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Computer simulation program for investigation of geochemical sampling problems

By

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Contents

Illustrations

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Introduction

An important difficulty encountered with the application of statistics and experimental design techniques to many geologic problems, as well as to problems in other fields, is that the success or failure of the techniques can only be evaluated theoretically or intuitively; for example, in sampling of a granite pluton to determine its bulk composition various sampling plans can be used and a number of different type mean compositions might be computed -- but the particular sampling plan and the particular mean that tend to provide the most accurate answer from the fewest samples remain a theoretical speculation.

This program has been prepared as an experiment designed to help evaluate the probable degree of success of various sampling plans that could be used in geologic and geochemical field problems, and to gain a better understanding of factors affecting frequency distributions and other statistical properties of geologic and geochemical data. The geologic aspects of the problem and the basic theory of the technique have been presented elsewhere (Miesch, Connor, and Eicher, 1964). The purpose of this report is to describe the details of the program and to provide instructions regarding its use. The program (Appendix D) is in ALGOL 58 and has been used on a Burroughs 220 computer with 10,000 words of core memory and magnetic tape.

A conceptual rock body is defined, or an actual rock body is simulated mathematically, and then "sampled" according to various plans. The results of the sampling, the sample values, are then processed through various other statistical programs (see Miesch and Eicher, 1964) in an attempt to recover the known parameters of the mathematical model. Sampling designs and statistical methods may then be compared for their relative success in this respect. It is anticipated that the success of various techniques will vary with the geologic and geochemical conditions simulated in each use of the program.

Mathematical models of rock bodies

In design of the program it has been assumed that spatial variation of rock body components and attributes of interest can be described, for the most part, by one or several low-order polynomial functions, plus a randomly distributed residual component having one of several types of frequency distributions. The independent variables of the polynomial functions are the X, XY, XYZ spatial coordinates, depending on whether the model is 1, 2, or 3 dimensional. Each model, therefore, is built on an X, XY, XYZ coordinate framework. Discontinuous, as well as continuous, types of spatial variation can be described by the polynomial functions, and the variances of randomly distributed residual components may or may not be homogeneous over the model framework.

The main output from the program is a set of N sample values, V_j, each representing a measurement of some kind on a hypothetical rock sample. The sample values are generated by evaluating the model at coordinate points, and are functions of the parameters built into the models.

The jth sample value, V_j, of N total sample values ($1 \leq j \leq N \leq 9999$) is given by the expression:

$$V_j = p_5T_j + p_{49}R_{1j} + p_{50}R_{2j} + p_{51}10^{R_{1j}} + p_{62}10^{R_{2j}} + p_{53}(10^{R_{1j}} + C_1)$$
$$+ p_{54}(10^{R_{2j}} + C_2) + p_{55}R_{1j}^2 + p_{56}R_{2j}^2 + p_{57}(R_{1j})^{\frac{1}{2}} + p_{58}(R_{2j})^{\frac{1}{2}}$$
$$+ p_{59}\tan R_{1j} + p_{60}\tan R_{2j} + p_{61}\sin R_{1j} + p_{62}\sin R_{2j} + p_{63}\cos R_{1j}$$
$$+ p_{64}\cos R_{2j} + p_{65}Q_{1j} + p_{66}Q_{2j}, \qquad (1)$$

where

1) $p = 0$ or $p = 1$[1] and the subscript number of p is the option number (see option card format in table 1).

2) If $p_5 = 1$ and the model is one dimensional (i.e., representing a trace or traverse), then,

$$T_j = p_6T_{111j} + p_7T_{112j} + p_8T_{121j} + p_9T_{122j} + p_{10}T_{131j} + p_{11}T_{132j}$$
$$+ p_{12}T_{141j} + p_{13}T_{142j} + p_{14}T_{151j} + p_{15}T_{152j}, \qquad (2)$$

where T_1 is a polynomial function with one independent variable, X. The second subscript number of T indicates the degree of the polynomial. For example, if all values of p_6 through p_{15} equal zero except p_6, p_7, and p_{14}, then

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[1] p_6 through p_{31} in equations (2), (7), and (11) may also equal 2, 3, or 4 for selected special options to be described later. However, in such cases p is replaced by one or zero prior to evaluation of the equations.

$$T_j = T_{111j} + T_{112j} + T_{151j}, \tag{3}$$

$$T_{111j} = a_0 + a_1X_j, \tag{4}$$

$$T_{112j} = b_0 + b_1X_j, \tag{5}$$

$$T_{151j} = c_0 + c_1X_j + c_2X_j^2 + c_3X_j^3 + c_4X_j^4 + c_5X_j^5, \tag{6}$$

where the a, b, c, ... coefficients are input.

If $p_5 = 1$ and the model is two dimensional (i.e., representing a map or areal problem), then

$$T_j = p_{16}T_{211j} + p_{17}T_{212j} + p_{18}T_{221j} + p_{19}T_{222j} + p_{20}T_{231j}$$
$$+ p_{21}T_{232j} + p_{22}T_{241j} + p_{23}T_{242j} + p_{24}T_{251j} + p_{25}T_{252j}, \tag{7}$$

where T_2 is a polynomial function with two independent variables, X and Y. The second T subscript again indicates the degree polynomial. For example, if all values of p_{16} through p_{25} equal zero except p_{16} and p_{18}, then

$$T_j = T_{211j} + T_{221j}, \tag{8}$$

$$T_{211j} = a_0 + a_1X_j + a_2Y_j, \tag{9}$$

$$T_{221j} = b_0 + b_1X_j + b_2X_j^2 + b_3Y_j + b_4X_jY_j + b_5Y_j^2. \tag{10}$$

If $p_5 = 1$ and the model is three dimensional (i.e., pertaining to variation in three dimensions within a rock body), then

$$T_j = p_{26}T_{311j} + p_{27}T_{312j} + p_{28}T_{321j} + p_{29}T_{322j} + p_{30}T_{331j}$$
$$+ p_{31}T_{332j}, \tag{11}$$

where T_3 is a polynomial function with three independent variables, X, Y, and Z. The second subscript of T again indicates the degree polynomial. For example, if all p coefficients are zero except p_{28}, then

$$T_j = T_{321j}, \tag{12}$$

$$T_{321j} = a_0 + a_1X_j + a_2X_j^2 + a_3Y_j + a_4X_jY_j + a_5Y_j^2 + a_6Z_j + a_7X_jZ_j + a_8Y_jZ_j + a_9Z_j^2. \tag{13}$$

An option in the program allows inclusion of discontinuous trend functions in the models. These discontinuous functions are used to simulate stable variation that is restricted to some part of the simulated rock body, such as local anomalies or locally distributed rock types within the larger rock body. Inclusion of discontinuous trends is accomplished by adjusting the constant term in one of the polynomial trend functions (a_0, b_0, or c_0 in equations 4 to 6, for example) so that trend values, T_j, of zero fall on the margins of the part of the model that is to contain the discontinuous trend. Then the polynomial function is evaluated in the program for specific coordinate values, and either negative or positive values of T_j can be replaced by zero, depending on the option chosen. Negative values of a trend function are replaced by zero if the corresponding value of p_6 through p_{31} is set equal to 2. Positive values are replaced by zero if p_6 through p_{31} is set equal to 3. If p_{16} in equation (7), for example, is set equal to 2 on input, then $T_{211j} = a_0 + a_1X_j + a_2Y_j$ only where the quantity $a_0 + a_1X_j + a_2Y_j$ is positive. Where this quantity is negative $T_{211j} = 0$. If p_{16} is set equal to 3, $T_{211j} = a_0 + a_1X_j + a_2Y_j$ only where the right side of the equation is negative. Where the right side of the equation is positive, $T_{211j} = 0$.

3) Each of the 16 possible sets of R_{ij} (R_{1j}, or R_{2j} in equation 1) consists of N normally distributed values with the population mean of each set constant over the XYZ coordinates of the model framework. The population means and variances of R_{ij} are specified and may be different for each of the 16 sets. The term $10^{R_{ij}}$ represents a set of N random numbers, RL_{ij}, whose logarithms are normally distributed. The term $(10^{R_{ij}} + C_i)$ represents a set of numbers, RLC_{ij}, whose logs are normally distributed if taken after increasing (or decreasing) the numbers by a specified constant, C_i (cf. Krige, 1960). The term R_{ij}^2 represents a set of numbers, RSR_{ij}, whose square roots are normally distributed. The term $(R_{ij})^{\frac{1}{2}}$ represents a set of numbers, RSQ_{ij}, whose squares are normally distributed. The term tan R_{ij} represents a set of numbers, RAT_{ij}, whose arctans are normally distributed. The term sin R_{ij} represents a set of numbers, RAS_{ij}, whose arcsins are normally distributed, and the term cos R_{ij} represents a set of numbers, RAC_{ij}, whose arccosines are normally distributed.

The 16 sets of R_{ij} are generated from corresponding sets of RN_{ij}, where RN_{ij} is normally distributed with population mean equal to zero, and population variance equal to one. The transformation is

$$R_{ij} = \sigma_i RN_{ij} + \mu_i, \qquad (14)$$

where σ_i and μ_i are the population standard deviation and mean, respectively, of R_{ij}. If the various sets of residuals are to be attached to different models, the same set of RN_{ij} may be used to generate all sets of R_{ij}, or different sets of RN_{ij} may be used.

Each set of RN_{ij} is derived from a set of uniformly distributed random numbers, using a transformation technique described by Kahn (1956, p. 12). The uniform random numbers are generated by a congruential method (Taussky and Todd, 1956, p. 17).

When R_{ij} is generated from (14), the variance of R_{ij} will tend to be constant over the entire model; i.e., σ_i^2 is independent of the model coordinates and is homogeneous. Heterogeneous variance of R_{ij} may be generated by letting σ_i in (14) vary as a polynomial function of the model coordinates. This is accomplished by setting any value of p_6 through p_{31} in (2), (7), or (11) equal to 4. The standard deviation term, σ_i, in (14), then, is replaced by a value of T_j corresponding to the value of p_6 through p_{31} which was set equal to 4. The option for heterogeneous variance in the residual may only be used when the population of residuals is normally distributed and when only one set of residuals is included in the model; i.e., p_{49} or p_{50} in equation (1) must equal one and p_{51} through p_{64} must equal zero. Whenever a trend, T_j, is to replace a standard deviation, σ_i, in using heterogeneous variance it <u>cannot</u> be used as a component part of the model.

4) Q_{1j} and Q_{2j} are sets of any N arbitrary values, and can be used to insert sets of extreme values or other irregularities into the model. Values of Q_{1j} and Q_{2j} are given as input and each value is added to the model at the X_j, X_jY_j, or $X_jY_jZ_j$ coordinate position having the same subscript value, j. If the coordinates are generated in the computer the location of a specific Q value will not be predictable, especially if the model is sampled randomly (see following section).

If cell sampling is used the locations of Q will be known only approximately, i.e., the cell in which Q_{1j} or Q_{2j} will be used will be known but its position within the cell will not. If the part of the model where Q will be used must be known precisely, and where random or cell sampling coordinates are generated in the program, two passes in the program are needed. The sampling coordinates are found on the first pass, the coordinates are then examined to determine the appropriate values of Q_{1j} and Q_{2j} to be used on the second. By use of the same starting random number (fig. 1) on the second pass the same coordinates will be generated.

Sampling the models

The $X_jY_jZ_j$ coordinates, defining locations where the model is to be sampled, may be either input into the program or generated in the computer. Giving $X_jY_jZ_j$ coordinates as input, of course, allows the user to employ any sampling plan whatsoever. If $X_jY_jZ_j$ are generated in the computer one of several sampling plans may be employed: 1) random sampling, 2) cell sampling, a form of stratified random sampling, or 3) variations of cell sampling wherein only selected cells are sampled (e.g., nested sampling).

In random sampling, N values of T_j are computed at N random $X_jY_jZ_j$ locations falling within the prescribed limits of the model, and summed with values of R or Q representing additional terms in the model being examined.

In cell sampling the model is divided into cells specified by increments of the $X_jY_jZ_j$ coordinates, and a number of sample values are computed at random locations within each cell. The cell may be an increment on a traverse, a rectangular area on a plane, or a rectangular volume within a three-dimensional model. The total number of cells within the model framework is given by NC = NCX • NCY • NCZ, where NCX is the number of cells along the X coordinate of the model, NCY is the number along the Y coordinate, and NCZ is the number along the Z coordinate. The sample values, V_j, from within a single cell may be listed on output separately or their average may be listed, depending on the type of output selected. Similarly, the $X_jY_jZ_j$ locations of each sample may be listed, or their averages may be listed. A further provision of the program allows the average sample value of each cell to be listed with the $X_jY_jZ_j$ coordinates of the center of the cell.

A special purpose for which this program was designed is to examine the variation in efficiency with increasing numbers of sample values in cell sampling. Consequently, provision has been made to allow one to take, say 2 samples per cell, and then add, say 4 more samples in each cell. (The number of samples taken from one cell to another need not be the same, however.) The first listing of average V_j values representing the cell will include averages based on 2 samples per cell. The second listing will be of averages based on 6 samples per cell or on as many samples as specified per cell. One may use as many as 8 sample subgroupings per cell. The first subgroup is equivalent to a preliminary sampling excursion, and each subsequent subgroup is equivalent to a return trip to the field for the collection of more samples to be added to those collected previously.

Generation and use of pseudo-random numbers

Pseudo-random numbers, generated in the program, are used for two purposes: 1) the derivation of random and cell sampling coordinates, and 2) the generation of sets of trend residuals, R_{ij}. Uniformly distributed numbers, RR values, are used to derive sampling coordinates, and normally distributed numbers, RN values, are used to derive the residuals (see equation 14).

