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AUTOMATIC CONTOURING OF GEOPHYSICAL DATA USING BICUBIC SPLINE INTERPOLATION

(Report and 7 figures)

M. T. Holroyd and B. K. Bhattacharyya

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DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

A method for automatic contouring of two-dimensional geophysical data is presented in this paper. The method is based on piecewise bicubic spline representation of uniformly-gridded data points derived from irregularly-spaced observations. The testing of this method has been carried out with a set of data digitized along flight lines at points of intersection with contour lines on a published aeromagnetic map. The map is conspicuous by the presence of steep gradient as well as broad, smoothly-varying regions. A critical examination of the machine-contoured map with respect to the published hand-drawn map establishes the accuracy and reliability of the automatic contouring program. In this paper a short account of bicubic splines is followed by a description of the contouring program, the input data required by the program, and the results.

AUTOMATIC CONTOURING OF GEOPHYSICAL DATA USING BICUBIC SPLINE INTERPOLATION

INTRODUCTION

Basic geological and geophysical data, when available in two-dimensional form, are normally presented as a contoured map. The map compiler relies basically on linear interpolation between data points and manual smoothing. In the process of contouring the compiler is greatly influenced by the trends and characteristic patterns apparent in the data. So the contoured map is essentially a product of his subjective interpretation of the patterns in the data, his ability to perform rapid linear interpolation and his skill in smoothing. The accuracy with which the map is drawn determines to a large degree the nature of application of the map to the problem of delineating geological features. For example, on an aeromagnetic map, the broad characteristics such as the direction and extent of a particular trend and the linear feature corresponding to a major fault stand out prominently and the degree of accuracy of the map can, therefore, be relaxed considerably. However, for detailed geological mapping and for thorough investigation of important anomalies, various quantitative methods of interpretation have to be used. Many such methods employ not only the amplitudes of the magnetic field but also its gradient and curvature. Thus in order that the results of interpretation become reliable, the amplitude, gradient and curvature of the field should be accurately maintained in the map. To achieve this objective, the interpolation scheme used for the production of aeromagnetic maps should provide continuity of the field, its gradient and curvature at all the data points and should introduce the minimum amount of smoothing.

An automatic machine contouring method has some distinct advantages over manual contouring. Firstly, there is a reduction in time between the acquisition of data and its presentation in the form of a map. Secondly, the map is contoured objectively. Thirdly, accurate interpolation schemes can be used. This third factor is the most important of all because the interpolated positions of the contours between the original data points determine essentially the accuracy of the map.

There have been a few papers recently on automatic contouring of two-dimensional data. Smith (1968) proposed a method of interpolation in which a circle or an ellipse of specified shape and angle of rotation is used to define a neighbourhood around a grid point. An average of the values of the independent variable in this neighbourhood, each weighted by the reciprocal of distance from the grid point or by the reciprocal of square of that distance or by some mixture of the two, is computed and stored at the grid point. Smith also tried to use a priori information on strike of the causative body to influence contouring.

Pelto *et al.* (1968) described a method of automatic contouring of irregularly spaced data. The method consists of three steps. Firstly, in

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regions with few or no observations, control values are interpolated by either linear or nonlinear methods. Secondly, a regional polynomial surface, commonly of eighth or twelfth degree, is fitted by least squares to the original and interpolated control points. Thirdly, a moving, weighted, least squares surface, which is essentially a continuous surface of first or second degree, with smoothly varying parameters, is forced to pass through the deviations between the regional surface and the observations. In this process all data points are weighted according to an inverse power of distance from the grid point. The final product of this method of contouring looks very similar to hand-drawn maps for smoothly-varying data.

It is obvious that the quality of the contoured map depends largely on the method of interpolation used, not only in the reduction of irregularly-distributed data to equispaced form but also in determining the co-ordinates of the points along individual contours. Crain and Bhattacharyya (1967) evaluated various methods of interpolation currently in use at many places, developed some new methods and published the results of application of these methods to actual aeromagnetic data. Of all the methods, only two, the Gram-Schmidt orthogonalization procedure and the quadratic, weighted-average method, are found to be satisfactory for interpolation in regions characterized by smooth and gentle variations of the observed variable. The results obtained with these methods in the presentation of small-scale features and large gradients in an aeromagnetic map are, in general, not of high quality and cannot surpass the performance achieved by manual contouring of the data.

For the above reasons a new technique using spline interpolation (Bhattacharyya, 1969) has been recently developed for computing values of an observed variable at equispaced points along two orthogonal directions with the help of irregularly-distributed data. The interpolation technique applied to aeromagnetic data obtained along nonlinear flight lines shows high resolution by maintaining the separation of neighbouring anomalies and small-scale features. The shapes, peaks and troughs of both large and small amplitude anomalies are faithfully reproduced. The gradients of the magnetic field are not found to undergo any appreciable distortion.

The excellent quality of the results obtained with spline interpolation suggests its use in the possible development of a good automatic method for contouring two-dimensional geophysical data. A method so developed is presented in this paper. The details of treatment of irregular observations for computing field values at regular grid points are given in the paper by Bhattacharyya (1969). In this paper it is therefore assumed that regular gridded data in two orthogonal directions are readily available. A short account of bicubic splines which are extensively used in the contouring method, precedes the description of the contouring program, the data to be contoured and the results. Finally, a listing of the program in FORTRAN language written for IBM 360 system is given.

BICUBIC SPLINES

Thin elastic splines are used by a draftsman to draw a smooth curve through a number of given points under the constraint of maintaining the continuity of slopes and curvatures along the curve. The bicubic spline interpolation method is a numerical analog of the draftsman's method for plotting curves in two dimensions. The interpolation scheme essentially generates piecewise cubic polynomials representing the field function in every interval between points of observation. For this generation, the scheme utilizes the continuity of the function and its first two successive derivatives at all data points. The potential strength of this method lies in the fact that the function and its slope and curvature are made continuous throughout the area of observations.

Let the values of a function $g(x, y)$ of two variables (x, y) be given at mesh-points $i = 0, 1, \ldots, M$ and $j = 0, 1, \ldots, N$. At the point (i, j) the value of the function is denoted by g_{ij}. The piecewise polynomial function, defined in each rectangular cell

$$x_{i-1} \leq x \leq x_i, \; y_{j-1} \leq y \leq y_j$$

of the grid, is of the following form

$$r_{ij} = \sum_{m=0}^{3} \sum_{n=0}^{3} a_{mn}^{ij} \; (x-x_{i-1})^m . (y-y_{j-1})^n . \tag{1}$$

In order to determine the coefficients a_{mn}^{ij}, it is required to know the derivatives at the boundary points of each cell, i.e.,

$$p_{ij} = g_x(x_i, y_j), \; q_{ij} = g_y(x_i, y_j), \tag{2}$$

and

$$s_{ij} = g_{xy}(x_i, y_j),$$

where the variables with respect to which $g(x, y)$ has been differentiated, are indicated in the subscripts of g.

Let there be known values of

$$p_{ij}, \; i = 0, M; \; j = 0, 1, \ldots, N,$$

$$q_{ij}, \; i = 0, 1, \ldots M; \; j = 0, N,$$

and s_{ij}, $i = 0, M; \; j = 0, N.$

Then it may be shown (DeBoor, 1962) that for the above values and the values of g_{ij} at the mesh-points, there exists one and only one piecewise bicubic polynomial of the form (1).

If g_{ij}, p_{ij}, q_{ij} and s_{ij} are known at all the mesh-points and if the station-spacing is assumed to be unity, the coefficients a_{mn}^{ij} are given by

$$a_{oo}^{ij} = g_{i-1,\, j-1}, \; a_{lo}^{ij} = p_{i-1,\, j-1},$$

$$a_{ol}^{ij} = q_{i-1,\, j-1}, \; a_{11}^{ij} = s_{i-1,\, j-1},$$

$$a_{02}^{ij} = \left[3\,(g_{i-1,\, j} - g_{i-1,\, j-1}) - (q_{i-1,\, j} + 2\, q_{i-1,\, j-1})\right],$$

$$a_{03}^{ij} = \left[(q_{i-1,\, j} + q_{i-1,\, j-1}) - 2(g_{i-1,\, j} - g_{i-1,\, j-1})\right],$$

$$a_{12}^{ij} = \left[3(p_{i-1,\, j} - p_{i-1,\, j-1}) - (s_{i-1,\, j} + 2\, s_{i-1,\, j-1})\right],$$

$$a_{13}^{ij} = \left[(s_{i-1,\ j} + s_{i-1,\ j-1}) - 2(p_{i-1,\ j} - p_{i-1,\ j-1})\right],$$

$$a_{20}^{ij} = \left[3(g_{i,\ j-1} - g_{i-1,\ j-1}) - (p_{i,\ j-1} + 2p_{i-1,\ j-1})\right],$$

$$a_{21}^{ij} = \left[3(q_{i,\ j-1} - q_{i-1,\ j-1}) - (s_{i,\ j-1} + 2\ s_{i-1,\ j-1})\right],$$

$$a_{22}^{ij} = 9\ \gamma_1 - 3\gamma_2 - 3\gamma_3 + \gamma_4,$$

$$a_{23}^{ij} = -6\ \gamma_1 + 2\gamma_2 + 3\gamma_3 - \gamma_4,$$

$$a_{30}^{ij} = \left[(p_{i,\ j-1} + p_{i-1,\ j-1}) - 2(g_{i,\ j-1} - g_{i-1,\ j-1})\right],$$

$$a_{31}^{ij} = \left[(s_{i,\ j-1} + s_{i-1,\ j-1}) - 2(q_{i,\ j-1} - q_{i-1,\ j-1})\right],$$

$$a_{32}^{ij} = -6\ \gamma_1 + 3\gamma_2 + 2\gamma_3 - \gamma_4,$$

and $a_{33}^{ij} = 4\ \gamma_1 - 2\gamma_2 - 2\gamma_3 + \gamma_4,$

where $\gamma_1 = (g_{ij} + g_{i-1,\ j-1} - g_{i,\ j-1} - g_{i-1,\ j}) + (p_{i-1,\ j-1} - p_{i-1,\ j} + q_{i-1,\ j-1} - q_{i,\ j-1}) + s_{i-1,\ j-1},$

$$\gamma_2 = p_{i-1,\ j-1} - p_{i,\ j-1} - p_{i-1,\ j} + s_{i-1,\ j-1} - s_{i,\ j-1},$$

$$\gamma_3 = q_{ij} + q_{i-1,\ j-1} - q_{i-1,\ j} - q_{i,\ j-1} + s_{i-1,\ j-1} - s_{i-1,\ j},$$

and $\gamma_4 = s_{ij} + s_{i-1,\ j-1} - s_{i,\ j-1} - s_{i-1,\ j}.$

The derivatives in the above set of equations for the coefficients can be evaluated by assuming the continuity of the following derivatives at all the interior mesh-points:

$g_{xx}(x_i,\ y_j)$, $g_{yy}(x_i,\ y_j)$, and either

$g_{x^2y}(x_i,\ y_j)$ or $g_{xy^2}(x_i,\ y_j)$.

The continuity of $g_{x2y}(x_i, y_j)$ has been used in the calculations presented in this paper. The scheme used for evaluating p_{ij}, q_{ij} and s_{ij} are briefly indicated in the following:

(i) Calculation of p_{ij}:

For each of the lines $j = 0, 1, \ldots N$, the observed values g_{ij} are represented by piecewise cubic polynomials in each of the intervals (x_{i-1}, x_i), $i = 1, \ldots, N$. Assuming the continuity of second derivatives at all the knots, we have (Bhattacharyya, 1969)

$$p_{i+1,\ j} + 4p_{i,\ j} + p_{i-1,\ j} = 3(g_{i+1,\ j} - g_{i-1,\ j}), \quad i = 1, \ldots, M-1. \tag{3}$$

The two other equations necessary for solving all the p_i's are provided by the conditions

$$g_{xx}(x_i, y_j) = 0,\ i = 0, M;\ j = 0, 1, \ldots N. \tag{4}$$

The assumption of the second derivatives being equal to zero at the end points of a given profile keeps the integral-square measure of approximation to the second derivative at a minimum value (Holladay, 1957; Walsh *et al.*, 1962).

(ii) Calculation of q_{ij}:

The equations for q are similar to those of p and are given below:

$$q_{i,\ j+1} + 4\,q_{ij} + q_{i,\ j-1} = 3(g_{i,\ j+1} - g_{i,\ j-1}), \quad j = 1, \ldots, N-1;\ i = 0, \ldots, M. \tag{5}$$

and

$$g_{yy}(x_i, y_j) = 0,\ i = 0, 1, \ldots M;\ j = 0, N. \tag{6}$$

(iii) Calculation of s_{ij}:

For computing s_{ij}, the values of p and q in (3) and (5) are used:

(a) For $j = 0, N$

$$s_{i+1,\ j} + 4\,s_{ij} + s_{i-1,\ j} = 3(q_{i+1,\ j} - q_{i-1,\ j}),\ i = 1, \ldots, M-1. \tag{7}$$

and $$g_{x^2y}(x_i, y_j) = 0,\ i = 0, M;\ j = 0, N. \tag{8}$$

(b) For $i = 0, 1, \ldots, M$

$$s_{i,\ j+1} + 4\,s_{ij} + s_{i,\ j-1} = 3(p_{i,\ j+1} - p_{i,\ j-1}),\ j = 1, \ldots, N-1. \tag{9}$$

The tridiagonal linear equations (3)-(9) are solved by standard methods. With the values of p, q, s thus determined it is now very straightforward to evaluate all the bicubic spline coefficients.

