DANIEL F. MERRIAM, Editor

FORTRAN IV PROGRAMS TO DETERMINE SURFACE ROUGHNESS IN TOPOGRAPHY FOR THE CDC 3400 COMPUTER

By

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Editor's Remarks

This report by R.D. Hobson, "FORTRAN IV programs to determine surface roughness in topography for the CDC 3400 computer" is the fourteenth COMPUTER CONTRIBUTION since initiation of the series by the Kansas Survey in 1966. Already there is a backlog of manuscripts and in some instances, a substantial delay in processing and distributing information. This lag is regrettable but unavoidable.

> The dynamics of dissemination may be summarized thus: The active scientist displays two seemingly irrepressible motives, one to obtain needed information and the other to publicize findings.
>
> W.D. Garvey and B.C. Griffith
> Science, v. 146, no. 3652,
> p. 1658, 1964

Computer programs published in the COMPUTER CONTRIBUTION series are timely, and because of rapid developments in hardware and software become obsolete quickly. It is necessary, then, to disseminate information as soon as possible to derive maximum value from it.

One reason for founding the COMPUTER CONTRIBUTION series was to avoid the long delay in publishing important results of computer-oriented research in national and local journals. Garvey and Griffith (1964) found in their interesting study of exchange of scientific information in psychology that (1) the interval between submission and publication was about 9 months, (2) work published was started from 30 to 36 months ago, (3) contents of a particular paper may be known to the most interested readers because exchange does not wait on journals, (4) rejection by a particular journal does not keep an article out of the literature but merely delays its publication, and (5) only a small percent of the journal receivers read a particular article. Some of these publication problems have been minimized in the COMPUTER CONTRIBUTION series.

Time between submission of a well prepared paper and publication in the COMPUTER CONTRIBUTION series is only 30 to 90 days. Most papers report results obtained within a period of 6 months prior to submission, and therefore contents are known to only a few workers before publication. Finally, the CONTRIBUTIONS are distributed only to individuals and organizations that have expressed a desire to receive such information so presumably each paper is read soon after receipt. Because of limited facilities only a few of the papers can be published, and criteria for publication are: (1) scientific merit or worth of manuscript, (2) applicability to Kansas resource development or Survey research program, (3) service to profession, that is, to what extent does it promote research or professional practice either in or out of state, (4) whether audience can be best reached in Survey series or outside journal, (5) extent of Survey participation in project, or (6) to what extent is it a pioneering effort deserving of "confidence" support.

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FORTRAN IV PROGRAMS TO DETERMINE SURFACE ROUGHNESS IN TOPOGRAPHY FOR THE CDC 3400 COMPUTER [1/]

By

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ABSTRACT

Current uses of remote sensing apparatus for geologic investigation place new demands upon types of information gathered by the field geologist. One new area of field investigation is surface roughness.

This paper presents several quantitative parameters for describing three aspects of surface roughness: (1) comparison of surface areas, (2) frequency distribution of surface irregularities, and (3) orientation of normals to surfaces. Mathematical methodologies for computing parameters are described. Three CDC 3400 FORTRAN IV programs for computing parameters are listed along with detailed operating instructions.

Data obtained from the NASA Pisgah Crater Test Site in California are used to illustrate typical uses of surface roughness parameters.

INTRODUCTION

Earth sensing and "ground truth" studies require certain types of geologic information which heretofore have been of little importance to the field geologist. For example, a map showing some characteristic (perhaps vegetation density or moisture content) of loose overburden covering an area may be of more importance to a sensing experiment than a classical geologic map showing distribution of rock types beneath that overburden. Experimentation with sensing apparatus indicates that certain factors, such as moisture content and specific gravity, strongly affect the sensed image of any particular test area. Another of these factors is surface roughness of topography (Dellwig and Moore, 1966).

A single concise definition of surface roughness probably is impossible. The only usable definitions are incomplete because they describe only a few of the physical or mathematical properties of a surface. There may be as many of these definitions as there are roughness studies themselves.

In the realm of earth sensing in which some type of electromagnetic wave form is directed upon an area, the surface roughness may be defined as a value on a scale ranging between equal ("smooth" surface) and random ("rough" surface) reflectance of those waves. On the other hand, terrain-analysis investigations may require roughness parameters describing larger scale irregularities of the surface than those affecting most remote sensing instruments.

It quickly becomes apparent that different types of investigations require particular sets of roughness parameters. For example, in Bechmann and Spizzichino's (1963) study of wave reflection, mathematical expressions of the surface are required. Kirchkoff approximations of the Rayleigh equations are used to generate these surfaces and then theoretical wave reflection patterns can be studied. It would be difficult to determine exact equations describing natural surfaces and thus other methods are necessary.

The current investigation is directed toward establishing roughness parameters that can be used to describe surface irregularities ranging from a few tenths of an inch to several tens of feet. For roughness parameters to be useful within this realm of terrain analysis, they must fulfill several basic requirements.

First, the parameters should be conceptually descriptive so that a value for any particular test area gives the investigator a mental image of the physical character of that area. The parameters should be easily measurable in the field so that large test sites can be quickly sampled. If possible, roughness parameters should be selected that require similar types of field measurements with a minimal amount of equipment. Parameters should be chosen which can be measured and compared at several different sampling scales and finally, they should be in a digital form suitable for numerical analysis.

The three terrain roughness parameters described in this investigation are: (1) comparison of estimated actual surface area with the corresponding planar area; (2) estimate of "bump," or elevation frequency distribution; and (3) comparison of the distribution and orientation of approximated planar surfaces within sampling domains. Three CDC 3400 FORTRAN IV computer programs for

1/ This report was prepared at Northwestern University, Evanston, Illinois, under Grant No. NGR-14-007-027 for the National Aeronautics and Space Administration.

converting field measurements of these "mega-roughness" features to standardized surface-roughness attributes are presented in the Appendices.

DESCRIPTION OF SURFACE-ROUGHNESS PARAMETERS

Surface Area.-This parameter is designed to determine the amount of similarity between the test area surface and a planar surface. It is hypothesized that the surface area increases with surface irregularity. Because there is a definite interplay between the number and magnitude of terrain irregularities such that similar surface area estimates could arise from different manipulations of these two variables, the surface area parameter is most effective when accompanied by other roughness parameters (e.g., bump frequency distribution and distribution of planes) describing the irregularities.

The basic field data for this parameter are a series of orthogonal traverse measurements ("l" and "w" of Fig. 1A), which are used to estimate the surface area by: (1) subdividing the traverses into segments, (2) forming rectangles from adjacent segments, and (3) summing the area contained within the rectangles (Fig. 1B). The area estimate (A') of the test site is then compared to the area of a plane (A) whose outer dimensions are the same as those of the site. The ratio (A'/A) shows a curvilinear relationship which asymptotically approaches infinity with increases in A'.

The number of traverses necessary to obtain a reliable estimate of A' is usually determined during field inspection of the types and areal distribution of irregularities at a site and this number may be different at different scales of sampling. Several methods for measuring traverses, which have been tested at Pisgah Crater, California, are: (1) trigonometric calculation based on data obtained from topographic maps; (2) measuring wheel (of about 14 inches in diameter) for sample areas with outside dimensions between ten and a few hundred feet; and (3) flexible cables and map-measuring devices for areas less than ten feet on a side.

Bump Frequency Distribution.-The bump frequency parameters are mean and variance statistics describing size distributions of surface irregularities. They are designed to characterize the magnitude and variation of topographic elevation readings. As presented, these statistics are insensitive to the actual spatial distribution of surface irregularities. Although the spatial distribution could be described by suitable autocorrelation methods (Rice, 1951), these techniques are not employed because natural topographic surfaces may be characterized by nearly identical monotonic autocovariance functions (Horton and others, 1962).

The bump frequency parameters are computed to describe elevation deviations (E_n) with respect to three possible orientations of sensing apparatus. The

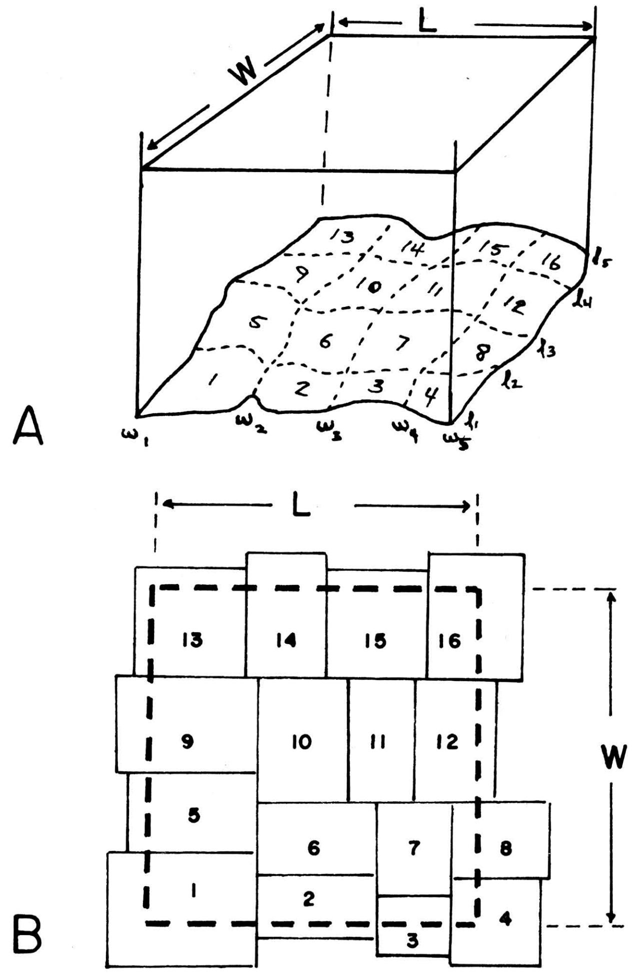


Figure 1.-A. Series of orthogonal traverse measurements from field data to estimate surface area; B. Rectangles formed from adjacent segments used to sum areas.

orientations shown in Figure 2A are: (1) vertically from a horizontal datum surface for the elevations (plane A, Fig. 2B), (2) in a direction normal to the best-fit planar surface for the elevations (plane B, Fig. 2B), and (3) vertically from the best-fit planar surface (the best-fit planar surface is found using the least-squares method). Actually, orientations "1" and "2" are similar in being directed normal to planar surfaces, but physically "1" might be analogous to the case of an airborne instrument directed normal to the horizon, whereas "2" could describe the case of a stationary instrument set up normal to a hillside.

Field data required for bump frequency statistics consist of an array of elevation readings and their geographic coordinates (e.g., u and v for reading no. 7, Fig. 2B). The three types of bump frequency values are determined for each reading in the array and are used to calculate mean and variance statistics.

The number of observations required depends upon the actual irregularities of the terrain. For example, results from one of the writer's current surface roughness investigations (unpublished) indicate that 16 elevation readings are sufficient to describe major terrain fluctuations of square sampled areas of 1 sq. ft. and of 10,000 sq. ft., whereas fewer readings may be sufficient for 100 sq. ft. areas.

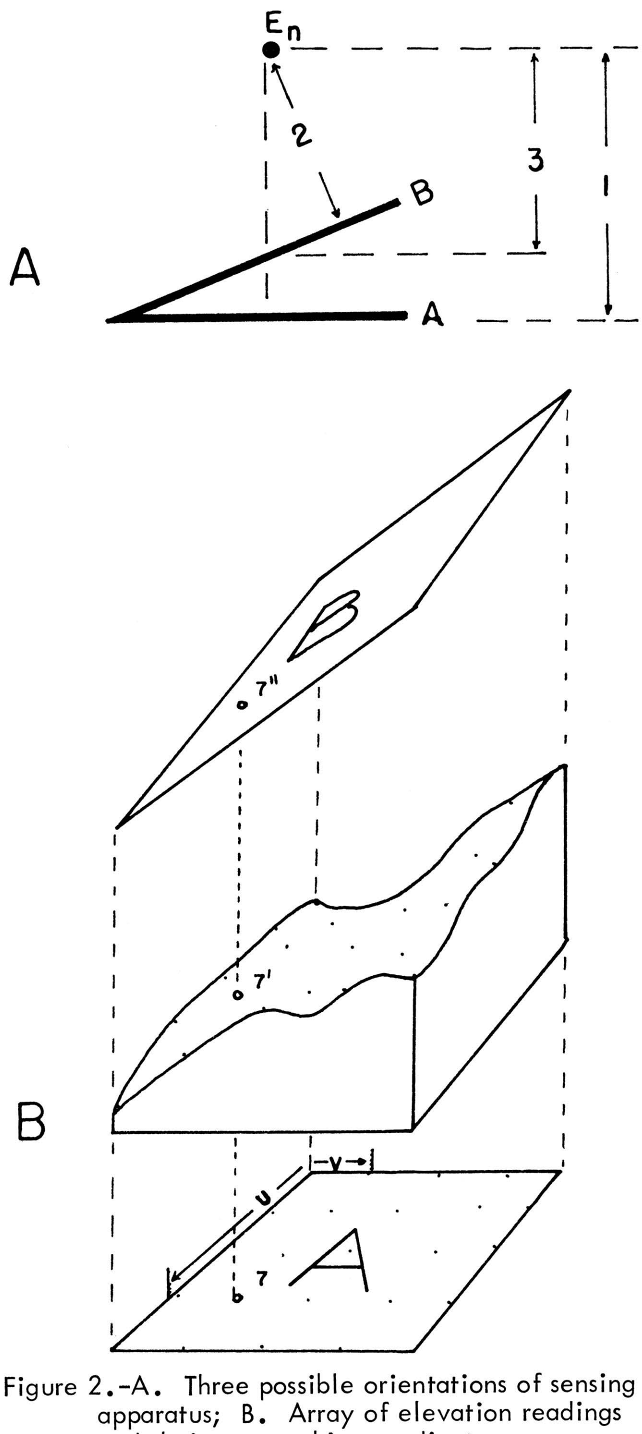


Figure 2.-A. Three possible orientations of sensing apparatus; B. Array of elevation readings and their geographic coordinates.