The procedure used to derive RR and RN values is diagrammed on figure 1. The RR values are derived by a congruential method (Taussky and Todd, 1956, p. 17), and a rejection technique (Kahn, 1956, p. 41) is used to transform them to RN values if trend residuals, rather than sampling coordinates, are to be determined. Each pass through the procedure on figure 1 produces one value of RR and RN. The value RR, which is given on output, is used as a beginning value in the next pass through the procedure when additional random numbers are needed in the computations. The first value of RR is taken from columns 68 - 77 of the option card on the first pass through the procedure. This value, the "starting random number," is a positive 10-digit integer chosen by the user.

Operation of the program

Input to the program consists of an identification card, an option card, as many as 7 types of parameter cards, and one or more sentinel cards. The types of parameter cards needed depends on the problem involved and is partly dependent on the use of various output symbols. Computing instructions are given completely on the option

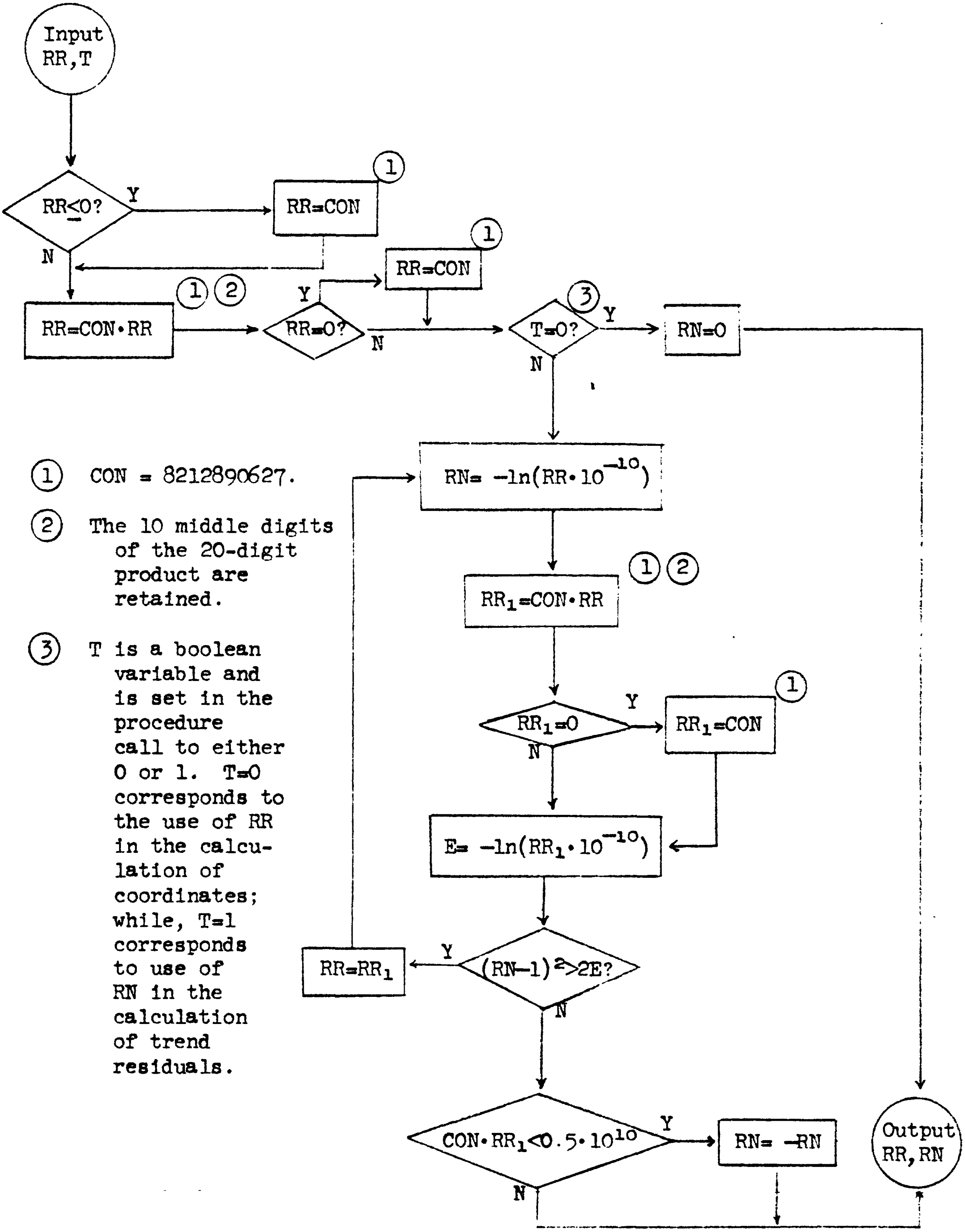


Figure 1. Flow diagram of procedure used to generate either uniformly distributed pseudo-random numbers, RR, or normally distributed pseudo-random numbers, RN. See appendix B for explanation of symbols.

card and its format and use are discussed here. The formats of the identification and parameter cards are described in a following section.

Option card: The format of the option card is given in table 1 which may be used as a guide or check list in completing the card form. The card columns 5 - 31 and 49 - 66 on the option card correspond to the subscripts of p in equations (1), (2), (7), and (11).

The number of sample values, V_j, to be evaluated from the model is given in columns 1 - 4.

If a trend component is to be included in the general model (equation 1) a 1 is entered in column 5. Otherwise column 5 should be zero or blank.

If the model is 1 dimensional, the trend component, if included, is a function of only one independent variable, the X coordinate; at least one of the columns 6 - 15 should contain a 1 to 4. A 1 is used if the trend is to be continuous across the entire model, 2 or 3 is used if the trend is to be discontinuous, and a 4 is used if the purpose of the trend is to generate heterogeneous residual variance. If a 2 is given the trend value, T_j, is set equal to zero if $T_j < 0$. If a 3 is given, T_j is set equal to zero if $T_j > 0$.

The first subscript of T on table 1, as in equations (1) to (13), denotes the dimensions of the model; the second subscript denotes the degree of the polynomial function used to describe the trend. Each model may contain 2 trends of the same dimension and degree; these are distinguished by the third subscript of T. The fourth subscript, j, denotes the sample value number ($1 \leq j \leq N$).

Table 1.--Format of the option card

(all entries are right justified, blank = 0)

	Card column	Value	Remarks
	1 - 4	$1 \leq N \leq 9{,}999$	Number of sample values (j max).
	5	TC = 0 or 1	If TC = 1, trend components are used in the model.
1-dimensional model	6	0 to 4	T_{111j} trend component used?
	7	do.	T_{112j} do.
	8	do.	T_{121j} do.
	9	do.	T_{122j} do.
	10	do.	T_{131j} do.
	11	do.	T_{132j} do.
	12	do.	T_{141j} do.
	13	do.	T_{142j} do.
	14	do.	T_{151j} do.
	15	do.	T_{152j} do.
2-dimensional model	16	do.	T_{211j} do.
	17	do.	T_{212j} do.
	18	do.	T_{221j} do.
	19	do.	T_{222j} do.
	20	do.	T_{231j} do.
	21	do.	T_{232j} do.
	22	do.	T_{241j} do.
	23	do.	T_{242j} do.
	24	do.	T_{251j} do.
	25	do.	T_{252j} do.

Table 1.--Format of the option card (continued)

(all entries are right justified, blank = 0)

	Card column	Value	Remarks
3-dimensional model	26	0 to 4	T_{311j} trend component used?
	27	do.	T_{312j} do.
	28	do.	T_{321j} do.
	29	do.	T_{322j} do.
	30	do.	T_{331j} do.
	31	do.	T_{332j} do.
	32	GR = 0 or 1	If GR = 0 coordinates, X, Y, and Z are given as input; if 1 they are generated in the program.
	33	CU = 0 or 1	If cell sampling is to be performed, CU = 1; otherwise CU = 0.
	34 - 36	$0 \leq NC \leq 225$	NC = total number of cells. NC = 0 if CU = 0. NC = NCX · NCY · NCZ.
	37 - 39	$0 \leq NCX \leq 225$	NCX = number of cells counted along X direction of model. NCX = 0 if CU = 0.
	40 - 42	$0 \leq NCY \leq 225$	NCY = number of cells counted along Y direction of model. NCY = 1 if model is 1-dimensional. NCY = 0 if CU = 0.

Table 1.--Format of the option card (continued)

(all entries are right justified, blank = 0)

	Card column	Value	Remarks
	43 - 45	$0 \leq NCZ \leq 225$	NCZ = number of cells counted along Z direction of model. NCZ = 1 if model is 1 or 2 dimensional. NCZ = 0 if CU = 0.
	46	$0 \leq NS \leq 8$	NS = number of subgroups within cells. NS = 0 if CU = 0.
	47	CC = 0 or 1	If CC = 1, and if output symbol (col. 67) = 4 or 8, the XYZ coordinates of geometric centers of sampling cells are given on output.
	48	RT = 0 or 1	If RT = 1, trend residuals are to be computed.
			Types of trend residuals
	49	0 or 1	$R1_j = R_{1j}$
	50	do.	$R2_j = R_{2j}$
	51	do.	$RL1_j = 10^{R_{1j}}$
	52	do.	$RL2_j = 10^{R_{2j}}$
	53	do.	$RLC1_j = 10^{R_{1j}} + C_1$
	54	do.	$RLC2_j = 10^{R_{2j}} + C_2$

Table 1.--Format of the option card (continued)

(all entries are right justified, blank = 0)

Card column	Value	Remarks
55	0 or 1	$RSR1_j = R_{1j}^2$
56	do.	$RSR2_j = R_{2j}^2$
57	do.	$RSQ1_j = R_{1j}^{\frac{1}{2}}$
58	do.	$RSQ2_j = R_{2j}^{\frac{1}{2}}$
59	do.	$RAT1_j = \tan R_{1j}$
60	do.	$RAT2_j = \tan R_{2j}$
61	do.	$RAS1_j = \sin R_{1j}$
62	do.	$RAS2_j = \sin R_{2j}$
63	do.	$RAC1_j = \cos R_{1j}$
64	do.	$RAC2_j = \cos R_{2j}$
65	$QR_1 = 0$ or 1	If QR = 1, a Q_{1j} component is added to the model.
66	$QR_2 = 0$ or 1	If QR = 1, a Q_{2j} component is added to the model.
67	$1 \leq$ output symbol ≤ 9	See text.
68 - 77	A positive 10 digit number or RR	(Needed if GR = 1 or any of the options 49 to 64 are selected; see text.)
78	$0 \leq D \leq 5$	If D is not zero or blank card output is given with D significant figures.

Table 1.--Format of the option card (continued)

(all entries are right justified, blank = 0)

	Card column	Value	Remarks
	79	2	Sequence number
	80	4	F/B number

Examples showing how to complete columns 5 - 15 of the option card are given on figure 2. The extension of the procedure to 2- and 3-dimensional models, using column 5 with columns 16 - 25 or 26 - 31, will be obvious.

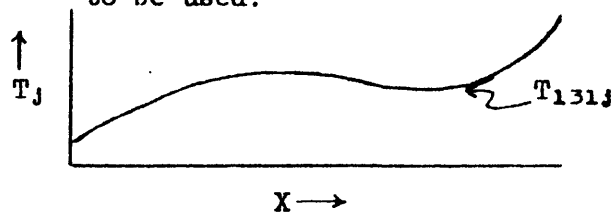
The coefficients of the trend equations to be used must be determined and given as input on "trend coefficient" cards to be described in a later section. Where the equations are higher than degree 1 or 2, we have found that the coefficients are most easily determined by least squares solutions employing values read from curves drawn to approximate the configuration of the trend we want to use.

As indicated on table 1, a 4 may be placed in columns 6 - 31. This is done when trend residuals with heterogeneous variance are to be added to the model. In this case, only one of the card columns 49 - 64 may contain a one; the remainder must be blank or zero. If heterogeneous trend residuals are used, the term σ_1 in equation (14) is replaced by the trend value whose subscript value of p is 4. That is, the standard deviation, σ_1, of the trend residuals varies as a polynomial function of the XYZ coordinates of the model. The coefficients of the function must be given on trend coefficient cards, just as when the trend functions are used for purposes previously described. However, although this trend has been evaluated it cannot be used as a component part of the model.

