A COMPUTER METHOD FOR PREPARING BETA DIAGRAMS (PROGRAM IN FORTRAN IV-H, USING AN IBM 360/67 COMPUTER)

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ABSTRACT.— A method for preparing beta diagrams has been programmed for the IBM OS/360 (FORTRAN H) computer. The 570 CALCOMP system has been used to output the resultant plots. The program finds spherical coordinates of intersections of traces of individual segments, then projects them on an equatorial plane by using stereographic projection principles. It makes necessary corrections to fit the projected points to an equal area polar net (Billing net). The program, then, to calculate intensity of distribution of projected points performs the following tasks: (a) distributes the additive value of each point to a one percent domain by using the Mellis method; (b) takes care of the values which might fall outside the primitive circle; (c) chooses a suitable contour interval and integrates the values between contours. The final distribution is displayed both by an output from line printer and an output from CALCOMP plotter on a 20-cm Billing net. The computer program described in this report may be used, by slight alterations, to prepare various diagrams used in structural geology and in fabric data analysis in structural petrology.

INTRODUCTION

This study was carried out by the author at Stanford University during the spring of 1968.

The program is prepared to draw beta diagrams, but by slight alterations can be used to prepare other useful diagrams.

Programs in different languages and using somewhat different techniques have been provided by Robinson (1963) and by Noble (1964). The method used in this program is believed by the present author to give more accurate results than the above-mentioned works; however no attempts will be made to compare between them.

In the following chapters the meaning of beta diagrams, the technique in their preparation and the computer program itself will be discussed rather briefly. A listing of the program and outputs from a test run are presented . at the end of the text. Operating instructions for the program are given in the program as comment statements in logical steps.

EQUAL AREA NET

The following paragraph which summarizes the use of equal area net is quoted from Turner and Weiss (1963) :

«... Structural analysis is concerned especially with orientation data relating to planes and lines (fabric elements) and their intersections. In study of crystal morphology the relative orientations of planes and lines are conventionally represented and their geometric relations determined by means of the familiar stereographic projection —a tool which is commonly employed, too, in graphic solution of many problems in structural geology. In structural analysis, the necessity to evaluate preferred orientations of fabric elements imposes a peculiar limitation on graphic procedure. All equal area on the surface of the reference sphere must remain equal on the projection itself. This is not true of the stereographic projection, in which centrally situated areas are diminished relatively to peripheral areas of equivalent size on the reference sphere. To obviate this difficulty it is customary in structural analysis to use a type of equal-area projection — also known as the Lambert projection (after its inventor) or the Schmidt projection (after W. Schmidt who first used it in structural geology).

Both types of projection employ a reference sphere in which planes and lines passing through the center intersect the surface as great circles and points respectively. In equal-area projection as in stereographic projection, these are projected — but from the lower hemisphere only — onto the equatorial plane; but the graphic procedure employed maintains the desired equal-area specification which is absent from stereographic projection. Because of this property, density distribution of points on the projection faithfully reflects the preferred orientation of the corresponding lines passing through the center of the reference sphere. Stereographic projection is from a point source, and circles on the reference sphere appear as arcs of circles on the projection. This is not true of the equal-area projection; circles are projected as elliptical arcs, save where they lie in or normal to the plane of projection (the boundary circle and diameters of the projection respectively)...

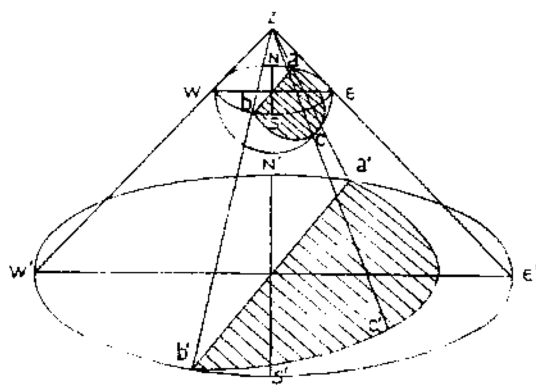


Fig. 1.

Figure 1 illustrates the principles of the stereographic projection. For the stereographic projection can the transfer of configuration on sphere of a plane be carried out by direct geometrical construfction. In equal-area type of projection the configuration is obtained by computational methods for which such concepts as the plane of projection, the center of projection and line of projection do not have a simple graphical meaning. Both, stereographic net (Wulff net) and equal-area net (Schmidt net or Lambert net) can be prepared as equatorial or polar projection. Equatorial projection is more often used because it enables the user to evaluate the coordinates of the intersections. In the present program the polar variety of equal-drea net (this net is also called Billing equal-area net) is used, because it can be drawn much easier by plotter, and coordinates of intersection vectors are calculated by mathematical methods. Polar and equatorial nets of stereographic and equal-area projection are illustrated in Figure 2. Scale and area distortion on these nets are also presented on the same figure.

STATISTICAL USE OF EQUAL-AREA NET

The nature and degree of preferred orientation of a given type of planar or linear fabric element are expressed graphically by the distribution on an equal-area projection of points (poles, in the case of planar elements), representing the individual orientations of a large number of representative measured elements of

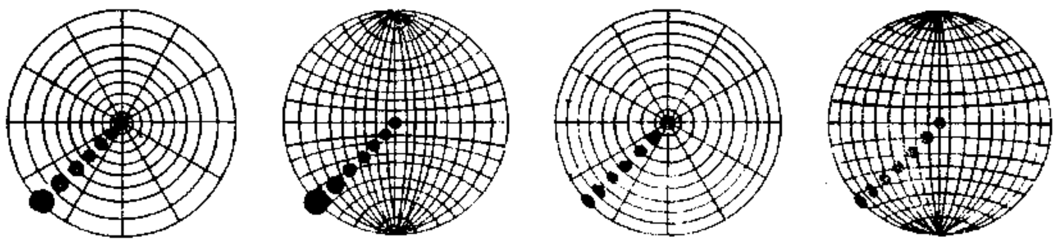


fig. 2.

the kind in question. The points so plotted constitute a pattern of preferred orientation or an orientation diagram of the given element. A statistically random orientation is expressed by a pattern in which there is no obvious tendency for reproducible local concentration of plotted points. Most orientation diagrams representing tectonite subfabric show marked reproducible local concentration and complementary voids or sparcely populated areas. These are graphic evidence of preferred orientation.

To sharpen the pattern of preferred orientation expressed by points on a net, it is customary in structural analysis to draw density contours on the point diagrams. Each contour delineates an area within which the density of distribution of plotted points exceeds some minimum value, e.g. 5 % of the total points per 1 % of the projection area.