Distribution of Planes.-These parameters are designed to describe the three-dimensional orientation of surfaces within a roughness test site. To do this, the site is simulated by a set of intersecting planar surfaces which are themselves defined by adjacent groups of three elevation readings (e.g., planes 1 and 2, Fig. 3A). Normals to these planes are represented by unit vectors. Vector mean, vector strength, and vector dispersion are computed using methods defined by Fisher (1953) and described by Watson (1957), and Watson and Irving (1957). Vector strength indicates the length of the resultant sum of the unit vectors and is obtained by using the direction cosine method (Johnson and Kiokemeister, 1957). Vector strength, in a standardized form (the square root of the squared sum of the direction cosines divided by the number of unit vectors), ranges in value from zero (no preferred orientation) to one (identical orientation). Dispersion, on the other hand, indicates the variability or spread of the unit vectors in space and is similar, in some respects, to the standard deviation of the normal distribution (Pincus, 1953, 1956). In summary, vector strength is usually high and vector dispersion low in areas characterized by similar elevations (Fig. 3B) or equal rates of elevation change, whereas nonsystematic elevation changes yield low vector strength and high vector dispersion (Fig. 3C).

Program Vector (Appendix C) calculates vector strength and dispersion using methods described by Watson (1957). Krumbein (1939) and Chayes (1954) described certain modifications of these methods, entailing doubling of angles for highly variable data, which can be included in Program Vector. Another addition which also can be included in the program prints out a standard equal-angle Wulff-net stereogram of the distribution of unit vectors (Loudon, 1964).

The basic data input requirement is an array of regularly spaced elevation readings. In general, the number of readings necessary for the calculation of the bump frequency parameters is adequate for the distribution-of-planes parameters as well.

DESCRIPTION AND PREPARATION OF PROGRAM COMPAREA

Program Comparea, in the form presented (Appendix A), is capable of handling up to twenty length and twenty width measurements for each sample area. There is no limit of the number of areas. If necessary, simple dimension changes in the program permit handling of more length and width measurements. Basic input for the program must include:

1. Four TITLE Cards
2. MASTER Card
3. Data Deck

TITLE Cards.-Four title cards are used to describe and identify the job. Each card may contain alphanumeric information in columns 1-80. Four typical cards might read:

N.A.S.A. TEST SITE EVALUATION
MAP SITE 3 - PISGAH CRATER
COMPARISON OF AREAS OF PLAYA LAKE AND LAVA FLOW
NORTHWESTERN UNIVERSITY - May, 14, 1966

MASTER Card.-Information contained on this card controls the flow of the program and is arranged according to the Format (10X, 2F6.2, 2I6, 6A6) where:

Columns	Purpose
1-10	blank, or may contain identification information not used in computations
11-18	ZLSA - length of the theoretical sample area (to two decimals)
19-26	WSA - width of theoretical sample area (to two decimals)
27-32	NL - number of traverse lengths
33-38	WL - number of traverse widths
39-74	FMT - format of the data showing the location of the sample area identification number (CONT) and the individual traverse lengths (ZL(I)) and widths (W(I)). (I, in this case, is an index identifying specific traverses and has a range of 1 to NL for the lengths and 1 to NW for the widths)

Data Deck.-For this particular form of Program Comparea, the master card is applicable to whole groups of sample areas and is read into the computer only once at the start of computations. If one of the common attributes of the sample areas is changed, such as length (ZLSA) or number of widths (NW), a new set of title cards and a new master card are required.

A common form for the data deck is to have two cards for each sample area. The area number (CONT) appears at the beginning of each card, and the remainder of the first card contains traverse lengths (ZL(I)) and the second, traverse widths (W(I)). The actual spacing of these variables

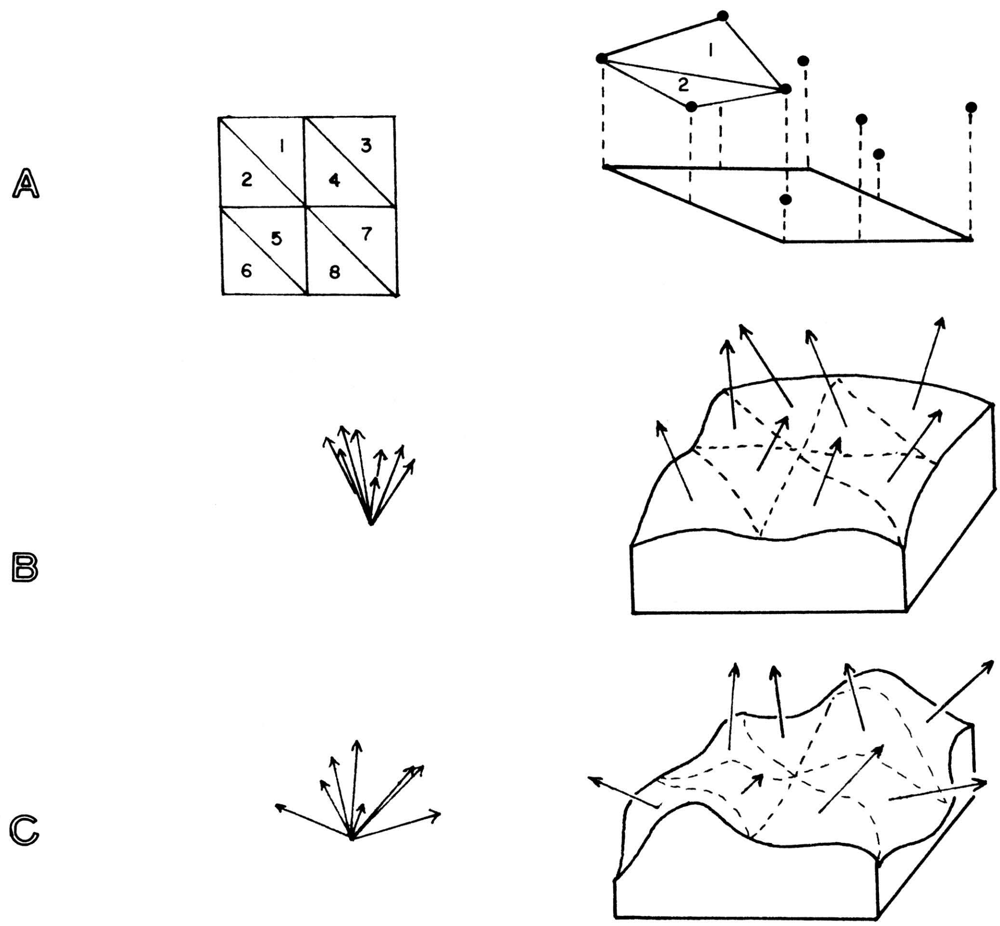


Figure 3.-A. Intersecting planar surfaces defined by adjacent groups of three elevation readings; B. Area with similar elevations producing high vector strength and low vector dispersion; C. Nonsystematic elevation changes yielding low vector strength and high vector dispersion.

on the cards is determined by the format (FMT) contained on the master card.

Description of Program Calculations.-The theoretical dimensions of the sample area (ZLSA and WSA), the number of length and width traverses (NL and NW), and the actual lengths of these traverses (ZL(I) and W(I)) are the basic input. Average length and width segments (ZLS(I) and WS(I)) are formed for each traverse (1, 2). Average widths (AWS(I)) and lengths (ALS(I)) are computed (3, 4) and used to estimate sub-areas (AREA(I,J)) which are themselves summed to give an estimate (TOTA) of the actual surface area of the sample location (5, 6). The theoretical sample area (TRUA) is computed (7) as well as ratios of the two area estimates (8).

Basic Equations Used in Program Comparea

$$ZLS(I) = ZL(I)/(NW-1) \quad (1)$$

for I = 1, NL; J = 1, NW

$$WS(J) = W(J)/(NL-1) \quad (2)$$

$$ALS(I) = (ZLS(I) + ZLS(I+1))/2 \quad (3)$$

$$AWS(J) = (WA(J) + WS(J+1))/2 \quad (4)$$

for I = 1, (NW-1); J = 1, (NL-1)

$$AREA(I,J) = (ALS(I)) * (AWS(J)) \quad (5)$$

$$TOTA = TOTA + AREA(I,J) \quad (6)$$

$$TRUA = (ZLSA) * (WSA) \quad (7)$$

$$TRTOTA = TRUA/TOTA \quad (8)$$

Output for the program in its present form includes:

1. Listing of TITLE Cards and MASTER Card.
2. Computed values of the theoretical area (TRUA), estimated surface area (TOTA), average traverse length (AVEL) and width (AVEW), and the two ratios (TRTOTA and TOTATR) for each sample area (CONT).

DESCRIPTION AND PREPARATION OF PROGRAM FREHUMP

Program Frehump (Appendix B) accepts up to 100 nongridded elevation readings as basic input for each sample area. There is no limit to the number of sample areas. Basic input for the program includes:

1. Four TITLE Cards
2. MASTER Card
3. Data Deck

TITLE Cards.-These cards identify the particular job and each contains alphanumeric information in columns 1-80. Examples of typical title cards can be found in the section describing Program Comparea.

MASTER Card.-The information contained on this card is arranged according to the Format (I6, 8A8).

Columns	Purpose
1-6	NE - number of elevation readings for each sample area
7-71	FMT - data format showing locations of geographic coordinates (U(I) and V(I)) and elevation readings (E(I)) for each sample area

Data Deck.-There are at least two data cards for each sample area. The first contains only an alphanumeric identification number of the area (columns 7-10). The second, and subsequent cards contain the geographic coordinates and values of the elevations for the area in a form described by the data format (FMT).

Description of Program Calculations.-All sampled elevation readings (E(I)) and their respective geographic coordinates (U(I) and V(I)) are used to compute the best-fit linear surface. In matrix form, the coefficients of this surface [B(I)] are found by solving for the product of the elevation matrix [E(I)] and inverse of the [U(I)V(I)] matrix (1). Statement 2 defines the contents of each matrix. Computed elevation values (COMPE(I)) are then formed for each location in the area (3). Sets of elevation deviations (DEV1(I), DEV2(I), and DEV3 (I)) are computed vertically from both a horizontal plane (4a) and the best-fit plane (4b) and the normal from the best-fit plane (4c). Finally, the mean (5), variance (6), and standard deviation (7) are determined for each of the three sets of elevations.

Basic Equations Used in Program Frehump

$$[B(I)] = [E(I)] \cdot [U(I)V(I)]^{-1} \quad (1)$$

$$\underbrace{\begin{bmatrix} N & \Sigma U(I) & \Sigma EV(I) \\ \Sigma U(I) & \Sigma U(I)^2 & \Sigma U(I)V(I) \\ \Sigma V(I) & \Sigma U(I)V(I) & \Sigma V(I)^2 \end{bmatrix}}_{[U(I)V(I)]} \cdot \underbrace{\begin{bmatrix} B(1) \\ B(2) \\ B(3) \end{bmatrix}}_{[B(I)]} = \underbrace{\begin{bmatrix} \Sigma E(I) \\ \Sigma U(I)E(I) \\ \Sigma V(I)E(I) \end{bmatrix}}_{[E(I)]} \quad (2)$$

$$COMPE(I) = B(1) + (B(2))(U(I)) + (B(3)V(I)) \quad (3)$$

$$TRUMN = E(I)/NE$$

$$D1(I) = TRUMN - E(I)$$

$$D2(I) = E(I) - COMPE(I)$$

QQ = largest negative D2(I)

Q = largest negative D1(I)

THETA = dip of the best-fit plane

CTHETA = 90.0 - THETA

$$DEV1(I) = E(I) + Q \quad (4a)$$

$$DEV2(I) = D2(I) - QQ \quad (4b)$$

$$DEV3(I) = (DEV2(I))(CTHETA) \quad (4c)$$

$$\bar{X}_1 = \Sigma DEV1(I)/NE \quad (5)$$

$$VAR1 = \Sigma(DEV1(I)^2) - ((\Sigma DEV1(I))^2/NE)/(NE-1) \quad (6)$$

$$STD1 = \sqrt{VAR1} \quad (7)$$

Output for the program includes:

1. Listing of the TITLE Card and MASTER Card.
2. Coefficients of the best-fit planar surface.
3. Dip angle of the mean plane.
4. Means, variances, and standard deviations for the three sets of deviation values.