If sampling coordinates, or coordinates at which the model is to be evaluated, are given on input, a zero is placed in column 32 of the

Example 1:

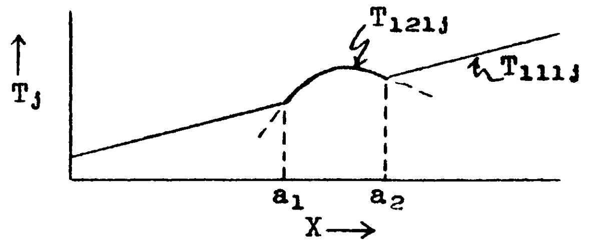
A. Approximate trend configuration to be used:



B. Option card:
- Col. 5 = 1
- Col. 6-9 = 0 or blank
- Col. 10 = 1
- Col. 11-15 = 0 or blank

Example 2:

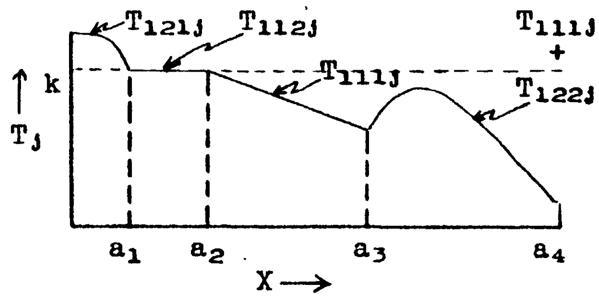
A. Approximate trend configuration and anomaly to be used:



B. Option card:
- Col. 5 = 1
- Col. 6 = 1
- Col. 7 = 0 or blank
- Col. 8 = 2 (coefficients of T_{121J} should be determined so that $T_{121J} = 0$ at $X = a_1$ and $X = a_2$.)
- Col. 9-15 = 0 or blank

Example 3:

A. Approximate discontinuous trend configurations to be used:



B. Option card:
- Col. 5 = 1
- Col. 6 = 3 (coefficients of T_{111J} should be fixed so that $T_{111J} = 0$ at $X = a_2$.)
- Col. 7 = 1 (T_{112J} is used here only to change the trend values by some constant increment, k; therefore, all coefficients of T_{112J} are fixed at zero except the equation constant, which is given as k.)
- Col. 8 = 2 (coefficients of T_{121J} should be fixed so that $T_{121J} = 0$ at $X = a_1$.)
- Col. 9 = 2 (coefficients of T_{122J} should be fixed so that $T_{122J} = 0$ at $X = a_3$ and $X = a_4$.)
- Col. 10-15 = 0 or blank

Figure 2. Examples showing how to complete columns 5 to 15 of option card in table 1.

option card, and the coordinates are given on "sampling coordinate" cards described in a later section. If the sampling coordinates are generated in the program, column 32 should contain a 1, and "model limit" parameter cards, described in a later section, should be completed.

If cell sampling is to be employed, column 33 should contain a 1, and "cell sampling" cards, described in a later section, must be completed.

The total number of cells in which the model is to be divided is given in columns 34 - 36.

The number of cells along the X direction of the model is given in columns 37 - 39.

The number of cells along the Y direction of the model is given in columns 40 - 42. For 1-dimensional models, NCY = 1.

The number of cells along the Z direction of the model is given in columns 43 - 45. For 1- and 2-dimensional models, NCZ = 1 (Note: $NC = NCX \cdot NCY \cdot NCZ$; NC = NCX = NCY = NCZ = 0 when CU = 0; and $NC \neq 0$, $NCX \neq 0$, $NCY \neq 0$, $NCZ \neq 0$ when CU = 1.).

The value, NS, in column 46 indicates the number of stages in sequential sampling of cells. Each stage is treated as an individual problem, and NS sets of output are obtained (Note: If CU = 0, NS = 0.). See later section on "cell sampling" cards.

If the coordinates of the geometric centers of sampling cells are to be given on output along with corresponding cell averages, a 1 should be punched in column 47 and "cell center" cards, described in a later section, must be completed. (Note: If CU = 0, then CC = 0; CC must equal 1 if column 67 contains a 4 or 8; CC may equal 1 or 0 if column 67 contains a 9; CC must equal 0 if column 67 contains a 1, 2, 3, 5, 6, or 7.) See later section on output options.

If trend residuals are to be added to the model column 48 must contain a 1.

Columns 49 - 64 are used to indicate the types of frequency distributions the trend residuals should exhibit. As many as 8 types and 16 individual sets of residuals may be used. Symbols given on output identifying the types and set are as follows:

Type	Symbol	Normal variate is:	Set	Selected by inserting a 1 in column:
1	R1	R1	1	49
	R2	R2	2	50
2	RL1	log(RL1)	1	51
	RL2	log(RL2)	2	52
3	RLC1	log(RLC1 + C1)	1	53
	RLC2	log(RLC2 + C2)	2	54
4	RSR1	$\sqrt{RSR1}$	1	55
	RSR2	$\sqrt{RSR2}$	2	56
5	RSQ1	$RSQ1^2$	1	57
	RSQ2	$RSQ2^2$	2	58
6	RAT1	arctan RAT1	1	59
	RAT2	arctan RAT2	2	60
7	RAS1	arcsin RAS1	1	61
	RAS2	arcsin RAS2	2	62
8	RAC1	arccos RAC1	1	63
	RAC2	arccos RAC2	2	64

As briefly described in a previous section, each set of residuals is generated by transforming a set of normally distributed pseudo-random numbers, RN, having a population mean of zero and variance of one. No transformation is required for sets of R1 and R2. Values of R_{ij} $(1 \leq i \leq 2;\ 1 \leq j \leq N)$ are used directly as derived from equation (14), and have a population mean of μ_i and variance of σ_i^2. Other types of trend residuals are derived from values of R_{ij} as indicated in equation (1).

All sets of trend residuals used on the same model are generated from different sets of RN and R_{ij} values. The properties of the population from which each set of residuals is derived depends on the type of frequency distribution specified on the option card and on the values of σ_i and μ_i specified for each set of R_{ij} values on "MSC" cards described in a later section. The properties of the actual set of computed residuals depends on the properties of the specified population and on the particular set of RR and RN values encountered in the program. These "sample pecularities," as well as the population characteristics of the residuals, may be kept constant from one model to another by proper use of the "starting random number" in columns 68 - 77 of the option card. This is described in detail in succeeding paragraphs.

Q-components are added to the model by placing a 1 in columns 65 or 66 of the option card and recording N values for each Q-component on "Q-component" cards. The format of these cards is described in a later section.

The output symbol, recorded in column 67 of the option card, determines the output information that is listed and punched and, to some degree, the flow of the program. The symbol can be any integer from 1 to 9. Four types of output information can be obtained; two of these apply only when cell sampling is employed. The cell sampling coordinates can either be given as input or generated in the program.

Type	Option symbol	Information on listing and punched cards
A	1 or 5	V_j from equation (1) and the XYZ sampling coordinates.
B	2 or 6	V_j from equation (1), all component terms given on the right sides of equations (1), (2), (7), and (11), and the XYZ sampling coordinates. All component terms not explicitly evaluated are set to zero by the program.
C	3 or 7	The average V_j for each of the NC cells and the average XYZ sampling coordinates for each cell.
D	4 or 8	The average V_j for each of the NC cells and the XYZ coordinates of the geometric center of each cell.

Examples of each of these 4 types of output are shown in figure 3.

Output symbol 9 is used in cases where the same trend calculations and the same sampling coordinates are used for a number of models, so that evaluation of the trend component for each model separately, as well as reading of parameter cards for each, is avoided. As an example, consider the problem of investigation of effects of various types of trend residuals and Q-components on the detection of a trend, T_{221j}. The complete card deck for input to the program may consist of 1) an identification card, 2) an option card with output symbol 9 in column 67 and options selected for T_{221j} (column 18) and all other

TYPE A output listing

J	V	X	Y	Z
1	.97568, 02	-.55000, 02	-.40000, 02	.00000, 00
2	.77935, 02	-.60000, 02	-.33000, 02	.00000, 00
3	.17842, 03	-.28000, 02	-.30000, 02	.00000, 00
4	.59569, 02	-.33000, 02	-.34000, 02	.00000, 00
5	.48344, 02	-.17000, 02	-.31000, 02	.00000, 00

TYPE B output listing

```
J                V               X              Y              Z             T111           T112           T121           T122
             T131            T132           T141           T142           T151           T152           T211           T212
          T221            T222           T231           T232           T241           T242           T251           T252
       T311            T312           T321           T322           T331           T332           R1             R2
     RL1             RL2            RLC1           RLC2           RSR1           RSR2           RSQ1           RSQ2
   RAT1            RAT2           RAS1           RAS2           RAC1           RAC2           Q1             Q2

 1      -.19807, 03   -.89000, 02   -.99000, 02   -.41000, 02    .00000, 00    .11000, 00    .00000, 00    .00000,00
       .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00   -.98890, 02    .00000,00
     .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00
   .00000, 00   -.99299, 02    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .98377, 01    .10159, 01
  .10087, 02    .97079, 01    .11207, 02    .10898, 02    .90383, 02    .99648, 00    .31480, 01    .99816, 00
.54339, 01    .15975, 01   -.77042,-01    .83768, 00   -.99804, 00    .54553, 00    .00000, 00    .00000, 00

 2      -.16470, 03   -.99000, 02   -.82000, 02   -.74000, 02    .00000, 00    .10000,-01    .00000, 00    .00000,00
       .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00   -.81990, 02    .00000,00
     .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .00000, 00
   .00000, 00   -.82729, 02    .00000, 00    .00000, 00    .00000, 00    .00000, 00    .98377, 01    .10159, 01
  .10087, 02    .97079, 01    .11207, 02    .10898, 02    .90383, 02    .99648, 00    .31480, 01    .99816, 00
.54339, 01    .15975, 01   -.77042,-01    .83768, 00   -.99804, 00    .54553, 00    .00000, 00    .00000, 00
```

TYPE C output listing

SC	SG	V AVE.	X AVE.	Y AVE.	Z AVE.
1	1	-.19807, 03	-.89000, 02	-.99000, 02	-.41000, 02
3	1	-.14868, 03	-.36000, 02	-.75000, 02	-.61000, 02
5	1	-.15038, 03	-.13000, 02	-.76000, 02	-.10000, 03
7	1	-.15090, 03	.30000, 02	-.77000, 02	-.80000, 02
9	1	-.17680, 03	.98000, 02	-.91000, 02	-.74000, 02
11	1	-.22239, 02	-.76000, 02	-.11000, 02	-.96000, 02
13	1	-.70639, 02	-.28000, 02	-.36000, 02	-.80000, 02

TYPE D output listing

SC	SG	V AVE.	XC	YC	ZC
1	1	.14810, 03	-.50000, 02	.30000, 02	.00000, 00
3	1	.45027, 02	-.30000, 02	.30000, 02	.00000, 00
5	1	.81816, 02	-.10000, 02	.30000, 02	.00000, 00
7	1	.19434, 02	.10000, 02	.30000, 02	.00000, 00
9	1	-.56852, 02	.30000, 02	.30000, 02	.00000, 00
11	1	.25773, 03	.50000, 02	.30000, 02	.00000, 00
13	1	.92354, 02	-.50000, 02	.10000, 02	.00000, 00

components to be used in the entire experiment, 3) parameter cards as required, 4) sentinel cards as required, and 5) identification and option cards for each model to be examined. Parameter cards, then, are not required for these latter option cards, since the parametric values will be retained in computer memory. Output symbol 9 may be useful even when a trend is not included in the model, just to save time in reading Q-component values and parameters of trend residuals. When output symbol 9 has been used on the first option card, all subsequent option cards contain the output symbols 5 to 8, rather than 1 to 4.

The function of the output symbol in controlling the flow of the program is diagrammed in figure 4. The initial identification and option cards are read first and the output symbol is tested. If the symbol is 1 to 4, or 9, the succeeding parameter cards are read, and the XYZ coordinate values either read or determined. These data are stored. The output symbol is tested again and if 1 to 4, the complete model, V_j (equation 1), is evaluated and given on output. If the output symbol is 9 the next identification and option cards are read before proceeding to the computation and output section of the program. Subsequent identification and option cards in the input deck are then read and computations performed accordingly.

The pseudo-random numbers generated by the procedure diagrammed in figure 1 may be thought of as occurring in a large table. The particular set of numbers obtained through use of the program, then, depends on the value in the table with which one starts, and the sets

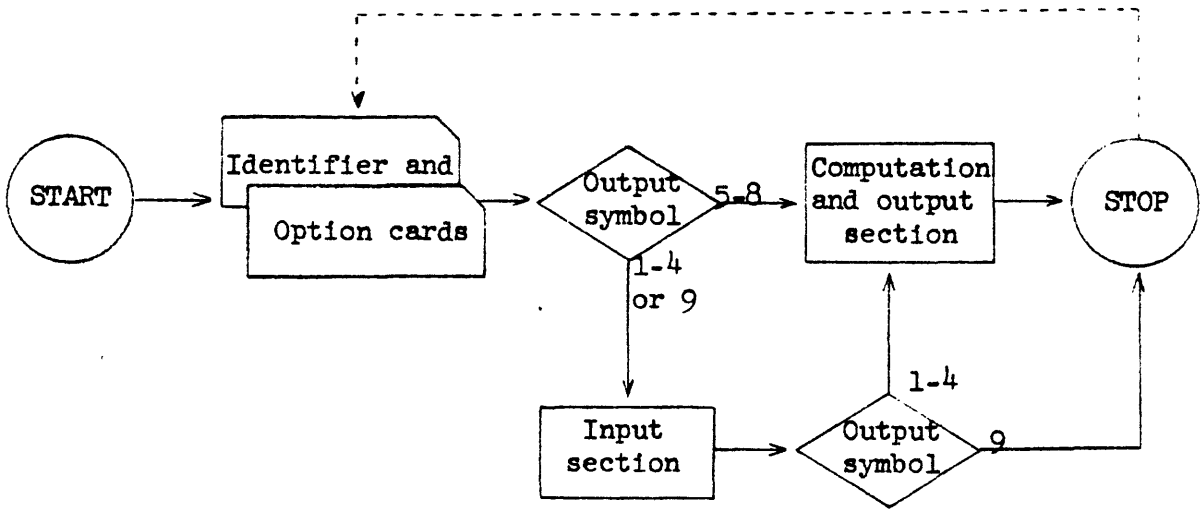


Figure 4. Diagram showing function of the output symbol.

See appendix B for explanation of symbols.

of N numbers obtained in each of several uses will always be the same if the same starting point is used.

A starting value of RR for use in the procedure diagrammed in figure 1 is required in columns 68 - 77 of the option card if: 1) random or cell sampling coordinates are to be generated in the computer, or 2) if trend residuals are to be included in the model. The starting value is a positive 10-digit integer.

