) = T(7,10) $ T(10,7) = T(7,10) $
T(9,9) = T(8,10)$ T(10,8)= T(8,10) $
T(10,6)= T(6,10)$
T(10,9)= T(9,10)$
COMMENT ASSIGN 3X3, 6X6, AND 10X10 PORTIONS OF T MATRIX TO NEW
MATRICES, TN(,),WHICH WILL BE USED IN SOLVING LINEAR EQUATIONS $
FOR I =(1,1,3) $ FOR J =(1,1,3) $T3(I,J) = T(I,J) $
FOR I =(1,1,6) $ FOR J =(1,1,6) $T6(I,J) = T(I,J) $
FOR I =(1,1,10)$ FOR J =(1,1,10)$T10(I,J)= T(I,J) $
COMMENT ASSIGN 3, 6, AND 10 PORTIONS OF COLUMN VECTOR R TO NEW VECTORS$
FOR I =(1,1,3) $ R3(I) = R(I) $
FOR I =(1,1,6) $ R6(I) = R(I) $
FOR I =(1,1,10)$ R10(I) =R(I) $
COMMENT SOLVE LINEAR MATRIX EQUATIONS OF GENERAL FORM TS = R $
EXTERNAL PROCEDURE INPROD() $
PROCEDURE SOLV(N$A(,),B(),Y()$SINGULAR)$
BEGIN
COMMENT THIS IS THE METHOD OF CROUT,WITH INTERCHANGES,
    TO SOLVE AY=B FOR Y,GIVEN A AND B.         $
    COMMENT   EXTERNAL PROCEDURE INPROD IS CALLED BY SOLV,
    SO INPROD MUST BE AVAILABLE WHEN SOLV IS CALLED.  $
COMMENT SINGULAR IS THE LABEL OF THE STATEMENT TO WHICH
    SOLV() EXITS IF A() IS SINGULAR$
COMMENT REAL A(,),B(),Y()$
INTEGER I,IMAX,J,K,N$
    FOR K=(1,1,N)$
    BEGIN
        TEMP = 0$
        FOR I=(K,1,N)$
        BEGIN
            XX = A(I,K) - INPROD(1,1,K-1,A(I,),A(,K))$
            A(I,K) = XX   $
            IF ABS(XX) GTR TEMP $
            BEGIN
                TEMP = ABS(XX)  $
                IMAX = I
            END
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      END$
      IF TEMP EQL 0.0$
      GO SINGULAR$
    COMMENT WE HAVE FOUND THAT A(IMAX,K) IS THE LARGEST PIVOT IN COL K.
      NOW WE INTERCHANGE ROWS K AND IMAX$
    IF IMAX NEQ K$
    BEGIN
      FOR J = (1,1,N)$
      BEGIN
         TEMP=A(K,J)$ A(K,J)=A(IMAX,J)$ A(IMAX,J)=TEMP
      END$
      TEMP=B(K)$B(K)=B(IMAX)$B(IMAX)=TEMP
    END$
    COMMENT NOW FOR THE ELIMINATION$
    DENOM = A(K,K)  $
    FOR I=(K+1,1,N)$
    A(I,K) = A(I,K)/DENOM $
    FOR  J = (K+1,1,N)$
      A(K,J) = A(K,J) - INPROD(1,1,K-1,A(K,),A(,J))   $
    B(K) = B(K) - INPROD(1,1,K-1,A(K,),B())
  END$
   FOR I=(1,1,N)$ Y(I) = A(I,I)$
  COMMENT NOW FOR THE BACK SUBSTITUTION$
  FOR K = (N,-1,1)$
    Y(K) = (B(K) - INPROD(K+1,K+1,N-K,A(K,),Y()))/A(K,K)   $
   RETURN
END SOLV()$
SOLV( 3$ T3(,), R3(), S3() $ MAT6) $
MAT6..
SOLV( 6$ T6(,), R6(), S6() $ MAT10)$
MAT10..