DETAILS OF THE CONTOURING PROGRAM

A. CONTROL CARDS:

These cards control the details of execution of the program by specifying the data grid, strip height, block width, subgrid numbers, scale, contour interval and title of the map. Some of these parameters are self-explanatory and the rest will be explained in the following paragraphs. Control parameters also determine whether the whole map or one detailed section of the map will be drawn. The total number of blocks per strip and strips per map and their physical dimensions are computed in the program. As will be noted later, various other optional features are available in the program.

B. BICUBIC SPLINE COEFFICIENTS:

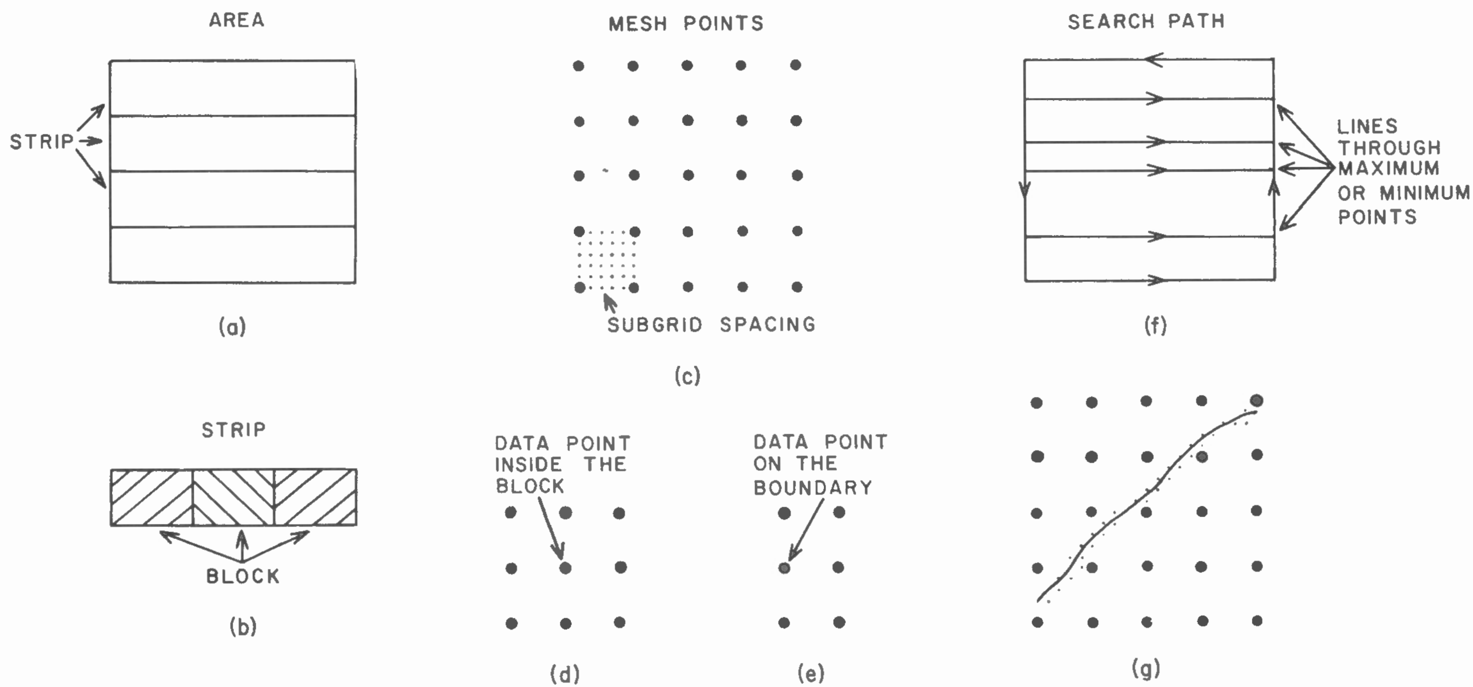
The bicubic spline coefficients are calculated in one operation for the basic data covering the whole area under study. There are sixteen coefficients for each rectangular cell defined by four adjacent mesh points. These coefficients are written on a magnetic tape sequentially from left to right for each row of cells beginning with the southernmost row.

Requirements for computer core storage have to be an acceptable maximum and provision has to be made in the program for coping with large and variable amounts of basic data. It is, therefore, not possible in the majority of cases to consider the whole area of the map for contouring in a single operation. Consequently, the given area is normally divided into a number of strips (Fig. 1a). A strip is defined by the whole width of the area and a specified number of cells in height. A strip is broken up into a number of blocks, each block covering the full height of the strip and a specified number of cells in width (Fig. 1b). This partitioning of the area is needed to keep the working storage requirements for contouring within prescribed limits. In order to achieve this objective, the height of the strip must be inversely proportional to the width. This scheme may occasionally give rise to strips of very small height and exceedingly large width. It is then necessary to divide the original rows of rectangular cells into smaller units of selected width and write the bicubic spline coefficients in the output magnetic tape in the fashion described before for each of these units. The perfect matching of the contours at the boundaries of the blocks is guaranteed by the way spline coefficients are calculated for the basic data.

It is now evident that regardless of the number of units into which the area is divided, the spline coefficients for a specific strip are considered alone for the process of contouring. When the contouring for the strip is completed, the spline coefficients for the next strip are obtained from the input tape for computation.

At this stage it should be noted that a control parameter, called subgrid spacing (Fig. 1c), which is a small fraction of the side of a rectangular cell, is so chosen that linear interpolation between two points separated by the subgrid spacing is valid anywhere in the whole area. The smoothness of the contoured map and the computation time depend on this parameter.

Values of the field to be plotted are calculated at every subgrid interval around the periphery of the block and along certain selected lines crossing the block parallel to its lower boundary. To trace the contours across the block, values of the field are calculated with the bicubic spline coefficients only at those subgrid points which lie in the neighbourhood of the passing contours. The locations of points on the contours are determined by linear interpolation between the values at subgrid points.



(a) An area divided into strips;
(b) A strip divided into blocks;
(c) Mesh points and the subgrid spacing;
(d) Mesh points immediately adjacent to a data point inside the block for finding out relative maximum or minimum points;
(e) Same as in (d) for a data point on the boundary of a block;
(f) Search path;
(g) Subgrid points close to a contour to be traced.

Figure 1. Diagrammatic representation of program steps.

C. STEPS OF COMPUTATION IN A BLOCK:

The block at the extreme left of the strip is first considered. The major steps of computation in a block are given below:

(i) Search for relative maxima and minima:

The data values are searched for relative maxima and minima from left to right row by row beginning with the southernmost row (Fig. 1d, e). The value of the field at a data point is compared with the values of the mesh points immediately adjacent to it for establishing a relative maximum or minimum (SUBROUTINE MAXMIN). The gradient of the field in the two orthogonal directions at such a point, calculated with the help of the spline coefficients, are used to locate correctly the cell containing the relative maximum or minimum point. If the cell lies within the block, the exact location of this point is determined by linear interpolation between the field values at the subgrid points within the cell. The significance of this maximum or minimum point with regard to the process of contouring is then tested and it is rejected if no contours traverse between the point and either the block boundary or the horizontal line through the previous maximum or minimum. The locations and values of all significant points are stored for future reference.

(ii) Location of contour intercepts:

With the help of bicubic spline coefficients the field values are calculated at all points separated by the subgrid interval along a 'search path' (Fig. 1f). These values are then used to find the absolute maximum and minimum within the given block and thus to ascertain the range of contours within the block. The starting point of the 'search path' is at the southwest corner of the block. This path first traverses anticlockwise along the boundary of the block and then from left to right along the horizontal lines passing through the significant maxima and minima points. The alternate points of intersection of each contour value with this path are determined by linear interpolation of the field values at subgrid points. The locations of these intersections are recorded as linear distances from the starting point to the contour intercepts along the 'search path'. If the range of contour values within the block is too great for the reserved working storage, the range is suitably divided into smaller groups. Each group is treated separately (SUBROUTINE CFIND).

(iii) Contour tracing:

In this step the locations of contour intercepts, as stored above, are converted from a linear co-ordinate to (x, y) co-ordinates (SUBROUTINE CSTART). The field values at only those subgrid points which are adjacent to the path of a contour to be traced, are calculated with the appropriate bicubic spline coefficients (Fig. 1g). These values are used to compute the (x, y) co-ordinates of the points necessary for drawing a particular contour. It is to be noted that by considering only the subgrid points in the vicinity of desired contours, computation time is made inversely proportional to the subgrid interval rather than to the square of the interval. The field values at the subgrid points are stored until all the contours in the block are traced.

In the case of contours originating on the boundary of the block, the storage of their alternate intersections with the search path precludes the possibility of a contour being traced twice or missed altogether. Because of this particular process of storage, contours originating on one of the internal maximum or minimum lines could not be missed but might be traced more than once. To prevent the possibility of retracing the same contour, any stored contour intercept on a maximum or minimum line, once considered in the process of tracing, is cancelled. Tracing is terminated when either a boundary is encountered or a contour returns to its starting point.

Due to sharp changes in horizontal gradients of the field, it is often not feasible to trace all the contours according to the contour interval specified in the control card. To avoid tracing a host of contours which will never appear on the map, the local contour density is checked every tenth point along selected contours. This density determines the contours to be traced. The method of checking the density will be described later.

For each point on a contour, its (x, y) co-ordinates and the difference between the field values at the two adjacent subgrid points are stored (SUBROUTINE CTRACE).

(iv) Contour drawing and labelling:

In the case of geological and geophysical data, particularly aeromagnetic data, a large variation in horizontal gradient is normally found over an area. A procedure is, therefore, incorporated in the program to achieve adequate contouring in regions of low gradient and to avoid crowding of the contours in places of high gradient.

As has been noted in the previous section, the differences between the field values at subgrid points lying on both sides of traced contours are stored. With this array of differences the contour density about each point on the contour is estimated. This density is averaged over a moving window of several points. The average value at a point of the contour is used to determine whether the contour shall be drawn, terminated or omitted. Values of the contour density are averaged in order to smooth out its fluctuations which may cause repeated termination and recommencement of a contour, thus simulating a dashed line. An input parameter allows the size of the moving window to be varied.

If the minimum value of the contour density at a series of points on a contour allow a label to be written without overwriting adjacent contours, a suitable short segment of the contour is replaced by a label. The centres of the numerals which make up the label, lie on a parabola fitted to the ends and midpoint of the omitted contour segment. Due to the necessary simplicity of the tests applied, labels may occasionally overwrite adjacent contours or labels. This problem may be minimized by narrowing the criteria for insertion of labels, thus reducing their total number (SUBROUTINES CDRAW and CLABEL). One of the control parameters read as input to the contouring program specifies the minimum separation between adjacent contours which permits a label to be inserted. This separation is expressed in terms of label numeral height.

Five orders of contour are defined within the program. Different types of line are drawn to distinguish between the orders. They are given below:

Order	Type of line	Multiples of basic contour interval
5	Solid, bold, beaded	Every 50th contour
4	Solid, bold	Every 10th contour
3	Solid	Every 5th contour
2	Dashed	Every 2nd (even) contour
1	Dotted	Remainder

The types of line and corresponding multiples of basic contour interval are specified as control parameters of the program.

D. PROGRAM OPTIONS:

In the initial stages of development of the contouring program, it was attempted to determine automatically an appropriate subgrid spacing for each individual block. The values of the curvature of the field obtained from the bicubic spline coefficients were tested along both axial directions at each of the data points. The maximum value of these curvatures was used to determine the suitable subgrid spacing. The resulting contours were remarkably smooth in every block and the computation time was kept to a reasonable magnitude. However, it was noted that contours did not match perfectly at the boundary of two adjacent blocks with different subgrid spacings. Moreover, highly complex data may result in extremely fine or coarse subgrid spacing in some regions. Because of these reasons, the method has not been used in the program presented in this paper. This method is, however, recommended for use with data having not too many big variations or in cases of production of preliminary maps and large scale maps of a single anomaly.

Sometimes after production of a map it is found that for detailed studies different sections of the map have to be replotted in a smaller scale. For this reason it is a good idea to split the program in two stages. In the first stage all possible contours are traced and the arrays defining them are written on a magnetic tape. In the second stage this tape is used for plotting the desired contours according to the required scale and labelling. In this way the whole map or any particular section can be drawn with different combinations of scale, contour interval, type of line and labelling with modest computation time and storage requirement.