DESCRIPTION AND PREPARATION OF PROGRAM VECTOR

Program Vector (Appendix C) handles up to a 20 x 20 matrix of elevation readings for each sample area. There is no limit to the number of sample areas. The program is presented in a general form suitable for FORTRAN modification. The basic input includes:

1. Four TITLE Cards
2. MASTER Card
3. FORMAT Card
4. PROBLEM Card
5. Data Deck

TITLE Cards.-These cards identify the particular job and contain alphanumeric information in columns 1-80. They are described in detail in the Program Comparea section.

MASTER Card.-This card is set up according to the Format (6X, 2I6, 4F6.3) where:

Columns	Purpose
1-6	blank, or contain job identification information which is not used in computations
7-12	M - number of elevation readings in each row
13-18	N - number of elevation readings in each column
19-24	USTART - geographic coordinate of the first elevation reading in row one/column one (commonly measured down from a position at the upper left corner of the map) (to three decimals)
25-30	VSTART - geographic coordinate of the first elevation reading in row one/column one (commonly measured to the right of a position at upper left corner of the map) (to three decimals)
31-36	USTEP - distance in the U direction between elevation readings
37-42	VSTEP - distance in the V direction between elevation readings

FORMAT Card.-Columns 1-80 contain the format describing the location of the elevation readings on the cards of the data deck.

PROBLEM Card.-Columns 7-10 are reserved for any alphanumeric identification of the area.

Data Deck.-The cards contained in the data deck are set up in the form described by the FORMAT cards.

Several modifications of the basic FORTRAN of Program Vector are commonly made to shorten computation time if the data are in special forms. For example, when each area is the same size and contains the same number of similarly spaced elevation readings, it is advantageous to include only one MASTER Card and one FORMAT Card for the whole series of areas. In this case, the problem number identifying the area is commonly included on the basic data cards as specified by the data format.

Description of Program Calculations.-The basic input includes the number of rows (M) and columns (N); geographic origin (USTART and VSTART) and spacing (USTEP and VSTEP) of the grid; and the elevation Matrix (E(I, J), where I = 1, M and J = 1, N). The U and V matrices are generated (1a, b) and used with the elevation matrix to compute direction cosines of the normals to the planes defined by successive groups of three elevation readings. (For simplicity, only the direction cosine calculations about the X-axis are included because the cosines relative to the Y and Z axes are calculated in a similar manner.) The direction cosines are summed (3) and these sums are used to estimate two forms (4a, b) of the vector strength (R1 and R) and Fisher's dispersion factor (ESTK, 5). The direction cosines (ALPHA, BETA, GAMMA) of the plane normal to the mean vector (R1) are then determined (6a, b, c) and used to calculate the dip (DIP) and strike (STRIKE) of that plane (7 and 8). The final calculations compute the dip distribution of the planes (DPLANE (K)) to each of the individual vectors (9) in terms of their mean (ZMEAN) and standard deviation (ST) statistics (10 and 11). Z-scores of each individual dip (ADIP(K)) are also calculated (12).

Basic Equations Used in Program Vector

$$U(I, J) = USTART + USTEP (I-1) \quad (1a)$$

$$V(I, J) = VSTART + VSTEP (J-1) \quad (1b)$$

for $I = 1, M; J = 1, N; K = 1, NK$

$$II = I + 1$$

$$JJ = J + 1$$

$$NK = (M - 1) (N - 1) (2)$$

$$XDN(K) = (VSTEP(E(II,J))) - (VSTEP(E(I,J)))$$

$$DIV(K) = ((XDN(K))^2 + (YDN(K))^2 + (ZDN(K))^2)^{1/2}$$

$$XNORM(K) = XDN(K)/DIV(K) \quad (2)$$

$$TOTX = XNORM(K) \quad (3)$$

$$R1 = ((TOTX^2) + (TOTY^2) + (TOTZ^2))^{1/2} \quad (4a)$$

$$R = R1/NK-1 \quad (4b)$$

$$ESTK = (NK-1)/(NK-R1) \quad (5)$$

$$ALPHA = TOTX/R1 \quad (6a)$$

$$BETA = TOTY/R1 \quad (6b)$$

$$GAMMA = TOTZ/R1 \quad (6c)$$

$$ANGG = \arccos (GAMMA)$$

$$AC = \cos (1.5708 - ANGG)$$

$$COSTH = BETA/AC$$

$$DIP = (1.5708 - ANGG) (57.2957) \quad (7)$$

$$STRIKE = (\arccos (COSTH - 1.5708) (57.2057) \quad (8)$$

$$K = 1, NK$$

$$ARCZ(K) = \arccos (ZNORM(K))$$

$$DPLANE(K) = 1.5708 - ARCZ(K) \quad (9)$$

$$ZMEAN = DPLANE(K)/NK \quad (10)$$

$$SUMDIP = \Sigma DPLANE(K)$$

$$SIMDPS = \Sigma(DPLANE(K)^2)$$

$$ST = ((SUMDPS - (ZMEAN) (SUMDIP))/(NK - 1))^{1/2} \quad (11)$$

$$ZDIP(K) = (DPLANE(K) - ZMEAN)/ST \quad (12)$$

Output for this form of Program Vector includes:

1. Print out of the TITLE Cards, MASTER, FORMAT and PROBLEM Cards.
2. Coefficients of the mean plane (ALPHA, BETA, GAMMA).
3. Both estimates of vector strength (R1, R).
4. Vector dispersion estimate (ESTK).
5. Strike and dip of the mean plane (STRIKE, DIP).
6. Mean (ZMEAN) and standard deviation (ST) of dip distribution.

PISGAH CRATER, AN EXAMPLE

This section describes a surface-roughness analysis of an area within the NASA test site at Pisgah Crater, California. The basic hypothesis considered is that surface roughness reflects some of the geologic characteristics of the area.

The area, located at the southern margin of the test site, covers approximately 11 square miles. It was the first area analyzed in the present surface-roughness program. Six rock types are mapped in the area (Diblee, 1966) and comparison of the topographic and geologic maps (Fig. 4A; 4B) shows that those portions of the area containing the same rock type generally have similar topography. For example, the areas of alluvium (Qa) are characterized by gentle, evenly dipping slopes, whereas those areas of Lava Bed Basalt (Qtb) have relatively high, irregular relief.

All data for this analysis were obtained from topographic maps. The basic roughness parameters were computed and these appear as Appendix D. The area was divided into 45 subareas (Fig. 4B) and 16 elevation readings and six traverse estimates were gathered from each (Appendix E).

Correlation.-Correlation among most variables is generally high (Table 1). This is not surprising considering the overall correspondence between topography and geology. For example, vector strength would be expected to decrease along with increases in the surface area ratio ($r = -0.86$), mean bump frequency ($r = -0.83$), and standard deviation of bump frequency ($r = -0.92$) if one walked from the smooth even surface of the playa lake onto the irregular surface of a basalt flow.

A few variables, such as vector dispersion (Variable 7, Table 1), do show surprising correlations suggesting the need for additional analysis. The signs of the coefficients between vector dispersion variable and the others are predictable but their magnitudes are generally lower than would be expected. The map of dispersion (not included in this report) shows a pattern almost identical to that of vector strength (Fig. 7A) despite the low correlation between the two variables ($r = 0.12$). The probable explanation is that these two variables are mathematically related in a curvilinear fashion whereas the correlation coefficient is only a measure of their linear similarity. That is, as vector strength increases from zero to one, vector dispersion changes geometrically from zero to infinity. It is possible that low correlations between dispersion and other variables also can be explained in terms of curvilinearity, but the interdependent nature of the variables makes this a multivariate problem which, as yet, has not been resolved.

Inspection of the standardized or z-score array (Table II) shows that most scores with absolute values greater than three standard deviation units are from subareas containing Lava Bed Basalt (Qtb) as the dominant rock type (e.g., subareas 9, 18, 27, Fig. 4B). These "abnormal" scores are explained, of course, by the high and variable relief that characterizes the subareas of Qtb, and their deletion

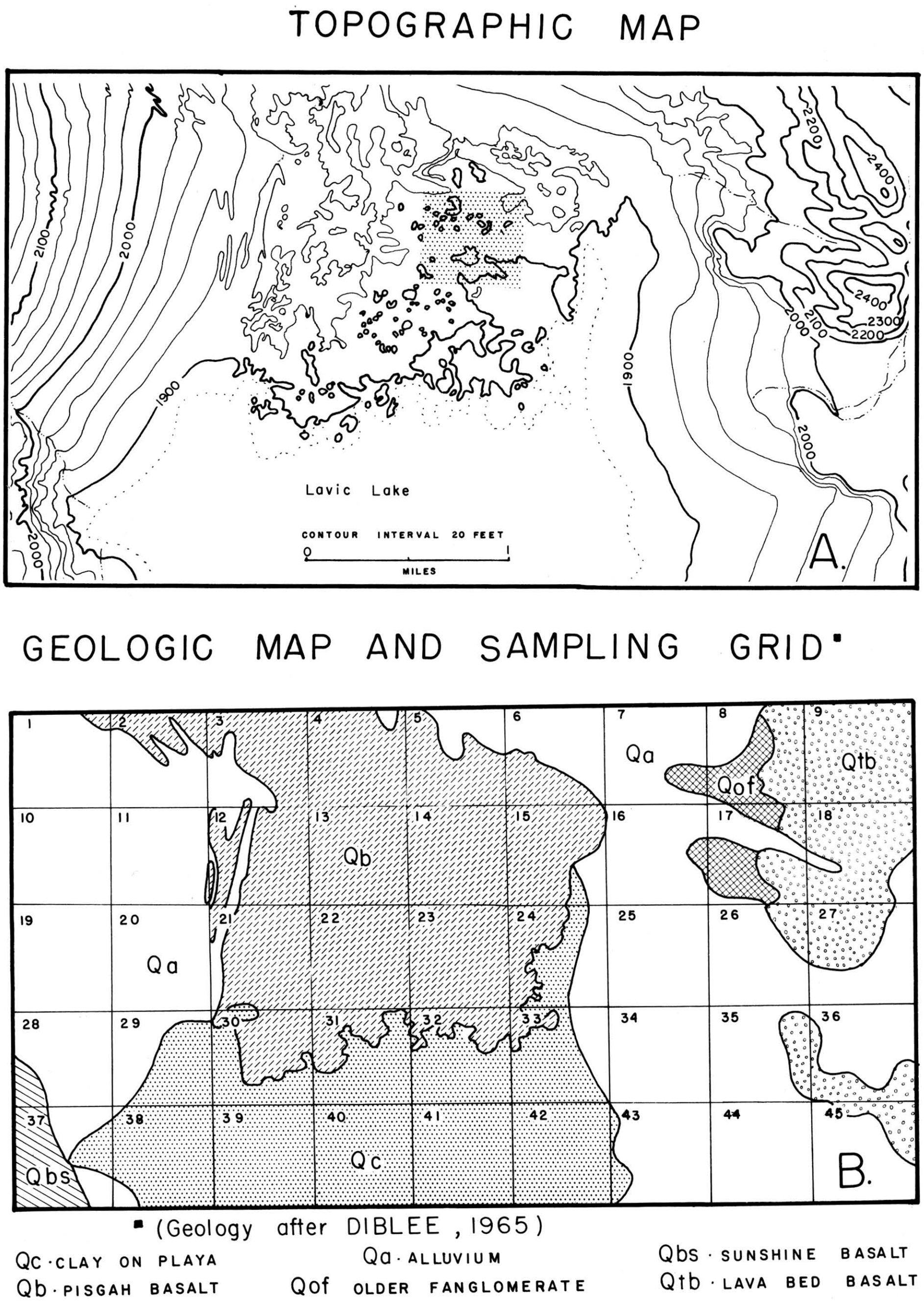


Figure 4.-A. and B. Comparison of topographic and geologic maps indicating areas with same rock type generally have similar topography.