SOLV(10$T10(,),R10(),S10() $ START)$
COMMENT SUBSTITUTE X AND Y MAP VALUES IN EQUATIONS OF FITTED SURFACES $
FOR I =(1,1,N) $
   BEGIN
      X(I,4) = S3(1) + (S3(2).X(I,1)) +(S3(3).X(I,2)) $
      X(I,5) = X(I,3) - X(I,4) $
      X(I,6) = S6(1) + (S6(2).X(I,1)) + (S6(3).X(I,2)) +
          (S6(4).(X(I,1)*2.0)) + (S6(5).(X(I,1).X(I,2))) +
          (S6(6).(X(I,2)*2.0)) $
      X(I,7) = X(I,3) -  X(I,6) $
      X(I,8) = S10(1) + (S10(2).X(I,1)) + (S10(3).X(I,2)) +
          (S10(4).(X(I,1)*2.0)) + (S10(5).(X(I,1).X(I,2))) +
          (S10(6).(X(I,2)*2.0)) +(S10(7).(X(I,1)*3.0)) +
          (S10(8).((X(I,1)*2.0).X(I,2)))+ (S10(9).(X(I,1).(X(I,2)*2.0)))
         +(S10(10).(X(I,2)*3.0)) $
      X(I,9) = X(I,3) -  X(I,8) $
   END $
COMMENT COMPUTE ERROR MEASURE AND PERCENT TOTAL SUM OF SQUARES FOR EACH
TREND SURFACE $
EM1 = EM2 = EM3 = 0.0 $
FOR I =(1,1,N) $
   BEGIN
      EM1 = EM1 +(X(I,5)*2.0) $
      EM2 = EM2 +(X(I,7)*2.0) $
      EM3 = EM3 +(X(I,9)*2.0) $
   END $
   E1  =  EM1/(N-1) $
   E2  =  EM2/(N-1) $
   E3  =  EM3/(N-1) $
SMLN = LNSQ = SMQD = QDSQ = SMCB = CBSQ = SMZ = ZSQ = 0.0 $
FOR I =(1,1,N) $
   BEGIN
      SMLN = SMLN + X(I,4) $
      LNSQ = LNSQ + (X(I,4)*2.0) $
      SMQD = SMQD + X(I,6) $
      QDSQ = QDSQ + (X(I,6)*2.0) $
      SMCB = SMCB + X(I,8) $
      CBSQ = CBSQ + (X(I,8)*2.0) $
      SMZ  = SMZ  + X(I,3) $
      ZSQ  = ZSQ  + (X(I,3)*2.0) $
   END $
ZOR =  ZSQ - ((SMZ*2.0)/(N-1)) $
PTS1 = 100.0((LNSQ -((SMLN*2.0)/(N-1)))/ZOR)$
PTS2 = 100.0((QDSQ -((SMQD*2.0)/(N-1)))/ZOR)$
PTS3 = 100.0((CBSQ -((SMCB*2.0)/(N-1)))/ZOR)$
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QDON = QDSQ - LNSQ $  CBON = CBSQ -  QDSQ          $
OUTPUT ERMA(E1 ,E2 ,E3 ,PTS1,PTS2,PTS3)$
FORMAT FMTR(*ERROR MEASURE LINEAR TREND SURFACE = *,X31.2,W,W,
             *ERROR MEASURE QUADRATIC TREND SURFACE = *,X28.2,W,W,
             *ERROR MEASURE CUBIC TREND SURFACE = *,X32.2,W,W,
             *PERCENT TOTAL SUM SQUARES LINEAR SURFACE = *,X25.2,W,W,
             *PERCENT TOTAL SUM SQUARES QUADRATIC SURFACE = *,X22.2,W,W,
             *PERCENT TOTAL SUM SQUARES CUBIC SURFACE = *,X26.2,W,W)$
OUTPUT VAR(LNSQ, EM1, QDSQ, QDON, EM2,      CBSQ, EM3, CBON      ) $
FORMAT FVAR(*SUM OF SQUARES DUE LINEAR COMPONENT = *,X30.2,W4,W,
             *SUM OF SQUARED DEVIATIONS FROM LINEAR = *,X28.2,W,W,
             *SUM OF SQUARES DUE LINEAR + QUADRATIC COMPONENT = *,X18.2,
          W,W,*SUM OF SQUARES DUE TO QUADRATIC ALONE = *,X28.2,W,W,
             *SUM OF SQUARED DEVIATIONS FROM LINEAR + QUADRATIC = *,
             X16.2,W,W,
             *SUM OF SQUARES DUE LINEAR+QUADRATIC+CUBIC = *,X24.2,W,W,
             *SUM OF SQUARED DEVIATIONS FROM LINEAR+QUADRATIC+CUBIC = *,
             X12.2,W,W,
             *SUM OF SQUARES DUE CUBIC ALONE = *,X35.2,W, W)$
AZM = R(1)/N $
OUTPUT ALPHA(A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12)$
OUTPUT ODS1(FOR I =(1,1,N) $ FOR J =(1,1,9) $ X(I,J)) $
 FORMAT FTPC(*5$*,12A6,*$*,W)$ WRITE ($$ALPHA,FTPC) $
FORMAT  FMTA(12A6,W3,W) $
OUTPUT C03(S3(1),S3(2),S3(3)),
        C06(S6(1),S6(2),S6(3),S6(4),S6(5),S6(6)),
        C10(S10(1),S10(2),S10(3),S10(4),S10(5),S10(6),S10(7),S10(8),
          S10(9),S10(10)) $
FORMAT CF3(W,*EQUATION COEFFICIENTS   *,W,*LINEAR, Z = *,X12.5,*+*,
          X12.5,*X +*,X12.5,*Y*,W,W),
        CF6(*LIN   + QUAD, Z = *,X12.5,*+*,X12.5,*X +*,X12.5,*Y +*,
          X12.5,*X2 +*,X12.5,*XY +*,X12.5,*Y2*,W,W),
        CF10(*LIN + QUAD + CUB, Z =*,X12.5,*+*,X12.5,*X +*,X12.5,*Y +*,
          X12.5,*X2 +*,X12.5,*XY +*,X12.5,*Y2*,W,B10,*+*,X12.5,*X3  +*,