TEST OF THE CONTOURING PROGRAM

DATA:

In Figure 2 a redrafted version of an aeromagnetic map published by the Geological Survey of Canada is presented. The contouring of this map has been done manually. The basic data needed for production of this map has been used for testing the efficiency of the automatic contouring program. It is to be noted that the same set of data played an important role in the studies of different interpolation methods applicable to nonuniformly spaced data (Crain and Bhattacharyya, 1967; Bhattacharyya, 1969). The main reason for using these data in all these studies is the conspicuous presence of very steep gradients as well as broad, smoothly-varying regions of the map.

The flight lines spaced about one-half mile apart are indicated by thin lines in Figure 2. The data in the map were digitized only along flight lines at points of intersection with contour lines with the aid of an electronic coordinatograph. Figure 3 presents the locations of the digitized data points marked by crosses and the best-fitting straight lines passing through them. It is evident from these two figures that the spacings between flight lines are not uniform, varying from one-quarter of a mile to 0.69 mile. However, for a great majority of the lines, the line-spacing is approximately one-half mile.

With the help of the method described in the paper by Bhattacharyya (1969), the nonequispaced data was reduced to regular gridded data. The area containing this regular data is outlined by dashed lines in Figure 2. The data available for the contouring program consists of 137 points by 119 points in the north-south and east-west directions respectively at a uniform spacing of one-eighth of a mile. Because it was found in earlier studies that a spacing of one quarter mile was sufficient for depicting practically all the details of the map, a set of data containing 69 points by 60 points at a uniform interval of one-quarter of a mile is extracted from the regular data for the present study.

ANALYSIS AND RESULTS:

The bicubic spline coefficients for the whole set of data are computed in one operation. Figure 4 presents a continuous profile along a least squares line, as shown in Figure 3, calculated with the help of the spline coefficients. The dots in the figure indicate the original flight line data values

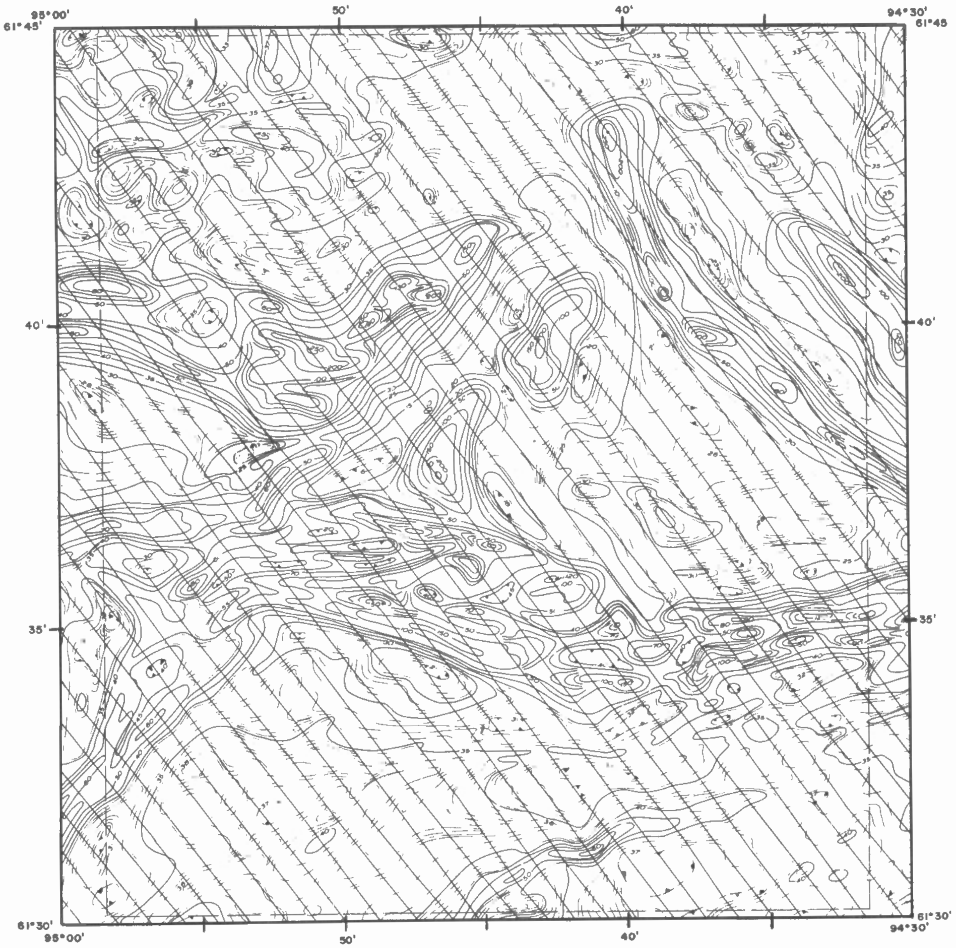


Figure 2. An aeromagnetic map from the Canadian Northwest Territories contoured in units of 100 gammas.

along the same profile. The correspondence between the actual and interpolated values is regarded as extremely good. The discrepancy between the two sets of values around some of the peaks is due to the insufficiency of the chosen grid spacing for proper definition of the peaks. However, to decrease the spacing for a better matching of the two curves will normally increase the total number of data points to an unmanageable level. The amount of smoothing introduced by spline interpolation at the peaks is, therefore, considered tolerable for practically all purposes and a reasonable compromise between conflicting requirements.

Within the automatic contouring program the data is contoured as 42 independent blocks. The complete machine-contoured map is shown in Figure 5. In the original scale of one inch to one mile of the published aeromagnetic map, it is not possible to detect the block boundaries by visual inspection.

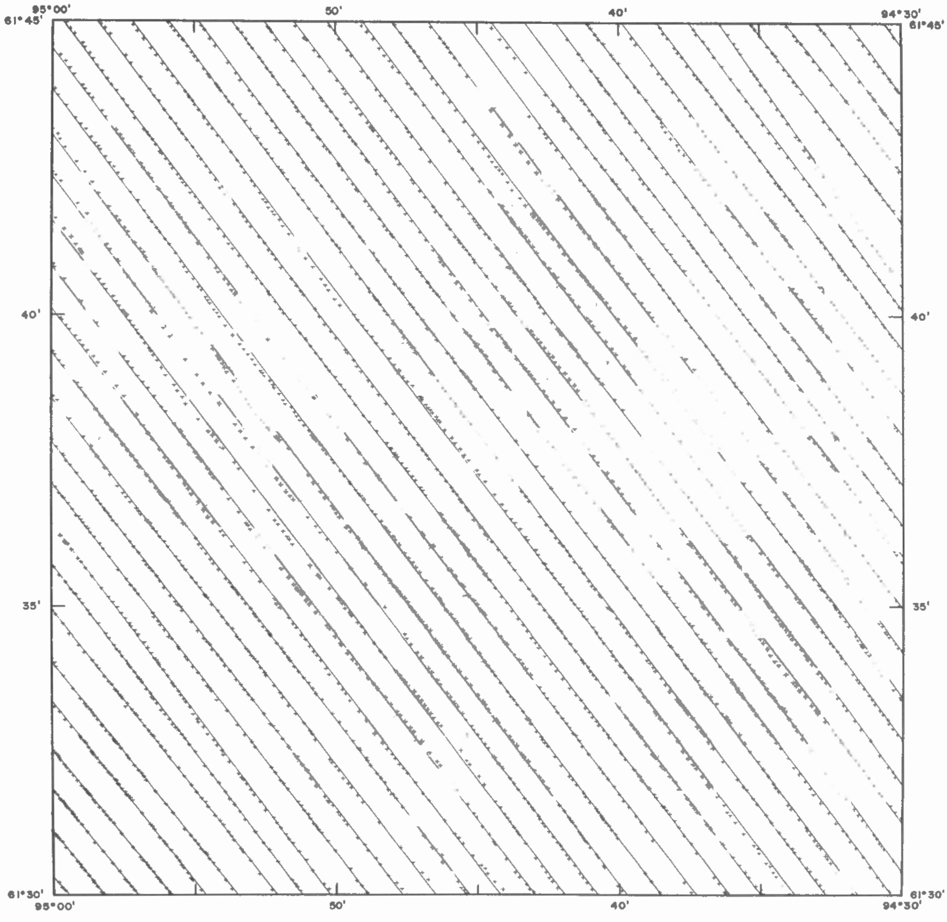


Figure 3. Best-fitting straight lines approximating actual flight lines from Figure 2 with locations of data marked by crosses.

To trace the contours in Figure 5, values of the field are calculated with the bicubic spline coefficients at the subgrid points being immediately adjacent to the passing contours. The subgrid interval has been chosen to be 1/32 inch. The final tracing of the contours is done by linear interpolation between subgrid values. The positions of the contours so determined may differ from those calculated exactly with bicubic spline interpolation by less than the thickness of the drawn line in the worst case and by a small fraction of this thickness in the majority of cases.

The basic contour interval in Figure 5 is 100 gammas. The interval between adjacent contours increases gradually with the horizontal gradient in the map from 100 gammas to a maximum of 5,000 gammas in regions of highest gradient at steps of 200, 500 and 1,000 gammas. As is evident in Figure 4, this automatic increase in contour interval up to 50 times the specified basic value does not give rise to any region in the map with excessive or inadequate coverage.

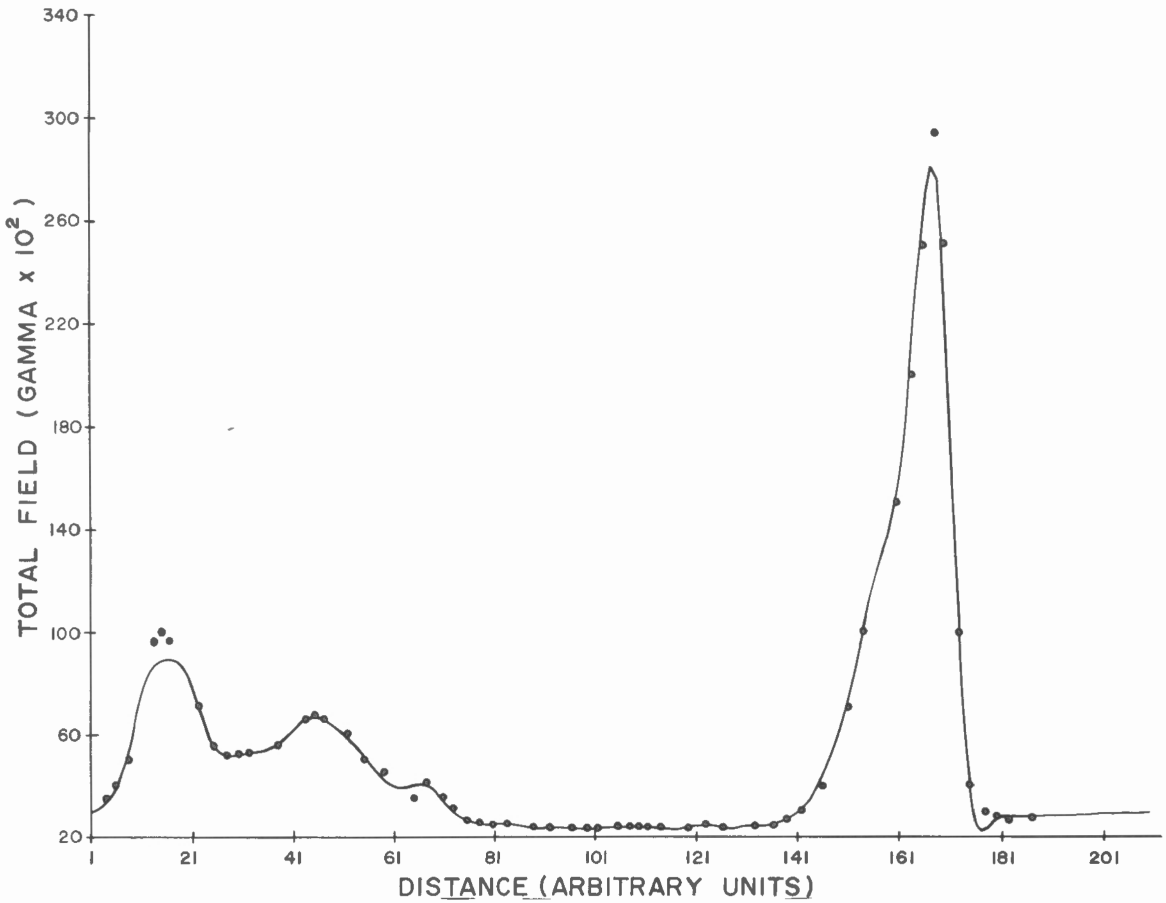


Figure 4. A continuous profile along one of the least squares lines in Figure 3 calculated with the help of spline coefficients fitted to the data marked by dots.