To count the points lying within any one percent circular area of the projection and to draw the contour, several contouring procedures are currently used: *Schmidt method* is by far widely used. In this method a contouring counter (Fig. 3a) is the principle device. It is a card with a circular hole 1/100 of the area of the complete equal-area net. This counter is placed on the net and the number of points which can be seen within the circle are counted and the percentage concentration is calculated (Fig. 3b). For example if there were 500 poles on the net, and at one position of the counter 10 occurred within the hole, then the percentage at the center of the counting circle would be (10 X 100/500) 2 percent. These percentages are recorded from place to place (usually controlled with a grid) on the net and the density distribution contoured. At the periphery of the net the percentage are calculated with a special counter (Fig. 36) so that a complete one percent area is used. *Mellis method* or circle method is another tool to contour the population density. Circles of 1 percent are drawn around each point taking the point as the center (Fig. 4a and 46). Overlapping area between two circles have a 2 percent concentration, those between

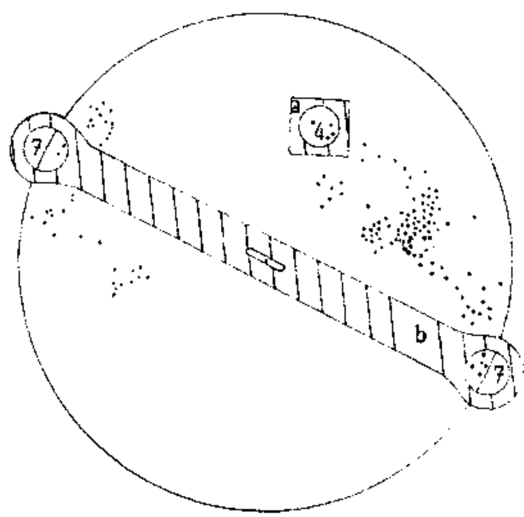
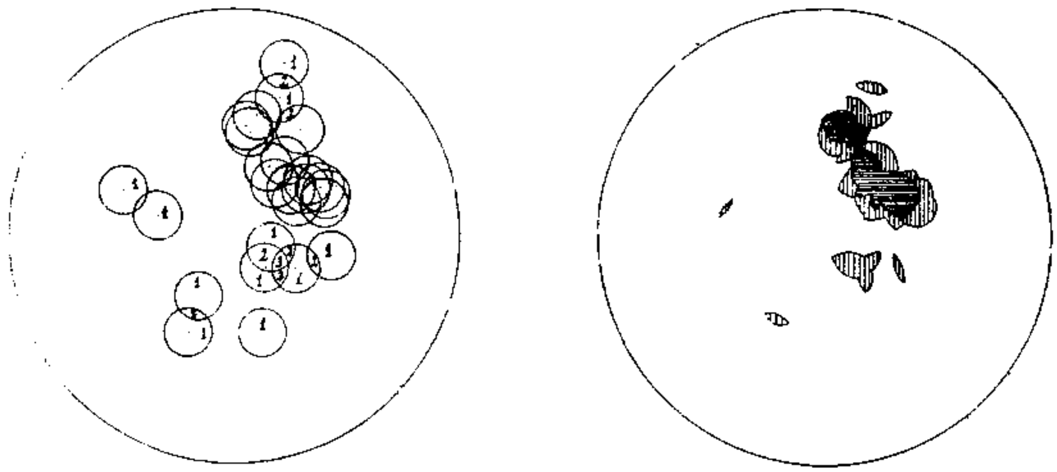


Fig. 3 (a-b).



a Fig. 4a-4b. b

three circles have 3 percent concentration, etc. This method has sounder statistical meaning; also, it is the least subjective method of contouring: the only one by which strictly identical diagrams will be produced from the same point diagram by independent workers. But its application is limited because it becomes almost impossible to count the number of overlapping circles. However this inconvenience is overcome by using computer (in our program we have used this method).

The object of counting is to draw density contours connecting centers of circular areas within which the measured points are equally concentrated. Contouring is an arbitrary procedure the statistical significance of which has not been rigorously evaluated. The following rules are recommended by Turner and Weiss (1963): (1) On any diagram the number of contours should not be more than six. (2) The highest contour is chosen to emphasize and differentiate maxima large enough to stand out clearly on a projection 2 to 3 inches in diameter. For instance, if the areas of local concentration of 10 to 12 percent are small, it may be advisable to draw the highest contour at 8 percent. (3) In any diagram contour intervals should preferably be uniform.

BETA DIAGRAMS

The following paragraph is quoted from Ramsay (1967) :

«...Surfaces within a cylindrical fold contain a line parallel to the rectilinear generator and therefore the intersections of any two observations of measured tangent planes to the folded surface intersect in a line parallel to this generator. This line is known as a beta axis and is parallel to the fold axis. The stereogram or equal-area projection offers a very convenient way for graphic determination of the orientation of such beta axes. All the beta axes computed in this manner should have a parallel orientation (i.e., all the great circles representing individual surfaces in the fold should pass through a single point). In practice, however, folds rarely have a perfectly cylindrical form and the measurements of the fold surfaces are always subject to a certain error. This means that the computed beta axes do not generally coincide, but they are unimodally grouped around a point which gives the best fit orientation for the mean beta axis or fold axis. The number of beta intersection produced by the intersection of n observed planes (tangent planes) in the fold is given by the arithmetic progression:

$$S = 0+1+2+3+ \ldots\ldots\ldots\ldots + (n-1) = \frac{n(n-1)}{2}$$

If n> 3, the number of beta intersections outnumbers the observation and in practice it may be almost impossible to determine their position in a single diagram (for example, if n = 500, then S = 124,750)...

However usage of high speed digital computers overcomes this impractica-bility.

Figures *5a* and *5b* illustrate the use of beta diagram.

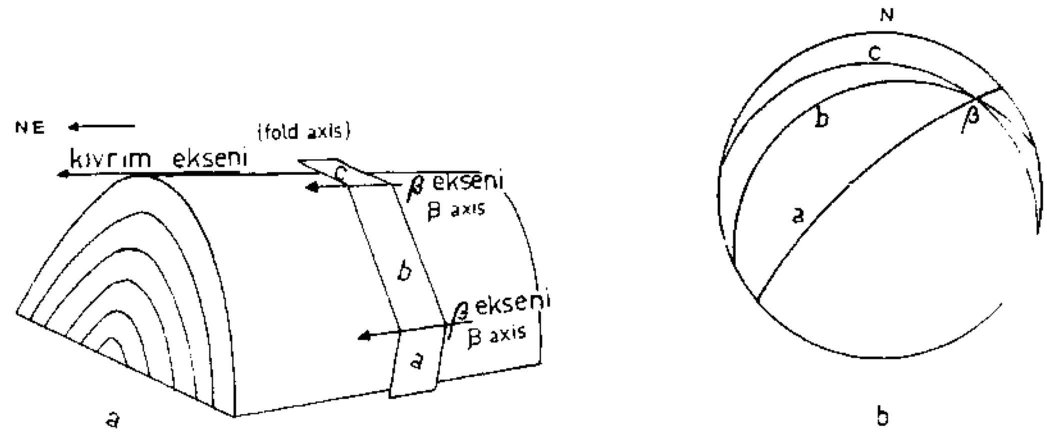


Fig. 5a-5b.