          X12.5,*X2Y +*,X12.5,*XY2 +*,X12.5,*Y3*,W,W)$
FORMAT HED(*   XCOORD  YCOORD Z-VALUE 1ST-TRD 1ST-RSD 2ND-TRD 2ND-RSD*,
          * 3RD-TRD 3RD-RSD*,W,W) $
FORMAT FMT1(*5*,9X8.1,W) $
WRITE ($$ ALPHA, FMTA) $
FORMAT JIM(*10 X 10 (X,Y) MATRIX VALUES *,W,W) $ WRITE ($$ JIM)$
OUTPUT   TRAY(FOR I=(1,1,10)$ FOR J=(1,1,10) $ T(I,J))$
FORMAT   FTRA(W,10F12.4,W) $
WRITE   ($$ TRAY,FTRA) $
FORMAT JOE(W,*1 X 10 COLUMN VECTOR VALUES*,W,W)$ WRITE ($$ JOE)$
OUTPUT   RAR(FOR I =(1,1,10)$  R(I))$   WRITE ($$ RAR, FTRA) $
WRITE ($$ C03, CF3) $ WRITE ($$ C06, CF6)$ WRITE ($$ C10, CF10) $
WRITE ($$ ERMA, FMTR ) $ WRITE ($$ VAR, FVAR) $
COMMENT CALCULATE VOLUME WITHIN MAP AREA BENEATH EACH OF THE THREE
TREND SURFACES BY INTEGRATING  IN RESPECT  TO BOTH X AND Y, AND EVALUA-
TING INTEGRAL EMPLOYING VALUES FOR MAP BOUNDARIES $
XD1 = XR - XL $ XD2 =  (XR.XR) - (XL.XL) $
XD3 = (XR.(XR.XR)) - (XL.(XL.XL)) $
XD4 = ((XR.XR).(XR.XR))  - ((XL.XL).(XL.XL)) $
YD1 = YB - YT $ YD2 =  (YB.YB) - (YT.YT) $
YD3 = (YB.(YB.YB)) - (YT.(YT.YT)) $
YD4 = ((YB.YB).(YB.YB))  - ((YT.YT).(YT.YT)) $
VLN = (((S3(1).XD1) + ((S3(2).XD2)/2)).YD1) +(((S3(3).XD1).YD2)/2) $
VQD = (((S6(1).XD1) + ((S6(2).XD2)/2)   +  ((S6(4).XD3)/3)).YD1)
        + ((((S6(3).XD1)/2)   + ((S6(5).XD2)/4)).YD2)
        +  (((S6(6).XD1).YD3)/3)  $
VCB =(((S10( 1).XD1) + ((S10(2).XD2)/2)  + ((S10(4).XD3)/3)
        +  ((S10(7).XD4)/4)).YD1)  +  ((((S10(3).XD1)/2)
        +  ((S10(5).XD2)/4)         +     ((S10(8).XD3)/6)).YD2)
        +((((S10(6).XD1)/3)         +     ((S10(9).XD2)/6)).YD3)
        + (((S10(10).XD1)/4).YD4)  $
AR = YD1.XD1 $
AZ1 =  VLN/AR  $  AZ2  =  VQD/AR  $
AZ3 =  VCB/AR $
OUTPUT VOL(VLN, VQD, VCB,AZM, AZ1, AZ2, AZ3, AR) $
FORMAT FMVL(W,*VOLUME BENEATH LINEAR SURFACE =*,B8,X12.2,W,W,
              *VOLUME BENEATH LIN+QUAD SURFACE =*,B6,X12.2,W,W,
              *VOLUME BENEATH LIN+QUAD+CUB SURFACE =*,B2,X12.2,W,W,
              *ARITH. MEAN Z, = SUM OF Z VALUES/ N   = *,X12.2,W,W,
              *AVERAGE Z VALUE, LINEAR SURFACE =*,B6,X12.2,W,W,
              *AVERAGE Z VALUE, LIN+QUAD SURFACE =*,B4,X12.2,W,W,
              *AVERAGE Z VALUE, LIN+QUAD+CUB SURFACE =*,X12.2,W,W,
              *AREA OF MAP IN SQUARED UNITS*,B11,X12.2,W,W) $
```

```
WRITE ($$ VOL, FMVL) $
WRITE ($$ HED) $
WRITE ($$ ODS1, FMT1) $
COMMENT CALCULATE DX AND DY, AND SUBSTITUTE PROGRESSIVELY INCREASING
VALUES OF X AND Y MAP VALUES IN FITTING EQUATIONS AND CONTOUR $
DX = (XR - XL)/HOR $
DY = (YB - YT)/VERT    $
OUTPUT  CNDATA(XL, XR, YT, YB, RF, CON) $
FORMAT CONDAT(*X VALUE LEFT EDGE OF MAP = *,X9.1,
        *        X VALUE RIGHT EDGE OF MAP =* ,X8.1,
        *        Y VALUE TOP EDGE OF MAP  = *,X8.1,W,
                *Y VALUE BOTTOM EDGE OF MAP = *,X7.1,
        *        REFERENCE CONTOUR VALUE = *,X9.1,
        *        CONTOUR INTERVAL = *,X16.1,W,W)$
W = 1 $
CALZ1..
I = 1 $
CALZ2..
 IF W GEQ 4 $ GO READY $
IF W EQL 1 $
   BEGIN
      WRITE ($$ ALPHA, FMTA) $
      FORMAT ZHED1(*CONTOURS OF LINEAR TREND SURFACE*,W ) $
      WRITE ($$ ZHED1 ) $
WRITE ($$ CNDATA,CONDAT) $
      CALZ3..
      BQX = S3(2).DX $
      BQ  = S3(1) + (S3(2).XL) +(S3(3).(YT +(DY.I))) $
      FOR A = (1.0,1.0,HAR) $
      Z(A) =  BQ + (A.BQX) $
      GO CONTOUR $
   END $
IF W EQL 2 $
   BEGIN
      WRITE ($$ ALPHA,FMTA) $
      FORMAT ZHED2(*CONTOURS OF LINEAR + QUADRATIC TREND SURFACE*,W)$
      WRITE   ($$ ZHED2 ) $
WRITE ($$ CNDATA,CONDAT) $
      BS1 = S6(2).DX   $
      BS2 = S6(4).(2XL.DX) $
      BS3 = S6(4).(DX.DX)  $
      CALZ4..