The starting random number is used first to generate random or cell sampling coordinates if these are called for on the option card (GR = 1 in column 32). If the starting random number is RR_0 the last value of RR used in generating the coordinates is RR_{3N} (this is true regardless of whether the model has X, XY, or XYZ coordinates). The starting random number used for generating trend residuals, then, is RR_{3N}, and pecularities of the sample set of trend residuals that is obtained depends on the values of RR that follow RR_{3N}. Therefore, sample sets of trend residuals with different parameters but with the same sample pecularities (e.g., a low mean or a tendency toward high positive skewness) may be obtained by generating each set using the same starting value of RR.

If output symbols 1 to 4 are used in column 67 of the option card, the starting random number for generation of sampling coordinates and then trend residuals is always read from columns 68 - 77 of the option card. The sample pecularities of sets of trend residuals from one run to another will always be the same if: 1) N is the same for each run, 2) sampling coordinates are generated for both runs or not generated in either run, and 3) the starting random number is the same for both runs.

If output symbol 9 is used followed by use of output symbols 5 to 8 on subsequent option cards, RR_o is read from the option card containing the symbol 9 and used to generate sampling coordinates (if GR = 1). If a sentinel card follows the parameter cards the value of RR_{3N} is stored in memory (and printed). Subsequent option cards, with output symbols 5 to 8, may contain another starting random number in columns 68 - 77 or an "R" in column 68. If a number is present it is used as a beginning RR value in generating trend residuals (from RN values; figure 1). If an "R" is present the previously stored RR_{3N} value is used.

Sets of trend residuals (columns 49 - 64) specified on any one option card containing an output symbol (column 67) of 1 to 8 will always be generated from different sets of RR and RN values, and any similarities in their sample pecularities will always be accidental.

If D, in column 78 of the option card, is zero or blank, only a listing is given on output. The format and information given on the listing depends on the output symbol given in column 67. If D is given as 1 to 5, punched card output, corresponding to the listing, will also be given. The data in the listing always contain 5 significant figures, whereas the quantity V_j (equation 1) on the punched cards is rounded to D figures. Most actual chemical determinations are reported to 4 figures or less.

Use of sentinel cards

Sentinel cards (cards containing the word SENTINEL in columns 2 - 9) serve 2 purposes in the program: 1) to place a final RR value in memory for repeated use as a beginning value (fig. 1) for generating other sets, and 2) to print the final RR value so that it can be recorded as a starting RR value on option cards for subsequent runs.

A sentinel card used in the input deck to place the final RR in memory should always follow parameter cards.

A sentinel card used to print the final RR value is always the last card in the input deck.

Formats of identification and parameter cards and card sequence

The card sequence of the input deck for the program depends on the output symbol used in column 67 of the first option card:

<u>Output symbol 1 to 4</u>

Identification card

Option card (output symbol 1 to 4)

Parameter cards (see p. 36-37)

Sentinel card

<u>Output symbol 9</u>

Identification card

Option card (output symbol 9)

Parameter cards (see p. 36-37)

Sentinel card (optional)

Identification card

Option card (output symbol 5 to 8)

Identification card

Option card (output symbol 5 to 8)

.

.

.

Sentinel card

The identification cards may contain any alphanumeric characters in columns 1 - 50, and must contain a 1 in column 79 and a 4 in column 80.

Option cards must contain a 2 in column 79 and a 4 in column 80 (see table 1).

The input deck may contain as many as 7 types of parameter cards—the functions of each type have been described in earlier sections. The formats of the cards are described here. All of the parameter cards except those for "cell sampling" have a general format consisting of 7 words (with floating decimal point), and a "row" number, a sequence number, and a 4 in column 80 (see appendix F), as follows:

Card column	Used for
1 - 8	Mantissa of word 1
9 - 10	Exponent of word 1
11 - 18	Mantissa of word 2
19 - 20	Exponent of word 2
.	.
.	.
.	.
61 - 68	Mantissa of word 7
69 - 70	Exponent of word 7
71 - 75	ID word
76 - 79	Sequence number
80	F/B = 4

Negative signs for the mantissa and for the exponents are indicated by an "11" overpunch in columns 1, 11, ... 61 and in columns 9, 19, ... 69, respectively. Mantissas are always left justified. Exponents, ID words, and card sequence numbers are right justified. The exponents are given according to floating point notation, wherein the decimal point of the mantissa precedes the first digit.

Trend coefficient cards (required when TC = 1): If the model is 1 dimensional (options 6 - 15) 2 to 6 coefficients, recorded as the first 2 to 6 words of the general parameter card, are required for each trend. The first three subscripts of T for the corresponding trend are recorded in the ID word columns. The trend coefficient cards are ordered according to the T subscripts, as shown on the option list (table 1).

When the model is 2 or 3 dimensional more than 7 coefficients may be necessary for each trend selection (columns 16 - 31 of the option card). In such cases the corresponding subscript of T is repeated in the ID word column on subsequent cards.

The first coefficient (the constant) for the trend equation is always recorded as the first word on the general parameter card. The sequence of the remaining coefficients is as follows:

1-dimensional models ($1 \leq d \leq 5$)

Give coefficients of: X, X^2, X^3, X^4, X^5.

2-dimensional models ($1 \leq d \leq 5$)

Give coefficients of: X, X^2, X^3, X^4, X^5, Y, XY, X^2Y, X^3Y, X^4Y, Y^2, XY^2, X^2Y^2, X^3Y^2, Y^3, XY^3, X^2Y^3, Y^4, XY^4, Y^5.

3-dimensional models $(1 \leq d \leq 3)$

Give coefficients of: X, X^2, X^3, Y, XY, X^2Y, Y^2, XY^2, Y^3, Z, XZ, X^2Z, YZ, XYZ, Y^2Z, Z^2, XZ^2, YZ^2, Z^3.

Where the trend is of degree = d only coefficients of terms whose powers sum to d or less are included. As many as 3 general parameter cards may be required for the coefficients of a single trend equation.

Sampling coordinate cards (required when GR = 0): If coordinates at which the model is to be evaluated are given rather than generated in the computer they must be recorded on the general parameter cards. The number of sampling coordinate cards will be equal to N, in columns 1 - 4, of the option card. The X coordinates are always given as word 1; Y and Z are given as words 2 and 3, respectively, if the model is 2 or 3 dimensional.

Model limit card (required when GR = 1): If random or cell sampling coordinates are to be generated in the computer the maximum absolute value of X should be given as word 1 on a general parameter card; the maximum absolute values of Y and Z are given as words 2 and 3, respectively. The origin of the coordinate system is always taken at the center of the model when coordinates are generated in the computer. The random numbers generated by the program lie in the range (0,1). These random coordinates are then transformed linearly so that the generated coordinates will always lie in the range -X(max) to +X(max), -Y(max) to +Y(max), and -Z(max) to +Z(max).

Cell sampling cards (required if CU = 1): Two types of "cell sampling" parameter cards are required: 1) cell indices cards, and 2) cell subgroups cards.

The cell indices cards contain the values of $(1 \leq j \leq N)$ for the first sample value from each of NC cells. Although the cells are viewed as being a linear array on the cell sample cards they are actually ordered according to their increasing X coordinates within increasing Y within increasing Z. The j indices of the cells increase in corresponding manner. The format of the cards consists of 18 four-digit words in columns 1 - 72; the first word occupies columns 1 - 4, the second word, columns 5 - 8, etc. When NC > 18 additional cell indices cards are required. Subsequent values of j always increase continuously across each card, by equal or unequal increments.

The cell subgroups cards have the same general format as the cell indices card, each consisting of 18 four-digit words in columns 1 - 72. The number of cell subgroup cards for each cell indices card is equal to NS (column 46 of option card). The first word on the first cell subgroup card is the number of sample values that are to be taken from the first cell for the first set of sample values. The subsequent words are, similarly, the number of sample values to be taken from the corresponding cells for the first set of sample values. The second cell subgroup card gives the sample values per cell for the second set of sample values. Subgroups within a particular cell should <u>increase or remain equal</u> in size.

All indices and subgroups cards are completed in figure 5 for the case where N = 123, NC = 21, and NS = 2. That is, 123 sample values are to be taken from 21 cells in 2 subgroups. The first subgroup consists of 2 + 8 + 2 + 4 . . . + 6 + 2 + 6 + 10 sample values and the second consists of all 123 values.

	1-4	5-8	9-12	13-16	69-72	76-79*	80
Cell indices card	1	7	19	21	83		4
Cell subgroups card	2	8	2	4	6		4
Cell subgroups card	6	12	2	5	15		4
Cell indices card	98	101	111				4
Cell subgroups card	2	6	10				4
Cell subgroups card	3	10	12				4

* Sequence number

Figure 5. Examples of cell indices and cell subgroup cards for case where N = 123, NC = 21, and NS = 2.

The sequence numbers of the cell indices cards and cell subgroups cards are given in columns 76 - 79 and a 4 is always present in column 80. All information on both types of cards is right justified.

Cell center cards (required if CC = 1 and output symbol equals 4 or 8): If coordinates of the geometric centers of sampling cells are to be given on punched card or printed output along with the average sample value of the corresponding cell the coordinates are given as input on general parameter cards. The number of cell center parameter cards is NC. The X coordinate is given as word 1; Y and Z coordinates are given as words 2 and 3, respectively, if the model is 2 or 3 dimensional. The sequence of the cell center parameter cards is given by increasing values of X within increasing values of Y within increasing values of Z. The first cell center parameter card contains the coordinates $-X(max) + [X(max)/NCX]$, $-Y(max) + [Y(max)/NCY]$, $-Z(max) + [Z(max)/NCZ]$. The last card contains the coordinates $X(max) - [X(max)/NCX]$, $Y(max) - [Y(max)/NCY]$, $Z(max) - [Z(max)/NCZ]$.

MSC cards (required if RT = 1): Values of mean, standard deviation, and possibly C transformation constants must be given on general parameter cards for each set of trend residuals selected in columns 49 - 64 of the option card. C constants are required only when options 53 or 54 are selected. The means and standard deviations are, respectively, the values μ_i and σ_i in equation (14). As many as 8 MSC cards may be required, one for each type of transformation listed on page 21 that are selected.

The values of μ_i, σ_i (and possibly C_i) for odd numbered options (49 - 64) are given as words 1, 2, and 3, respectively, on the general parameter card. The same values for even numbered options (49 - 64) are given as words 4, 5, and 6. The type of transformation (1 to 8 on page 21) applicable to this set of constants is given in the ID word column right justified as the number 1 - 8 which is appropriate.

<u>Q-component cards</u> (required if QR_1 or $QR_2 = 1$): If Q-components are included in the model the values of Q must be given on general parameter cards, using words 1 and 2 for values of Q_1 and Q_2, respectively. The number of Q-component cards must be equal to N.

<u>Sequence and sequence numbers for parameter cards</u>: The sequence of parameter cards following the identification and option cards in the input deck must be as follows:

1. Trend coefficient cards: These must be in order by subscript of T in ID word column, as shown on table 1.
2. Sampling coordinate cards: These N cards may be in any order unless cell averages (output symbols 3, 4, 7, or 8) are to be determined.
3. Model limit card.
4. Cell sampling cards: These are ordered as follows:

   Cell indices card (for cells 1 - 18).

   Cell subgroup card no. 1.

   Cell subgroup card no. 2.

   .

   .

   .

   Cell subgroup card no. NS.

Cell indices card (for cells 19 - 36).

Cell subgroup card no. NS + 1.

Cell subgroup card no. NS + 2.

.
.
.

Cell subgroup card no. 2 NS.

etc.

5. Cell centers cards: Order given by:

   Increasing values of X within increasing values of Y within increasing values of Z.

6. MSC cards: Ordered by transformation type number (1 - 8) given in ID word columns.

7. Q-component cards: If random sampling coordinates are generated in the computer, the order of the Q-component cards is unimportant. If cell sample coordinates are generated, the Q-components will be added in sequence; that is, the jth Q-component will be added to a sample value from the cell with highest starting j indices (see cell indices card) not greater than j.

When all required parameter cards are assembled they are numbered consecutively in columns 76 - 79 (right justified) beginning with 3.