Beta diagrams can also be used to solve complex folding by dividing it to cylindrical portions. A fan of cleavage can be analysed by using beta diagrams. Other orientation studies can be performed by making slight changes in the present program or/and using only parts of it. (The function of every part in the program is explained by comment statements in the program itself and also in the next chapter so that one could modify the program.)

MAJOR STEPS IN THE PROGRAM

A real (100 X 100) array is used to fill in the values to be used in plotting, and an integer array KAR (100 X 100) is used to transfer values in real array to the corresponding percentage.

In PART ONE[1] the cells of the array outside the projection circle (net) are filled with 10,000 (Fig. 6).

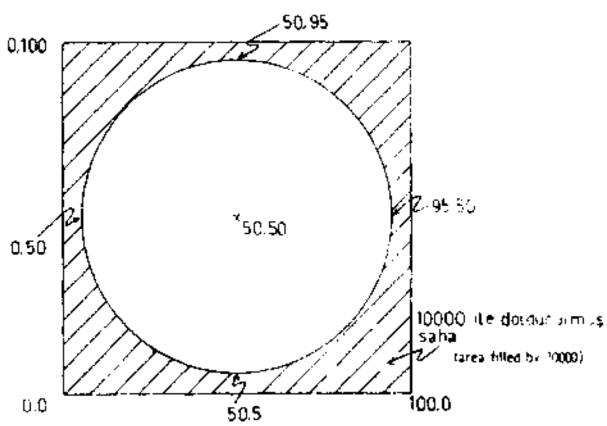


Fig. 6

In PART TWO angles representing measured form surfaces are read in (see chapter explaining the

[1] The beginning and end of parts are indicated in the program by means of comment statements.

inputs to the program). Pole of these surfaces are computed and direction cosines of the computed poles are stored in X, Y, Z arrays. (Positive X direction is to the north, Y to the east and Z downward.) These arrays are declared with 200 spaces each. This means one has to adjust this size if he wants to deal with more than 200 measurements. No other change in the program is required for such a modification. But it should be remembered that number (IS) of intersection is related to the number of the measurements by the formula mentioned above. IS might be a little smaller than the value predicted by the formula, because for surfaces having the same attitude, intersection is not possible. This fact is taken into account in the program (see Part Three).

In PART THREE direction cosines of vectors generated by the intersection of every two surfaces are evaluated using the following relations :

$$X'A + Y'B + Z'C = 0 \text{ (cross product)}$$
$$X''A + Y''B + Z''C = 0 \text{ (cross product)}$$
$$A^2 + B^2 + C^2 = 1 \text{ (theorem for direction cos.)}$$

where X', Y', Z' are direction cosines of one and X", Y", Z" are direction cosines of another vector. A, B, C are the corresponding direction cosines of the vector generated by intersection. Then these coordinates on the sphere are projected to an equatorial plane. Billing equal-area net is used in this case. For the equal-area projection the basic equation connecting the radius vector o with the polar distance (-) has the form

$$\varrho' = 2 R \sin \frac{\Theta}{2} \quad \text{(Vistelius 1966)}$$

In the program A and B are transformed using the above formula and geometrical relations (Fig. 7).

$$\varrho = \overline{OR}^2 - C^2 = 1 - C^2 \quad \text{(OR is radius and equals 1)}$$
$$\varrho' = 2 \sin \frac{\Theta}{2} \qquad \text{(OR = 1)}$$
$$2 \sin \frac{\Theta}{2} = 2 \sqrt{\frac{1 - \cos \Theta}{2}} \quad \text{trigonometric relation}$$
$$\frac{\varrho'}{\varrho} = \frac{2 \sqrt{\frac{1 - \cos \Theta}{2}}}{\sqrt{1 - C^2}}$$

But Cos Θ = C and the formula takes the following form :

$$\frac{\varrho'}{\varrho} = \sqrt{\frac{2}{1 + C}}$$

From similar triangles shown on Fig. 8
AA/A and BB/B ratios can be calculated

$$AA = A \sqrt{\frac{2}{1 + C}} \qquad BB = B \sqrt{\frac{2}{1 + C}}$$

The next step is to fill the AR array by using AA and BB coordinates

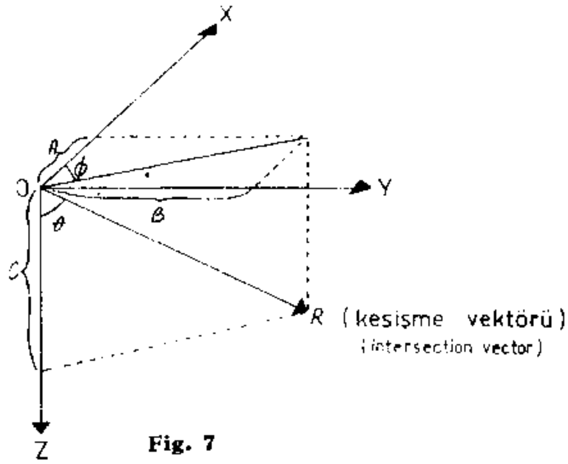


Fig. 7

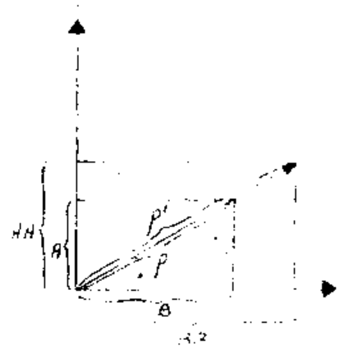


Fig. 8

Diameter of the projection net is 90 cells as shown on Figure 6. One percent circle will have a diameter of 9 cells. The filling operation is illustrated in Figure 9.

x,x' are the cells defined by AA and BB and (AA)' (BB)'. The values are added to previous values of the neighboring cells (occurring in 1 percent influence circle). It could be figured out that several (even thousands) of circles may comprise the same cell.

In PART FOUR the value in cells outside the net are added to their corresponding portion inside the net (Fig. 10). Outside cells are left filled with 10,000 to differentiate them from all of the inner cells.