      BSY = YT +(DY.I) $
      BS4 = S6(5).(BSY.DX) $
      BS  = S6(1) +(S6(2).XL) + (S6(3).BSY) + (S6(4).(XL.XL)) +
         (S6(5).(BSY.XL)) + (S6(6).(BSY.BSY)) $
      BSA = BS1 + BS2 + BS4 $
      FOR A =(1.0,1.0,HAR) $
      Z(A) = (BSA.A) + (BS3.(A.A)) + BS $
      GO CONTOUR $
   END $
IF W EQL 3 $
   BEGIN
      WRITE ($$ ALPHA, FMTA) $
      FORMAT ZHED3(*CONTOURS OF LINEAR + QUADRATIC + CUBIC TREND *,
         *SURFACE*,W) $
      WRITE ($$ ZHED3) $
WRITE ($$ CNDATA,CONDAT) $
      BT1 = S10(2).DX  $
      BT2 = (2.DX).(XL.S10(4)) $
      BT4 = S10(7) .(3DX(XL.XL))   $
      BT5 = S10(7).(3XL.(DX.DX))   $
      BT6 = S10(7).(DX.(DX.DX))    $
      BT10=S10(4).(DX.DX)  $
      CALZ5..
      BTY = YT +(DY.I) $
      BT3 = S10(5).(BTY.DX) $
      BT7 = S10(8).(2XL.(DX.BTY)) $
      BT8 = S10(8).(BTY.(DX.DX))  $
      BT9 = S10(9).(DX.(BTY.BTY)) $
      BT  = S10(1) + (S10(2).XL) + (S10(3).BTY) + (S10(4).(XL.XL)) +
         (S10(5).(BTY.XL)) + (S10(6).(BTY.BTY)) + (S10(7).(XL.(XL.XL)))
         + (S10(8).(BTY.(XL.XL))) + (S10(9).(XL.(BTY.BTY))) +
         (S10(10).(BTY.(BTY.BTY))) $
      BTA = BT1 + BT2 + BT3 + BT4 + BT7 + BT9 $
      BTAA = BT5 + BT8 + BT10 $
      FOR A =(1.0,1.0,HAR) $
```

```
        Z(A) = (BTA.A) + (BTAA.(A.A)) + (BT6.(A.(A.A))) + BT $
        GO CONTOUR $
    END $
CONTOUR..
FOR J =(1,1,HOR) $
    BEGIN
        IF Z(J) LSS RF $
            BEGIN
                CV(J) = ARMIN(MOD(FIX((RF-Z(J))/CON),40) +1) $
                GO THERE $
            END $
        CV(J) = ARPLS(MOD(FIX((Z(J)-RF)/CON),40)+1) $
THERE..  END  $
OUTPUT ODCV(FOR J =(1,1,HOR) $ CV(J))$
FORMAT FTCV(132A1,W) $
WRITE ($$ ODCV,FTCV) $
I = I + 1 $
IF (W EQL 1) AND (I LEQ VERT) $ GO CALZ3 $
IF (W EQL 2) AND (I LEQ VERT) $ GO CALZ4 $
IF (W EQL 3) AND (I LEQ VERT) $ GO CALZ5 $
W = W + 1 $ GO CALZ1 $
 READY..
 OUTPUT OUT(FOR I =(1,1,K) $ PRINT(2,I)) $
 FOR I =(1,1,N) $
    BEGIN
        IY(I) =  X(I,2)/DY  $
        IX(I) =  X(I,1)/DX  $
    END  $
FOR Q =(3,2,9) $
BEGIN
WRITE ($$ ALPHA,FMTA)$ WRITE ($$ PLOT, PLFT) $
FOR LINE =(1,1,VERT) $
    BEGIN
        K=0$
        FOR J =(1,1,N) $
            BEGIN
                IF IY(J) EQL LINE $
                 BEGIN
                    K = K + 1 $
                    PRINT(1,K) = IX(J) $
                    PRINT(2,K) =  X(J,Q) $
                    DIGITS(K)= 0.4343.LOG((QQQ= ABS(X(J,Q))) +(QQQ LSS 1.0
                          ))+ 2 $
                 END $
            END $
        FOR I =(2,1,K) $ FOR J =(1,1,I-1)$
            BEGIN
                IF PRINT(1,I) LSS PRINT(1,J) $
                    BEGIN
                        FOR L = 1,2 $
                            BEGIN
                                TEMP = PRINT(L,J) $
                                PRINT(L,J) = PRINT(L,I) $
                                PRINT(L,I) = TEMP $
                            END $
                            TEMP = DIGITS(J)$ DIGITS(J)=DIGITS(I)$
                            DIGITS(I) = TEMP $
                    END $
            END $
        FOR I = (2,1,K) $ PRINT(3,I) = 0 $
        PRINT(3,1) = PRINT(1,1)- DIGITS(1) $
        FOR I = (2,1,K) $
            BEGIN
                IF PRINT(3,I-1) LSS 0 $
                    BEGIN
                        PRINT(3,I) = PRINT(3,I-1) $
                        PRINT(3,I-1) = 0 $
                    END$
                PRINT(3,I) = PRINT(1,I) + PRINT(3,I) - PRINT(1,I-1)
                    - DIGITS(I) $
            END$
        WRITE ($$ OUT, FORM) $
    END $
END $
GO START $ FINISH $
1 ((G  7   ()G
J ,X)*PE.2 9 '76'75'7447 '7X'76 7 77X'75 449' 7448' '4 '' 9' '4 '' 9' 7
J7((*P'-   74'G  04'9 '76 75 6 '06705'-4'76 75 74 549
 FINISH $
```

(23) Evaluate data values with respect to reference contour and contour interval, and express value as an appropriate character as assigned in alphanumeric arrays ARMIN and ARPLS: lines 380-397.