Flow diagram

Figure 6 illustrates the flow of the input section of the program. The following steps are the principal operations established by this portion of the program. Although it is not indicated in the flow diagram the values of X, Y, Z, Q_1, and Q_2 are stored on magnetic tape

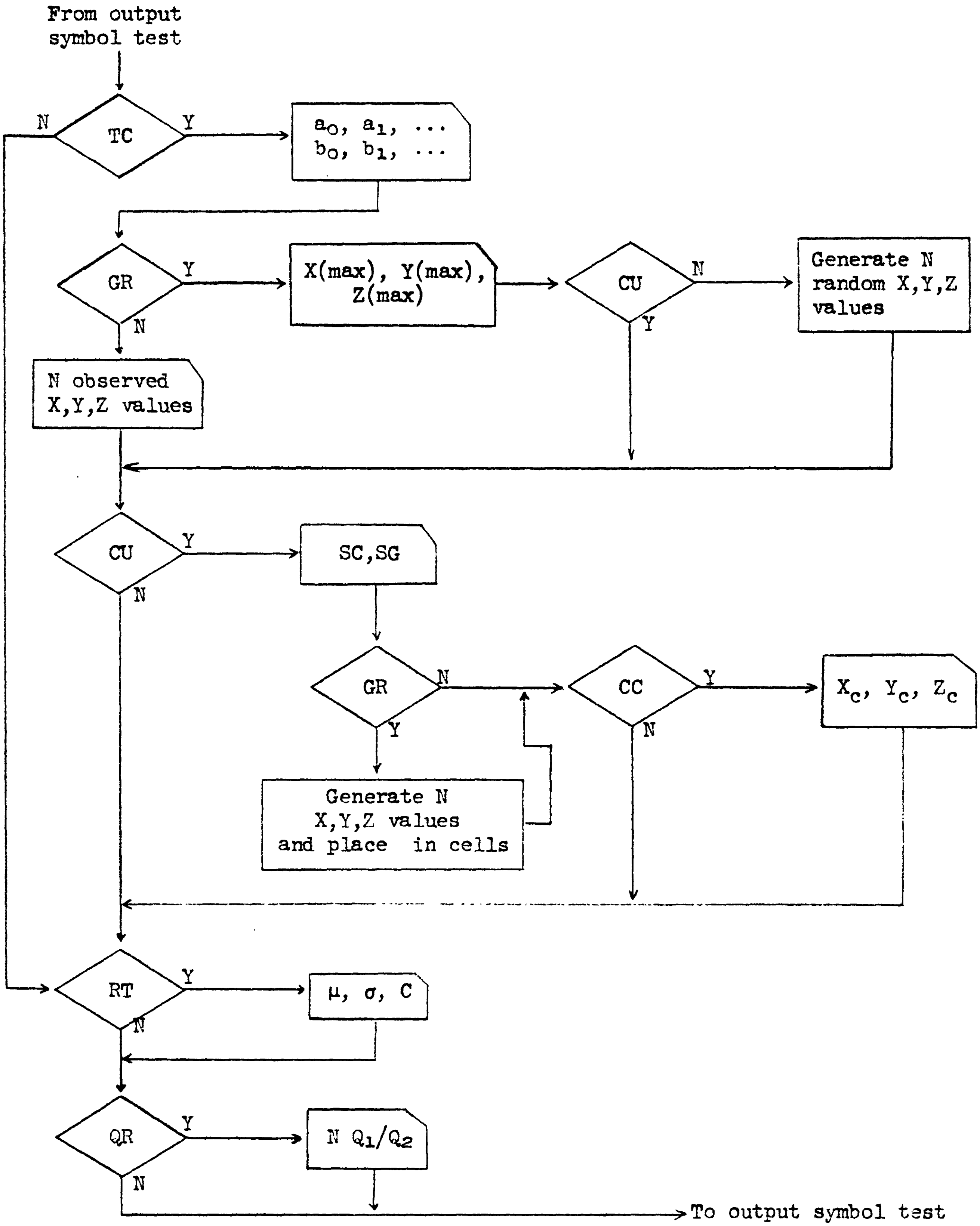


Figure 6. Flow diagram of input section of the program. See figure 4.

See appendix B for explanation of symbols.

(according to the format outlined in appendix C) as these values are read from cards or generated (in the case of the sample coordinates) in the input section.

1. Transfer is made to this section of the program only when the output symbol is 1, 2, 3, 4, or 9 (see fig. 4).

2. If trend components, TC(=1)[a], are to be used, the associated coefficients, a_0, a_1, ..., b_0, b_1, ... are read from input cards.

3. If sample coordinates are to be generated randomly, GR(=1), then:

   a. The maximum ranges of the coordinates are read from an input card.

   b. If cells are not to be used, CU(=0), N random X, Y, Z values, within the ranges of X(max), Y(max), Z(max), are generated.

4. If the variable GR = 0, then N observed X, Y, Z coordinates are read from input cards in lieu of step 3.

5. If cells are to be used, CU(=1), then:

   a. The cell indices and subgroups are read from input cards.

   b. If sample coordinates are to be generated[3], GR(=1), N values of X, Y, and Z are generated and placed in the appropriate cells according to the cell indices, the maximum ranges of X, Y, Z, and the number of cells along each axis.

---

[a] Several variables used in the flow charts are represented by the boolean values of 0 meaning N(o) (or false) and 1 meaning Y(es) (or true).

[3] If cell sampling is to be used and X, Y, Z values are given as input on cards then care should be exercised in ordering them so that they fall in the same order as when generated.

c. If cell centers are given, CC(=1), NC values of X_c, Y_c, Z_c, are read from input cards.

6. If trend residuals are to be included, RT(=1), the associated values of μ, σ, C are read from input cards.

7. If Q-components are required, QR_1(=1) or QR_2(=1), then N values of Q_1 or Q_2 are read from input cards.

8. Transfer is made to the second test of the output symbol in figure 4.

Figure 7 illustrates the flow of the computation and output section of the program. The principal operations of this portion of the program are outlined in the steps which follow. As in the input section magnetic tape procedures are not indicated in the flow diagram. However, the values of X, Y, Z, Q_1, and Q_2 (already stored on magnetic tape by the input section) are read from magnetic tape when they are required, and in addition, when output symbols 3 or 4 are employed the sample value, V, is added to the tape record as indicated on the tape format shown in appendix C.

1. Entry can be made to this portion of the program from either of the output symbol tests made in figure 4 (i.é., only when the output symbol is other than 9).

2. If the output symbol is 5, 6, 7, or 8 it is reduced by 4 so that it becomes 1, 2, 3, or 4.

3. The next step is a second test of the output symbol and dependent upon the results of this test the program diverges along one of two paths. The output symbol is tested to see if it is 1 or 2 (if it is not 1 or 2 implies that it must be 3 or 4).

4. Since the subroutine LOCAL is common to both of these divergent paths it will be described before proceeding in either direction. Subroutine LOCAL is used for evaluating a trend and then determining if it is to be used for a discontinuous trend function restricted to some local part of the larger rock body or for heterogeneous variance in the trend residuals.

   a. Immediately upon entering the subroutine a trend function is evaluated.

   b. If the option for this trend is TOPT(=1), an immediate return is made from the subroutine.

   c. If the chosen option is 4, σ is set equal to T, T is set to 0, and a return made from the subroutine.

   d. If the chosen option is 2 or 3 (for a discontinuous trend), a further test is made. If it is:

      1) 2, and the evaluated trend is negative, T is set to 0.

      2) 3, and the evaluated trend is positive, T is set to 0.

      3) After each of the two preceding steps a return is made from the subroutine.

5. Steps 6 - 15 relate the events which occur along the path of the flow diagram when the option symbol is 1 or 2.

6. The sample value, V, is set to zero.

7. If trend components, TC(=1), are to be used, then:

   a. If a particular trend, TOPT(>0), is desired, subroutine LOCAL evaluates that trend component and it is added to the sample value.

b. If TOPT(=0), that trend component is set to zero in lieu of step a.

c. Either of the two preceding steps is repeated for each trend component.

8. If the variable TC = 0 and the output symbol is 2, each of the possible trend components is set to zero in place of step 7.

9. If trend residuals, RT(=1), are to be included, then:

a. If a particular trend residual, TRANS(=1), is to be included, the proper transformation is applied and the trend residual added to the sample value.

b. If TRANS(=0), that trend residual is set to zero in place of step a.

c. One of the two preceding steps is repeated for each trend residual.

10. If the variable RT = 0 and the output symbol is 2, each of the possible trend residuals is set to zero in lieu of step 9.

11. If Q-components are to be added, QR_1(=1) or QR_2(=1), then the appropriate Q-component is added to the sample value; otherwise, the Q-component is set to zero.

12. If the output symbol is 1:

a. A line is printed containing the values of j, V, X, Y, and Z.

b. And, if $D > 0$, a card is punched containing these same values. The quantity V is rounded to D significant digits.

13. If the output symbol is 2:

a. Seven lines are printed containing the values of j, V, X, Y, Z, and all other intermediate terms.

b. And if D > 0, 7 cards are punched containing these same values. The quantity V is rounded to D significant digits.

14. Steps 6 - 13 are repeated for j = 1, ..., N.

15. Transfer is made to the stop symbol, figure 4.

16. Steps 17 - 28 relate the events occurring along the second path of this section of the program where output symbols 3 or 4 are employed.

17. The sample value, V, is set to zero.

18. If trend components, TC(=1) are to be used, then:

a. If a particular trend component, TOPT(>0), is desired, subroutine LOCAL evaluates the trend and it is added to the sample value.

b. The preceding step is repeated for each trend component.

19. If trend residuals, RT(=1), are desired, then:

a. If a particular trend residual, TRANS(=1), is to be used, it is evaluated and added to the sample value.

b. The preceding step is repeated for each trend residual.

20. If Q-components, $QR_1(=1)$ or $QR_2(=1)$, are desired, then the appropriate Q-component is added to the sample value.

21. Steps 17 - 20 are repeated for j = 1, ..., N.

22. Sample values are summed for each cell according to the index and subgroups for that cell.

23. If the output symbol is 3, X, Y, and Z values are summed over the same points as those for V.

24. The average sample value is calculated for the required subgroup in that cell.

25. If the output symbol is 3:

a. The average X, Y, and Z for the required subgroup in that cell is determined.

b. A line is printed containing SC, SG, $\bar{V}$, $\bar{X}$, $\bar{Y}$, and $\bar{Z}$.

c. If $D > 0$, a card is punched containing these values. The quantity $\bar{V}$ is rounded to D significant digits.

26. If the output symbol is 4:

a. A line is printed containing SC, SG, $\bar{V}$, X_c, Y_c, and Z_c.

b. If $D > 0$, a card is punched containing these values. The quantity $\bar{V}$ is rounded to D significant digits.

27. Steps 17 - 26 are repeated first for each cell index and then for each additional cell subgrouping.

28. Transfer is made to the stop symbol, figure 4.

Literature cited

Kahn, Herman, 1956, Application of Monte Carlo: Research Memo. RM-1237-AEC, The Rand Corp., 259 p.

Krige, D. G., 1960, On the departure of ore value distributions from the lognormal model in South African Gold mines: Jour. South African Inst. Min. and Metall., v. 61, no. 4, p. 231-244.

Miesch, A. T., Connor, J. J., and Eicher, R. N., 1964, Investigation of geochemical sampling problems by computer simulation: Colorado School Mines Quart., v. 59, no. 4, p. 131-148.

Miesch, A. T., and Eicher, R. N., 1964, A system of statistical computer programs for geologic research: Colorado School Mines Quart., v. 59, no. 4, p. 259-286.

Taussky, Olga, and Todd, John, 1956, Generation and testing of pseudo-random numbers, in Meyer, H. A., ed., Symposium on Monte Carlo methods, March 16-17, 1954: New York, John Wiley and Sons, Inc., 382 p.

Appendix A

The following list of definitions and notations serves to relate these variables as they appear in the documentation and in the program. Differences when they occur are noted. The differences have risen out of the need to present an adequate explanation of the application in the documentation. Variables are of three types -- integer, floating (real), or boolean -- depending on their use in the program. Ranges of variables (when appropriate) are indicated.

$a_0, a_1, \ldots$
$b_0, b_1, \ldots$
$c_0, c_1, \ldots$ — Coefficients of the trend components, T; floating. In the program these are identified as TRCOF.

CC — A variable designating the use of cell centers; boolean.

CU — A variable designating the use of cells; boolean.

D — A variable used to designate card output and the number of significant digits desired for V or $\tilde{V}$; integer.

GR — A variable designating the use of randomly generated "sample" coordinates; boolean.

i, j, k, ℓ, m, n — Indices; integer.

$INDQ_\ell$ — An individual Q-component; floating, $(1 \leq \ell \leq 2)$. Not identified in the documentation.

$INDR_{k\ell}$	An individual residual error; floating, $(1 \leq k \leq 8,\ 1 \leq \ell \leq 2)$. Not identified in the documentation.
$INDTR_{k\ell}$	An individual trend component; floating, $(1 \leq k \leq 13,\ 1 \leq \ell \leq 2)$. Not identified in the documentation.
N	Number of samples (j max); integer.
NC	The total number of cells; integer, $(1 \leq NC \leq 225)$.
NCX, NCY, NCZ	The number of cells along the X, Y, and Z axes, respectively; integer.
NS	The number of subgroups within cells; integer, $(1 \leq NS \leq 8)$.
p	In the documentation the variable p is used, collectively, to denote the choice of the individual components comprising the complete rock body model. In the program all variables identified as boolean as well as the integral variable, TOPT, are included in p.
$Q_{\ell j}$	Any arbitrary values to be added to the sample value; floating, $(\ell = 1$ or 2, $1 \leq j \leq N)$.

QR_ℓ	A variable designating that Q-components are present; boolean, (ℓ = 1 or 2).
R_ℓ	A normally distributed random number; floating, (ℓ = 1 or 2).
RN	A random number from a population having a normal distribution with a mean of zero and a standard deviation of unity; floating.
RQ	The beginning random number used when the repeat feature is employed; integer. This variable is identified in the documentation as RR_{3N}.
RR	A random number from a population having a rectangular distribution; integer.
RT	A variable used to designate the use of trend residuals; boolean.
SC	Cell indices (the values for the location of the first sample value from each of the cells); integer, ($1 \leq SC \leq N$).
SG	Size of cell subgroups; integer.
T_j	A composite trend represented by polynomial functions in X, Y, and Z (not identified in the program) ($1 \leq j \leq N$).