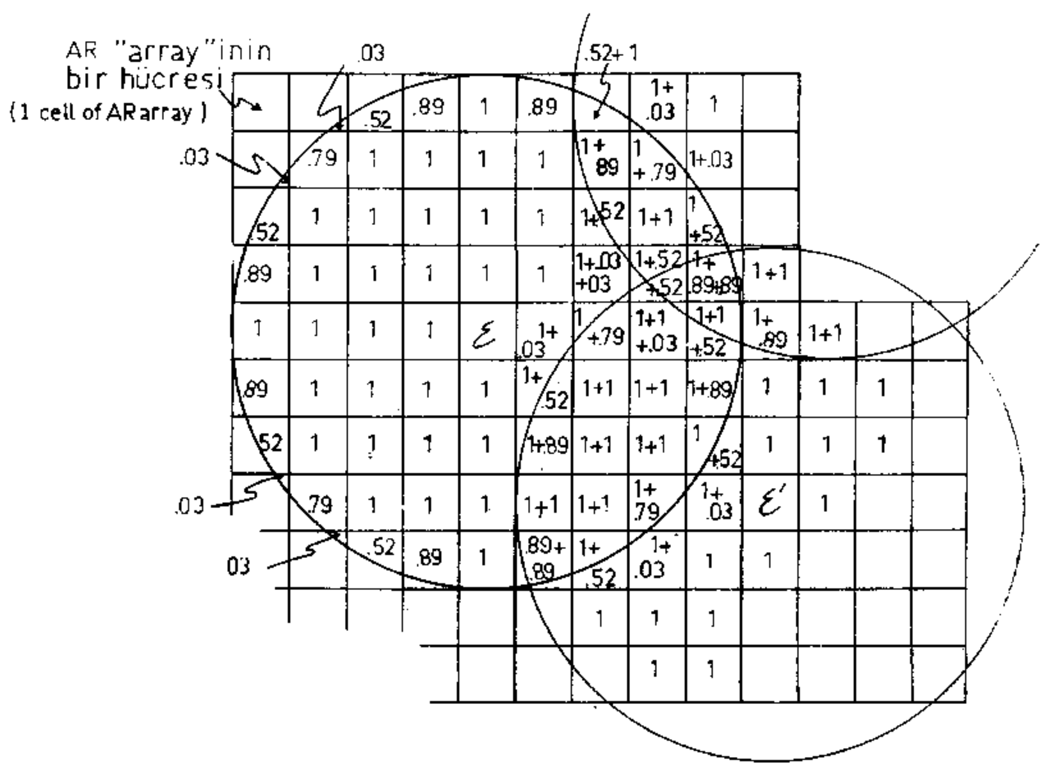


Fig. 9

In PART FIVE values of AR array are transported to integer KAR array and in the mean time values in each cell are divided by (total number of points in the net/100) to find representative percentage value.

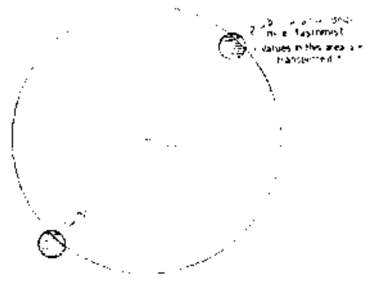


Fig. 10

In PART SIX the final value of each cell is printed out. Coordinate axes are also printed. The circle is deformed to an ellipse, due to rectangular form of the characters. Area outside of the primitive circle is filled with = sign. The values smaller than 1 are not printed. Values larger than 9 are represented by alphabetical symbols. A table of these symbols is given at the bottom of the map. The maximum value on the map is also printed below them. The main objective of printing out such a map, despite the great distortion, is to furnish user with a reference table showing actual values in each cell.

In PART SEVEN 'CALCOMP' plotter subroutines are called to draw a 20-cm Billing equal-area net. 10° interval is used.

In PART EIGHT 'CALCOMP' plotter subroutines are called to plot the cell values by classifying them as it is shown in the table below. Symbols used in plotting are :

N, S, E, W for north, south, east, west.

★ for values > 4/5 of the max. value.

○ for values > 3/5 but ≤ 4/5 of max.

△ for values > 2/5 but ≤ 3/5 of max.

✳ for values > 1/5 but ≤ 2/5 of max.

□ for values ≤ 1/5
values less than one are ignored and left blank.

INPUTS TO THE PROGRAM

The number N of measurements to be used should be punched in the very first data card. 15 format is used for this purpose. The upper limit for this N number is limited with the size of X, Y, Z arrays and it is set to 200 in this program. It could be augmented by simply changing the size of these arrays,.

N data cards must follow the very first card bearing the value of N. 215 format is used in these cards. First number being the azimuth and the second latitude of vectors representing dips. Azimuth value is the angle (from 0 to 360°) which the direction of the dip of measured plane makes with the north (clockwise direction being positive). It is expressed as integer degrees. Latitude is also expressed as integer degrees. It is the angle that the dip vector makes with the horizontal (from.0 to 90°).

JCL card must contain a special sign to cause page ejects to be supressed, thus permitting to obtain a map printed without gap across page margins.

Another job control statement should designate that plotter is going to be used. One should examine the listing of the program for detail, but should also keep in mind that these formats are subject to change any time.

The program consumed maximum 2 minutes computer time for a data set of 50 measurements.

Manuscript received April 14, 1970

REFERENCES

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ROBINSON, P.; ROBINSON, R. & GARLAND, S. (1963) : Preparation of beta diagrams in structural geology by digital computer. *Am. Journal Sci.,* v. 261, pp. 913-928.

TURNER, F.J. & WEISS, L.E. (1963) : Structural analysis of metamorphic tectonites. *McGraw-Hill* Co., 545 p.

VISTELIUS, A.B. (1966) : Structural diagrams. *Pergamon Press,* 178 p.