Table 1.-Array of correlation coefficients.

	Area Ratio	Bump Freq. Mean 1	Bump Freq. Mean 2	Bump Freq. Std. Dev. 1	Bump Freq. Std. Dev. 2	Vector Strength	Vector Dispersion	Planes Dip Mean	Planes Dip Std. Dev.
	1	2	3	4	5	6	7	8	9
1	1.0000	0.3314	0.7156	0.7970	0.8193	-0.8557	-0.1162	-0.2773	0.7364
2	0.3314	1.0000	0.5506	0.3732	0.3865	-0.3646	-0.0784	-0.0859	0.2055
3	0.7156	0.5506	1.0000	0.8846	0.8974	-0.8355	-0.2001	-0.2879	0.8021
4	0.7970	0.3732	0.8846	1.0000	0.9203	-0.9126	-0.2289	-0.2591	0.9138
5	0.8193	0.3865	0.8974	0.9203	1.0000	-0.9267	-0.2014	-0.3235	0.9390
6	-0.8557	-0.3646	-0.8355	-0.9126	-0.9267	1.0000	0.1235	0.3231	-0.8934
7	-0.1162	-0.0784	-0.2001	-0.2289	-0.2014	0.1235	1.0000	0.2638	-0.2122
8	-0.2773	-0.0859	-0.2879	-0.2591	-0.3235	0.3231	0.2638	1.0000	-0.3488
9	0.7364	0.2055	0.8021	0.9138	0.9390	-0.8934	-0.2122	-0.3488	1.0000

from the data matrix would probably result in a general increase in size of most of the correlation coefficients.

Surface Area.-Considering the number and density of data control points, the map on the surface area ratio (Fig. 5A) delineates the major geologic units extremely well. An interesting feature of the map is that although some subareas are occupied by two (e.g., 29, 36, Fig. 4B) or even three (17, 37) rock types, the general shape of the geologic contacts is still maintained. Another interesting relationship is that small differences in the value of surface area ratios (usually at the third or fourth decimal place) can be used to distinguish between subareas containing different rock types. This relationship is illustrated by Figure 5B.

In Figure 5B the frequency of ratio values and their spread for each rock type is plotted. Overlap is small of ratio values between rock types and some transition subareas have narrow, characteristic ranges (e.g., the transition from the alluvium to the Lava Bed Basalt and Older Fanglomerate). Analysis of variance has also been used successfully to show these differences between the group of ratios associated with each particular rock type.

Bump Frequency and Distribution of Planes.-Maps of the bump frequency and distribution of planes parameters (Fig. 6A, 6B, 7A, and 7B), as the surface area ratio, tend to delineate the major geologic patterns in the study area. Again, as shown by vector strength (Fig. 7A) and by the mean dip of planes Fig. 7B), subtle differences in the value of a variable can be used accurately to predict the rock type characterizing the different subareas.

One interesting feature common to all maps of surface-roughness parameters included in this report is a small, closed contour located in the north-central portion of each. The contour always circles subarea 14 (Fig. 4B) and inspection of the topographic map shows that this subarea (shaded area, Fig. 4A) covers a series of small depressions on the basalt flow. One effect of the locally anomalous nature of the topography within subarea 14 is that elevation values are more variable than those sampled from other subareas on the flow resulting in higher mean bump frequency, bump standard deviation, mean dip of planes, and lower vector strength. Surface area ratio, on the other hand, is surprisingly low. Again, inspection of the sampling procedure provides the explanation: the positioning of the length and width traverses was such that nearly all traverses missed the depressions and thus the estimated surface area was less than that for the subareas nearby.

These relationships associated with subarea 14 are included to emphasize that the adequacy and reliability of any parameter is only as good as the effectiveness of its sampling procedures. In fairly simple analyses such as the present study, certain sampling inadequacies are apparent. In more rigorous analyses in which there is complicated data interlock, anomalous features of the variables might well go unnoticed and in these situations the original sampling design takes on extreme importance.

In conclusion, this study provides an adequate, if somewhat simplified, example of the use of the various surface-roughness parameters. The original hypothesis that surface roughness reflects the geologic nature of rocks appears to be correct. In more complicated studies it is recommended that sampling be conducted at several scales of measurement and that the variability of each parameter at each scale be compared. Several multivariate techniques such as factor analysis and discriminant analysis should be helpful in distinguishing surface-roughness differences between various types of geologic areas, whereas trend-surface and Fourier techniques might be helpful in mapping the systematic and residual trends of the variables.

Table II.-Array of standardized z-scores.*

Sub-Area	Area Ratio	Bump Freq. Mean 1	Bump Freq. Mean 2	Bump Freq. Std. Dev. 1	Bump Freq. Std. Dev. 2	Vector Strength	Vector Dispersion	Planes Dip Mean	Planes Dip Std. Dev.
	1	2	3	4	5	6	7	8	9
1	-0.36	1.00	1.16	0.51	0.60	0.29	-0.26	1.05	0.37
2	-0.25	0.15	0.24	0.44	1.14	-0.67	-0.26	0.96	1.08
3	-0.32	0.49	-0.44	-0.48	-0.48	0.39	-0.25	1.11	-0.44
4	-0.21	0.56	-0.52	-0.77	-0.58	0.46	-0.18	1.14	-0.69
5	-0.24	0.12	-0.42	-0.66	-0.50	0.44	-0.23	1.13	-0.52
6	-0.36	0.10	-0.63	-0.67	-0.60	0.46	-0.20	1.14	-0.61
7	-0.25	0.02	-0.46	-0.14	-0.41	0.37	-0.25	1.09	-0.60
8	1.43	0.17	1.17	2.08	0.81	-1.05	-0.26	0.92	1.22
9	1.08	4.52	3.20	2.54	2.69	-2.38	-0.26	-1.10	1.79
10	-0.37	1.67	1.47	0.42	0.42	-0.08	-0.26	-0.89	0.70
11	-0.38	0.46	0.06	-0.28	-0.33	0.38	-0.25	-0.82	-0.48
12	-0.15	0.28	-0.24	-0.55	-0.35	0.42	-0.24	-0.80	-0.42
13	-0.28	-0.07	-0.34	-0.42	-0.25	0.38	-0.25	-0.82	-0.27
14	-0.34	-1.59	0.56	0.68	1.47	-1.04	-0.26	-0.98	1.66
15	-0.22	-1.53	-0.27	0.06	0.43	-0.40	-0.26	-0.90	1.54
16	-0.26	-0.75	-0.39	-0.14	-0.26	0.32	-0.25	-0.83	-0.06
17	1.41	-0.46	0.18	1.02	0.66	-0.34	-0.26	-0.91	1.16
18	4.83	1.93	2.29	2.04	3.11	-2.88	-0.26	-1.13	2.01
19	-0.33	0.86	-0.62	0.31	-0.62	0.29	-0.25	1.07	-0.61
20	-0.42	-0.33	-0.64	-0.24	-0.58	0.41	-0.24	1.11	-0.52
21	-0.00	-0.51	1.40	0.07	0.45	0.36	-0.25	1.09	-0.42
22	-0.25	-0.13	-0.44	-0.64	-0.49	0.44	-0.23	-1.18	-0.62
23	-0.26	-0.17	-0.41	-0.65	-0.42	0.45	-0.21	-0.79	-0.69
24	-0.38	-0.54	-0.49	-0.64	-0.41	0.43	-0.24	-0.80	-0.50
25	-0.43	-0.39	-0.73	-0.47	-0.71	0.44	-0.23	-0.79	-0.74
26	0.43	-1.63	0.15	0.85	0.87	-0.05	-0.26	-0.87	1.07
27	3.27	0.04	3.22	3.88	3.28	-4.64	-0.26	-1.18	3.71
28	-0.33	-0.05	1.04	0.04	-0.47	0.34	-0.25	-0.83	-0.39
29	-0.44	-0.44	-0.63	-0.72	-0.59	0.46	-0.14	-0.77	-0.62
30	-0.36	-0.28	-0.61	-0.77	-0.64	0.47	-0.13	-0.77	-0.69
31	-0.38	-0.31	-0.72	-0.72	-0.71	0.47	-0.13	-0.78	-0.73
32	-0.42	-0.37	-0.71	-0.72	-0.71	0.46	-0.14	-0.77	-0.70
33	-0.44	-0.31	-0.73	-0.79	-0.71	0.47	-0.03	-0.77	-0.75
34	-0.43	-0.25	-0.70	-0.46	-0.70	0.20	-0.23	-0.80	-0.78
35	-0.13	-0.01	-0.06	0.34	0.08	0.15	-0.26	-0.85	0.49
36	-0.19	1.46	0.01	0.02	0.05	0.14	-0.25	-0.84	0.32
37	-0.19	-1.07	-0.24	0.32	-0.11	0.23	-0.25	1.06	-0.02
38	-0.45	-0.26	-0.70	-0.22	-0.69	0.46	-0.16	1.15	-0.66
39	-0.45	-0.36	-0.71	-0.82	-0.70	0.47	-0.01	1.15	-0.72
40	-0.45	-0.37	-0.73	-0.85	-0.71	0.47	0.12	1.15	-0.75
41	-0.45	-0.33	-0.77	-0.90	-0.78	0.47	4.08	1.16	-0.82
42	-0.45	-0.29	-0.79	-0.90	-0.79	0.47	5.02	1.16	-0.84
43	-0.44	-0.27	-0.70	-0.68	-0.68	0.46	-0.18	1.14	-0.69
44	-0.44	0.07	-0.32	-0.60	-0.53	0.43	-0.24	1.12	-0.43
45	0.05	-0.83	0.01	0.28	0.42	0.17	-0.26	1.08	0.66

* A Z-Score is defined as:

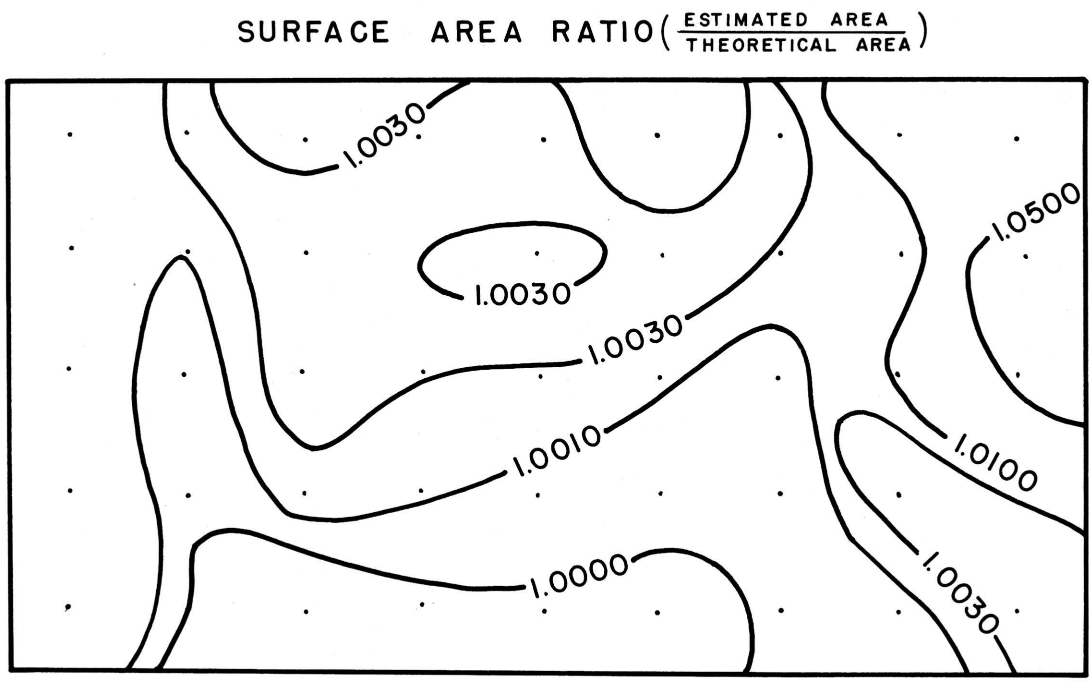
$$Z_{ij} = (X_{ij} - \overline{X}_i) / s_i$$

where:

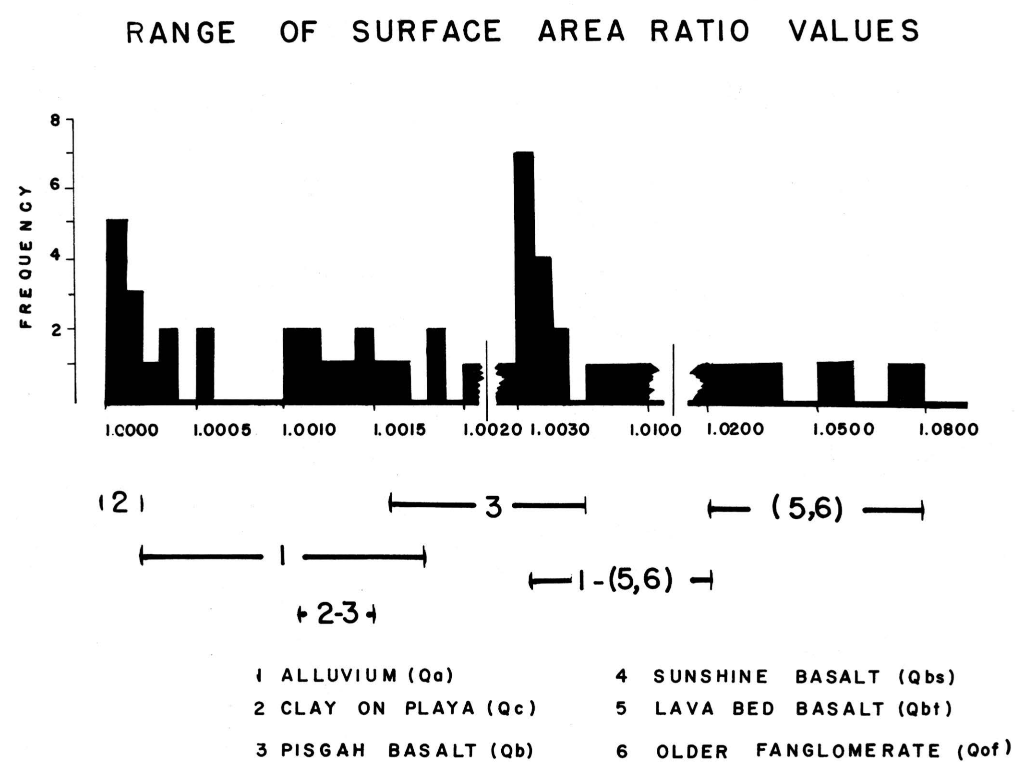
i and j identify the variable and the sub-area

$\overline{X}_i$ and s_i are the mean and standard deviation of variable i

X_{ij} is the observation of variable i in sub-area j



A



B

Figure 5.-A. Map of surface area ratio; B. Range of surface area ratio values.

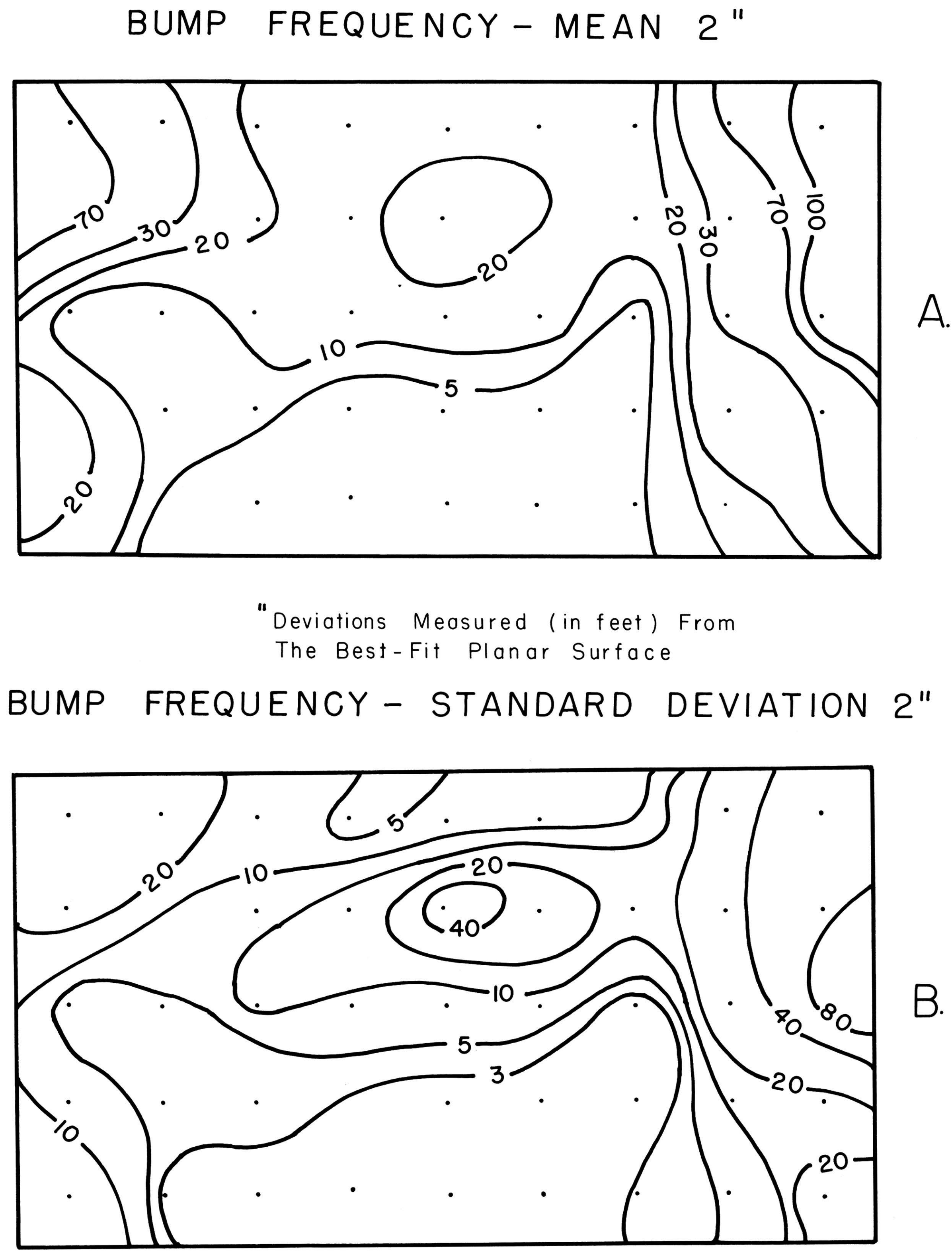


Figure 6.-A. and B. Maps of bump frequency and distribution of planes parameters.

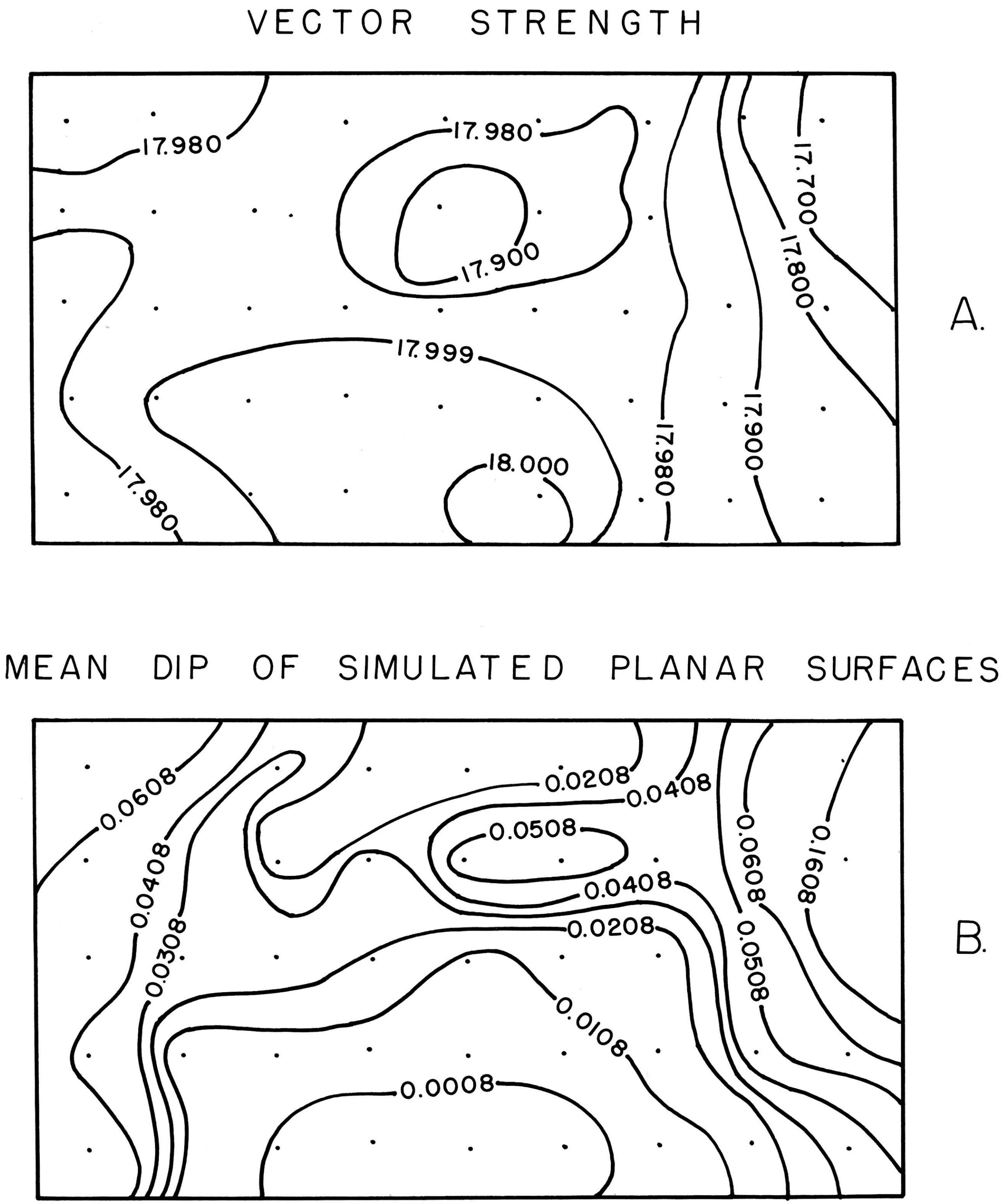


Figure 7.- A. Map showing vector strength; B. Map showing mean dip of planes.

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APPENDIX A.-Complete FORTRAN 3400 Listing of Program Comparea.

```
      PROGRAM COMPAREA
      FORM A   -  NOV. 1965
C     R.D.HOBSON
            76N 69 4 (NRG 14-007-027)
C     VERSION WHICH ALLOWS MULTIPLE
C      COMPUTATIONS USING THE SAME NUMBER OF WIDTHS AND LENGTHS
C      AND FORMAT
C       PROGRAM READS IN LENGTHS FIRST AND THEN WIDTHS
C      THE FIRST CARD CONTAINING BOTH LENGTHS AND WIDTHS MUST ALSO HAVE
C         A VALUE OF CONTROL
C-----* -           --                   --             --              --------
      DIMENSION ZL(20),W(20),ZLS(100),WS(100),AREA(100,100),TITLE(40)
      DIMENSION FMT(5),ALS(100),AWS(100)
   98 FORMAT (1H1)
   99 FORMAT (//,2X,40H-----------                    *            )
  100 FORMAT (10A8)
  101 FORMAT (10X,2F8.2,2I6,6A6)
  102 FORMAT (10X,16HSAMPLE AREA DATA/6X,6HLENGTH,5X,5HWIDTH,3X,
     1 6HNO. OF,4X,6HNO. OF,10X,6HSAMPLE/24X,7HLENGTHS,4X,
     16HWIDTHS,11X,4HAREA/4X,F8.2,2X,F8.2,6X,I2,9X,I2, 8X,F12.2)
  103  FORMAT (10X,11HDATA FORMAT/15X,6A6)
  104 FORMAT (11X,3HNO.,5X,7HAVERAGE,5X,7HAVERAGE,8X,5HTOTAL,9X,
     1 6HTR-TOT,5X,6HTOT-TR/21X,6HLENGTH,8X,5HWIDTH,9X,4HAREA)
  105 FORMAT (4X,A8,  4X,F8.2,4X,F8.2,4X,F12.2,8X,F8.4,4X,F8.4)
      READ 100,TITLE
      PRINT 98
      PRINT 100,TITLE
      PRINT 99
      READ 101,~LSA,WSA ,NL,NW,FMT
      TRUA = ZLSA*WSA
      PRINT 102,ZLSA,WSA,NL,NW,TRUA
      PRINT 103,FMT
      PRINT 99
      PRINT 104
 1000 CONTINUE
      W(I) = 0.0
      ZL(I) = 0.0
      ZLS(I) = 0.0
      AWS(I) = 0.0
      WS(I) =0.0
      ALS(I) =0.0
      AL =0.0
      AW =0.0
      CONT = 0.0
      READ FMT,CONT,(ZL(I),I=1,NL),(W(I),I=1,NW)
      IF(EOF,60)2,3
    2 STOP
    3 DO 500 I=1,NL
  500 AL =AL+ZL(I)
      AVEL = AL/NL
      DO 502 I=1,NW
  502 AW = AW +W(I)
      AVEW = AW/NW
      NMW=NW-1
      NML=NL-1
      DO 200 I=1,NL
```

```
  200 ZLS(I) = ZL(I)/NMW
      DO 400 I=1,NL
  400 ALS(I)=(ZLS(I)+ZLS(I+1))/2
      DO 201 J=1,NW
  201 WS(J) = W(J)/NML
      DO 401 J=1,NW
  401 AWS(J)=(WS(J)+WS(J+1))/2
      TOTA = 0.0
      DO 202 I=1,NMW
      DO 202 J=1,NML
      AREA(I,J)=(ALS(I))*(AWS(J))
  202 TOTA = TOTA + AREA (I,J)
      TRTOTA= TRUA/TOTA
      TOTATR = TOTA/TRUA
      PRINT 105,CONT,AVEL,AVEW,TOTA,TRTOTA,TOTATR
      GO TO 1000
      END
         SCOPE
'LOAD
'RUN,10,5000
```