TC	A variable designating the use of trend components; boolean.
$TOPT_{k\ell}$	A variable used to designate a desired trend; integer, $(1 \leq k \leq 13,$ $1 \leq \ell \leq 2,$ $0 \leq TOPT \leq 4)$.
$TRANS_{k\ell}$	A variable used to denote the desired trend residual; boolean, $(1 \leq k \leq 8,$ $1 \leq \ell \leq 2)$. Not identified in the documentation.
$TRCOF_{ijk}$	The coefficients of the trend components (used only in the program); floating, $(1 \leq i \leq 13,$ $1 \leq j \leq 2,$ $1 \leq k \leq 27)$.
T_{vdkj}	An isolated trend component (not identified in the program) where v indicates the number of independent variables, d the degree of the polynomial, and k the coefficients to be used $(1 \leq v \leq 3,$ $1 \leq d \leq 5,$ $1 \leq k \leq 2,$ $1 \leq j \leq N)$.
V_j	A complete rock body model; floating, $(1 \leq j \leq N)$.
X_j, Y_j, Z_j	Sample coordinates; floating, $(1 \leq j \leq N)$.
X_{cj}, Y_{cj}, Z_{cj}	Cell centers; floating, $(1 \leq j \leq N)$.

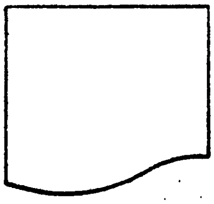
X(max), Y(max), Z(max) Maximum ranges (in absolute value) of the coordinates if they are to be generated; floating.

Appendix B

The following conventions have been used in flow diagramming the various stages of the program:

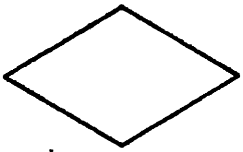
punched card input/output

processing

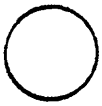


printer output

flow direction



test or comparison



terminal operations (start, stop, etc.) or connectors

Appendix C

The format for a typical magnetic tape record is illustrated below.

Word no.	Contents
1	search key, j
2	data sum (words 3 - 8)
3	X_j
4	Y_j
5	Z_j
6	Q_{1j}
7	Q_{2j}
8	V_j
9	blank
10	blank

```
0200                 BAC-220 STANDARD VERSION   2/1/62

0200   COMMENT  TREND SIMULATION  RE.. AL MIESCH  JOB NO. 9752  5/3/63  RNES   I1
0200   BOOLEAN TC, CU, RT, TRANS(,), QR(), GR, CC, SENTS                       I2
0200   INTEGER K, ID(), CDNO, N, I, NC, NS, OUT, RR, SEQ, J, NOC(), L, INDEX,  I3
0200          TRSUB(), CDATA(), NCX, NCY, NCZ, D, M, VA, EA, ALP..., CELLS(,), I4
0200          RQ, TOPT(,)$                                                     I4.1
0200   ARRAY  ID(10), TOPT(13,2), TRANS(8,2), QR(2), NOC(13)=(2,3,4,5,6,3,6,   I5
0200          10,15,21,4,10,20), MANT(7), EXPNT(7), TRSUB(13)=(11,12,13,14,15, I6
0200          21,22,23,24,25,31,32,33), TRCOF(13,2,21), XYZ(3), CDATA(18),     I7
0200          CELLS(9,225), CNTRS(225,3), RCONS(8,2,3), Q(2), RANGE(3),        I8
0200          SUM(3), INDTR(13,2), INDR(8,2), ALPV(3), ALPVE(3), ALPTR(13,2),  I9
0200          ALPTE(13,2), ALPR(8,2), ALPRE(8,2), ALPQ(2), ALPQE(2), INDQ(2)$  I10
0200   INPUT  IDENT(FOR K=(1,1,10)$ ID(K), CDNO),                              I10.1
0224          OPTPR(N, TC, FOR K=(1,1,13)$ FOR I=1,2$ TOPT(K,I), GR, CU, NC,   I11
0273              NCX, NCY, NCZ, NS, CC, RT, FOR K=(1,1,8)$ FOR I=1,2$         I12
0309              TRANS(K,I), FOR I=1,2$ QR(I), OUT, VA, D, CDNO),             I13
0351          COEFF(FOR L=(1,1,7)$(MANT(L), EXPNT(L)), INDEX, CDNO),           I14
0382          COORD(FOR L=1,2,3$(MANT(L), EXPNT(L)), CDNO),                    I15
0411          SCELL(FOR L=(1,1,18)$ CDATA(L), CDNO),                           I16
0435          RSTAT(FOR L=(1,1,6)$(MANT(L), EXPNT(L)), INDEX, CDNO),           I17
0466          ARBOV(FOR L=1,2$(MANT(L), EXPNT(L)), CDNO)$                      I18
0491   OUTPUT LINEI(FOR K=(1,1,10)$ ID(K)),                                    I19
0512          LINE1(J, V, FOR K=1,2,3$ XYZ(K)),                                I20
0540          CARD1(VA, EA, FOR K=1,2,3$(ALPV(K), ALPVE(K)), J, J),            I21
0578          LINE2(J, V, FOR K=1,2,3$ XYZ(K), FOR K=(1,1,13)$ FOR I=1,2$      I22
0622              INDTR(K,I), FOR K=(1,1,8)$ FOR I=1,2$ INDR(K,I),             I23
0668              INDQ(1), INDQ(2)),                                           I24
0676          CARD2(VA, EA, FOR K=1,2,3$(ALPV(K), ALPVE(K)), FOR I=1,2$        I25
0712              (ALPTR(1,I), ALPTE(1,I)), ALPTR(2,1), ALPTE(2,1), J,         I26
0733              SEQ, ALPTR(2,2), ALPTE(2,2), FOR K=3,4,5$ FOR I=1,2$         I27
0761              (ALPTR(K,I), ALPTE(K,I)), J, SEQ+1, FOR K=6,7,8$             I28
0801              FOR I=1,2$(ALPTR(K,I), ALPTE(K,I)), ALPTR(9,1),              I29
0836              ALPTE(9,1), J, SEQ+2, ALPTR(9,2), ALPTE(9,2),                I30
0852              FOR K=11,12,13$ FOR I=1,2$(ALPTR(K,I), ALPTE(K,I)), J,       I31
0897              SEQ+3, FOR I=1,2$(ALPTR(13,I), ALPTE(13,I)), FOR K=1,2$      I32
0931              FOR I=1,2$(ALPR(K,I), ALPRE(K,I)), ALPR(3,1),                I33
0966              ALPRE(3,1), J, SEQ+4, ALPR(3,2), ALPRE(3,2),                 I34
0982              FOR K=4,5,6$ FOR I=1,2$(ALPR(K,I), ALPRE(K,I)), J,           I35
1027              SEQ+5, FOR K=7,8$ FOR I=1,2$(ALPR(K,I), ALPRE(K,I)),         I36
1069              FOR I=1,2$(ALPQ(I), ALPQE(I)), J, SEQ+6),                    I37
```

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1096          LINE3(CELLS(1,M), CELLS(N,M), SUMV, FOR K=1,2,3$ SUM(K)),              138
1134          CARD3(VA, EA, FOR K=1,2,3$(ALPV(K), ALPVE(K)), SEQ, SEQ),              139
1172          LINE4(CELLS(1,M), CELLS(N,M), SUMV, FOR K=1,2,3$ CNTRS(M,K)),          140
1215          LINE5(RR)$                                                             140.1
1222   FORMAT FMTID(R,10A5,B28,I1,B1),                                               141
1222          FMTOP(R,I4,I1,13(I1,I1),I1,I1,I3,I3,I3,I3,I1,I1,I1,8(I1,I1),2I1,       142
1222               I1,J100,I1,I1,B1),                                                143
1222          FMTCF(R,7(Y88.8,Y22.0),B2,I3,I4,B1),                                   144
1222          FMTCO(R,3(Y88.8,Y22.0),B45,I4,B1),                                     145
1222          FMTSC(R,18I4,B3,I4,B1),                                                146
1222          FMTRS(R,6(Y88.8,Y22.0),B14,I1,I4,B1),                                  147
1222          FMTAV(R,2(Y88.8,Y22.0),B55,I4,B1),                                     148
1222          FMTIT(W3,A50,W0),                                                      149
1222          FMTH1(W3,B2,*J*,B11,*V*,B14,*X*,B14,*Y*,B14,*Z*,W0),                   150
1222          FMTL1(I4,4F15.5,W0),                                                   151
1222          FMTC1(4(A5,B3,A2),B30,I5,I4,*4*,P),                                    152
1222          FMTH2(W3,B2,*J*,B13,*V*,B13,*X*,B13,*Y*,B13,*Z*,B12,*T111*,B10,        153
1222               *T112*,B10,*T121*,B10,*T122*,W0,B13,*T131*,B10,*T132*,            154
1222               B10,*T141*,B10,*T142*,B10,*T151*,B10,*T152*,B10,*T211*,           155
1222               B10,*T212*,W0,B11,*T221*,B10,*T222*,B10,*T231*,B10,               156
1222               *T232*,B10,*T241*,B10,*T242*,B10,*T251*,B10,*T252*,W0,            157
1222               B9,*T311*,B10,*T312*,B10,*T321*,B10,*T322*,B10,*T331*,            158
1222               B10,*T332*,B11,*R1*,B12,*R2*,W0,B7,*RL1*,B11,*RL2*,B11,           159
1222               *RLC1*,B10,*RLC2*,B10,*RSR1*,B10,*RSR2*,B10,*RSQ1*,B10,           160
1222               *RSQ2*,W0,B5,*RAT1*,B10,*RAT2*,B10,*RAS1*,B10,*RAS2*,             161
1222               B10,*RAC1*,B10,*RAC2*,B11,*Q1*,B12,*Q2*,W0),                      162
1222          FMTL2(I4,B3,8F14.5,W4,B5,8F14.5,W0,B3,8F14.5,W0,B1,8F14.5,W0,          163
1222               F13.5,7F14.5,W0,F11.5,7F14.5,W0),                                 164
1222          FMTC2(6(7(A5,B3,A2),I5,I4,*4*,P),6(A5,B3,A2),B10,I5,I4,*4*,P),         165
1222          FMTH3(W3,*  SC*,B6,*SG*,B8,*V AVE.*,B9,*X AVE.*,B9,*Y AVE.*,B9,        166
1222               *Z AVE.*,W0),                                                     167
1222          FMTL3(I4,I8,4F15.5,W0),                                                168
1222          FMTH4(W3,*  SC*,B6,*SG*,B8,*V AVE.*,B11,*XC*,B13,*YC*,B13,*ZC*,        169
1222               W0),                                                              169.1
1222          FMTL5(W3,*THE RANDOM NUMBER, R(R), TO BE USED FOR THE NEXT *,          170
1222               *COMPUTER RUN IS$*,I15,W0),                                       171
1222          FMTL6(W3,*A NEGATIVE VALUE FOR R HAS BEEN GENERATED.  THE *,           172
1222               *PROGRAM CANNOT BE CONTINUED.*,W0)$                               173
1545   EXTERNAL PROCEDURE ALPHA(F,DSM,E)$                                            174
1545   EXTERNAL PROCEDURE MTS(J)$                                                    175
1545   EXTERNAL PROCEDURE MOW(J,XYZ(),Q(),V)$                                        176
```

```
1545   EXTERNAL PROCEDURE MRD(JSXYZ(),Q(),V)$                               I77
1545   EXTERNAL PROCEDURE RMULT(R)$                                         I78
1545   PROCEDURE NRMDV(R,TSR,DEVSRM())$                                     NRMDV 1
1549   BEGIN                                                                NRMDV 2
1545   COMMENT  R IS A GIVEN INTEGER REPRESENTING A PSEUDO-RANDOM NUMBER MULT- NRMDV 3
1545          IPLIED BY 10*10.  R ON OUTPUT IS TO BE USED AS INPUT ON THE NEXT NRMDV 4
1545          CALL.  IF THE BOOLEAN VARIABLE, T, IS EQUAL TO 1, THE DEVIATE,   NRMDV 5
1545          DEV, IS COMPUTED., OTHERWISE, IT IS SET TO 0.  DEV IS APPROXIM-  NRMDV 6
1545          ATELY NORMAL (0,1).  REFERENCE-  APPLICATIONS OF MONTE CARLO BY  NRMDV 7
1545          HERMAN KAHN, RESEARCH MEMORANDUM RM-1237-AEC, THE RAND CORPORAT- NRMDV 8
1545          ION, APRIL 19, 1954, REVISED APRIL 27, 1956$                     NRMDV 9
1549   INTEGER R, R1, RM()$ BOOLEAN T$ IF R LEQ 0$ R=8212890627$            NRMDV10
1554          R=RM(R)$ IF R EQL 0$ R=8212890627$                            NRMDV11
1563          EITHER IF T$ BEGIN                                            NRMDV12
1575   GRAND..        DEV=-LOG(R.10.0*-10)$ R1=RM(R)$ IF R1 EQL 0$          NRMDV13
1589                  R1=8212890627$ E=-LOG(R1.10.0*-10)$                   NRMDV14
1604                  IF (DEV-1.0)*2.0 GTR 2E$ BEGIN R=R1$ GO GRAND END$     NRMDV15
1618                  IF 8212890627R1 LSS 5000000000$ DEV=-DEV END$         NRMDV16
1627          OTHERWISE$ DEV=0$                                             NRMDV17
1629   RETURN END NRMDV()$                                                  NRMDV18
1652   PROCEDURE TREND(VD,XYZ(),A())$                                       T1
1652   BEGIN                                                                T2
1656   INTEGER VD, I, J, K, L, V, DI, DJ, DK, PWR()$  ARRAY PWR(3)$         T3
1656          V=VD/10$ DI=DJ=DK=VD-10V$ SWITCH V,(T51,T52,T53)$             T4
1670          T51..DJ=0$ T52..DK=0$ T53..L=1$ T=0$                          T5
1675          FOR K=(0,1,DK)$ BEGIN  PWR(3)=K$ FOR J=(0,1,DJ-K)$ BEGIN      T6
1706          PWR(2)=J$ FOR I=(0,1,DI-K-J)$ BEGIN  PWR(1)=I$ PROD=A(L)$     T7
1730          FOR V=1,2,3$ BEGIN  IF XYZ(V) NEQ 0$ PROD=PROD.XYZ(V)*PWR(V)  T8
1760          END$  T=T+PROD$ L=L+1 END END END$ TREND()=T$                 T9
1771   RETURN END TREND()$                                                  T10
1779   SUBROUTINE LOCAL$                                                    L1
1779   BEGIN                                                                L2
1785          TRND=TREND(TRSUB(K),XYZ(),TRCOF(K,I,))$                       L3
1803                 EITHER IF (TOPT(K,I) EQL 1) OR ((TOPT(K,I) EQL 2) AND  L4
1837                        (TRND GTR 0)) OR ((TOPT(K,I) EQL 3) AND         L5
1861                        (TRND LSS 0))$ RETURN$                          L6
1867                 OR IF TOPT(K,I) EQL 4$ BEGIN                           L7
1879                        FOR M=(1,1,8)$ FOR L=1,2$ BEGIN                 L8
1900                              IF TRANS(M,L)$                            L9
1908                              RCONS(M,L,2)=TRND END END END$            L10
1922                 TRND=0$                                                L11
```