(24) Plot original data and residual values of first-, second-, and third-degree surfaces on maps that are same scale as contoured trend-surface maps. Data are sorted first according to Y coordinate values, and second according to X coordinate values: lines 398-450.

(25) Go to START to read in new set of data, if present, or terminate use of program if no more data sets are available: line 451.

(26) Binary external procedure INPROD used in matrix inversion procedure SOLV: lines 452-455.

Please note that on the actual program cards, a 2 should be punched in column 1, and the line numbers should be placed within columns 73-80.

INPUT TO TREND-SURFACE PROGRAM

Alphanumeric heading card.--The first card of each set of data must be a card containing alphabetical and numerical (alphanumeric) information for identification purposes. This information will be reproduced at the top of maps (Fig. 2) and other pages (Table 2) printed by the computer's printer. The card must be punched as follows:

(1) 5 in column 1.

(2) $ in columns 2 and 75.

(3) Any desired combination of letters, numbers, characters, and blanks in columns 3 through 74.

Program-control card.--The second card that accompanies each data set must be a program-control card containing the following information, in the order listed below. Note that each number is to be separated from adjacent numbers by at least one blank space on the card.

(1) 5 in column 1.

(2) An integer specifying whether the data are in integer or decimal form. Punch 2222 if data are integer; punch 4444 if data are decimal. (OP in program).

(3) An integer specifying the number of data points (N).

(4) An integer specifying the number of printed rows that map is to contain (VERT).

(5) An integer specifying the number of columns in maps that are to be printed (HOR). Note that there are 10 columns and 6 rows to the inch. Appropriate numbers for VERT and HOR must be chosen so that maps printed by computer are not distorted in respect to the ratio of length to width. The maximum number of columns is 132 (assuming that an IBM 1403 printer is used).

(6) A decimal number specifying the coordinate value of the right edge of the map (XR). Note that all coordinate values specifying edges of maps to be printed must be in the same units as X and Y coordinate values of data points.

(7) A decimal number specifying coordinate value of left edge of map (XL).

(8) A decimal number specifying coordinate value of bottom edge of map (YB).

(9) A decimal number specifying coordinate value of top edge of map (YT).

(10) A decimal number specifying the reference contour value (RF).

(11) A decimal number specifying the contour interval (CON).

Data cards.--Data cards follow the control card. Each data card should have 5 punched in column 1. Data values must be separated by at least one space, and any convenient number of data values may be placed on a card, columns 2 through 80 being available. In BALGOL, format input specifications for data are not used. Each data point has three values which must be listed in the following order:

(1) X or horizontal coordinate value.

(2) Y or vertical coordinate value.

(3) Z value.

In reading the data from the cards, the computer will read the numbers in groups of three. It is essential that the number of data points (three numbers per point) be exactly equal to the number N specified on the control card. The maximum number of data points (Z values) specified is 500, although this limit can be readily increased with very minor changes in the program.

The X and Y coordinate values may be in any convenient units. I have found tenths of an inch to be convenient, but miles, feet, kilometers, or any unit may be used. In order to keep all values positive, it is suggested that the coordinate origin be placed in the upper left corner of the map. The location of the origin is arbitrary and may be either at the corner of the area to be mapped or outside it. The X or horizontal coordinate values have positive signs and increase moving toward the right from the coordinate origin. The Y or vertical coordinate values have positive signs and increase moving downward from the coordinate origin. The control points may be irregularly spaced.

OUTPUT FROM TREND-SURFACE PROGRAM

X-Y matrix values.--Examples of output from the trend-surface program are shown in Table 2 and Figure 2. At the top of Table 2 are shown the elements of the 10 x 10 matrix used in solving the normal equations. Although the values of the matrix elements are not usually of interest in themselves, it may be helpful to scan them to insure that the capacity of the computer has not been exceeded if very large numbers are being used in the original data.

Equation constants.--The constants of the equations that describe first-, second-, and third-degree surfaces are printed out. The algebraic signs of constants are included.

Statistical measures of surfaces.--The following statistical measures of the trend surfaces and their residuals are calculated:

(1) Error measure.

(2) Percent of total sum of squares of each surface.

(3) Sum of squares due to linear, quadratic, and cubic components, separately and combined, and sum of squared deviations from the first-, second-, and third-degree surfaces.

Table 2.--Example of output of tabular data from trend-surface program.