APPENDIX B.-Complete FORTRAN 3400 Listing of Program Frehump.

```
      PROGRAM FREHUMP
C     FORM A -  APRIL,1966
      DIMENSION TITLE (40), FMT(8), D1(100),D2(100),DEV1(100), DEV2(100)
      DIMENSION DEV3(100),ZMEAN(3), VAR(3), STD(3), UV(3,3), X(3)
      DIMENSION UVI(3,3), B(3),C(3)   , CONT(100),  U(100), V(100)
      DIMENSION E(100), SUMD(3), SUMDS(3),DATA(100,3), COMPE(100)
  100 FORMAT (1H1)
  102 FORMAT (//2X,40H---------                                    )
  104 FORMAT (10A8)
  106 FORMAT (I6,8A8)
  108 FORMAT (6X,27HCOMPUTED BY PROGRAM FREHUMP//20X,I3,3X,
     1 11HDATA POINTS//20X,11HDATA FORMAT/25X,8A8)
  125 FORMAT(/10X,12HDATA SUMMARY//)
  126 FORMAT (16X,21HCOEFFICIENTS OF PLANE,10X,3HDIP,17X,
     1 15HDEVIATION MEANS,17X,19HDEVIATION STD.DEVS./16X,1HA,9X,1HB,
     2 9X,1HG,26X,1H1,9X,1H2,9X,1H3,12X,1H1,9X,1H2,9X,1H3//)
  128 FORMAT (2X,A4,4X,3F10.4,2X,1F10.4,6X,3F10.4,6X,3F10.4)
  129 FORMAT (6X,A4)
    1 READ 104,TITLE
      PRINT 100
      PRINT 104,TITLE
      READ 106,NE,FMT
      PRINT 102
      PRINT 108,NE,FMT
      PRINT 102
      PRINT 125
      PRINT 126
    4 READ 129,"UMBER
      IF (EOF,6U)2,3
    2 STOP
    3 CONTINUE
      DO 44  I=1,NE
   44 READ FMT,U(I),V(I),E(I)
      DO 800 J=1,3
      DO 800 K=1,3
      C(J) =0.0
      X(J)=0.0
      UV(J,K)=0.0
  800 UVI(J,K)=0.0
      DO 5 I=1,NE
      C(1) = 1.0
      C(2)= U(I)
       C(3) = V(I)
C      GENERATE U,V AND UVX MATRICES-----------------
      DO 200 J=1,3
      DO 200 K=1,3
  200 UV(J,K)=UV(J,K) +(C(J)*C(K))
      DO 5 K=1,3
    5 X(K) = X(K) + (E(I)*C(K))
C      GENERATE INVERSE OF (U,V) MATRIX ------------
      DO 6 J=1,3
      DO 6 K=1,3
    6 UVI(J,K)=UV(J,K)
      DO 10 K=1,3
      DIV = UVI(K,K)
      UVI(K,K) = 1.0
      DO 7, J=1,3
    7 UVI(K,J)= UVI(K,J)/DIV
```

```
      DO 10 I=1,3
      IF(I-K)8,10,8
    8 DIV=UVI(I,K)
      UVI(I,K)= 0.0
      DO 9 J=1,3
    9 UVI(I,J)=UVI(I,J)-DIV*UVI(K,J)
   10 CONTINUE
C      SOLVE FOR BETA (COEFF. MATRIX) - (IUV)*(X)=(B) -------
      DO 11 I=1,3
   11 B(I) = 0.0
      DO 12 I=1,3
      DO 12 J=1,3
   12 B(I) = B(I) +UVI(I,J)*X(J)
      TRUMN = X(1)/NE
C      COMPUTE DIP OF MEAN PLANE (THETA)-------------
      ALPHA = ATANF (B(2)/B(3))
      SALPHA = SINF(ALPHA)
      GAMMA = ATANF (B(2)/SALPHA)
      THE = 1.5708-GAMMA
      STHETA = SINF (THE)
      CTHETA = COSF(THE)
      THETA = THE * 57.2957
      Q = - .0001
      QQ= - .0001
      DO 801 I=1,NE
      DO 801  J=1,3
      COMPE(I) =0.0
  801 DATA(I,J)=0.0
C      COMPUTE ELEVATION VALUES ON LINEAR SURFACE ----------
      DO 16 I=1,NE
      DATA(I,1)=1.0
      DATA (I,2)=U(I)
   16 DATA (I,3)=V(I)
      DO 19 I=1,NE
      D1(I)=TRUMN-E(I)
      IF(D1(I)-Q)13,14,14
   13 Q=D1(I)
   14 CONTINUE
      DO 17 J=1,3
   17 COMPE(I) = COMPE(I)+DATA(I,J)*B(J)
       D2(I) = E(I)-COMPE(I)
      IF (D2(I)-QQ)18,19,19
   18 QQ=D2(I)
   19 CONTINUE
C      COMPUTE THE THREE  TYPES OF DEVIATIONS -------
      DO 23 I=1,NE
      DEV1(I)=E(I) + Q
      DEV2(I)=D2(I)-QQ
   23 DEV3(I)=DEV2(I)*CTHETA
C      COMPUTE MEANS,VARIANCES AND STANDARD DEVIATIONS -----
      DO 802 J=1,3
      ZMEAN(J) = 0.0
      VAR(J) = 0.0
      STD(J) = 0.0
      SUMD(J) = 0.0
  802 SUMDS(J) = 0.0
      DO 24 I=1,NE
      SUMD(1)=SUMD(1)+DEV1(I)
      SUMD(2)=SUMD(2)+DEV2(I)
      SUMD(3) = SUMD(3)+DEV3(I)
```

```
      SUMDS(1) = SUMDS(1) + DEV1(I)**2
      SUMDS(2) = SUMDS(2)+DEV2(I)**2
   24 SUMDS(3) = SUMDS(3) + DEV3(I)**2
      DO 30 J=1,3
      ZMEAN(J) = SUMD(J)/NE
      VAR(J) = (SUMDS(J)- ((SUMD(J)**2)/NE))/(NE-1)
   30 STD(J) = SQRTF(VAR(J))
      PRINT 128,NUMBER,B(1),B(2),B(3),THETA,ZMEAN(1),ZMEAN(2),ZMEAN(3),
     1 STD(1),STD(2),STD(3)
      GO TO 4
      END
```

APPENDIX C.-Complete FORTRAN 3400 Listing of Program Vector.

```
      PROGRAM VECTOR
C       FORM A    - JAN. 1966
C       R.D.HOBSON
C      NASA  SPONSORED (NGR - 14 - 007 - 027)
C      DESIGNED AS ONE TECHNIQUE FOR ESTIMATING QUANTITATIVE
C      ASPECTS OF SURFACE ROUGHNESS
      DIMENSION  U(20,20), V(20,20), E(20,20),T(20,20)
     1 TITLE(40), FMT(10), XDN(400), YDN(400), ZDN(400), DIV(400),
     2 XNORM(400), YNORM(400),ZNORM(400), DPLANE(400), ZDIP(400),
     5 ARCZ(400) ,Z2(400)
  108 FORMAT (10A8)
  109 FORMAT (6X,2I6,4F6.3)
  110 FORMAT (//10X,30HCOMPUTATIONS BY PROGRAM VECTOR)
  116 FORMAT (2X,40H-------- -  ---               -----           )
  138 FORMAT(1H1, 10A8/10A8/10A8/10A8)
  112 FORMAT(6X,A4)
  100 FORMAT (10X,1HM,5X,1HN,5X,6HUSTART,4X,6HVSTART,5X,5HUSTEP,5X,
     15HVSTEP)
  101 FORMAT (/6X,2I6,4F10.2//10X,11HDATA FORMAT,6X,10A6)
  130 FORMAT (//6X,19HCOMPUTATION RESULTS//)
  131 FORMAT (7X,3HNO.,5X,5HALPHA,4X,4HBETA,3X,5HGAMMA,8X,4HR*NK,4X,1HR,
     19X,1HK,14X,6HSTRIKE,4X,3HDIP,10X,4HMEAN,3X,7HST.DEV./)
  132 FORMAT (2X,A8,2X,3F8.4,4X,2F8.4,2X,1F12.4,6X ,2F8.4,6X,2F8.4)
C     READ TITLE AND MASTER -------                ----
   12 READ 108,TITLE
      READ 109,M,N,USTART,VSTART,USTEP,VSTEP
      PRINT 110
      PRINT 138,TITLE
      PRINT 116
C     READ FORMAT AND DATA --------                ---*
      READ 108,FMT
      PRINT 100
      PRINT 101,M,N,USTART,VSTART,USTEP,VSTEP,FMT
      PRINT 116
      PRINT 130
      PRINT 131
  500 READ 112,PROB
      IF(EOF,60)13,14
   13 STOP
   14 CONTINUE
      DO 31 I=1,M
   31 READ FMT, (E(I,J),J=1,N)
C     GENERATE U AND V MATRICES --- *              ----
      DO 44 I=1,M
      DO 44 J=1,N
      U(I,J) = 0.0
   44 V(I,J) = 0.0
      DO 41  I=1,M
      DO 41 J=1,N
   41 V(I,J) = VSTART + VSTEP * (J-1)
      DO 42    I=1,M
      DO 42     J=1,N
   42 U(I,J) = USTART + USTEP * (I-1)
C     GENERATE NORMALS TO TRIANGLES - METHOD ONE -------- --
C          METHOD ONE USES POSITIONS (1,1),(1,2),(2,1) FOR FIRST
C          TRIANGLE
```

```
      MM=M-1
      NN = N-1
      K = 1
      DO 50  I=1,MM
      II=I+1
      DO 50  J=1,NN
      JJ=J+1
      XDN(K)=(VSTEP*E(II,J))-(VSTEP*E(I,J))
      YDN(K)=((USTEP*E(I,J))-(USTEP*E(I,JJ)))*(-1.0)
      ZDN(K)=USTEP*VSTEP
      DIV(K) = SQRTF (XDN(K)**2+YDN(K)**2+ZDN(K)**2)
      XNORM(K) = XDN(K)/DIV(K)
      YNORM(K) = YDN(K)/DIV(K)
      ZNORM(K) = ZDN(K)/DIV(K)
      K = K+1
      XDN(K)=(VSTEP*E(II,J))+(VSTEP*E(I,JJ)) -(VSTEP*E(II,J))-(VSTEP*
     1E(II,JJ))
      YDN(K)=((USTEP*E(II,JJ))+ (USTEP*E( I,JJ))- (USTEP*E(II,J))-
     1(USTEP*E(I,JJ)))*(-1.0)
      ZDN(K)=USTEP*VSTEP
      DIV(K) = SQRTF (XDN(K)**2 +YDN(K)**2+ZDN(K)**2)
      XNORM(K)= XDN(K)/DIV(K)
      YNORM(K)=YDN(K)/DIV(K)
      ZNORM(K)=ZDN(K)/DIV(K)
   50 K=K+1
      NK=K-1
C     COMPUTE VECTOR MEAN AND STRENGTH FOR METHOD ONE ---------
      TOTX = 0.0
      TOTY = 0.0
      TOTZ = 0.0
      DO 70 K=1,NK
      TOTX = TOTX + XNORM(K)
      TOTY = TOTY + YNORM(K)
   70 TOTZ=TOTZ+ZNORM(K)
C     VECTOR STRENGTH (R1) --------                  ---*
      ZR = (TOTX**2)+(TOTY**2)+(TOTZ**2)
      R1=SQRTF(ZR)
      R=R1/NK
C     DIRECTION COSINES OF MEAN VECTOR ------------
      ALPHA = TOTX/R1
      BETA = TOTY/R1
      GAMMA = TOTZ/(R1)
      ESTK = (NK-1)/(NK-R1)
C     GENERATE DIP AND STRIKE OF MEAN PLANE -------
      AB = BETA
      ANGG = ACOSF (GAMMA)
      AC = COSF(1.5708-ANGG)
      COSTH = AB/AC
      STRIKE = (ACOSF(COSTH)-1.5708)*(57.2957)
      DIP = (1.5708-ANGG)  * 57.2957
C     GENERATE TWO-DIMENSIONAL DISTRIBUTION OF PLANE DIPS ------
C     CHANGE COSINES TO ANGLES ----                  ----
  510 DO 80 K=1,NK
      ARCZ(K)=ACOSF(ZNORM(K))
   80 DPLANE(K)=1.5708-ARCZ(K)
C     COMPUTE MEAN AND STANDARD DEVIATIONS OF DIPS
      SUMDIP = 0.0
      SUMDPS = 0.0
      DO 90 K=1,NK
      SUMDIP = SUMDIP + DPLANE(K)
   90 SUMDPS = SUMDPS +(DPLANE(K)**2)
```

```
      ZMEAN= (SUMDIP/NK)
      ZMEANDP =ZMEAN * 57.2957
      DEVIA = SUMDPS -ZMEAN* ( SUMDIP )
      ST    =    SQRTF (DEVIA/(NK-1))
      STDIPS = ST*57.2957
C      Z MATRIX OF DIPS  - METHOD ONE -------------
      DO 60 K =1,NK
   60 ZDIP(K)=(DPLANE(K)-ZMEAN   )/ST
      PRINT132,PROB,ALPHA,BETA,GAMMA,R1,R,ESTK,STRIKE,DIP,ZMEAN,STDIPS
      GO TO 500
       END
```

APPENDIX D.-Complete Listing of Data Used for Pisgah Crater Surface-Roughness Test.