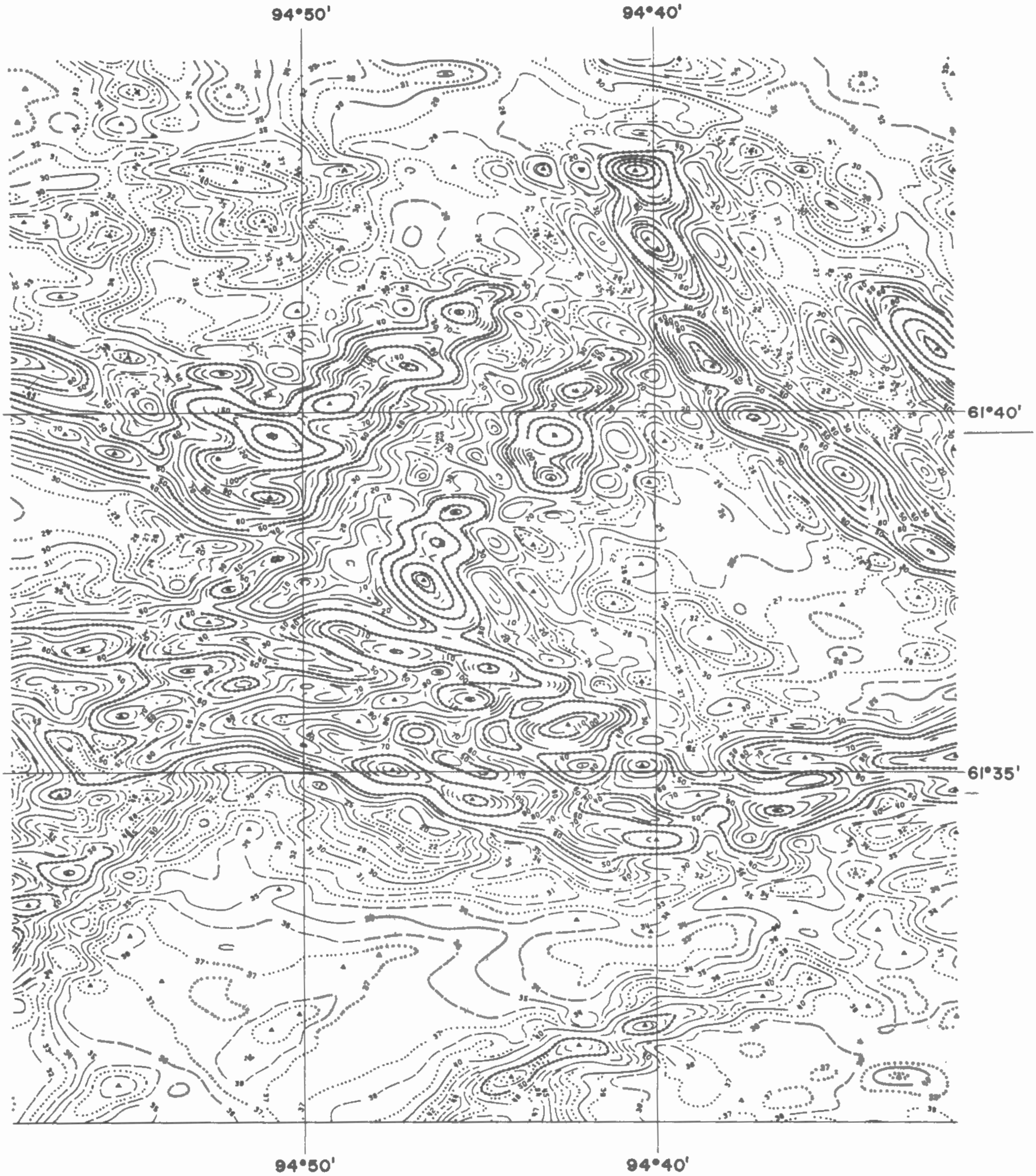


Figure 5. Machine-contoured map of the digitized data, the locations of which are given by Figure 3. The basic contour interval is 100 gammas.

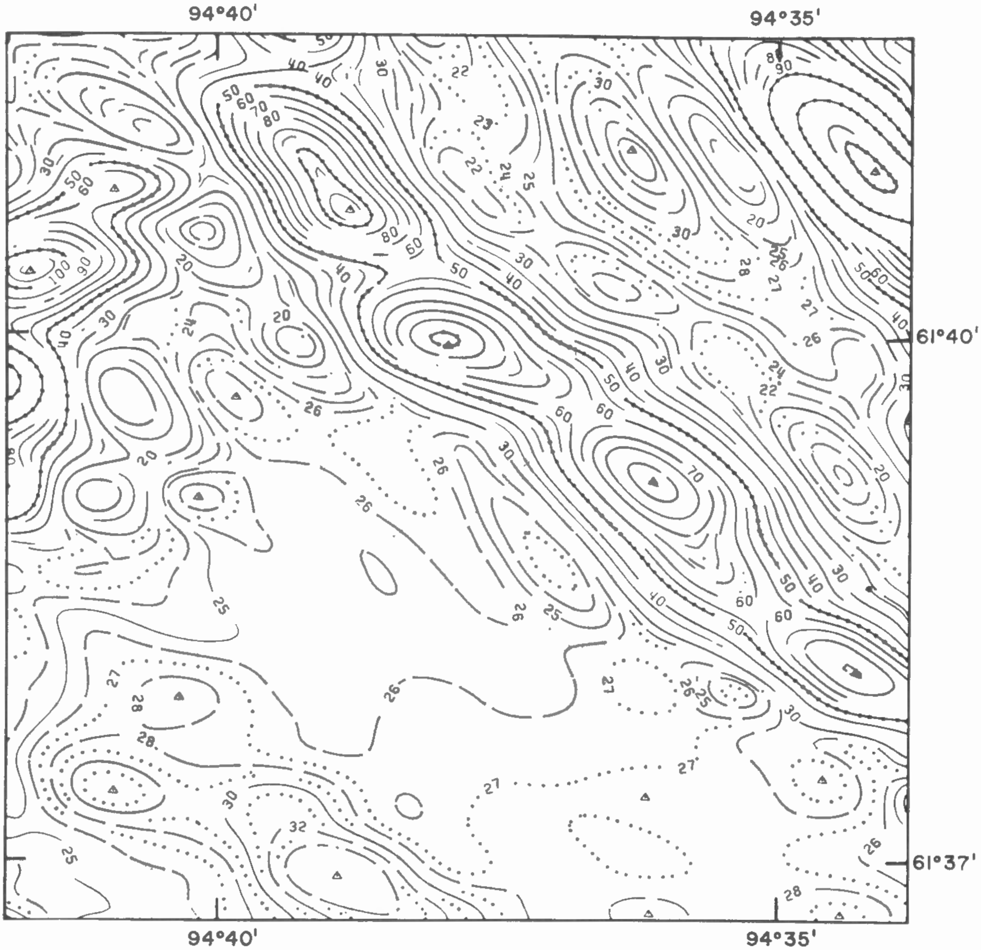


Figure 6. A northwesterly-trending group of anomalies with very steep gradients. This diagram shows the effects of the contour termination and labelling.

The very high resolution of the map presented in Figure 5 is borne out by the separation of neighbouring anomalies and good representation of small-scale features. The shapes of the anomalies are well maintained. The peaks and troughs of both large- and small-scale anomalies are faithfully reproduced. The gradients of the magnetic field in Figure 5 appear to be correct and this is very important from the point of quantitative interpretation of data.

The machine-contoured map (Fig. 5) differs in one respect from the hand-drawn map (Fig. 2). There are more closures of contours and so more isolated anomalies in Figure 5 in comparison to those in Figure 2. An examination of the hand-drawn map reveals a tendency on the part of the compiler to maintain trends beyond the supporting ability of the data. This tendency results in linking a series of contour intercepts across several flight lines by a single continuous contour rather than closing off the contour between flight lines in the absence of definite indication from the data. So it is concluded that Figure 5 presents a more objectively contoured version of the available data than does Figure 2.

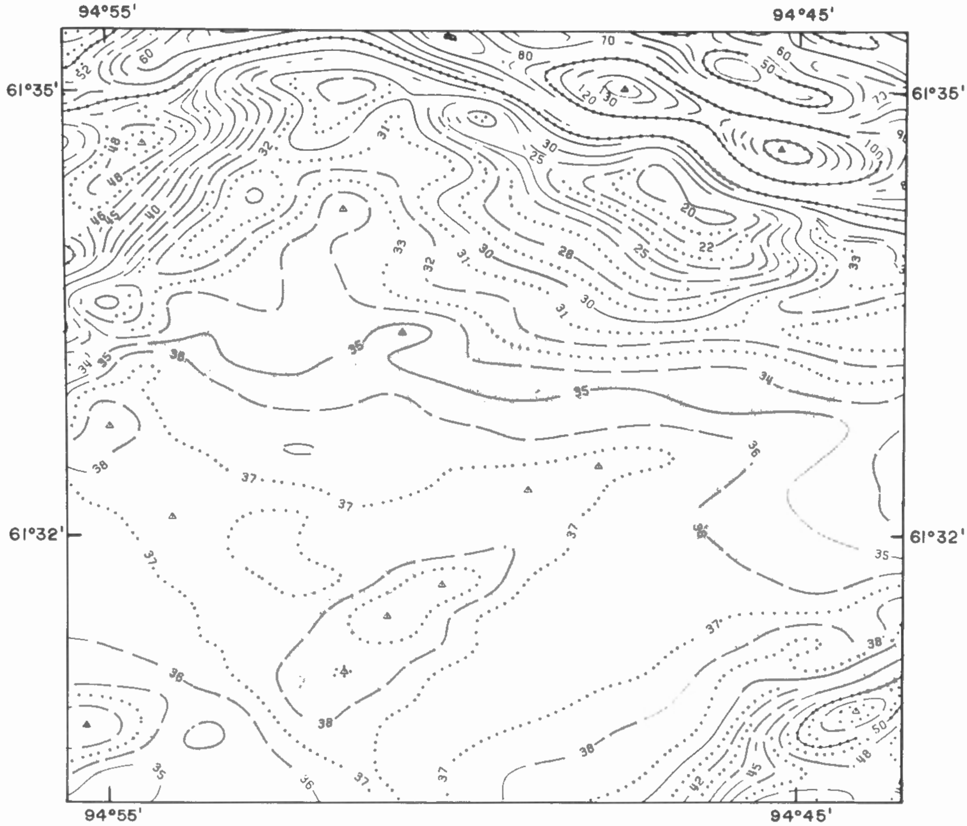


Figure 7. A region with a relatively small variation of the magnetic field.

Let us now consider two of the major features of the original aeromagnetic map. There is a northwesterly-trending group of anomalies starting at an approximate location of 61°38'N and 94°30'W. Figure 6 shows details of these anomalies from the machine-contoured map. This also illustrates the effects of the contour termination and labelling.

An area with a relatively small variation of the magnetic field is centred at 61°32'N and 94°51'W. The machine-contoured map of this area (Fig. 7) seems to be adequate and reasonably good.