BOUGUER GRAVITY ANOMALIES IN NORTHWESTERN KANSAS - CI = 10 MG

10 X 10 (X,Y) MATRIX VALUES

1.000, 02	3.841, 02	4.398, 02	2.038, 03	1.687, 03	2.591, 03	1.224, 04	8.916, 03	9.952, 03	1.709, 04
3.841, 02	2.038, 03	1.687, 03	1.224, 04	8.916, 03	9.952, 03	7.848, 04	5.309, 04	5.257, 04	6.572, 04
4.398, 02	1.687, 03	2.591, 03	8.916, 03	9.952, 03	1.709, 04	5.309, 04	5.257, 04	6.572, 04	1.196, 05
2.038, 03	1.224, 04	8.916, 03	7.848, 04	5.309, 04	5.257, 04	5.244, 05	3.371, 05	3.120, 05	3.473, 05
1.687, 03	8.916, 03	9.952, 03	5.309, 04	5.257, 04	6.572, 04	3.371, 05	3.120, 05	3.473, 05	4.600, 05
2.591, 03	9.952, 03	1.709, 04	5.257, 04	6.572, 04	1.196, 05	3.120, 05	3.473, 05	4.600, 05	8.702, 05
1.224, 04	7.848, 04	5.309, 04	5.244, 05	3.371, 05	3.120, 05	3.603, 06	2.228, 06	1.971, 06	2.056, 06
8.916, 03	5.309, 04	5.257, 04	3.371, 05	3.120, 05	3.473, 05	2.228, 06	1.971, 06	2.056, 06	2.431, 06
9.952, 03	5.257, 04	6.572, 04	3.120, 05	3.473, 05	4.600, 05	1.971, 06	2.056, 06	2.431, 06	3.338, 06
1.709, 04	6.572, 04	1.196, 05	3.473, 05	4.600, 05	8.702, 05	2.056, 06	2.431, 06	3.338, 06	6.499, 06

1 X 10 COLUMN VECTOR VALUES

-1.029, 04	-3.529, 04	-4.479, 04	-1.772, 05	-1.551, 05	-2.610, 05	-1.029, 06	-7.828, 05	-9.061, 05	-1.707, 06

EQUATION COEFFICIENTS

LINEAR, Z = -134.90545+ 7.51003X + .72270Y

LIN + QUAD, Z = -139.28436+ 11.75949X + -1.77729Y + -.29449X2 + -.45042XY + .48825Y2

LIN + QUAD + CUB, Z = -137.15641+ 12.71459X + -7.19410Y + -.52583X2 + -.93808XY + 2.49575Y2 + .04022X3 + -.05862X2Y + .10580XY2 + -.18306Y3

ERROR MEASURE LINEAR TREND SURFACE = 50.85

ERROR MEASURE QUADRATIC TREND SURFACE = 34.15

ERROR MEASURE CUBIC TREND SURFACE = 24.83

PERCENT TOTAL SUM SQUARES LINEAR SURFACE = 80.93

PERCENT TOTAL SUM SQUARES QUADRATIC SURFACE = 87.19

PERCENT TOTAL SUM SQUARES CUBIC SURFACE = 90.69

SUM OF SQUARES DUE LINEAR COMPONENT = 1090505.40

SUM OF SQUARED DEVIATIONS FROM LINEAR = 5034.33

SUM OF SQUARES DUE LINEAR + QUADRATIC COMPONENT = 1092158.80

SUM OF SQUARES DUE TO QUADRATIC ALONE = 1653.39

SUM OF SQUARED DEVIATIONS FROM LINEAR + QUADRATIC = 3380.91

SUM OF SQUARES DUE LINEAR+QUADRATIC+CUBIC = 1093081.61

SUM OF SQUARED DEVIATIONS FROM LINEAR+QUADRATIC+CUBIC = 2457.78

SUM OF SQUARES DUE CUBIC ALONE = 922.81

VOLUME BENEATH LINEAR SURFACE = -6798.72

VOLUME BENEATH LIN+QUAD SURFACE = -6806.03

VOLUME BENEATH LIN+QUAD+CUB SURFACE = -6809.02

ARITH. MEAN Z, = SUM OF Z VALUES/ N = -102.88

AVERAGE Z VALUE, LINEAR SURFACE = -102.54

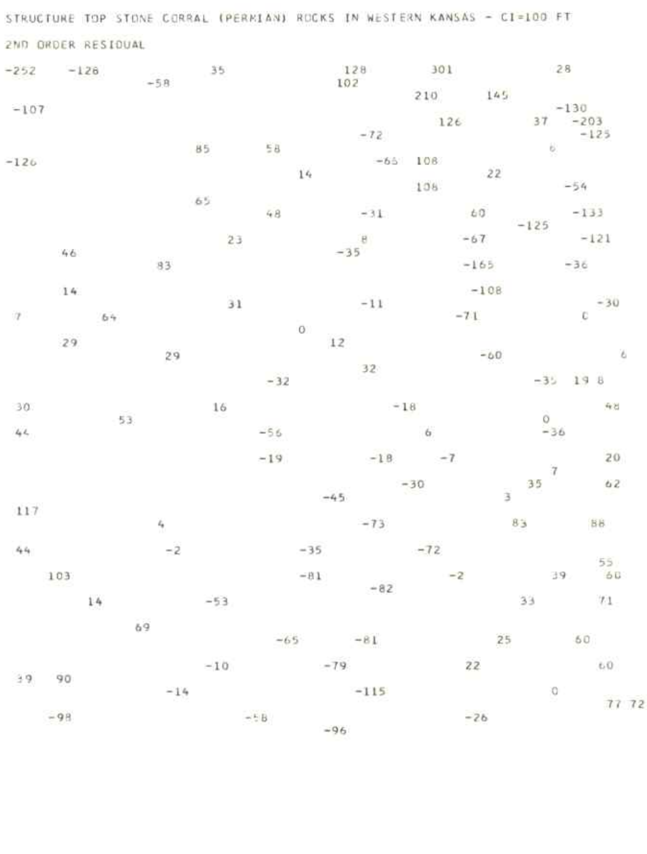
AVERAGE Z VALUE, LIN+QUAD SURFACE = -102.65

AVERAGE Z VALUE, LIN+QUAD+CUB SURFACE = -102.70

AREA OF MAP IN SQUARED UNITS 66.30

	XCOORD	YCCCRD	Z-VALUE	1ST-TRD	1ST-RSD	2ND-TRD	2ND-RSD	3RD-TRD	3RD-RSD
5	5.2	1.7	-93.0	-94.6	1.6	-91.7	-1.3	-94.9	1.9
5	7.8	7.1	-77.0	-71.2	-5.8	-78.4	1.4	-77.3	.3
5	4.7	5.0	-102.0	-96.0	-6.0	-97.8	-4.2	-97.4	-4.6
5	2.1	5.2	-109.0	-115.4	6.4	-116.8	7.8	-113.6	4.6