	NO	U	V	1 RATIO AREA	2 MEAN 1 BMP.FREQ.	3 MEAN 2 BMP.FREQ.	4 STD.DEV.1 BMP.FREQ.	5 STD.DEV.2 BMP.FREQ.
SR1	1	1	1	1.0013	1952.7500	74.5750	43.7079	28.6489
SR 1	2	1	2	1.0031	1908.3750	39.7625	41.5583	39.5567
SR 1	3	1	3	1.0020	1925.8750	14.0625	13.4556	6.6779
SR 1	4	1	4	1.0036	1930.0000	11.2000	4.8028	4.7469
SR 1	5	1	5	1.0032	1906.5000	15.0250	8.1199	6.3411
SR 1	6	1	6	1.0014	1905.7500	6.8250	7.7363	4.3386
SR 1	7	1	7	1.0031	1901.1250	13.4375	23.8299	8.1585
SR 1	8	1	8	1.0287	1909.2500	74.9500	91.1496	32.7470
SR 1	9	1	9	1.0234	2138.3750	152.1375	105.1369	70.8290
SR 1	10	2	1	1.0012	1988.1250	86.5125	40.9544	24.9206
SR 1	11	2	2	1.0010	1924.5000	33.0750	19.7400	9.7671
SR 1	12	2	3	1.0045	1915.0000	21.6500	11.3549	9.3904
SR 1	13	2	4	1.0026	1896.6250	17.8125	15.4907	11.3561
SR 1	14	2	5	1.0016	1816.5000	51.9750	48.7777	46.1285
SR 1	15	2	6	1.0035	1819.7500	20.5250	29.8527	25.1793
SR 1	16	2	7	1.0029	1860.8750	15.9625	24.0304	11.2437
SR 1	17	2	8	1.0285	1875.8750	37.6125	59.2143	29.8095
SR 1	18	2	9	1.0808	2002.1250	117.6125	89.9225	79.3735
SR 1	19	3	1	1.0018	1945.7500	7.2000	37.6526	3.8601
SR 1	20	3	2	1.0005	1883.0000	6.3750	20.8423	4.7732
SR 1	21	3	3	1.0068	1873.3750	83.7625	30.3737	25.4883
SR 1	22	3	4	1.0030	1893.5000	14.0000	8.8129	6.5345
SR 1	23	3	5	1.0029	1891.3750	15.3375	8.4358	7.9470
SR 1	24	3	6	1.0011	1871.8750	12.1125	8.7290	8.1740
SR 1	25	3	7	1.0003	1879.6250	3.0875	13.9246	2.1527
SR 1	26	3	8	1.0134	1814.5000	36.4250	53.9178	34.0495
SR 1	27	3	9	1.0569	1902.3750	152.9375	145.9197	82.7908
SR 1	28	4	1	1.0018	1897.5000	70.2500	29.2449	6.9711
SR 1	29	4	2	1.0001	1877.3750	6.8375	6.2740	4.5359
SR 1	30	4	3	1.0014	1885.7500	7.5250	4.7311	3.4905
SR 1	31	4	4	1.0011	1884.2500	3.6500	6.2490	2.1463
SR 1	32	4	5	1.0005	1880.8750	4.0375	6.4650	2.1574
SR 1	33	4	6	1.0001	1883.7500	3.2750	4.1453	2.1610
SR 1	34	4	7	1.0003	1887.0000	4.4500	14.2642	2.3310
SR 1	35	4	8	1.0049	1899.7500	28.5000	38.4931	17.9901
SR 1	36	4	9	1.0040	1977.3750	31.0625	28.7593	17.5298
SR 1	37	5	1	1.0039	1843.8750	21.8625	37.8329	14.1714
SR 1	38	5	2	1.0000	1886.6250	4.2875	21.5199	2.4264
SR 1	39	5	3	1.0000	1881.6250	4.0625	3.2806	2.3354
SR 1	40	5	4	1.0000	1881.0000	3.3250	2.3664	1.9655
SR 1	41	5	5	1.0000	1883.1250	1.5375	0.7719	0.5605
SR 1	42	5	6	1.0000	1885.1250	0.7375	0.7719	0.3926
SR 1	43	5	7	1.0001	1886.2500	4.4000	7.6409	2.6796
SR 1	44	5	8	1.0002	1904.2500	18.8000	10.0855	5.6939
SR 1	45	5	9	1.0077	1856.5000	31.2000	36.5304	24.9566
				000054	CARDS			

	NO	U	V	6 VECTOR STR.	7 VECTOR DISP.	8 PLANES DIP. MEAN	9 PLANES DIP. STD.DEV.
SR 1	1	1	1	17.9779	403.5422	1.5117	2.3858
SR 1	2	1	2	17.8606	121.9512	1.4639	3.7766
SR 1	3	1	3	17.9904	1770.4137	1.5410	0.8176
SR 1	4	1	4	17.9985	11493.2878	1.5592	0.3255
SR 1	5	1	5	17.9966	4958.9267	1.5547	0.6630
SR 1	6	1	6	17.9981	9004.1709	1.5586	0.4750
SR 1	7	1	7	17.9875	1359.5632	1.5345	0.5033
SR 1	8	1	8	17.8145	91.6853	1.4444	4.0379
SR 1	9	1	9	17.6531	49.0000	0.3917	5.1577
SR 1	10	2	1	17.9331	254.2820	0.5015	3.0325
SR 1	11	2	2	17.9890	545.8869	0.5382	0.7425
SR 1	12	2	3	17.9936	2694.7418	0.5483	0.8515
SR 1	13	2	4	17.9888	1519.3473	0.5412	1.1465
SR 1	14	2	5	17.8164	92.5965	0.4543	4.8969
SR 1	15	2	6	17.8944	160.9702	0.4965	4.6623
SR 1	16	2	7	17.9818	932.1909	0.5344	1.5631
SR 1	17	2	8	17.9018	173.1518	0.4897	3.9330
SR 1	18	2	9	17.5917	41.6402	0.3790	5.5832
SR 1	19	3	1	17.9779	770.5749	1.5219	0.4746
SR 1	20	3	2	17.9926	2299.6587	1.5443	0.6526
SR 1	21	3	3	17.9860	1215.8209	1.5338	0.8494
SR 1	22	3	4	17.9964	4774.3272	0.3524	0.4695
SR 1	23	3	5	17.9976	7115.9640	0.5550	0.3364
SR 1	24	3	6	17.9951	3500.0848	0.5504	0.6941
SR 1	25	3	7	17.9967	5089.0615	0.5519	0.2365
SR 1	26	3	8	17.9363	266.9736	0.5123	3.7620
SR 1	27	3	9	17.3781	27.3339	0.3530	8.8899
SR 1	28	4	1	17.9838	1050.1784	0.5313	0.9095
SR 1	29	4	2	17.9991	18996.6854	0.5640	0.4635
SR 1	30	4	3	17.9992	20011.1503	0.5626	0.3209
SR 1	31	4	4	17.9992	20235.2377	0.5621	0.2568
SR 1	32	4	5	17.9991	19050.1651	0.5623	0.3040
SR 1	33	4	6	17.9995	35605.0263	0.5644	0.2118
SR 1	34	4	7	17.9665	4789.8721	0.5511	0.1597
SR 1	35	4	8	17.9604	429.0199	0.5214	2.6182
SR 1	36	4	9	17.9602	552.6186	0.5271	2.2895
SR 1	37	5	1	17.9703	563.3203	1.5199	1.6311
SR 1	38	5	2	17.9989	15465.0466	1.5620	0.3925
SR 1	39	5	3	17.9996	39288.7052	1.5657	0.2782
SR 1	40	5	4	17.9997	59350.7210	1.5665	0.2173
SR 1	41	5	5	18.0000	676598.4398	1.5696	0.0672
SR 1	42	5	6	18.0000	822790.6697	1.5694	0.0385
SR 1	43	5	7	17.9986	12643.4210	1.5595	0.3267
SR 1	44	5	8	17.9948	3248.3833	1.5511	0.8258
SR 1	45	5	9	17.9633	463.8096	1.5293	2.9542

APPENDIX E.-Listing of Elevation and Traverse Data Required to Compute Roughness Parameters.

ELEVATION DATA

(ELEVATIONS ARE READ INTO THE MACHINE BY ROWS. CARD 1 CONTAINS THE FIRST FOUR ELEVATION READINGS FROM AREAS 1,2, AND 3. THE SECOND CARD CONTAINS THE FIRST FOUR READINGS IN THE FIRST ROW FOR AREAS 5, 6, AND 7. SEE FIGURE 4-B)

ROW												
1	2015	2075	2055	2038	2012	1995	1962	1958	1942	1964	1966	1962
1	1940	1938	1940	1945	1930	1930	1924	1921	1928	1932	1938	1950
1	1968	1980	1978	2006	2020	2030	2108	2250	2310	2230	2210	1985
2	2112	2085	2059	2030	2008	1990	1967	1955	1935	1952	1962	1945
2	1940	1935	1938	1935	1938	1922	1920	1925	1930	1925	1925	1928
2	1941	1955	1965	1970	1990	2010	2045	2195	2370	2375	2235	2235
3	2118	2087	2055	2030	2002	2086	2070	2055	1945	1938	1959	1930
3	1938	1928	1935	1938	1925	1925	1920	1920	1918	1925	1930	1928
3	1922	1938	1937	1960	1982	2030	2115	2227	2330	2362	2282	2238
4	2185	2090	2038	2030	1998	1982	1965	1950	1945	1927	1928	1935
4	1948	1938	1943	1945	1919	1902	1910	1925	1919	1920	1925	1925
4	1930	1920	1932	1955	1982	2020	2075	2195	2270	2420	2400	2215
5	2120	1980	2055	2025	1985	1975	1955	1938	1935	1918	1910	1935
5	1915	1930	1915	1918	1919	1905	1912	1925	1935	1930	1915	1925
5	1904	1918	1925	1935	1975	1990	2050	2078	2200	2310	2500	2250
6	2115	2075	2045	2018	1945	1967	1948	1935	1932	1938	1940	1938
6	1950	1935	1925	1905	2000	2055	2002	2000	1925	1918	2010	1895
6	1895	1912	1926	1960	1970	1992	2014	2080	2172	2240	2290	2190
7	2105	2070	2040	2015	1985	1965	1945	1930	1925	1925	1945	1950
7	1942	1938	1930	1910	1910	1904	1910	1910	1910	1917	1890	1895
7	1892	1910	1918	1980	2018	2020	2095	2080	2080	2165	2300	2290
8	2095	2065	2035	2007	1980	1960	1938	1925	1920	1922	1942	1945
8	1938	1932	1960	1910	1907	1910	1908	1895	1896	1902	1890	1885
8	1892	1905	1917	1938	2023	2018	2060	2208	2260	2250	2240	2280
9	2090	2055	2025	1992	1970	1942	1930	1915	1915	1920	1940	1938
9	1920	1918	1907	1892	1910	1907	1890	1885	1890	1910	1887	1918
9	1898	1910	1919	1932	1952	1970	2000	2160	2220	2378	2430	2250
10	2070	2042	2010	1987	1958	1938	1922	1913	1918	1945	1930	1918
10	1918	1904	1900	1900	1910	1908	1900	1890	1890	1898	1888	1895
10	1900	1917	1927	1937	1943	1958	1975	2060	2300	2320	2318	2050
11	2050	2027	1995	1970	1945	1925	1917	1910	1910	1918	1817	1895
11	1922	1910	1906	1910	1895	1902	1910	1902	1900	1885	1890	1895
11	1907	1916	1927	1939	1950	1967	1978	1996	2060	2082	2058	2050
12	2035	2002	1978	1958	1930	1917	1907	1885	1895	1900	1910	1878
12	1910	1895	1910	1902	1890	1902	1910	1900	1898	1892	1888	1895
12	1903	1916	1927	1942	1952	1965	1978	1992	2008	2022	2015	2098
13	1993	1972	1952	1933	1917	1900	1890	1890	1892	1898	2007	2000
13	1905	1899	1901	1897	1898	1903	1898	1900	1893	1890	1893	1896
13	2904	1914	1926	1940	1952	1967	1977	2050	2008	2016	2030	2080
14	1986	1964	1942	1922	1904	1896	1895	1894	1897	1900	1898	1898
14	1899	1898	1900	1898	1896	1895	1896	1897	1886	1887	1890	1893
14	1899	1910	1921	1935	1945	1958	1967	2045	2020	2018	2022	2032
15	1978	1950	1932	1913	1898	1896	1895	1894	1896	1897	1898	1899
15	1898	1893	1892	1890	1889	1887	1886	1885	1884	1885	1886	1893
15	1897	1910	1917	1929	1940	1950	1957	2028	2017	2010	2018	2088
16	1980	1922	1918	1902	1898	1897	1896	1895	1893	1892	1890	1887
16	1887	1886	1886	1885	1886	1884	1885	1886	1886	1885	1884	1883
16	1890	1898	1909	1917	1939	1947	1953	2023	2020	2045	2060	2095