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```
                                                                      00000080
                                                                      00000090
      CONTOUR FROM  EQUISPACED DATA GRID  N BY M
      DIMENSICN DATA(4000),A(41,16,4,4),G(81,81),GP(16,16)
      DIMENSICN XC(440),YC(440),XD(440),YD(440),GR(440),KSP(440)
      DIMENSION JM(50),GM(50),IM(50),MCM(50), CV(120),NOC(120)
      DIMENSION XCB(120,15),KNT(1000)
      DIMENSICN AB(4),GG(4),ABC(100)
      DIMENSICN NGX(4)
      DIMENSION LIN(5)
      DIMENSION XLD(1C),XBO(10),YBO(10)
      EQUIVALENCE (ABC(1),A(1)),(GP(1), XC(1))
      CALL PLOTS(DATA(1),4000)
      CALL PLOT (0.0,3.0,-3)
      REWIND 5
      NRG=120
      LO=0
      READ(1,110) MTOT,NTCT,MSUB,NSUB,NGRDX,NGRDY,MJI,NPROX,SCLLX,
     1SCLLY,HL
 3000 FORMAT(1H ,5I5)
      READ(1,110) NMAP,NSTART,MSTART,ILAB,LINET,LABET
      READ(1,110) MING,NAV,NLAT,NC,NCSEPL
      READ(1,110) NTT,(LIN(I),I=1,NTT)
C$$$$$$$$$$$$$$$$*******************$$$$$$$$$$$$$$$$$$************************$$$$$$$$$$$$$$$$
C     MTOT,NTOT= NO.OF GRID CELLS IN X & Y DIRECTICNS RESP. FOR 1ST MAP
C     MSUB,NSUB =    ------ DITTC ------------              FOR A BLOCK
C     NGRDX,NGRDY = NO. OF SUB-CELLS PER GRID CELL IN X & Y DIRECTIONS RESP.
C     MJI= BASIC CONTOUR INTERVAL
C     NPROX = MAXIMUM NO. OF CONTOURS/INCH TO BE DRAWN
C     SCLLX,SCLLY = NO. OF GRID CELLS/INCH IN X & Y DIRECTIONS RESP.
C     HL = HEIGHT OF LABEL NUMERALS IN INCHES.
C     NMAP = NO. CF ADJACENT MAPS ( CCNFIGURATION OF SPLINE CELL COFS. AS WRITTE
C    -N ON DATA TAPE )
C     MSTART,NSTART = NO. OF CELLS IN FROM LEFT AND UP FROM BOTTOM OF GRID
C    - RESP AT WHICH MAP IS TO START.
C      IF ILAB = C NO CONTOUR LABELS.
C      IF LINET = 0  ONLY 2 TYPES OF CONTOUR DRAWN :- SOLID & SOLID-BOLD
C      IF LINET = 1 5 TYPES. DOTTED, DASHED, SOLID, SOLID-BOLD, & SOLID-BOLD-BEA
C    -DED.
C     IF LABET = 0 LABEL = FULL VALUE CF CCNTOUR, LABET = 1 LABEL = VALUE OF
C    - CONTOUR/MJI .
C     MING = SCME NUMBER  LESS THAN LOWEST VALUE OF OF FUNCTION EXPECTED.
C      NAV = NO. OF POINTS TO BE TAKEN IN MCVING WINDOW AVERAGE OF GRADIENT .
C     NLAT 6= NO. OF LAT. & LONG VALUES TO BE WRITTEN ON MAP )
C     NC = NO. OF TITLE CARDS.
C     CSEPL = THE RATIO (DISTANCE BETWEEN ADJACENT CONTOURS)/(HEIGHT OF LABEL
C     NUMERALS) WHICH MUST BE EXCEEDED BEFORE A LABEL MAY BE INSERTED .
C    NTT = NO. OF LINE TYPES ( UP TO 5 )
C     LIN(I) ARE THE REPETITION NUMBERS OF EACH LINE TYPE . E.G. IF LIN(1)=50
C    - THEN EVERY 50TH CONTCUR WILL BE  SOLID-BOLD-BEADED. ETC ETC .
C$$$$$$$$$$$$$$$$*******************$$$$$$$$$$$$$$$$$$************************$$$$$$$$$$$$$$$$
  110 FORMAT(8I5,3F10.4)
      SCLX=SCLLX
```

```
0022           SCLY=SCLLY
0023           HT=HL*2.0
0024           NA=NC*20
0025           READ(1,115)(ABC(I),I=1,NA)
0026       115 FORMAT( 20A4)
0027           NA=NA*4
0028           CALL    SYMBOL(0.0,0.0,HT,ABC,0.0,NA)
0029           CALL PLOT (0.0,2.0,-3)
0030           MAP=0
0031      1000 CONTINUE
0032           IF(NSTART.EQ.0) GO TO  411
0033           DO 410 J=1,NSTART
0034           DO 410 I=1,MTOT
0035       410 READ(9,111)((A(1,1,K,L),K=1,4),L=1,4)
0036           NTOT=NTOT-NSTART
0037       411 CONTINUE
0038           MTOT=MTOT-MSTART
         C********************************************************************************
         C     CALC OF NO. OF BASIC CONTOURS PER INCH AT WHICH CONTOURS OF EACH ORDER
         C     WILL BE TERMINATED
         C********************************************************************************
0039           NCPROX=NPROX*100*HL
0040           NP1=NPROX
0041           NP1=NPROX
0042           NP2=NPROX*LIN(4)
0043           NP3=NPROX*LIN(3)
0044           NP4=NPROX*LIN(2)
0045           NMPROX=NP3
0046       106 FORMAT( 2I5,5F10.4)
         C********************************************************************************
         C     CALC OF NO. OF , AND SIZE (INCHES), OF BLOCKS & STRIPS
         C********************************************************************************
0047           MBLOCK=MTOT/MSUB
0048           MLAST=MTOT-MBLOCK*MSUB
0049           IF (MLAST.NE.0)MBLOCK=MBLOCK+1
0050           IF (MLAST.EQ.0)MLAST=MSUB
0051           NSTRIP=NTOT/NSUB
0052           NLAST=NTOT-NSTRIP*NSUB
0053           IF (NLAST.NE.0)NSTRIP=NSTRIP+1
0054           IF (NLAST.EQ.0)NLAST=NSUB
0055           XBL=MSUB/SCLX
0056           XXBL=(MBLOCK-1)*XBL
0057           YBL=NSUB/SCLY
0058           NST=0
0059           WRITE(3,310)MTOT,NTOT,MSUB,NSUB,MJI,SCLX,SCLY,MBLOCK,MLAST,NSTRIP,
              1 NLAST,MING,NGRDX,NGRDY,HL
0060       310 FORMAT( 1H0,2X,5I5,2F10.4,7I5,F10.4)
0061           SCLX=SCLX*NGRDX
0062           SCLY=SCLY*NGRDY
0063           XYP=SCLY/SCLX
         C********************************************************************************
         C     NEW STRIP
         C********************************************************************************
```

```
  300 NST=NST+1
      NS=2
      IF (NST.EQ.1)NS=1
      NF=NSUB+1
      IF (NST.EQ.NSTRIP)NF=NLAST
      DO 301 J=NS,NF
      WRITE (3,310) J
      IF(MSTART.EQ.0) GO TO 1003
      DO 1002 I=1,MSTART
      READ(9,111)((ASTART,K=1,4),L=1,4)
 1002 CONTINUE
 1003 CONTINUE
      DO 301 I=1,MTOT
      READ(9,111)((A(I,J,K,L),K=1,4),L=1,4)
  301 CONTINUE
  111 FORMAT (1H ,8E16.8)
      MBL=0
C*************************************************************************
C     NEW BLOCK
C*************************************************************************
  302 MBL=MBL+1
      JUMP=0
      NF=NSUB+1
      IF(NST.EQ.NSTRIP) NF=NLAST
      WRITE (3,306)NST
  306 FORMAT (1H0,25X,5HSTRIP,I6)
      WRITE (3,307)MBL
  307 FORMAT (1H0,25X,5HBLOCK,I6)
      MS=(MBL-1)*MSUB+1
      MF=MS+MSUB
      IF (MBL.EQ.MBLOCK)MF=MS+MLAST-1
      NSTAGE=1
      II=0
      MAPG=0
      DO 308 I=MS,MF
      II=II+1
      DO 308 J=1,NF
      GP(II,J)=A(I,J,1,1)
  308 CONTINUE
      DO 325 J=1,NF
  325 WRITE(3,107)(A(I,J,1,1),I=MS,MF)
      GMAX=GP(1,1)
      GMIN=GP(1,1)
      MT=MF-MS+1
      NMAX=1
      JM(1)=1
      CALL MAXMIN(GP,MT,NF,NMAX,IM,JM,GM,MCM,    MJI,JK,IK,GMIN,GMAX,GPP)
      NMT=NMAX-1
      NM=1
      N=NSUB*NGRDY+1
      M=MSUB*NGRDX+1
      IF(MBL.EQ.MBLOCK)  M=MLAST*NGRDX+1
      IF(NST.EQ.NSTRIP)  N=NLAST*NGRDY+1
```

```
C***********************************************************************
C     SET ALL SUB GRID VALUES TO LT. MING
C***********************************************************************
      DO 316 I=1,M
      DO 316 J=1,N
  316 G(I,J)=MING-100
      IF(NST.NE.NSTRIP) NF=NF-1
      IF(MBL.NE.MBLOCK) MF=MF-1
      NMM=1
      IF(NMAX.EQ.1) GO TO 315
  604 FORMAT( 1H ,10X,7HMAX/MIN,2X,2F10.4,I5,10(/,5X,2I5,F10.4,I5))
      WRITE(3,604) GMAX,GMIN,NMAX,(IM(I),JM(I),GM(I),MOM(I),I=2,NMAX)
  309 NM=NM+1
      IF(NM.GT.NMAX) GO TO 315
C***********************************************************************
C     USE GRADIENTS XG,YG,   TO FIND CELL CONTAINING PARTICULAR REL. MAX/MIN
C***********************************************************************
  311 I=IM(NM)+MS-1
      J=JM(NM)
      JL=(J-1)*NGRDY+1
      IL=(I-MS)*NGRDX+1
      GPP=GM(NM)
      XG=A(I,J,2,1)*MOM(NM)
      YG=A(I,J,1,2)*MOM(NM)
      WRITE(3,111) XG,YG
      IF(XG.LT.0) I=I-1
      IF(YG.LT.0) J=J-1
      WRITE(3,371)NM,I,J
  371 FORMAT( 1H ,20X,10HMAX/MIN # ,3I6)
C***********************************************************************
C     REJECT MAX/MIN OUTSIDE BLOCK BOUNDARY
C***********************************************************************
      IF(J.EQ.0.OR.J.GT.NF.OR.I.LT.MS.OR.I.GT.MF) GO TO 309
      IX=(I-MS)*NGRDX
      JY=(J-1)*NGRDY
      NGJ=NGRDY
      IF(J.EQ.NF) NGJ=NGRDY+1
      NGI=NGRDX
      IF(I.EQ.MF) NGI=NGRDX+1
C***********************************************************************
C     CALC ALL SUB GRID VALUES WITHIN CELL CONTAINING MAX/MIN
C***********************************************************************
      DO 314 L=1,NGJ
      LL=JY+L
      DO 314 K=1,NGI
      KK=IX+K
      IF(G(KK,LL).LT.MING) G(KK,LL)=SPLINE(A,KK,LL,NGRDX,NGRDY,M,N,MS)
C***********************************************************************
C     FIND LOCATION OF MAX/MIN WITHIN CELL
C***********************************************************************
      IF(MOM(NM).GT.0. AND.G(KK,LL).LE.GPP) GO TO 314
      IF(MOM(NM).LT.0. AND.G(KK,LL).GE.GPP) GO TO 314
      IL=KK
```

```
0152          JL=LL
0153          GPP=G(KK,LL)
0154      314 GP(K,L)=G(KK,LL)
0155          IF(MOM(NM).LT.0) GO TO 361
0156          X=IL/SCLX
0157          Y=JL/SCLY
        C**********************************************************************
        C     DRAW TRIANGLE AT MAX POSITION
        C**********************************************************************
0158          CALL SYMBOL (X,Y,HL,2,0.0,-1)
0159      361 CONTINUE
0160      107 FORMAT (1H ,2X,17(F7.1))
0161          WRITE(3,366) IL,JL,GPP
0162      366 FORMAT(1H ,20X,2I6,5F10.4)
0163          NREJ=0
        C**********************************************************************
        C     REJECT MAX/MIN ON BLOCK BOUNDARY OR ON PREVIOUS MAX/MIN LINE
        C**********************************************************************
0164          IF(IL.EQ.1.OR.JL.EQ.1.OR.IL.EQ.M.OR.JL.EQ.N.OR.JL.EQ.JM(NMM))
             1 NREJ=3
0165          IF(NREJ.EQ.3) WRITE(3,368) IL,JL,GPP
0166      368 FORMAT(1H ,20X,21HTHIS MAX/MIN REJECTED,2I6,F10.4)
0167          IF(NREJ.EQ.3) GO TO 309
        C**********************************************************************
        C/    REJECT INSIGNIFICANT MAX/MIN
        C**********************************************************************
0168          NGP=GPP/MJI
0169          NGX(1)=G(1,JL)/MJI
0170          NGX(2)=G(NGI,JL)/MJI
0171          NGX(3)=G(IL,NGJ)/MJI
0172          JPL=JM(NMM)
0173          IF(G(IL,JPL).LT. MING)   G(IL,JPL)=SPLINE(A,IL,JPL,NGRDX,NGRDY,
             1M,N,MS)
0174          NGX(4)=G(IL,JPL)/MJI
0175          DO 381 L=1,4
0176          DIF=NGP-NGX(L)
0177          IF(DIF.EQ.0) GO TO 370
0178      381 CONTINUE
0179          NMM=NMM+1
0180          IM(NMM)=IL
0181          JM(NMM)=JL
0182          GM(NMM)=GPP
0183          GO TO 309
0184      370 WRITE(3,368)IL,JL,GPP
0185          GO TO 309
0186      315 CONTINUE
       'C**********************************************************************
        C     CALC ALL VALUES AT SUB GRID INTERVAL AROUND BOUNDARY AND ACROSS
        C     ALL MAX/MIN LINES
        C**********************************************************************
0187          NMAX=NMM+1
0188          JM(NMAX)=N
0189          DO 313 JS=1,NMAX
```