5	7.3	1.2	-71.0	-79.2	8.2	-74.5	3.5	-72.9	1.9
5	4.8	5.9	-100.0	-94.6	-5.4	-95.9	-4.1	-93.8	-6.2
5	.6	3.6	-138.0	-127.8	-10.2	-133.4	-4.6	-133.1	-4.9
5	3.0	3.5	-109.0	-109.8	.8	-111.6	2.6	-112.9	3.9
5	1.7	3.8	-124.0	-119.4	-4.6	-122.8	-1.2	-122.3	-1.7
5	3.6	4.9	-95.0	-104.3	9.3	-105.7	10.7	-104.3	9.3
5	6.1	2.5	-92.0	-87.3	-4.7	-86.8	-5.2	-91.0	-1.
5	2.3	6.3	-98.0	-113.1	15.1	-112.1	14.1	-108.1	10.1
5	3.3	4.1	-104.0	-107.2	3.2	-108.9	4.9	-109.1	5.1
5	7.8	1.1	-70.0	-75.5	5.5	-70.7	.7	-67.0	-3.0
5	2.0	1.1	-120.0	-119.1	-.9	-119.3	-.7	-120.7	.7
5	5.0	8.1	-95.0	-91.5	-3.5	-88.5	-6.5	-88.7	-6.3
5	3.8	5.6	-100.0	-102.3	2.3	-103.1	3.1	-100.5	.5
5	4.5	2.8	-110.0	-99.1	-10.9	-99.2	-10.8	-102.9	-7.1
5	1.9	5.5	-116.0	-116.7	.7	-117.7	1.7	-114.0	-2.0
5	2.4	.1	-115.0	-116.8	1.8	-113.0	-2.0	-110.1	-4.9
5	6.1	2.0	-88.0	-87.6	-.4	-85.6	-2.4	-89.1	1.1
5	4.3	4.1	-99.0	-99.6	.6	-101.2	2.2	-102.5	3.5
5	4.8	1.0	-101.0	-98.1	-2.9	-93.1	-7.9	-94.0	-7.0
5	4.1	7.6	-92.0	-98.6	6.6	-95.4	3.4	-93.6	1.6
5	1.9	4.8	-124.0	-117.2	-6.8	-119.4	-4.6	-116.8	-7.2
5	4.8	7.4	-85.0	-93.5	8.5	-92.0	7.0	-90.0	5.0
5	6.4	7.7	-81.1	-81.3	.2	-83.0	1.9	-82.3	1.2
5	6.6	8.4	-77.0	-79.3	2.3	-79.9	2.9	-81.6	4.6
5	2.8	1.2	-112.0	-113.0	1.0	-111.6	-.4	-113.4	1.4
5	2.8	6.2	-100.0	-109.4	9.4	-108.7	8.7	-104.8	4.8
5	7.0	7.4	-81.0	-77.0	-4.0	-81.1	.1	-80.2	-.8
5	7.6	3.3	-79.0	-75.4	-3.6	-78.8	-.2	-82.3	3.3
5	6.9	8.4	-75.0	-77.0	2.0	-78.7	3.7	-80.4	5.4
5	5.9	6.5	-90.0	-85.9	-4.1	-88.4	-1.6	-86.6	-3.4

A



B

Figure 2. Examples of printed maps produced as output from trend-surface program: A, contours on second-degree trend surface; B, residual values from second-degree trend surface shown in A.

(4) Volume beneath first-, second-, and third-degree surfaces within limits of mapped area.

(5) Average Z values based on arithmetic mean, and spatially weighted values beneath first-, second-, and third-degree surfaces.

(6) Mapped area in square units.

For a thorough discussion of the mathematical principles involved in computation and application of these statistical methods see Harbaugh (in press). The method of calculating volumes and spatially weighted averages has been adapted from Whitten (1962).

Values at individual data points.--The following values of individual data points are printed out and may also be simultaneously punched on cards if desired by changing the W in line 260 to C.

(1) X or horizontal coordinate value.

(2) Y or vertical coordinate value.

(3) Z value.

(4) Value of first-degree trend surface at that point.

(5) Value of first-degree residual.

(6) Second-degree trend value.

(7) Second-degree residual value.

(8) Third-degree trend value.

(9) Third-degree residual value.

Maps.--The following maps are printed out:

(1) First-degree trend map.

(2) Second-degree trend map (Fig. 2).

(3) Third-degree trend map.

(4) Map on which Z values are plotted.