COMPUTER PROGRAM LISTING

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LEVEL 13  (22 MAY 67)                    OS/360  FORTRAN H                    DATE  68.159/00.40.05

        COMPILER OPTIONS - NAME=  MAIN,OPT=00,LINECNT=57,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID
                C           PREPARATION OF BETA DIAGRAMS
                C
                C
                C
                C******************************BEGINNING OF PART ONE
  ISN 0002            DIMENSION AR(100,100)
  ISN 0003            DO 2000 K=1,100
  ISN 0004              DO 2000 L=1,100
  ISN 0005     2000     AR(K,L)=0.
  ISN 0006            DO 2100 K=1,5
  ISN 0007              DO 2100 L=1,100
  ISN 0008              AR(K,L)=10000.
  ISN 0009              AR(L,K)=10000.
  ISN 0010              AR(K+95,L)=10000.
  ISN 0011     2100     AR(L,K+95)=10000.
  ISN 0012            DO 2800 IM=1,2
  ISN 0013              DO 2800 IN=1,2
  ISN 0014              NI=55
  ISN 0015              MI=61
  ISN 0016              KI=6
  ISN 0017              IF(IM.EQ.1) GO TO 21
  ISN 0019              MI=101-MI
  ISN 0020              MI=6
  ISN 0021              IF(IN.EQ.1) GO TO 22
  ISN 0023              KI=101-KI
  ISN 0024       22       DO 2200 K=MI, NI
  ISN 0025     2200       AR(K,KI)=10000.
  ISN 0026              MI=65
  ISN 0027              KI=7
  ISN 0028              IF(IM.EQ.1) GO TO 23
  ISN 0030              NI=101-MI
  ISN 0031              MI=6
  ISN 0032       23     IF(IN.EQ.1) GO TO 24
  ISN 0034              KI=101-KI
  ISN 0035       24       DO 2300 K=MI,NI
  ISN 0036     2300       AR(K,KI)=10000.
  ISN 0037                DO 2400 K=2,12,2
  ISN 0039                MI=66+K
  ISN 0039                KI=7+K/2
  ISN 0040                IF(IM.EQ.1) GO TO 25
  ISN 0042                NI=101-MI
  ISN 0043                MI=6
  ISN 0044       25       IF(IN.EQ.1) GO TO 26
  ISN 0046                KI=101-KI
  ISN 0047       26         DO 2400 M=MI,NI
  ISN 0048     2400         AR(M,KI)=10000.
  ISN 0049                DO 2500 K=1,10
  ISN 0050                MI=78+K
  ISN 0051                KI=13+K
  ISN 0052                IF(IM.EQ.1) GO TO 27
  ISN 0054                NI=101-MI
  ISN 0055                MI=6
  ISN 0056       27       IF(IN.EQ.1) GO TO 28
  ISN 0058                KI=101-KI
  ISN 0059       28         DO 2500 M=MI,NI
  ISN 0060     2500         AR(M,KI)= 10000.

  ISN 0061                DO 2600 K=2,10,2                                                                PAGE 002
  ISN 0062                MI= 88+K/2
  ISN 0063                IF(IM.EQ.1) GO TO 29
  ISN 0065                NI=101-MI
  ISN 0066                MI=6
  ISN 0067       29         DO 2600 IK=1,2
  ISN 0068                  KI=21+K+IK
  ISN 0069                  IF(IN.EQ.1) GO TO 31
  ISN 0071                  KI=101-KI
  ISN 0072       31           DO 2600 M=MI,NI
  ISN 0073     2600           AR(M,KI)=10000.
  ISN 0074              MI=54
  ISN 0075              IF(IM.EQ.1) GO TO 32
  ISN 0077              NI=101-MI
  ISN 0078              MI=6
  ISN 0079       32       DO 2700 L=MI,NI
  ISN 0080                  DO 2700 K=1,3
  ISN 0081                  KI=33+K
  ISN 0082                  IF(IN.EQ.1) GO TO 2700
  ISN 0084                  KI=101-KI
  ISN 0085     2700         AR(L,KI)=10000.
  ISN 0086              MI=55
  ISN 0087              KI=36
  ISN 0088              IF(IM.EQ.1) GO TO 33
  ISN 0090              MI=6
  ISN 0091       33     IF(IN.EQ.1) GO TO 34
  ISN 0093              KI=60
  ISN 0094       34       DO 2800 K=1,4
  ISN 0095     2800       AR(MI,KI+K)= 10000.
                C******************************END OF PART ONE