```
      LL=JM(JS)
      DO 313 KK=1,M
      IF(G(KK,LL).LT.MING) G(KK,LL)=SPLINE(A,KK,LL,NGRDX,NGRDY,M,N,MS)
      IF(G(KK,LL).LT.GMIN) GMIN=G(KK,LL)
      IF(G(KK,LL).GT.GMAX) GMAX=G(KK,LL)
  313 CONTINUE
  505 FORMAT(1H ,2X,10F12.4)
      KK=1
  317 DO 318 LL=1,N
      IF(G(KK,LL).LT.MING) G(KK,LL)=SPLINE(A,KK,LL,NGRDX,NGRDY,M,N,MS)
      IF(G(KK,LL).GT.GMAX) GMAX=G(KK,LL)
      IF(G(KK,LL).LT.GMIN) GMIN=G(KK,LL)
  318 CONTINUE
      IF(KK.EQ.M) GO TO 319
      KK=M
      GO TO 317
  319 CONTINUE
      NMT=NMAX-1
      WRITE(3,605) GMAX,GMIN,NMAX
  605 FORMAT(1H ,2X,2F10.4,5I6)
      IF(NMAX.GT.2) WRITE(3,606)(IM(I),JM(I),GM(I),MOM(I),I=2,NMT)
  606 FORMAT(1H ,10X,2I6,F10.4,I6)
C*****************************************************************************
C     CALC NO. OF CONTOUR INTERVALS REQUIRED TO COVER RANGE OF FUNCTION WITHIN
C     BLOCK
C*****************************************************************************
      NGMIN=GMIN/MJI
      NGMAX=GMAX/MJI
      IF(GMIN.LT.0) NGMIN=NGMIN-1
      IF(GMAX.LT.0) NGMAX=NGMAX-1
      NRANGE=NGMAX-NGMIN
      IF(NRANGE.LE.NRG) GO TO 804
C*****************************************************************************
C    RANGE EXCEEDS ALLOWED VALUE:  CONTOUR UP TO ALLOWED RANGE
C*****************************************************************************
      NRN=NRANGE
      NRANGE=NRG
      GO TO 804
C*****************************************************************************@
C     MOVE BASE OF ALLOWED RANGE UP TO TOP OF PREVIOUSLY CONTOURED VALUES AND
C         CONTOUR NEXT SET UP TO ALLOWED RANGE  : THIS PROCEDURE REPEATED
C     UNTIL FULL RANGE OF CONTOURS WITHIN BLOCK IS COVERED
C*****************************************************************************
  800 NGMIN=NGMIN+NRG
      NRANGE=NRN-NRANGE
      JUMP=0
      IF(NRANGE.LT.NRG) GO TO 804
      NRN=NRANGE
      NRANGE=NRG
  804 CONTINUE
C*****************************************************************************
C     SET UP CONTOUR VALUES
C*****************************************************************************
```

```
0228          DO 502 KK=1,NRANGE
0229          NOC(KK)=0
0230      502 CV(KK)=(KK+NGMIN)*MJI
0231                CALL CFIND(NMAX,NPER,M,N,JW,G,NOC,XCB,CV,MJI,NGMIN,JUMP)
        C*****************************************************************************
        C     BEGIN WITH LOWEST CONTOUR VALUE
        C*****************************************************************************
0232       17 K=1
0233          NRR=(NMAX-2)*M
0234          NOR=-2
0235          CCV=ABS(CV(K)/MJI)
0236          DO 1004 ILT=1,NTT
0237          NOR=NOR+1
0238          CVV=CCV/LIN(ILT)
0239          ICV=CVV
0240          IF(ICV-CVV) 1004,1005,1004
0241     1004 CONTINUE
0242          NOR=NOR+1
0243     1005 CONTINUE
0244          GO TO 16
        C*****************************************************************************
        C     GO TO NEXT CONTOUR
        C*****************************************************************************
0245       18 K=K+1
0246          IF (K.GT.NRANGE) GO TC 600
0247          CCV=ABS(CV(K)/MJI)
        C*****************************************************************************
        C     CALC ORDER OF CONTOUR ( NOR)
        C*****************************************************************************
0248          NOR=-2
0249          DO 1006 ILT=1,NTT
0250          NOR=NOR+1
0251          CVV=CCV/LIN(ILT)
0252          ICV=CVV
0253          IF(ICV-CVV) 1006,1007,1006
0254     1006 CONTINUE
0255          NOR=NOR+1
0256     1007 CONTINUE
0257       16 DO 15 KJ=1,NRR
0258       15 KNT(KJ)=0
0259          L=0
        C*****************************************************************************
        C     GO TO NEXT OCCURENCE OF THIS PARTICULAR  CONTOUR
        C*****************************************************************************
0260       99 L=L+1
0261          IF (L.GT.NOC(K)) GO TC 18
0262          NSQ=XCB(K,L)
0263          NQD=NSQ-2*N-2*M
0264          IF(NQD.LT.1) GO TO 98
0265          IF(KNT(NQD).EQ.1) GO TO 99
0266          KNT(NQD)=1
0267       98 CONTINUE
0268          IX=0
```