(5) Map of first-degree residuals.

(6) Map of second-degree residuals (Fig. 2).

(7) Map of third-degree residuals.

Identifying information is printed out at the top of each map. Alternating bands of printed characters and blanks represent contours on the trend maps and permit each contour line to be identified. The printed characters used are listed in Table 3. The printed characters have been arranged so that there is little likelihood of ambiguity. The steps in calculating the values of contour lines are as follows:

(1) Determine the number of contour intervals above or below the reference contour as represented by the bands of characters or blanks referred to in Table 3.

(2) Multiply this number by the contour interval (declared on program control card, CON).

(3) Add algebraically to the reference contour value. For example, if the reference contour value

is 100, and the contour interval is 10, then the contour value represented by the lower edge of the band printed with B's is 60. The reference contour value is marked by the edge of the band of $'s which faces the band of A's.

Table 3.--List of characters that correspond with contour intervals of printed contour maps. Empty places in column indicate that no character has been printed.

Number of contour intervals above (+) or below (-) reference contour.	Character printed (or blank) in band, of which lower edge denotes contour value.	Number of contour intervals above (+) or below (-) reference contour.	Character printed (or blank) in band, of which lower edge denotes contour value.
-40	T	+ 1	
-39		+ 2	1
-38	S	+ 3	
-37		+ 4	2
-36	R	+ 5	
-35		+ 6	3
-34	Q	+ 7	
-33		+ 8	4
-32	P	+ 9	
-31		+10	5
-30	O	+11	
-29		+12	6
-28	N	+13	
-27		+14	7
-26	M	+15	
-25		+16	8
-24	L	+17	
-23		+18	9
-22	K	+19	
-21		+20	0
-20	J	+21	
-19		+22	$
-18	I	+23	
-17		+24	*
-16	H	+25	
-15		+26	-
-14	G	+27	
-13		+28	.
-12	F	+29	
-11		+30	+
-10	E	+31	
- 9		+32	=
- 8	D	+33	
- 7		+34	W
- 6	C	+35	
- 5		+36	X
- 4	B	+37	
- 3		+38	Y
- 2	A	+39	
- 1			
0	$		

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Forgotson, J. M., Jr., 1963, How computers help find oil: The Oil and Gas Journal, v. 61, no. 11, p. 100-109.

Harbaugh, J. W., in press, A computer method for four-variable trend analysis applied to crude oil gravity variations in southeastern Kansas: Kansas Geol. Survey Bull.

Krumbein, W. C., 1959, Trend surface analysis of contour-type maps with irregular control-point spacing: Jour. Geophys. Research, v. 64, no. 7, p. 823-834.

Merriam, D. F., and Harbaugh, J. W., in press, Computer analysis of regional and residual components of geologic structure in Kansas: Kansas Geol. Survey Bull.

Whitten, E. H. T., 1962, A new method for determination of the average composition of a granite massif: Geochimica et Cosmochimica Acta, v. 26, p. 545-560.

KANSAS GEOLOGICAL SURVEY COMPUTER PROGRAM
THE UNIVERSITY OF KANSAS, LAWRENCE

PROGRAM ABSTRACT

Title (If subroutine state in title):

BALGOL program for trend-surface mapping using an IBM 7090 computer

Computer: IBM 7090 Date: August 1963

Programming language: BALGOL

Author, organization: John W. Harbaugh, Department of Geology, Stanford University
Stanford, California

Direct inquiries to: author or to Daniel F. Merriam, State Geological Survey, Lawrence, Kansas

Name: John W. Harbaugh (author) Address: Department of Geology, Stanford University
Stanford, California

Purpose/description: Fitting of first-, second-, and third-degree trend surfaces to geological and other data. Accepts irregularly spaced data points. Automatically contours trend surfaces and plots original data as well as first-, second-, and third-degree residual values in a series of maps. In addition, calculates various statistical properties of trend and residual surfaces including (a) error measure, (b) sums of squares, (c) percent of total sums of squares, (d) volume beneath each trend surface, (e) spatially weighted averages, and (f) arithmetic mean.

Mathematical method: Generates matrix and vector; obtains constants of equations of trend surfaces by matrix inversion.

Restrictions, range: Present limit is 500 data points, but this can be increased substantially by changing the array dimensions.

Storage requirements: ______

Equipment specifications: (not pertinent, inasmuch as 7090's have 32,000+ words of high-speed memory)

Memory 20K______ 40K______ 60K______ K______

Automatic divide: Yes______ No______ Indirect addressing: Yes______ No______

Other special features required______

Additional remarks (include at author's discretion: fixed/float, relocatability; optional: running time, approximate number of times run successfully, programming hours) Compiles from BALGOL source deck in 18 seconds; typical running time, assuming 200 data points and maps that contain 60 square inches, is about 30 seconds. The Stanford University Computation Center will make its BALGOL compiler tape available to any 7090 user, provided the user will send a tape from a 7090 tape unit to the Stanford Computation Center.

Special
Distribution
Publication

1. The Kansas mineral industry...1962; with directory of Kansas mineral producers, by Grace Muilenburg, R. G. Hardy, and Allison Hornbaker, 1963.

2. Economic development for Kansas, mineral and water resources: Report of the Governor's Economic Development Committee, by W. W. Hambleton, and others, 1962.

3. BALGOL program for trend-surface mapping using an IBM 7090 computer, by J. W. Harbaugh, 1963.