                C
                C
```

```
              C
              C******************************BEGINNING OF PART TWO  /
ISN 0096            INTEGER AZIMUT, DIP,G
ISN 0097            DIMENSION X(200), Y(200), Z(200)
ISN 0098            RAD=0.01745
ISN 0099            READ(5,10) N
ISN 0100         10 FORMAT(2I5)
ISN 0101            DO 100 I=1,N
ISN 0102            READ(5,10) AZIMUT,DIP
              C*********THE DIRECTION OF THE PERPENDICULAR(THE POLE) TO THE PLANE IS CALCULATED
              C*********IN THE NEXT 5 LINES
ISN 0103            IF(AZIMUT .LE.180) GO TO 1
ISN 0105            RADAZI=(AZIMUT-180)*RAD
ISN 0106            GO TO 2
ISN 0107          1 RADAZI=(AZIMUT+180)*RAD
ISN 0108          2 RADDIP=(90-DIP)*RAD
              C*********SPHERICAL COORDINATES OF THE POLE IS CALCULATED IN THE NEXT 4 LINES AND
              C*********STORED IN X,Y,Z ARRAYS
ISN 0109            COSDIP=COS(RADDIP)
ISN 0110            X(I)=COSDIP*COS(RADAZI)
ISN 0111            Y(I)=COSDIP*SIN(RADAZI)
ISN 0112        100 Z(I)=SIN(RADDIP)
              C******************************END OF PART TWO
              C
              C                                                                              PAGE 003
              C
              C******************************BEGINNING OF PART THREE
ISN 0113            IS=0
ISN 0114            M=N-1
ISN 0115            DIMENSION E(7)
ISN 0116            DATA E/0.03,0.52,0.89,1.,0.89,0.52,0.03/
ISN 0117            DO 200 K=1,M
ISN 0118            J=K+1
ISN 0119            DO 200 I=J,N
              C*********IN THE NEXT 4 LINES POLES WITH SAME COORDINATES ARE CHOSEN AND  JUMPED
ISN 0120            IF(X(K).NE.X(I)) GO TO 3
ISN 0122            IF(Y(K).NE.Y(I)) GO TO 3
ISN 0124            IF(Z(K).NE.Z(I)) GO TO 3
ISN 0126            GO TO 200
              C*********IN THE NEXT 12 LINES THE SPHERICAL COORDINATES OF THE INTERSECTION ARE
              C*********CALCULATED
ISN 0127          3 X1Z2=X(K)*Z(I)
ISN 0128            X1Y2=X(K)*Y(I)
ISN 0129            X2Y1=X(I)*Y(K)
ISN 0130            X2Z1=X(I)*Z(K)
ISN 0131            Y1Z2=Y(K)*Z(I)
ISN 0132            Y2Z1=Y(I)*Z(K)
ISN 0133            IF(X1Y2.EQ.X2Y1) GO TO 200
ISN 0135            IS=IS+1
ISN 0136            C=SQRT(1./(((X2Z1-X1Z2)/(X1Y2-X2Y1))**2+((Y1Z2-Y2Z1)/(X1Y2-X2Y1))*
                   1*2+1.))
ISN 0137            B=(C*(X2Z1-X1Z2))/(X1Y2-X2Y1)
ISN 0138            A=(C*(Y1Z2-Y2Z1))/(X1Y2-X2Y1)
              C*********IN THE FOLLOWING PART, UNTIL STATEMENT NUMBERED 200, SPHERICAL  COORDI-
              C*********NATES ARE TRANSFORMED TO A HILLING NET AND ONE PERCENT CIRCLE A REA ARE
              C*********FILLED WITH VALUES
ISN 0139            TRANS=SQRT((2.-2.*C)/(1.-(C**2)))
ISN 0140            AA=A*TRANS
ISN 0141            BB=B*TRANS
ISN 0142            AAI=(AA/0.031426)+50.
ISN 0143            BBI=(BB/0.031426)+50.
ISN 0144            IAA=AAI
ISN 0145            IBB=BBI
ISN 0146            IAAM2=IAA-2
ISN 0147            IAAP2=IAA+2
ISN 0148            IBBM3=IBB-3
ISN 0149            IBBP3=IBB+3
ISN 0150            IBBM2=IBB-2
ISN 0151            IBBP2=IBB+2
ISN 0152            DO 3000 L=IAAM2,IAAP2
ISN 0153              DO 3000 G=IBBM3, IBBP3
ISN 0154       3000   AR(L,G)=AR(L,G)+1.
ISN 0155            DO 3100 L=IBBM2, IBBP2
ISN 0156            AR(IAA-3,L)=AR(IAA-3,L)+1.
ISN 0157       3100 AR(IAA+3,L)=AR(IAA+3,L)+1.
ISN 0158            DO 3200 L=1,9,8
ISN 0159              DO 3200 G=1,7
ISN 0160       3200   AR(IAA-5+L,IBB-4+G)=AR(IAA-5+L,IBB-4+G)+E(G)
ISN 0161            DO 3300 L=1,9,8
ISN 0162              DO 3300 G=1,7
ISN 0163       3300   AR(IAA-4+G,IBB-5+L)=AR(IAA-4+G,IBB-5+L)+E(G)
ISN 0164            DO 3400 L=1,7,6