```
0269            JX=0
0270                  CALL CSTART(A,G,GR,XC,YC,XCB,NOC,KNT,NPER,JM,M,N,KV,I,J,K,L
              1 ,MS,NGRDX,NGRDY,XYP,NMAX,NSQ,IX,JX,NST,MBL,MING)
0271         24 CONTINUE
0272            SCL=SCLX
0273                  CALL CTRACE(A,G,XC,YC,GR,KNT,JM,KV,NMAX,NGRDX,NGRDY,M,N,MS,
              1 I,J,K,CV,II,IX,JX,SCL,NOR,NDR,NP1,NP2,NP3,MJI,NP4,MING,XYP)
0274            IF(NDR.EQ.0) GO TO 99
0275            IF(NDR.EQ.-1) II=II-1
0276                  CALL CDRAW(XC,YC,XD,YD,GR,KSP,CV, MJI,SCL,NPROX,NCPROX,
              1 JL,NAV,NOR,HL,II,K,NP1,NP2,NP3,NP4,ILAB,LINET,LABET,LIN, CSEPL)
0277            GO TO 99
0278        600 CONTINUE
0279            IF(JUMP.EQ.0) GO TO 801
          C*********************************************************************
          C     A FURTHER RANGE OF CONTOURS REMAINS TO BE COVERED WITHIN THIS BLOCK
          C*********************************************************************
0280            WRITE(3,802)
0281        802 FORMAT(1H0,4HJUMP)
0282            GO TO 800
0283        801 CONTINUE
0284            IF(MBL.EQ.MBLOCK) GO TO 303
          C*********************************************************************
          C     GO TO NEXT BLOCK
          C*********************************************************************
0285            CALL PLOT (XBL,0.0,-3)
0286            GO TO 302
0287        303 IF(NST.EQ.NSTRIP) GO TO 380
          C*********************************************************************
          C     GO TO NEXT STRIP
          C*********************************************************************
0288            CALL PLOT (-XXBL,YBL,-3)
0289            DO 305 I=1,MTOT
0290            DO 305 K=1,4
0291            DO 305 L=1,4
0292        305 A(I,1,K,L)=A(I,NF+1,K,L)
0293            GO TO 300
          C*********************************************************************
          C     GO TO NEXT MAP
          C*********************************************************************
0294        380 MAP=MAP+1
0295            IF(MAP.EQ.NMAP) GO TO 1001
0296            YSHF=(NLAST-NTOT)/SCLLY
0297            XSHF=MLAST/SCLLX
0298            CALL PLOT(XSHF,YSHF,-3)
0299            MSTART=0
0300            SCLX=SCLLX
0301            SCLY=SCLLY
0302            READ (1,110) MTOT,NTOT
0303            GO TO 1000
0304       1001 REWIND 9
0305            CALL PLOT (120.0,0.0,3)
0306            CALL PLOT (0.0,0.0,999)
```

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              WRITE(3,610)
          610 FORMAT(1H ,10X,6HFINISH)
              CALL EXIT
              END
```

```
FORTRAN IV G LEVEL  18                SPLINE            DATE = 70134         18/08/19              PAGE 0001

              FUNCTION SPLINE (A,K,L,NGRDX,NGRDY,M,N,MS)
C*****************************************************************************
C     CALC. A VALUE OF THE APPROPRIATE BICUBIC AT SOME POINT WITHIN SPLINE CELL
C*****************************************************************************
              DIMENSION A(41,16,4,4),AB(4)
              XINC=1.C/NGRDX
              I=MS-1+K/NGRDX
              KX=K-(I-MS+1)*NGRDX
              IF(KX.NE.O.AND.K.NE.M) I=I+1
              IF(KX.EQ.C) KX=NGRDX
              X=(KX-1)*XINC
              IF(K.EQ.M) X=1
              YINC=1.C/NGRDY
              J=L/NGRDY
              LY=L-J*NGRDY
              IF(LY.NE.O.AND.L.NE.N) J=J+1
              IF(LY.EQ.0)LY=NGRDY
              Y=(LY-1)*YINC
              IF(L.EQ.N) Y=1
              IF(X.EQ.0.0.AND.Y.EQ.0.0) GO TO 4
              Y2=Y*Y
              Y3=Y2*Y
              IF(X.EQ.C.0) GO TO 2
              X2=X*X
              X3=X2*X
              IF(Y.EQ.0.0) GO TO 3
              DO 1 IY=1,4
            1 AB(IY)=A(I,J,IY,1)+A(I,J,IY,2)*Y+A(I,J,IY,3)*Y2+A(I,J,IY,4)*Y3
              SPLINE=AB(1)+AB(2)*X+AB(3)*X2+AB(4)*X3
              RETURN
            2 SPLINE=A(I,J,1,1)+A(I,J,1,2)*Y+A(I,J,1,3)*Y2+A(I,J,1,4)*Y3
              RETURN
            3 SPLINE= A(I,J,1,1)+A(I,J,2,1)*X+A(I,J,3,1)*X2+A(I,J,4,1)*X3
              RETURN
            4 SPLINE=A(I,J,1,1)
              RETURN
              END
```

```
      SUBROUTINE MAXMIN (GP,M,N,NMAX,IM,JM,GM,MOM,   MJI,JK,IK,GMIN,
     1 GMAX,GPP)
C***********************************************************************
C     DETECT RELATIVE MAXIMA OR MINIMA. ( BASIC GRID VALUES SURROUNDED BY 8 LARG
C     ER OR 8 SMALLER VALUES )
C***********************************************************************
      DIMENSION GP(16,16),JM(50),IM(50),GM(50),MOM(50)
      DIMENSION NGG(4)
      DO 4 J=1,N
      JK=J
      DO 4 I=1,M
      IK=I
      NEG=0
      KV=0
      DO 2 KK=1,8
      K=-1
      L=-1
      IF(KK.EQ.1.OR.KK.EQ.5) K=0
      IF(KK.GT.5) K=1
      IF(KK.EQ.3.OR.KK.EQ.7) L=0
      IF(KK.GT.3.AND.KK.LT.7) L=1
      KX=I+K
      LY=J+L
      IF(LY.EQ.0.OR.LY.GT.N.OR.KX.EQ.0.OR.KX.GT.M) GO TO 2
      KV=KV+1
      DIF=GP(I,J)-GP(KX,LY)
    1 IF(DIF.LT.0.0) NEG=NEG+1
      IF(NEG.GT.0.AND.NEG.LT.KV) GO TO 4
    2 CONTINUE
      GPP=GP(IK,JK)
      IF(GPP.GT.GMAX) GMAX=GPP
      IF(GPP.LT.GMIN) GMIN=GPP
      NMAX=NMAX+1
      MOM(NMAX)=-1
      IF(NEG.EQ.0) MOM(NMAX)=1
      JM(NMAX)=JK
      IM(NMAX)=IK
      GM(NMAX)=GPP
    4 CONTINUE
    5 RETURN
      END
```

```
      SUBROUTINE CFIND(NMAX,NPER,M,N,JM,G,NOC,XCB,CV,MJI,NGMIN,JUMP)
C*******************************************************************************
C     FIND POSITION OF EACH ALTERNATE INTERCEPT OF EACH CONTOUR WITH EITHER BLOC
C     K BOUNDARY OR WITH THE INTERNAL MAX/MIN LINES. ( INTERCEPT COORDINATE =
C     LINEAR DISTANCE ANTICLOCKWISE ARCUND BLOCK BOUNDARY FROM LR. L.H. CORNER
C     THEN ACROSS MAX/MIN LINES L. TO R. BEGINING WITH LOWEST MAX/MIN LINE )
C*******************************************************************************
      DIMENSION  JM(50),G(81,81),NOC(120),XCB(120,15),CV(120)
      DIMENSICN NO(120)
      DO 401 IZ=1,120
  401 NO(IZ)=0
      NRG=120
      NXT=0
      NEND=0
      NPER=2+NMAX
      DO 508 KKK=1,NPER
      NXT=NXT+NEND
      WRITE(3,400) KKK ,NXT
  400 FORMAT(1H ,10X,4HKKK=,I2,2X,4HNXT=,I4)
      KZ=1
      IF (KKK.EQ.2.OR.KKK.EQ.3)KZ=NEND
      NEND=M
      IF (KKK.EQ.2.OR.KKK.EQ.4)NEND=N
      IF (KKK.GT.4)KZ=JM(KKK-3)
      DO 508 KVV=2,NEND
      KV=KVV
      IF(KKK.EQ.3.OR.KKK.EQ.4) KV=NEND-KVV+2
      NSQ=NXT+KV-1
      IF(KKK.EQ.2.OR.KKK.EQ.4) GO TO 505
      I=KV
      K=I-1
      J=KZ
      L=KZ
      GO TO 506
  505 J=KV
      L=J-1
      K=KZ
      I=KZ
  506 CONTINUE
      K4=0
      NG2=G(I,J)/MJI
      NG1=G(K,L)/MJI
      NDIF=NG2-NG1
      NCV=IABS(NDIF)
      IF(G(K,L).GT.0.0.AND.G(I,J).GT.0.0) GO TO 510
      K4=-1
      IF(G(K,L).LT.0.0.AND.G(I,J).LT.0.0) GO TO 511
      NCV=NCV+1
      NDIF=NCV
      IF(G(K,L).GT.G(I,J)) NDIF=-NCV
      IF(NDIF.LT.0) K4=0
  511 CONTINUE
  510 CONTINUE
```

```
      IF (NCV.EQ.0) GO TO 508
C***********************************************************************
C     CONTOUR INTERCEPTS FOUND IN THIS SUB-GRID INTERVAL. ( NCV = NO. OF CONTOUR
C     INTERCEPTS )
C***********************************************************************
      K2=NCV/NDIF
      K3=(K2+1)/2
      KK=NG1+K3-NGMIN+K4
      IF(CV(KK+NCV-1).EQ.G(I,J)) G(I,J)=G(I,J)+MJI*0.001
      IF(CV(KK).EQ.G(K,L)) G(K,L)=G(K,L)+MJI*0.001
      DIF=G(I,J)-G(K,L)
      DO 507 KCV=1,NCV
C***********************************************************************
C     IGNORE ANY CONTOUR VALUES OUTSIDE PRESENT RANGE BEING CONSIDERED( CONTOUR
C     VALUES BELOW PRESENT RANGE HAVE BEEN COVERED IN PREVIOUS RUN, VALUES
C     ABOVE PRESENT RANGE WILL BE COVERED IN NEXT RUN )
C***********************************************************************
      IF(KK.LT.1) GO TO 507
      IF(KK.LE.NRG) GO TO 509
      JUMP=1
      GO TO 507
  509 CONTINUE
      NO(KK)=NO(KK)+1
      IF(NO(KK).GT.1) NO(KK)=0
C***********************************************************************
C     SKIP EVERY OTHER OCCURENCE OF EACH CONTOUR
C***********************************************************************
      IF(NO(KK).EQ.0) GO TO 507
      NOC(KK)=NOC(KK)+1
      LL=NOC(KK)
      IF(LL.LE.15) GO TO 502
C***********************************************************************
C     IF MORE THAN 30 OCCURENCES OF ANY PARTICULAR CONTOUR HAVE BEEN FOUND , SKI
C     P ANY FURTHER OCCURENCES OF THIS CONTOUR .
C***********************************************************************
C***********************************************************************
      NOC(KK)=NOC(KK)-1
      WRITE(3,503) CV(KK),I,J,K,L
  503 FORMAT(1H0,2X,F10.1,17H FIND POINTS > 30, 4I6)
      GO TO 507
  502 CONTINUE
      XCB(KK,LL)=NSQ+(CV(KK)-G(K,L))/DIF
  507 KK=KK+K2
  508 CONTINUE
      RETURN
      END
```

```
0001          SUBROUTINE CSTART(A,G,GR,XC,YC,XCB,NOC,KNT,NPER,JM,M,N,KV,I,J,K,L
             1 ,MS,NGRDX,NGRDY,XYP,NMAX,NSQ,IX,JX,NST,MBL,MING)
        C***********************************************************************
        C     CONVERT LINEAR COORD. OF CONTOUR INTERCEPT TO X & Y COORDS  AS 1ST POINT O
        C     N CONTOUR TO BE TRACED.
        C***********************************************************************
0002          DIMENSION A(41,16,4,4),G(81,81),XC(440),YC(440),GR(440),JM(50),
             1 KNT(891) ,XCB(120,15),NOC(120)
0003          NXT=0
0004          NM=1
0005          DO 20 KV=1,NPER
0006          IF(KV.GT.4) NM=NM+1
0007          ZZ=XCB(K,L)-NXT
0008          NXT=NXT+M
0009          IF (KV.EQ.2.OR.KV.EQ.4)NXT=NXT-M+N
0010          IF(XCB(K,L).LT.NXT) GO TO 21
0011       20 CONTINUE
0012       21 IF (KV.EQ.2.OR.KV.EQ.4) GO TO 22
        C***********************************************************************
        C     INTERCEPT ON LOWER OR UPPER BLOCK BOUNDARY OR ON MAX/MIN LINE
        C***********************************************************************
0013          NXT=NXT-M
0014          I=ZZ
0015          J=JM(NM)
0016          IF(KV.EQ.3)J=JM(NMAX)
0017          IF(KV.EQ.3) JX=-1
0018          XC(1)=ZZ
0019          YC(1)=J/XYP
0020          IP=I+1
0021          IF(G(IP, J).LT.MING) G(IP, J)=SPLINE(A,IP, J,NGRDX,NGRDY,M,N,MS)
0022          IF(G( I, J).LT.MING) G( I, J)=SPLINE(A, I, J,NGRDX,NGRDY,M,N,MS)
0023          GR(1)=G(I+1,J)-G(I,J)
0024          IF(KV.GT.4) KV=1
0025          GO TO 24
0026       22 I=1
        C***********************************************************************
        C     INTERCEPT ON L.H. OR R.H. BLOCK BOUNDARY
        C***********************************************************************
0027          NXT=NXT-N
0028          IF (KV.EQ.2)I=M
0029          IF(KV.EQ.2) IX=-1
0030          J=ZZ
0031          XC(1)=I
0032          YC(1)=ZZ/XYP
0033          JP=J+1
0034          IF(G( I,JP).LT.MING) G( I,JP)=SPLINE(A, I,JP,NGRDX,NGRDY,M,N,MS)
0035          IF(G( I, J).LT.MING) G( I, J)=SPLINE(A, I, J,NGRDX,NGRDY,M,N,MS)
0036          GR(1)=G(I,J+1)-G(I,J)
0037          GR(1)=GR(1)*XYP
0038          NMX=NMAX-1
0039       24 RETURN
0040          END
```

```
0001          SUBROUTINE CTRACE(A,G,XC,YC,GR,KNT,JM,KV,NMAX,NGRDX,NGRDY,M,N,MS,
             1 I,J,K,CV,II,IX,JX,SCL,NOR,NDR,NP1,NP2,NP3,MJI,NP4,MING,XYP)
        C**************************************************************************a
        C     TRACE CONTOUR FROM START ON BLOCK BOUNDARY TO END ON BLOCK BOUNDARY, OR
        C        FROM START ON MAX/MIN LINE BACK TO START.
        C**************************************************************************a
0002          DIMENSION A(41,16,4,4), G(81,81),XC(440),YC(440),GR(440),CV(120)
             1,JM(50),KNT(891)
0003          NDR=1
0004          NLP=0
0005          IF(K.EQ.1) NPR=1
0006          IF(NOR.LT.2) NPR=0
0007          IG=10
0008          NXS=0
0009          NYS=0
0010          II=1
        C***************************************************************************
        C     CONSIDER SUB-GRID CELL INTO WHICH NEXT INCREMENT OF CONTOUR PROJECTS
        C**************************************************************************a
0011      100 I=I+IX
0012          J=J+JX
        C***************************************************************************
        C     SEARCH BOUNDARY OF SUB CELL ANTICLOCKWISE TO FIND EXIT POINT OF CONTOUR
        C     CALC VALUES AT CORNERS OF SUB CELL AS AND IF REQUIRED
        C**************************************************************************a
0013      101 KV=KV+1
0014          NLP=NLP+1
0015          IF(KV.EQ.5) KV=1
0016          IF(NLP.LT.4) GO TO 1
0017          WRITE(3,150) KV,I,J,K,CV(K),G(I,J),G(I+1,J),G(I+1,J+1),G(I,J+1)
0018     150  FORMAT(1H ,1X,4HLOOP ,10X,4I5,5F10.4)
0019          GO TO 15
0020     1    CONTINUE
0021          KN=0
0022          LN=0
0023          KP=1
0024          LP=1
0025          IF(KV.EQ.1) LP=0
0026          IF(KV.EQ.2) KN=1
0027          IF(KV.EQ.3) LN=1
0028          IF(KV.EQ.4) KP=0
0029          IN=I+KN
0030          JN=J+LN
0031          IP=I+KP
0032          JP=J+LP
0033          IF(G(IP,JP).LT.MING) G(IP,JP)=SPLINE(A,IP,JP,NGRDX,NGRDY,M,N,MS)
0034          IF(G(IN,JN).LT.MING) G(IN,JN)=SPLINE(A,IN,JN,NGRDX,NGRDY,M,N,MS)