17	1958	1903	1895	1893	1890	1888	1888	1888	1887	1887	1887	1887
17	1886	1886	1885	1885	1885	1885	1884	1884	1885	1885	1886	1887
17	1890	1898	1910	1911	1916	1919	1923	1931	1940	1950	1960	2095
18	1960	1940	1897	1890	1889	1899	1888	1888	1887	1887	1886	1886
18	1886	1886	1885	1885	1885	1885	1885	1885	1886	1886	1887	1887
18	1889	1893	1898	1910	1916	1919	1927	1937	1950	1962	1975	1990
19	1990	1940	1899	1898	1897	1896	1894	1890	1886	1889	1885	1885
19	1884	1884	1883	1883	1884	1885	1885	1885	1885	1886	1886	1887
19	1892	1894	1898	1907	1911	1919	1909	1938	1950	1962	1975	1995
20	2013	1953	1917	1909	1899	1898	1897	1896	1895	1894	1893	1892
20	1891	1890	1889	1888	1887	1886	1886	1885	1885	1886	1886	1887
20	1890	1895	1898	1905	1915	1923	1932	1943	1954	1968	1983	2003

TRAVERSE DISTANCE ESTIMATES

IDENTIFICATION (I.D.) NUMBER IDENTIFIES SUB-AREA (SEE FIGURE 4-B) AND THE LETTER LENGTH (L) OR WIDTH (W) TRAVERSE

I. D.				
1	L	2640.08	2640.05	2640.10
1	W	2644.53	2643.25	2642.79
2	L	2640.38	2646.18	2642.54
2	W	2652.04	2642.35	2641.03
3	L	2641.68	2642.34	2640.49
3	W	2645.70	2643.48	2641.72
4	L	2646.07	2644.38	2640.91
4	W	2643.43	2648.75	2641.48
5	L	2645.94	2644.31	2645.63
5	W	2640.52	2643.30	2646.63
6	L	2645.41	2640.69	2640.18
6	W	2640.24	2640.08	2647.83
7	L	2641.60	2646.33	2640.19
7	W	2645.62	2645.69	2641.14
8	L	2645.53	2660.37	2691.73
8	W	2710.85	2691.88	2668.22
9	L	2662.20	2668.58	2644.60
9	W	2658.45	2680.34	2702.99
10	L	2640.61	2640.13	2640.15
10	W	2642.82	2642.92	2642.82
11	L	2640.15	2640.15	2640.18
11	W	2643.81	2641.44	2643.64
12	L	2640.46	2643.53	2644.88
12	W	2647.57	2647.87	2652.20
13	L	2645.11	2641.44	2640.15
13	W	2642.79	2645.80	2645.20
14	L	2642.08	2641.14	2643.15
14	W	2642.95	2642.66	2640.79
15	L	2640.78	2643.56	2642.0
15	W	2645.87	2647.78	2645.92
16	L	2640.12	2640.10	2647.59
16	W	2642.32	2647.70	2644.82
17	L	2646.92	2654.02	2738.89
17	W	2665.91	2663.15	2732.66
18	L	2667.40	2815.67	2776.58
18	W	2808.20	2702.84	2667.85
19	L	2642.61	2641.63	2641.58
19	W	2643.32	2642.76	2642.56
20	L	2641.24	2640.35	2640.17
20	W	2641.49	2640.73	2640.59

21	L	2643.80	2643.92	2649.88
21	W	2653.03	2651.00	2654.80
22	L	2642.94	2643.19	2643.70
22	W	2646.78	2643.92	2643.57
23	L	2642.62	2644.89	2642.40
23	W	2645.79	2643.17	2643.89
24	L	2640.14	2640.65	2640.05
24	W	2643.13	2642.67	2641.5
25	L	2640.15	2640.14	2640.16
25	W	2640.52	2640.57	2640.51
26	L	2640.85	2640.53	2676.86
26	W	2691.14	2665.50	2640.50
27	L	2700.90	2709.74	2672.20
27	W	2770.63	2749.10	2651.38
28	L	2643.75	2641.43	2640.5
28	W	2642.05	2643.49	2643.29
29	L	2640.20	2640.07	2640.05
29	W	2640.46	2640.15	2640.04
30	L	2640.10	2643.03	2641.33
30	W	2646.43	2640.15	2640.05
31	L	2641.00	2641.75	2640.07
31	W	2646.78	2640.13	2640.05
32	L	2640.30	2640.09	2640.15
32	W	2644.23	2640.05	2640.05
33	L	2640.10	2640.05	2640.05
33	W	2640.10	2640.07	2640.06
34	L	2640.03	2640.31	2640.20
34	W	2640.56	2640.54	2640.54
35	L	2640.30	2640.40	2655.29
35	W	2647.35	2648.46	2651.14
36	L	2646.02	2642.04	2655.61
36	W	2645.43	2640.42	2650.37
37	L	2647.35	2642.37	2640.11
37	W	2646.07	2646.74	2649.82
38	L	2640.10	2640.05	2640.05
38	W	2640.05	2640.05	2640.07
39	L	2640.05	2640.05	2640.05
39	W	2640.05	2640.05	2640.05
40	L	2640.05	2640.05	2640.05
40	W	2640.05	2640.05	2640.05
41	L	2640.05	2640.05	2640.05
41	W	2640.05	2640.05	2640.05
42	L	2640.05	2640.05	2640.05
42	W	2640.05	2640.05	2640.05
43	L	2640.07	2640.09	2640.07
43	W	2640.12	2640.12	2640.12
44	L	2640.07	2640.43	2640.12
44	W	2640.11	2640.32	2640.40
45	L	2640.97	2649.80	2653.51
45	W	2659.68	2653.35	2640.78

KANSAS GEOLOGICAL SURVEY COMPUTER PROGRAM
THE UNIVERSITY OF KANSAS, LAWRENCE

PROGRAM ABSTRACT

Title (If subroutine state in title):

FORTRAN IV programs (Program Comparea, Program Frehump, Program Vector) to determine surface roughness in topography for the CDC 3400 computer.

Computer: CDC 3400 Date: February 23, 1967

Programming language: FORTRAN 3400 (FORTRAN IV)

Author, organization: R.D. Hobson, Department of Geology
Northwestern University, Evanston, Illinois

Direct inquiries to: Author, or

Name: D.F. Merriam Address: Kansas Geological Survey - University of Kansas, Lawrence.

Purpose/description: Program Comparea: compares areas of rough surfaces with similar sized smooth surfaces. Program Frehump: describes the distribution of irregularities on rough surfaces. Program Vector: simulates rough surfaces as planar elements and describes the distribution of these elements. All three programs describe surface roughness.

Mathematical method:

Restrictions, range:

Storage requirements:

Equipment specifications: Memory 20K___ 40K___ 60K___ K 32

Automatic divide: Yes X No___ Indirect addressing Yes___ No___

Other special features required Floating point option.

Additional remarks (include at author's discretion: fixed/float, relocatability; optional: running time, approximate number of times run successfully, programming hours)

Material is out of date in about 3 to 5 years and already several of the computer publications in the Special Distribution Publication series have been taken out of circulation. Several early versions of the computer programs have been updated and replaced. Undoubtedly it will be necessary to do this many times in the future - such is the way of the computer.

At present the COMPUTER CONTRIBUTION series is being distributed to workers in 37 states, the District of Columbia, and 30 foreign countries. From the comments and suggestions received, it is obvious that the information is being used. At least eleven universities are using the series as teaching aids and two companies are using them for continuing education manuals. Programs have been sent all over the world and have been adapted for use in fifteen countries. Computer applications in the earth sciences is a rapidly expanding and quickly developing area of interest, thus the growing demand for information. The Kansas Survey is helping meet this challenge with the COMPUTER CONTRIBUTIONS.

The Kansas Geological Survey is the only geological organization known to be actively distributing computer program decks as well as data decks. The programs are sold for a limited time at a nominal cost. Versions of the programs have been executed on Burroughs B5500, CDC 3400, Elliott 803C, GE 625, and IBM 1620, 7040, 7090 and 7094 computer systems. For a limited time, the Survey will make available the card deck of the surface roughness program in CDC FORTRAN IV for $7.50. An up-to-date list of available decks can be obtained by writing, Editor, COMPUTER CONTRIBUTIONS, at the Survey offices in Lawrence.

Comments and suggestions concerning the COMPUTER CONTRIBUTION series are welcome and should be addressed to the Editor. An up-to-date list of publications is available on request.

COMPUTER CONTRIBUTIONS

Kansas Geological Survey
University of Kansas
Lawrence, Kansas

Computer Contribution

1. Mathematical simulation of marine sedimentation with IBM 7090/7094 computers, by J.W. Harbaugh, 1966. . . . . $1.00
2. A generalized two-dimensional regression procedure, by J.R. Dempsey, 1966 . . . . . . $0.50
3. FORTRAN IV and MAP program for computation and plotting of trend surfaces for degrees 1 through 6, by Mont O'Leary, R.H. Lippert, and O.T. Spitz, 1966 . . . . $0.75
4. FORTRAN II program for multivariate discriminant analysis using an IBM 1620 computer, by J.C. Davis and R.J. Sampson, 1966 . . . . $0.50
5. FORTRAN IV program using double Fourier series for surface fitting of irregularly spaced data, by W.R. James, 1966 . . . . $0.75
6. FORTRAN IV program for estimation of cladistic relationships using the IBM 7040, by R.L. Bartcher, 1966 . . . . $1.00
7. Computer applications in the earth sciences: Colloquium on classification procedures, edited by D.F. Merriam, 1966 . . . . $1.00
8. Prediction of the performance of a solution gas drive reservoir by Muskat's Equation, by Apolonio Baca, 1967 . . . . $1.00
9. FORTRAN IV program for mathematical simulation of marine sedimentation with IBM 7040 or 7094 computers, by J.W. Harbaugh and W.J. Wahlstedt, 1967 . . . . $1.00
10. Three-dimensional response surface program in FORTRAN II for the IBM 1620 computer, by R.J. Sampson and J.C. Davis, 1967 . . . . $0.75
11. FORTRAN IV program for vector trend analyses of directional data, by W. T. Fox, 1967 . . $1.00
12. Computer applications in the earth sciences: Colloquium on trend analysis, edited by D.F. Merriam and N.C. Cocke, 1967 . . . . $1.00
13. FORTRAN IV computer programs for Markov chain experiments in geology, by W.C. Krumbein, 1967. . . . . $1.00
14. FORTRAN IV programs to determine surface roughness in topography for the CDC 3400 computer, by R.D. Hobson, 1967. . . . . $1.00