ISN 0165              DO 3400 G=1,7,6
ISN 0166       3400   AR(IAA-4+L,IBB-4+G)=AR(IAA-4+L,IBB-4+G)+.79
ISN 0167        200 CONTINUE                                                              PAGE 004
              C******************************END OF PART THREE
              C
              C
```

```
C
C******************************BEGINNING OF PART FOUR
            DO 4000 L=1,100
              DO 4000 M=1,100
              IF (AR(L,M).LE.10000.) GO TO 4000
              ILL=101-2*L
              RILL=FLOAT(ILL)
              IMM=101-2*M
              RIMM=FLOAT(IMM)
              RILLL=50./SQRT((RIMM/RILL)**2+1.)
              ILLL=IFIX(RILLL)
              RIMMM=50./SQRT((RILL/RIMM)**2+1.)
              IMMM=IFIX(RIMMM)
              IF(ILL.LT.0.0) GO TO 42
              ILLLL=L+ILLL
              GO TO 43
   42         ILLLL=L-ILLL
   43         IF(IMM.LT.0.0) GO TO 44
              IMMMM=M+IMMM
              GO TO 45
   44         IMMMM=M-IMMM
   45         AR(ILLLL,IMMMM)=AR(ILLLL,IMMMM)+AR(L,M)-10000.
              AR(L,M)=10000.
 4000       CONTINUE
C******************************END OF PART FOUR
C
C
C
C******************************BEGINNING OF PART FIVE
      INTEGER KAR(100,100)
      RIS=FLOAT(IS)
      SI=RIS/100.
      DO 5000 K=1,100
        DO 5000 L=1,100
        IF(AR(K,L).EQ.10000.) GO TO 52
        IF(AR(K,L).EQ.0.0) GO TO 51
        KAR (K,L)=AR(K,L)/SI
        GO TO 5000
   51   KAR(K,L)=0
        GO TO 5000
   52   KAR(K,L)=110
 5000   CONTINUE
C******************************END OF PART FIVE
C
C
C
C******************************BEGINNING OF PART SIX
   60 FORMAT(1H1)
      WRITE(6,60)
   20 FORMAT(' K',I3,100A1)
      DIMENSION PAR(30), RKUM(100)
```



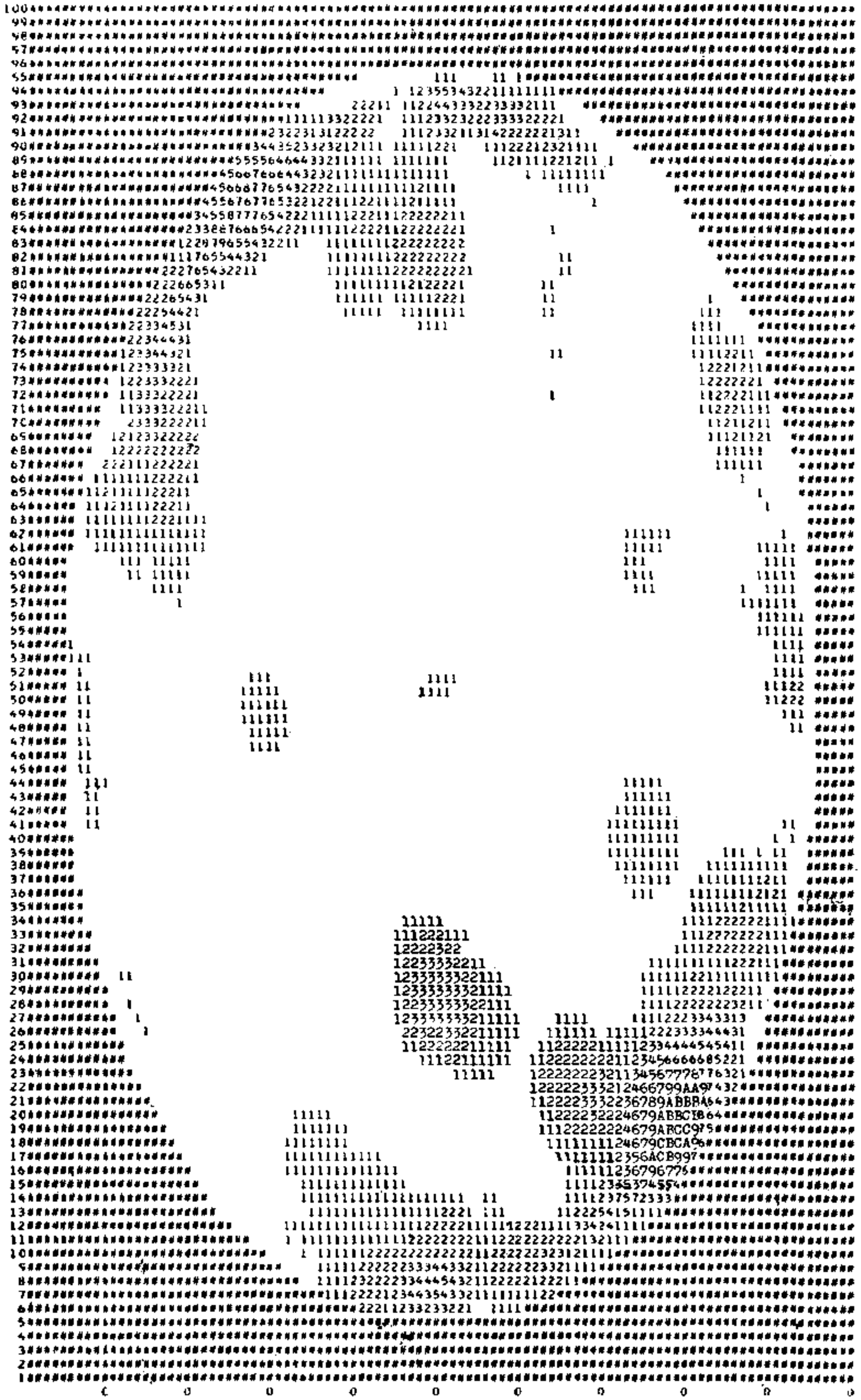
```
C********VALUES FROM 1 TO NINE WILL BE PRINTED WITH THEIR NUMERICAL VALU ES
C********VALUES GREATER THEN NINE  WILL HAVE THEIR CORESPONDING ALPHABET ICAL
C********NOTATION  STORED IN PAR ARRAY
C********VALUES SMALLER THEN 1 WILL BE LEFT BLANK
      DATA PAR/'1','2','3','4','5','6','7','8','9','A','B','C','D','E','
     1F','G','H','I','J','K','L','M','N','O','P','Q','R','S','T','U'/,
     1RKUMX/'X'/,RKUMY/' '/,RKUMZ/'#'/
      DO 6000 KLL=1,100
      K=101-KOL
        DO 6100 L=1,100
        I=KAR(K,L)
        IF(I.LT.110) GO TO 64
        RKUM(L)=RKUMZ
        GO TO 6100
   64   IF(I.GE.1) GO TO 63
        RKUM(L)=RKUMY
        GO TO 6100
   63   IF(I.LE.30) GO TO 61
        RKUM(L)=RKUMX
        GO TO 6100
   61   RKUM(L)=PAR(I)
 6100   CONTINUE
        WRITE(6,20)(K,(RKUM(L),L=1,100))
 6000   CONTINUE
      DIMENSION ICCR(10)
      DATA ICCR/10*0/
   70 FORMAT('      ',10I10)
      WRITE(6,70) ICOR
   30 FORMAT(/////)
      WRITE(6,30)
   40 FORMAT(' A=10,B=11,C=12,D=13,E=14,F=15,G=16',/' H=17,I=18,J=19,K=2
     70,L=21,M=22,N=23',/' O=24,P=25,Q=26,R=27,S=28,T=29,U=30',/' X=31-1
     700')
      WRITE(6,40)
C******************************END OF PART SIX
C
C
C
C******************************BEGINNING OF PART SEVEN
      MAX=KAR(40,40)
      DO 8000 K=1,100
        DO 8000 L=1,100
        IF(KAR(K,L).EQ.110) GO TO 8000
        IF(KAR(K,L).GT.MAX) MAX=KAR(K,L)
 8000   CONTINUE
      MAX45=(MAX*4)/5
      MAX35=(MAX*3)/5
      MAX25=(MAX*2)/5
      MAX15=MAX/5
      WRITE(6,30)
   50 FORMAT(' MAX=',I5)
      WRITE(6,50)MAX
              CALL STRTPL(10)
              REAL TETA,FI,DIA,V,W,PI/3.14159265/,PI18,PI180,DIV,SCFAC
              PI18=PI/18.
              PI180=PI/180.
              DIV=20./(2.54*90.)
```