0035          IF(G(IN,JN).EQ.CV(K)) G(IN,JN)=G(IN,JN)+MJI*0.001
0036          IF(G(IP,JP).EQ.CV(K)) G(IP,JP)=G(IP,JP)+MJI*0.001
0037      200 FORMAT(1H ,2X,3(2I5,2X,F12.7))
0038          IF(G(I+KN,J+LN).GE.CV(K).AND.G(I+KP,J+LP).LE.CV(K)) GO TO 102
0039          IF(G(I+KN,J+LN).LE.CV(K).AND.G(I+KP,J+LP).GE.CV(K)) GO TO 102
0040          GO TO 101
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0041          102 II=II+1
            C*************************************************************************a
            C      EXIT POINT OF CONTOUR FOUND . CALC X&Y COORDS OF POINT.
            C*************************************************************************a
0042              NLP=0
0043          210 FORMAT(1H ,20X,10I5)
0044              GR(II)=G(I+KP,J+LP)-G(I+KN,J+LN)
0045              IF(KV.EQ.2.OR.KV.EQ.4)GR(II)=GR(II)*XYP
0046              IF(IG.NE.10) GO TO 20
0047              IG=0
0048              DIF1=GR(II-1)
0049              DIF1=ABS(DIF1)
0050              DIF2=GR(II)
0051              DIF2=ABS(DIF2)
0052              DIF=DIF1
0053              IF(DIF2.GT.DIF1) DIF=DIF2
0054              NPI=SCL*DIF/(MJI*2)
0055              IF(NDR.LT.2. AND.NPI.LT.NP3) NPR=1
0056              IF(NDR.EQ.2.AND.NPI.GT.NP2.AND.NPR.EQ.0) NDR=0
0057              IF(NDR.EQ.3.AND.NPI.GT.NP1.AND.NPR.EQ.0) NDR=0
0058              IF(II.GT.2.AND.NDR.EQ.0) NDR=-1
0059              IF(NDR.LT.1)  GO TO 19
0060           20 CONTINUE
0061              IG=IG+1
0062              DEL=(CV(K)-G(I+KN,J+LN))/GR(II)
0063              IF(KV.EQ.2.OR.KV.EQ.4) GO TO 103
0064              XC(II)=I+DEL
0065              YC(II)=(J+LN)/XYP
0066              IX=0
0067              JX=-1
0068              IF(KV.EQ.3) JX=1
0069              NYS=NYS+JX
0070              KV=KV+2
0071              IF(KV.EQ.5) KV=1
0072              JT=J+LN
0073              DO 23 NM=1,NMAX
0074              NMX=NM
0075              IF(JT.EQ.JM(NM)) GO TO 86
0076           23 CONTINUE
0077              GO TO 100
            C*************************************************************************
            C      CONTOUR POINT IS ON MAX/MIN LINE OR UPPER OR LOWER BLOCK BOUNDARY
            C*************************************************************************a
0078           86 CONTINUE
0079              NXT=2*M+2*N+(NMX-2)*M
0080              IF(NMX.EQ.1) NXT=0
0081              IF(NMX.EQ.NMAX) NXT=N+M
0082              NSQ=NXT+I
0083              NQ=NSQ-2*N-2*M
0084              IF(NQ.GT.0) KNT(NQ)=1
0085              IF(XC(II).EQ.XC(1).AND.YC(II).EQ.YC(1)) GO TO 19
0086              IF(NXS.EQ.0.AND.NYS.EQ.0) GO TO 19
0087              IF (JT.EQ.1.OR.JT.EQ.N) GO TO 19
```

```
0088           GO TO 100
         C**************************************************************************
         C     CONTOUR POINT IS ON LEFT OR RIGHT BLOCK BOUNDARY
         C*************************************************************************@
0089       103 XC(II)=I+KN
               YC(II)=J/XYP+DEL
0091           JX=0
0092           IX=-1
0093           IF(KV.EQ.2)IX=1
0094           NXS=NXS+IX
0095           KV=KV+2
0096           IF(KV.EQ.6) KV=2
0097           IT=I+KN
0098           IF(IT.NE.1.AND.IT.NE.M) GO TO 100
0099           NXT=M
0100           IF(IT.EQ.1) NXT=2*M+N
0101        10 RETURN
0102           END
```

```
0001          SUBROUTINE CDRAW(XC,YC,XD,YD,GR,KSP,CV, MJI,SCL,NPROX,NCPROX,
             1 JL,NAV,NOR,HL,II,K,NP1,NP2,NP3,NP4,ILAB,LINET,LABET,LIN, CSEPL)
0002          DIMENSION XC(440),YC(440),XD(440),YD(440),GR(440),KSP(440),CV(120)
0003          DIMENSION LIN(5)
        C*****************************************************************************
        C     II IS NO. OF POINTS ON CONTOUR
        C****************************************************************************a
0004          NP=II
0005          KFG=0
0006          IF(II.GT.NAV) GO TO 882
0007          JL=100
0008          AVGM=10.0**6
0009          AVG=0.0
0010          DO 881 IL=1,II
0011          A1=GR(IL)
0012      881 AVG=AVG+ABS(A1)/II
0013          NPI=SCL*AVG/MJI
0014          DO 229 IL=1,II
0015          KSP(IL)=0.0
0016          IF(NPI.GT.NP1) KSP(IL)=1
0017          IF(NPI.GT.NP2) KSP(IL)=2
0018          IF(NPI.GT.NP3) KSP(IL)=3
0019          IF(NPI.GT.NP4) KSP(IL)=4
0020      229 CONTINUE
0021          GO TO 780
        C*****************************************************************************
        C     TAKES MOVING WINDOW AVERAGE OF GRADIENT
        C****************************************************************************a
0022      882 CONTINUE
0023          NV=NAV/2
0024          AVG=0
0025          DO 225 IL=2,NAV
0026          A1=GR(IL-1)
0027          AVG=AVG+ABS(A1)/NAV
0028      225 CONTINUE
0029          NPP=II-NV
0030          NPQ=NV+1
0031          A2=0
0032          DO 756 IL=NPQ,NPP
0033          A1=GR( IL+NV)                                                       M
0034          IF(IL.EQ.NPQ) GO TO 226                                             M
0035          A2=GR(IL-NV-1)
0036      226 CONTINUE
0037          AVG=AVG+(ABS(A1)-ABS(A2))/NAV
0038          IF(IL.EQ.NPQ) AVGM=AVG*2.0
0039          IF(AVG.GE.AVGM) GO TO 801
        C*****************************************************************************
        C     FIND MINIMUM GRADIENT POINT ON CONTOUR SEGMENT
        C     THIS POINT TO BE LABEL POSITION IF ADJACENT CONTOUR DENSITY ALLOWS
        C****************************************************************************a
0040          AVGM=AVG
0041          JL=IL-2
0042          XB=XC(JL)
```

```
0043            YB=YC(JL)
0044        801 CONTINUE
      C*********************************************************************************
      C     ESTIMATES NO. OF BASIC CONTOURS/INCH ADJACENT TO EACH POINT ON CONTOUR
      C********************************************************************************@
0045            NPI=SCL*AVG/MJI
0046            KSP(IL)=0
0047            IF(NPI.GT.NP1) KSP(IL)=1
0048            IF(NPI.GT.NP2) KSP(IL)=2
0049            IF(NPI.GT.NP3) KSP(IL)=3
0050            IF(NPI.GT.NP4) KSP(IL)=4
0051        756 CONTINUE
0052            DO 227 IL=1,NV
0053            KSP(IL)=KSP(NV+1)
0054            KSP(NPP+IL)=KSP(NPP)
0055        227 CONTINUE
0056        780 CONTINUE
      C*********************************************************************************
      C     ESTIMATE  NO. OF CONTOURS /INCH AT LABEL POSITION
      C********************************************************************************@
0057            NPI=SCL*AVGM/MJI
0058            NCL=II-JL
0059            IF(NCL.GE.25) GO TO 333
0060            JL=II-25
0061            IF(JL.LT.0) JL=0
0062            DIF1=GR(JL+1)
0063            DIF1=ABS(DIF1)
0064            DIF2=GR(JL+2)
0065            DIF2=ABS(DIF2)
0066            DIF=DIF1
0067            IF(DIF2.GT.DIF1) DIF=DIF2
0068            NPI=1.5*SCL*DIF/MJI
0069        333 CONTINUE
0070            IJ=0
0071            IK=0
0072            NDR=0
0073            IF(NPI.GE.NP1.AND.NPI.LT.NP2) NPI=NPI/LIN(4)
0074            IF(NPI.GE.NP2.AND.NPI.LT.NP3) NPI=NPI/LIN(3)
0075            IF(NPI.GE.NP3.AND.NPI.LT.NP4) NPI=NPI/LIN(2)
0076            IF(NPI.GE.NP4)                NPI=NPI/LIN(1)
0077            IF(NPI.EQ.0) NPI=1
0078            CSEP=1.0/(NPI*HL)
0079            NW=0
0080            IF(CSEP.GT. CSEPL) NW=1
      C*********************************************************************************
      C     SEPARATES DRAW AND NO DRAW SEGMENTS OF CONTOUR
      C********************************************************************************@
0081        757 IK=IK+1
0082            IQ=IK-1
0083            IF (IK.GT.II.AND.NDR.EQ.0) GO TO 99
0084            IF (IK.GT.II.AND.NDR.EQ.1) GO TO 759
0085            KSQ=KSP(IK)+NOP
0086            IF(KSQ.LT.4) GO TO 758
```

```
          IF (NOR.EQ.1) GO TO 759
          GO TO 757
      758 NOR=1
             IF(NW.EQ.1.AND.IQ.EQ.JL.AND.ILAB.EQ.1) GO TO 720
          IJ=IJ+1
          XD(IJ)=XC(IK)
          YD(IJ)=YC(IK)
          GO TO 757
      720 KFG=1
C***********************************************************************a
C      DRAW A SEGMENT OF CONTOUR
C***********************************************************************a
      759 NR=IJ
          IK=IK-1
          NOR=0
          IJ=0
          IF(NR.EQ.0) GO TO 814
          IF(LINET.EQ.0) GO TO 811
          IF(NOR.NE.2) GO TO 811
          NOUT=3
          NIN=10
          NNN=NIN-1
          I=0
      815 DO 812 NI=1,NIN
          I=I+1
          NU=NI
          XD(NI)=XD(I)
          YD(NI)=YD(I)
          IF(I.EQ.NR) GO TO 813
      812 CONTINUE
      813 XD(NU+1)=0.0
          YD(NU+1)=0.0
          XD(NU+2)=SCL
          YD(NU+2)=SCL
          CALL BLINE(XD,YD,NU,1,NNN,1,0.01)
          I=I+NOUT-1
          IF(I.GE.NR) GO TO 814
          GO TO 815
      811 CONTINUE
          XD(NR+1)=0.0
          YD(NR+1)=0.0
          XD(NR+2)=SCL
          YD(NR+2)=SCL
          IF(LINET.EQ.0) GO TO 1000
          IF(NOR.NE.3) GO TO 816
          CALL BLINE(XD,YD,NR,1,-3,1,0.02)
          GO TO 814
      816 CONTINUE
      402 FORMAT(1H ,10X,4I6,4(2X,F10.2))
          IF(NOR.EQ.-1) CALL BLINE(XD,YD,NR,1,3,1,0.03)
     1000 CONTINUE
          NBOLD=0
      730 NBOLD=NBOLD+1
```

```
      CALL LINE (XD,YD,NR,1,0,0)
      IF(NOR.LT.1.AND.NBOLD.LT.4) GO TC 730
  814 CONTINUE
      IF (KFG.EQ.0) GO TO 757
C***********************************************************************@
C     DRAW LABEL
C***********************************************************************@
      KFG=0
      CK=CV(K)
            CALL CLABEL( XC,YC,HL,JL,II,CK,NKG,SCL,MJI,LABET)
      IK=IK+NKG-1
      IF(NKG.EQ.0) IK=IK+2
      GO TO 757
   99 RETURN
      END
```

```
      SUBROUTINE CLABEL( XC,YC,HL,JL,II,CK,NKG,SCL,MJI,LABET)
      DIMENSION XC(440),YC(440),XP(10),YP(10),XPP(10),YPP(10),CL(10),
     1 L(11)
      IF(JL.EQ.0) GO TO 2
      CVL=ABS(CK)
      IF(LABET.EQ.1) CVL=CVL/MJI
      NF=1
C*******************************************************************************
C     SEPARATES LABEL NUMBER INTO INDIVIDUAL DIGITS.
C******************************************************************************@
      DO 6 I=1,10
      NDIG=I+1
      NF=NF*10
      IF(CVL.LT.NF) GO TO 7
    6 CONTINUE
    7 IF(CK.GE.0) NDIG=NDIG-1
      TL=(2+NDIG)*HL
      IS=1
      IF(CK.LT.0) IS=2
      DO 8 I=IS,NDIG
    8 L(I)=CVL/10**(I-IS)
      L(NDIG+1)=0
      IR=NDIG+1
      DO 9 I=IS,NDIG
      IR=IR-1
    9 CL(IR)=L(I)-L(I+1)*10
C*******************************************************************************
C     CREATES GAP OF CORRECT SIZE
C******************************************************************************@
      DO 1 K=1,50
      KK=JL+K
      NKG=K
      IF(KK.GT.II) GO TO 2
      AD=SQRT(( XC(JL)-XC(KK))**2+(YC(JL)-YC(KK))**2)/SCL
      IF(AD.GT.TL) GO TO 3
    1 CONTINUE
    2 NKG=0
      RETURN
C*******************************************************************************
C     FITS PARABOLA TO MID AND END POINTS OF GAP
C******************************************************************************@
    3 NH=NKG/2
      NH=NH+JL
  100 FORMAT(1H ,10X,6F10.4,4I5)
      NKG=NKG+JL
      D1=SQRT((XC(JL)-XC(NH))**2+(YC(JL)-YC(NH))**2)/SCL
      D2=SQRT((XC(NH)-XC(NKG))**2+(YC(NH)-YC(NKG))**2)/SCL
      COMP=D1/D2
      IF(COMP.GT.1.50.OR.COMP.LT.0.67)GO TO 2
      STR=(YC(NKG)-YC(JL))/(AD*SCL)
      CTR=(XC(NKG)-XC(JL))/(AD*SCL)
      ST=(YC(NH)-YC(JL))/(D1*SCL)
      CT=(XC(NH)-XC(JL))/(D1*SCL)
```

```
      X1=(CT*CTR+ST*STR)*D1
      Y1=(ST*CTR-CT*STR)*D1
      X2=AD
      IF(Y1.GT.HL) GO TO 2
      AP=Y1/(X1**2-X1*X2)
      BP=-AP*X2
      HH=-HL/2.0
      IF(XC(JL).GT.XC(NKG)) HH=-HH
C*********************************************************************
C     CALC COORDS OF CORNERS OF DIGITS
C********************************************************************@
      DO 4 I=1,NDIG
      XP(I)=HL*I
      YP(I)=AP*XP(I)**2+BP*XP(I)+HH
      DP=SQRT(XP(I)**2+YP(I)**2)
      STB=YP(I)/DP
      CTB=XP(I)/DP
      YP(I)=(STB*CTR+CTB*STR)*DP+YC(JL)/SCL
    4 XP(I)=(CTB*CTR-STB*STR)*DP+XC(JL)/SCL
      TH=ARSIN(STR)
      TH=TH*180.0/3.1416
      IF(HH.GT.0) GO TO 11
      GO TO 14
   11 TH=-TH
      DO 13 I=1,NDIG
      YPP(I)=YP(I)
   13 XPP(I)=XP(I)
      KP=NDIG+1
      DO 15 I=1,NDIG
      KP=KP-1
      XP(KP)=XPP(I)
   15 YP(KP)=YPP(I)
   14 IF(CK.GE.0) GO TO 12
      X=XP(1)
      Y=YP(1)
  101 FORMAT(1H ,10X,3F10.4)
C********************************************************************@
C     IF CONTOUR VALUE -VE, WRITE MINUS SIGN
C********************************************************************@
      CALL SYMBOL(X,Y,HL,60,TH,-1)
   12 DO 10 I=IS,NDIG
      X=XP(I)
      Y=YP(I)
      CJ=CL(I)
      IF (CJ.LT.0.5.AND.CJ.GT.-0.5) CJ=0.0
C********************************************************************@
C     WRITE EACH DIGIT OF CONTOUR LABEL AT CALCULATED POSITION;
C********************************************************************@
      CALL NUMBER (X,Y,HL,CJ,TH,-1)
   10 CONTINUE
      NKG=NKG-JL
      RETURN
      END
```