```
1923     RETURN END LOCAL$                                                        L12
1925     START..RCARD($$SENT$IDENT,FMTID)$                                        1
1936                  IF SENT$ GO TO L172$                                        1.1
1939                  IF CDNO NEQ 1$ BEGIN                                        2
1945                           STOP 5250001$ GO TO START END$                     3
1946             WRITE($$LINEI,FMTIT)$                                            4
1954     L5..    RCARD($$OPTPR,FMTOP)$                                            5
1962                  IF CDNO NEQ 2$ BEGIN                                        6
1968                           STOP 5250002$ GO TO L5 END$                        7
1969             EITHER IF (OUT GTR 4) AND (OUT NEQ 9)$ BEGIN                     7.1
1990                  IF VA LSS 0$ RR=RQ$ OUT=OUT-4$ GO TO L6$ END$               7.2
1994             OTHERWISE$ RR=VA$ SEQ=3$                                         8
1999             FOR K=1,2,3$ XYZ(K)=0$ Q(1)=Q(2)=V=0$                            8.1
2018             MTS(1)$                                                          8.2
2021             IF TC$ BEGIN                                                     9
2023                  FOR K=(1,1,13)$ FOR I=1,2$ BEGIN                            10
2044                           IF TOPT(K,I) NEQ 0$ BEGIN                          11
2052                                    FOR J=(1,7,NOC(K))$ BEGIN                 12
2069     L13..   RCAND($$COEFF,FMTCF)$                                            13
2073                  IF CDNO NEQ SEQ$ BEGIN                                      14
2079                           STOP 5250003$ GO TO L13 END$                       15
2080                  IF INDEX NEQ 10TRSUB(K)+I$ BEGIN                            16
2089                           STOP 5250004$ GO TO L13 END$                       17
2090                           FOR L=(1,1,MIN(7,NOC(K)+1-J))$                     18
2109                                    TRCOF(K,I,J+L-1)=MANT(L).10*EXPNT(L)$     19
2129                                             SEQ=SEQ+1 END END END$           20
2135             EITHER IF GR$ BEGIN                                              20.1
2141     L20X1..RCARD($$COORD,FMTCO)$                                             20.2
2145                  IF CDNO NEQ SEQ$ BEGIN                                      20.3
2151                           STOP 5250005$ GO TO L20X1 END$                     20.4
2152                           FOR L=1,2,3$ RANGE(L)=MANT(L).10*EXPNT(L)$         20.5
2174                                    SEQ=SEQ+1$                                20.6
2177                  IF NOT CU$ BEGIN                                            20.7
2180                  FOR J=(1,1,N)$ BEGIN                                        20.8
2194                           FOR L=1,2,3$ BEGIN                                 20.8.1
2208                           NRMDV(RR,0$RR,RN$RMULT())$                         20.9
2220                           XYZ(L)=ENTIRE(RANGE(L)(2**-10.FLOAT(RR)-1.0))      20.9.1
2227                                    END$                                      20.9.2
2232             MOW(J,XYZ(),Q(),V)                                               20.9.3
2245                                    END END END$                              20.10
2249             OTHERWISE$ BEGIN                                                 20.11
```

```
2250                  FOR J=(1,1,N)S BEGIN                                      21
2266     L22..  RCARD(SSCOORD,FMTCO)S                                            22
2270                  IF CDNO NEQ SEQS BEGIN                                     23
2276                          STOP 5250006S GO TO L22 ENDS                       24
2277                          FOR L=1,2,3S XYZ(L)=MANT(L).10*EXPNT(L)S           25
2299            MOW(J,XYZ(),Q(),V)S                                              25.1
2315                                  SEQ=SEQ+1 END ENDS                         26
2319            IF CUS BEGIN                                                     27
2321                  FOR J=(1,18,NC)S BEGIN                                     28
2337     L29..  RCARD(SSSCELL,FMTSC)S                                            29
2341                  IF CDNO NEQ SEQS BEGIN                                     30
2347                          STOP 5250007S GO TO L29 ENDS                       31
2348                  FOR L=(1,1,MIN(18,NC+1-J))S CELLS(1,J+L-1)=CDATA(L)S       32
2375                          SEQ=SEQ+1S FOR K=(2,1,NS+1)S BEGIN                 33
2397     L34..  RCARD(SSSCELL,FMTSC)S                                            34
2401                  IF CDNO NEQ SEQS BEGIN                                     35
2407                          STOP 5250008S GO TO L34 ENDS                       36
2408                  FOR L=(1,1,MIN(18,NC+1-J))S CELLS(K,J+L-1)=CDATA(L)S       37
2438                                  SEQ=SEQ+1 END ENDS                         38
2443                  IF GRS BEGIN                                               38.1
2456                  DELX=2.0RANGE(1)/NCXS DELY=2.0RANGE(2)/NCYS                38.2
2467                          DELZ=2.0RANGE(3)/NCZS M=1S                         38.3
2480                  FOR K=(1,1,NCZ)S FOR J=(1,1,NCY)S FOR I=(1,1,NCX)S BEGIN   38.4
2480                          EITHER IF M EQL 1S BEGIN                           38.5
2523                                  VA=1S EA=CELLS(1,2)-1 ENDS                 38.6
2526                          OR IF M EQL NCS BEGIN                              38.7
2532                                  VA=CELLS(1,M)S EA=N ENDS                   38.8
2537                          OTHERWISES BEGIN                                   38.9
2538                                  VA=CELLS(1,M)S EA=CELLS(1,M+1)-1 ENDS      38.10
2545                          FOR L=(VA,1,EA)S BEGIN                             38.11
2560                                  NRMOV(RR,OSRR,RNSRMULT())S                 38.12
2572                                  XYZ(1)=ENTIRE((I-1+1**-10.FLOAT(RR))       38.13
2582                                          DELX-RANGE(1))S                    38.13.1
2587                                  NRMOV(RR,OSRR,RNSRMULT())S                 38.14
2602                                  XYZ(2)=ENTIRE((J-1+1**-10.FLOAT(RR))       38.15
2612                                          DELY-RANGE(2))S                    38.15.1
2617                                  NRMOV(RR,OSRR,RNSRMULT())S                 38.16
2632                                  XYZ(3)=ENTIRE((K-1+1**-10.FLOAT(RR))       38.17
2642                                          DELZ-RANGE(3))S                    38.17.1
2647            MOW(L,XYZ(),Q(),V)                                               38.17.2
2660                                  ENDS                                       38.17.3
```

```
2664                                         M=M+1 END ENDS               38.18
2670                 IF CCS BEGIN                                         38.19
2672                 FOR J=(1,1,NC)S BEGIN                                39
2688     L40..  RCARD(SSCOORD,FMTCO)S                                     40
2692                 IF CDNO NEQ SEQS BEGIN                               41
2698                      STOP 525000S GO TO L40 ENDS                     42
2699                      FOR L=1,2,3S CNTRS(J,L)=MANT(L).10*EXPNT(L)S    43
2727                           SEQ=SEQ+1 END END END ENDS                 44
2731            IF RTS BEGIN                                              45
2733                 FOR K=(1,1,8)S BEGIN                                 46
2745                      IF TRANS(K,1) OR TRANS(K,2)S BEGIN              47
2763     L48..  RCARD(SSRSTAT,FMTRS)S                                     48
2767                 IF CDNO NEQ SEQS BEGIN                               49
2773                      STOP 5250010S GO TO L48 ENDS                    50
2774                 IF INDEX NEQ KS BEGIN                                51
2780                      STOP 5250011S GO TO L48 ENDS                    52
2781                 FOR I=1,2S FOR L=1,2,3S                              53
2800                      RCONS(K,I,L)=MANT(3(I-1)+L).10*EXPNT(3(I-1)+L)S 54
2834                           SEQ=SEQ+1 END END ENDS                     55
2838            IF QR(1) OR QR(2)S BEGIN                                  56
2842            MTS(1)S                                                   56.1
2845                 FOR J=(1,1,N)S BEGIN                                 57
2861     L58..  RCARD(SSARBQV,FMTAV)S                                     58
2865                 IF CDNO NEQ SEQS BEGIN                               59
2871                      STOP 5250012S GO TO L58 ENDS                    60
2872            MRD(JSXYZ(),Q(),V)S                                       60.1
2889            MTS(J)S                                                   60.2
2892                      FOR L=1,2S Q(L)=MANT(L).10*EXPNT(L)S            61
2910            MOW(J,XYZ(),Q(),V)S                                       61.1
2926                           SEQ=SEQ+1 END ENDS                         62
2930     L63..       L=99S SEQ=1S                                         63
2934            MTS(1)S                                                   63.1
2937                 XYZ(1)=XYZ(2)=XYZ(3)=Q(1)=Q(2)=0S                    63.2
2942            EITHER IF (OUT EQL 1) OR (OUT EQL 2)S BEGIN               64
2960            FOR J=(1,1,N)S BEGIN                                      65
2960                 IF TC OR QR(1) OR QR(2)S                             65.0.1
2981            MRD(JSXYZ(),Q(),V)S                                       65.1
2995                 V=0S EITHER IF TCS BEGIN                             66
2998                 FOR K=(1,1,13)S FOR I=1,2S BEGIN                     67
3019                      EITHER IF TOPT(K,I) NEQ 0S BEGIN                68
3019                           ENTER LOCALS                               69
```

```
3029                              INDTR(K,I)=TRNDS V=V+TRND ENDS         70
3040                         OTHERWISES INDTR(K,I)=0 END ENDS            71
3050                    OTHERWISES BEGIN                                 71.1
3050                         IF OUT EQL 2S BEGIN                         71.2
3056                         FOR K=(1,1,13)S FOR I=1,2S INDTR(K,I)=0 END ENDS 71.3
3086                    EITHER IF RTS BEGIN                              72
3088                    FOR K=(1,1,8)S FOR I=1,2S BEGIN                  73
3109                         EITHER IF TRANS(K,I)S BEGIN                 74
3120                              NRMDV(RR,1SRR,RNSRMULT(I))S            75
3132                              R=RCONS(K,I,1)+RN,RCONS(K,I,2)S        75.1
3152                         SWITCH K,(L77,L78,L79,L80,L81,L82,L83,L84)S 76
3162    L77..                     INDR(K,I)=RS GO TO L85S                77
3171    L78..                     INDR(K,I)=10*RS GO TO L85S             78
3183    L79..                     INDR(K,I)=10*R+RCONS(K,I,3)S GO TO L85S 79
3207    L80..                     INDR(K,I)=R*2.0S GO TO L85S            80
3217    L81..                     IF SIGN(R) EQL -1S GO TO L174S         81
3227                              INDR(K,I)=SQRT(R)S GO TO L85S          81.1
3238    L82..                     INDR(K,I)=TAN(R)S GO TO L85S           82
3249    L83..                     INDR(K,I)=SIN(R)S GO TO L85S           83
3260    L84..                     INDR(K,I)=COS(R)S                      84
3270    L85..                     V=V+INDR(K,I) ENDS                     85
3279                         OTHERWISES INDR(K,I)=0 END ENDS             86
3289                    OTHERWISES BEGIN                                 86.1
3289                         IF OUT EQL 2S BEGIN                         86.2
3295                         FOR K=(1,1,8)S FOR I=1,2S INDR(K,I)=0 END ENDS 86.3
3325                    FOR I=1,2S BEGIN                                 87
3325                         EITHER IF QR(I)S BEGIN                      88
3340                              INDQ(I)=Q(I)S V=V+INDQ(I) ENDS         88.1
3344                         OTHERWISES INDQ(I)=0 ENDS                   88.2
3348                    EITHER IF OUT EQL 1S BEGIN                       89
3348                         IF L GTR 53S BEGIN                          90
3358               WRITE(SSFMTH1)S                                       91
3362                         L=0 ENDS                                    92
3363               WRITE(SSLINE1,FMTL1)S                                 93
3371                         IF D NEQ 0S BEGIN                           94
3376                         ALPHA(V,DSVA,EA)S                           95
3385                         FOR K=1,2,3S ALPHA(XYZ(K),SSALPV(K),ALPVE(K))S 96
3414               WRITE(SSCARD1,FMTC1) ENDS                             97
3422                         L=L+1 ENDS                                  98
3425                    OTHERWISES BEGIN                                 99
3425                         IF L GTR 48S BEGIN                          100
```