```
ISN 0261                SCFAC=(10./2.54)/(2.*SIN((90./2.)*RADI))
ISN 0262                V=50.*DIV
ISN 0263                W=5.0*DIV
ISN 0264                CALL PLOT1(V,W,3)
ISN 0265                DO 7000  ITETA=10,90,10
ISN 0266                DIA=2*SIN(((ITETA/2)*PI18*.1)*SCFAC
ISN 0267                  DO 7000 IFI=1,361
ISN 0268                  FI=((IFI-1)*PI180
ISN 0269                  V=SIN(FI)*DIA+50.*DIV
ISN 0270                  W=COS(FI)*DIA+50.*DIV
ISN 0271                  CALL PLOT1(V,W,2)
ISN 0272      7000        CONTINUE
          C******************************END OF PART SEVEN
          C
          C
          C
          C
          C******************************BEGINNING OF PART EIGHT
ISN 0273                DIA=2*SIN((90./2.)*RADI)*SCFAC
ISN 0274                DO 7100 IFI=1,19
ISN 0275                FI=((IFI-1)*PI18
ISN 0276                V=SIN(FI)*DIA+50.*DIV
ISN 0277                W=COS(FI)*DIA+50.*DIV
ISN 0278                CALL PLOT1(V,W,3)
ISN 0279                FI=((IFI+17)*PI18
ISN 0280                V=SIN(FI)*DIA+50.*DIV
ISN 0281                W=COS(FI)*DIA+50.*DIV
ISN 0282                CALL PLOT1(V,W,2)
ISN 0283      7100      CONTINUE
ISN 0284            V4=(4.-0.5)*DIV
ISN 0285            V50=(50.0-0.5)*DIV
ISN 0286            V96=(96.-0.5)*DIV
ISN 0287            DIMENSION BCD(10)
ISN 0288            DATA  BCD/266,245,262,255,70E,170,202,75C,244/
ISN 0289            CALL SYMBL1(V4,V50,0.08,BCD(1),0.0,-1)
ISN 0290            CALL SYMBL1(V96,V50,0.08,BCD(2),0.0,-1)
ISN 0291            CALL SYMBL1(V50,V4,0.08,BCD(3),0.0,-1)
ISN 0292            CALL SYMBL1(V50,V96,0.08,BCD(4),0.0,-1)
ISN 0293            DO 8100 K=1,100
ISN 0294              DO 8100 L=1,100
ISN 0295              IF(KAR(K,L).LE.1.OR.KAR(K,L).GT.105) GO TO 8100
ISN 0297              IF(KAR(K,L).LE.MAX45) GO TO 82
ISN 0299              ERK1=K
ISN 0300              ERK2=(ERK1-0.5)*DIV
ISN 0301              ERL1=L
ISN 0302              ERL2=(ERL1-0.5)*DIV
ISN 0303              CALL SYMBL1(ERL2,ERK2,0.08,BCD(5),0.0,-1)
ISN 0304              GO TO 8100
ISN 0305       82     IF(KAR(K,L).LE.MAX35) GO TO 83
ISN 0307              ERK1=K
ISN 0308              ERK2=(ERK1-0.5)*DIV
ISN 0309              ERL1=L
ISN 0310              ERL2=(ERL1-0.5)*DIV
ISN 0311              CALL SYMBL1(ERL2,ERK2,0.08,BCD(6),0.0,-1)
ISN 0312              GO TO 8100
ISN 0313       83     IF(KAR(K,L).LE.MAX25) GO TO 84
ISN 0315              ERK1=K
```



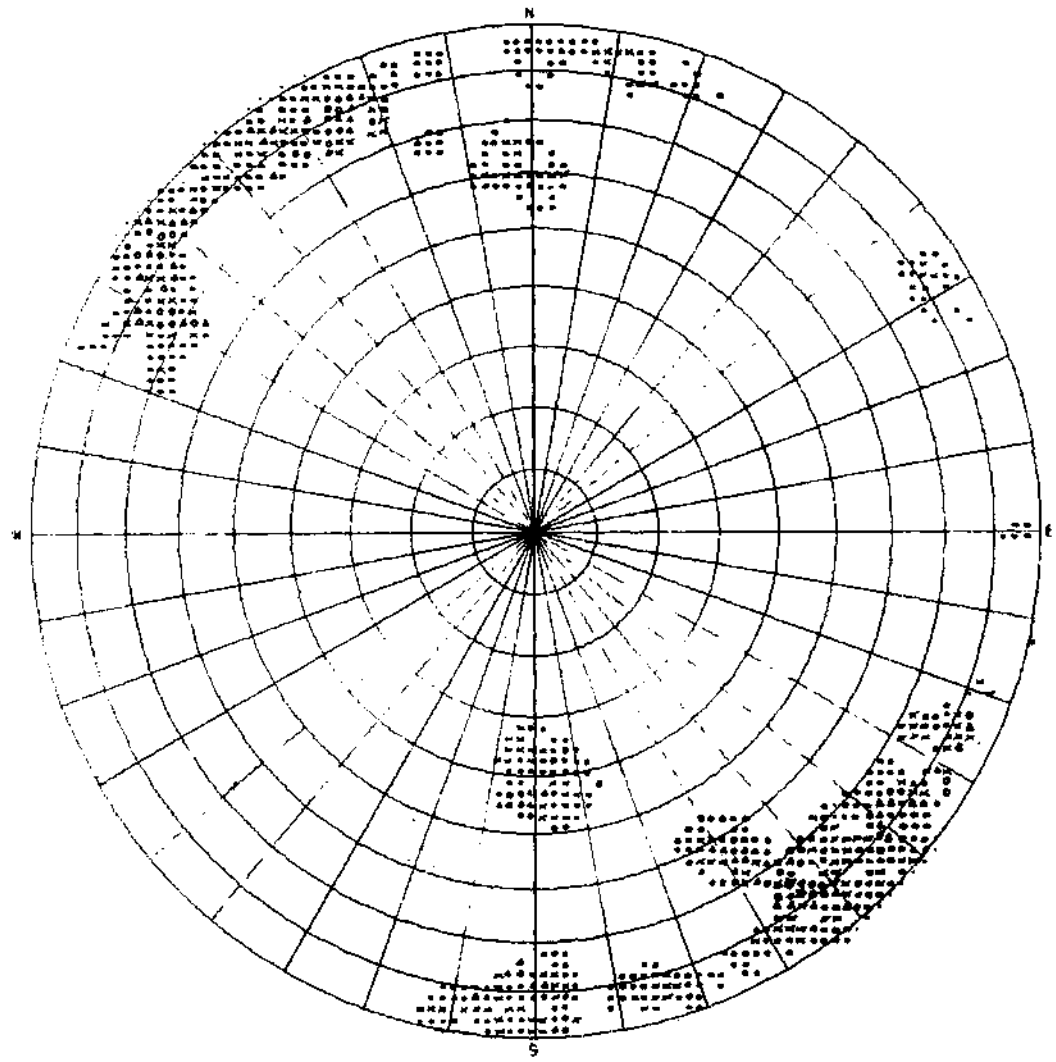
```
ISN 0316              ERK2=(ERK1-0.5)*DIV
ISN 0317              ERL1=L
ISN 0318              ERL2=(ERL1-0.5)*DIV
ISN 0319              CALL SYMBL1(ERL2,ERK2,0.08,BCD(7),0.0,-1)
ISN 0320              GO TO 8100
ISN 0321       84     IF(KAR(K,L).LE.MAX15) GO TO 85
ISN 0323              ERK1=K
ISN 0324              ERK2=(ERK1-0.5)*DIV
ISN 0325              ERL1=L
ISN 0326              ERL2=(ERL1-0.5)*DIV
ISN 0327              CALL SYMBL1(ERL2,ERK2,0.08,BCD(8),0.0,-1)
ISN 0328              GO TO 8100
ISN 0329       85     IF(MAX.LT.5) GO TO 8100
ISN 0331              ERK1=K
ISN 0332              ERK2=(ERK1-0.5)*DIV
ISN 0333              ERL1=L
ISN 0334              ERL2=(ERL1-0.5)*DIV
ISN 0335              CALL SYMBL1(ERL2,ERK2,0.08,BCD(9),0.0,-1)
ISN 0336     8100     CONTINUE
ISN 0337             CALL ENDPL
          C******************************END OF PART EIGHT
ISN 0338            RETURN
ISN 0339            END
```

BETA DIAGRAM DRAWN BY LINE PRINTER DURING A TEST RUN OF THE PROGRAM



A=10,B=11,C=12,D=13,E=14,F=15,G=16
H=17,I=18,J=19,K=20,L=21,M=22,N=23
O=24,P=25,Q=26,R=27,S=28,T=29,U=30
X=31-100

MAX= 12



Beta diagram entirely drawn by CALCOMP plotter during a test run of the program. (Original diameter was 20 cm. The symbols are darkened by hand for printing purposes)