```
3431          WRITE($$FMTH2)$                                              101
3435                        L=0 END$                                       102
3436          WRITE($$LINE2,FMTL2)$                                        103
3444                        IF D NEQ 0$ BEGIN                              104
3449                        ALPHA(V,DSVA,EA)$                              105
3458                        FOR K=1,2,3$ ALPHA(XYZ(K),5$ALPV(K),ALPVE(K))$ 106
3487                        FOR K=(1,1,13)$ FOR I=1,2$                     107
3505                        ALPHA(INDTR(K,I),5$ALPTR(K,I),ALPTE(K,I))$     108
3536                        FOR K=(1,1,8)$ FOR I=1,2$                      109
3554                        ALPHA(INDR(K,I),5$ALPR(K,I),ALPRE(K,I))$       110
3585                        FOR I=1,2$ ALPHA(INDQ(I),5$ALPQ(I),ALPQE(I))$  111
3610          WRITE($$CARD2,FMTC2)$                                        112
3618                        SEQ=SEQ+7 END$                                 113
3621                        L=L+7 END END END$                             114
3625          OR IF (OUT EQL 3) OR (OUT EQL 4)$ BEGIN                      115
3644          FOR J=(1,1,N)$ BEGIN                                         116
3659          MRD(J$XYZ(),Q(),V)$                                          116.1
3673          MTS(J)$                                                      116.2
3676                 V=0$ IF TC$ BEGIN                                     117
3679                 FOR K=(1,1,13)$ FOR I=1,2$ BEGIN                      118
3700                        IF TOPT(K,I) NEQ 0$ BEGIN                      119
3710                        ENTER LOCAL$ V=V+TRND END END END$             120
3715                 IF RT$ BEGIN                                          121
3717                 FOR K=(1,1,8)$ FOR I=1,2$ BEGIN                       122
3738                        IF TRANS(K,I)$ BEGIN                           123
3749                        NRMDV(RR,1$RR,RN$RMULT())$                     124
3761                               R=RCONS(K,I,1)+RN.RCONS(K,I,2)$         124.1
3781                        SWITCH K,(L127,L128,L129,L130,L131,L133,L134,  125
3790                               L135)$                                  126
3791    L127..                     V=V+R$ GO TO L136$                      127
3795    L128..                     V=V+10*R$ GO TO L136$                   128
3802    L129..                     V=V+10*R+RCONS(K,I,3)$ GO TO L136$      129
3821    L130..                     V=V+R*2.0$ GO TO L136$                  130
3826    L131..                     IF SIGN(R) EQL -1$ GO TO L174$          131
3836                               V=V+SQRT(R)$ GO TO L136$                132
3842    L133..                     V=V+TAN(R)$ GO TO L136$                 133
3848    L134..                     V=V+SIN(R)$ GO TO L136$                 134
3854    L135..                     V=V+COS(R)$                             135
3859    L136..                            END END END$                     136
3861                 FOR I=1,2$ BEGIN                                      137
3877                        IF QR(I)$ V=V+Q(I) END$                        138
```

```
3878          MOW(J,XYZ(),Q(),V)$                                          138.1
3894                                  END$                                 139
3895          FOR N=(2,1,NS+1)$ FOR M=(1,1,NC)$ BEGIN                      140
3924               FOR K=1,2,3$ SUM(K)=0$ SUMV=0$                          141
3939               FOR J=(CELLS(1,M),1,CELLS(1,M)+CELLS(N,M)-1)$ BEGIN     142
3963          MTS(J)$                                                      142.1
3966          MRD(J$XYZ(),Q(),V)$                                          142.2
3983                    SUMV=SUMV+V$                                       143
3986                    IF OUT EQL 3$ BEGIN                                144
3993                    FOR K=1,2,3$ SUM(K)=SUM(K)+XYZ(K) END END$         145
4010               SUMV=SUMV/CELLS(N,M)$                                   146
4024               EITHER IF OUT EQL 3$ BEGIN                              147
4031                    FOR K=1,2,3$                                       148
4039                         SUM(K)=SUM(K)/CELLS(N,M)$                     149
4058                    IF L GTR 53$ BEGIN                                 150
4063          WRITE($$FMTH3)$                                              151
4067                    L=0 END$                                           152
4068          WRITE($$LINE3,FMTL3)$                                        153
4076                    IF D NEQ 0$ BEGIN                                  154
4081                    ALPHA(SUMV,D$VA,EA)$                               155
4090                    FOR K=1,2,3$ ALPHA(SUM(K),5$ALPV(K),ALPVE(K))$     156
4119          WRITE($$CARD3,FMTC1)$                                        157
4127                    SEQ=SEQ+1 END END$                                 158
4130               OTHERWISE$ BEGIN                                        159
4130                    IF L GTR 53$ BEGIN                                 160
4136          WRITE($$FMTH4)$                                              161
4140                    L=0 END$                                           162
4141          WRITE($$LINE4,FMTL3)$                                        163
4149                    IF D NEQ 0$ BEGIN                                  164
4154                    ALPHA(SUMV,D$VA,EA)$                               165
4163                    FOR K=1,2,3$                                       166
4173                         ALPHA(CNTRS(M,K),5$ALPV(K),ALPVE(K))$         167
4197          WRITE($$CARD3,FMTC1)$                                        168
4205                    SEQ=SEQ+1 END END$                                 169
4208                    L=L+1 END END END$                                 170
4214               IF PCS(1)$ STOP 5250013$ GO TO START$                   171
4221      L172.. WRITE($$LINE5,FMTL5)$                                     172
4229               RQ=RR$ IF PCS(2)$                                       172.1
4237               STOP 757071704 74$ GO TO START$                         173
4238      L174.. WRITE($$FMTL6)$                                           174
4242                    STOP 5250014$                                      175
```

```
4244     FINISHS
4246     MTSS
                                   3965                  4246
                                   3964                  4246
                                   3675                  4246
                                   3674                  4246
                                   2936                  4246
                                   2935                  4246
                                   2891                  4246
                                   2890                  4246
                                   2844                  4246
                                   2843                  4246
                                   2020                  4246
                                   2019                  4246
                                   4246    0 0000 01 9999
                                   4247    0 0000 40 0199
                                   4248    0 1000 50 0199
                                   4249    0 0000 42 4246
                                   4250    1 0000 30 0000
4251     MOWS
                                   3893                  4251
                                   3892                  4251
                                   3879                  4251
                                   2925                  4251
                                   2924                  4251
                                   2911                  4251
                                   2662                  4251
                                   2661                  4251
                                   2648                  4251
                                   2314                  4251
                                   2313                  4251
                                   2300                  4251
                                   2247                  4251
                                   2246                  4251
                                   2233                  4251
                                   4251    0 0199 01 9999
                                   4252    0 0000 40 0107
                                   4253    0 0000 10 0196
                                   4254    0 0000 12 0195
                                   4255    0 0410 40 4261
                                   4256    0 0000 10 0198
                                   4257    0 0000 12 0197
                                   4258    0 0410 40 4260
                                   4259    0 0000 42 4266
                                   4260    0 0030 29 9999
                                   4261    0 0020 29 9999
                                   4262    0 0000 10 0199
                                   4263    0 0000 40 0100
                                   4264    0 0000 46 0101
                                   4265    0 0000 42 4273
                                   4266    1 0000 10 0102
                                   4267    0 0000 19 0101
                                   4268    0 0000 31 4269
                                   4269    0 0001 21 4266
                                   4270    0 1110 56 0100
                                   4271    0 0000 42 4251
                                   4272    1 0000 30 0000
                                   4273    0 0000 00 0005
4274     MRDS
                                   3982                  4274
                                   3981                  4274
                                   3967                  4274
                                   3672                  4274
                                   3671                  4274
                                   3657                  4274
                                   2994                  4274
                                   2993                  4274
                                   2979                  4274
                                   2888                  4274
                                   2887                  4274
                                   2873                  4274
                                   4274    0 0199 01 9999
                                   4275    0 0410 40 4298
                                   4276    0 0000 30 4278
                                   4277    0 1000 50 0199
                                   4278    0 1101 52 0100
                                   4279    0 0000 10 0199
                                   4280    0 0000 18 0100
                                   4281    0 0000 35 4286
                                   4282    0 0000 10 4285
                                   4283    0 0137 00 7310
                                   4284    0 0000 30 4277
```

```
4285   0 0005 25 0015
4286   0 0000 42 4287
4287   0 0001 45 0005
4288   1 0000 12 0102
4289   0 0000 31 4290
4290   0 0001 21 4288
4291   0 0000 18 0101
4292   0 0000 35 4297
4293   0 0000 10 4296
4294   0 0137 00 7310
4295   0 0000 30 4277
4296   0 0005 25 0016
4297   0 0000 41 0107
4298   0 0001 40 9999
4299   0 0000 42 0196
4300   0 0001 20 4301
4301   0 0020 29 0105
4302   0 0000 42 0198
4303   0 0001 20 4304
4304   0 0030 29 0102
4305   0 0000 42 4274
4306   1 0000 30 0000

4307   ALPHAS

4195             4307
4194             4307
4183             4307
4162             4307
4161             4307
4152             4307
4117             4307
4116             4307
4105             4307
4089             4307
4088             4307
4079             4307
3608             4307
3607             4307
3596             4307
3582             4307
3581             4307
3564             4307
3533             4307
3532             4307
3515             4307
3485             4307
3484             4307
3473             4307
3457             4307
3456             4307
3447             4307
3412             4307
3411             4307
3400             4307
3384             4307
3383             4307
3374             4307
4307   0 0102 01 9999
4308   0 0410 40 4330
4309   0 0410 40 4336
4310   0 0410 40 4357
4311   0 0000 10 0100
4312   0 0410 40 4359
4313   0 0000 10 0101
4314   0 0000 49 0006
4315   0 4210 40 4319
4316   0 0000 10 0102
4317   0 0800 36 4357
4318   0 2310 40 4362
4319   0 2200 27 4362
4320   0 0000 22 4362
4321   0 0001 48 0008
4322   0 0000 43 0000
4323   0 0000 13 4363
4324   0 0001 33 4333
4325   0 0000 12 4364
4326   0 0002 49 0010
4327   0 0000 49 0001
4328   0 0002 49 0007
4329   0 0000 12 4366
4330   0 0000 40 9999
4331   0 2100 36 4336
```

```
                                        4332   0 0000 30 4337
                                        4333   0 0000 43 0020
                                        4334   0 0000 12 4365
                                        4335   0 0000 30 4326
                                        4336   0 1103 27 9999
                                        4337   0 0001 49 0000
                                        4338   0 0000 42 0101
                                        4339   0 0001 33 4342
                                        4340   0 0000 10 4367
                                        4341   0 0001 21 4347
                                        4342   0 0000 10 4368
                                        4343   0 0001 48 0000
                                        4344   0 0001 21 4347
                                        4345   0 0000 49 0001
                                        4346   0 0000 12 4369
                                        4347   0 0001 49 0001
                                        4348   0 0001 21 4345
                                        4349   0 0001 48 0010
                                        4350   0 0000 10 4333
                                        4351   0 0000 13 0101
                                        4352   0 0000 13 0101
                                        4353   0.0410 40 4355
                                        4354   0 0001 45 0000
                                        4355   0 0001 49 9999
                                        4356   0 0000 30 4359
                                        4357   0 0000 46 9999
                                        4358   0 0001 45 0000
                                        4359   0 0000 40 9999
                                        4360   0 0000 42 4307
                                        4361   1 0000 30 0000
                                        4362   0 0050 00 0000
                                        4363   0 0000 00 0050
                                        4364   0 0000 00 0400
                                        4365   0 0000 00 0500
                                        4366   0 0080 00 0000
                                        4367   0 0000 00 0004
                                        4368   0 0000 00 0005
                                        4369   0 0000 00 0008
4370      RMULT. INTEGERS
                                        3758                4370
                                        3129                4370
                                        2629                4370
                                        2599                4370
                                        2569                4370
                                        2217                4370
                                        4370   0 0000 01 9999
                                        4371   0 0000 14 4375
                                        4372   0 0001 49 0005
                                        4373   0 0000 42 4370
                                        4374   1 0000 30 0000
                                        4375   0 8212 89 0627

4376      FINISHS
COMPILED PROGRAM ENDS AT 4375
PROGRAM VARIABLES BEGIN AT 4477
```

Appendix E

Several sections of machine coding have been incorporated into the program as external procedures. In practice the dummy variables used in the procedure declarations are replaced by the appropriate variables on the procedure call. The function of each of these procedures is briefly outlined below.

ALPHA - This procedure has as input, a floating number, F, which is rounded to D decimal places. The machine exponent is converted to a power of 10, coded alphanumerically, and assigned to E, while the mantissa is coded alphanumerically and assigned to M. The purpose of this procedure is to allow certain variables to be punched as output (see pages 42, 43, 44) in the standard data format outlined on page 30 for further processing in other statistical programs.

MTS - Used for searching magnetic tape for block J.

MOW - Writes a block of magnetic tape with a block number, J, coordinates X, Y, and Z, arbitrary values of Q_1 and Q_2, and the complete rock body, V.

MRD - Reads a block of tape using the same variables as MOW.

RMULT - Extracts the middle ten digits of the twenty digit product 8212890627R.

Appendix F

65-52

±	word 1	±	E	±	word 2	±	E	±	word 3	±	E	±	word 4	±	E	±	word 5	±	E	±	word 6	±	E	±	word 7	±	E	ID word	CARD SEQUENCE	
1	8	9	10	11	18	19	20	21	28	29	30	31	38	39	40	41	48	49	50	51	58	59	60	61	68	69	70	71 75	76 79	80
																														4
																														4
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