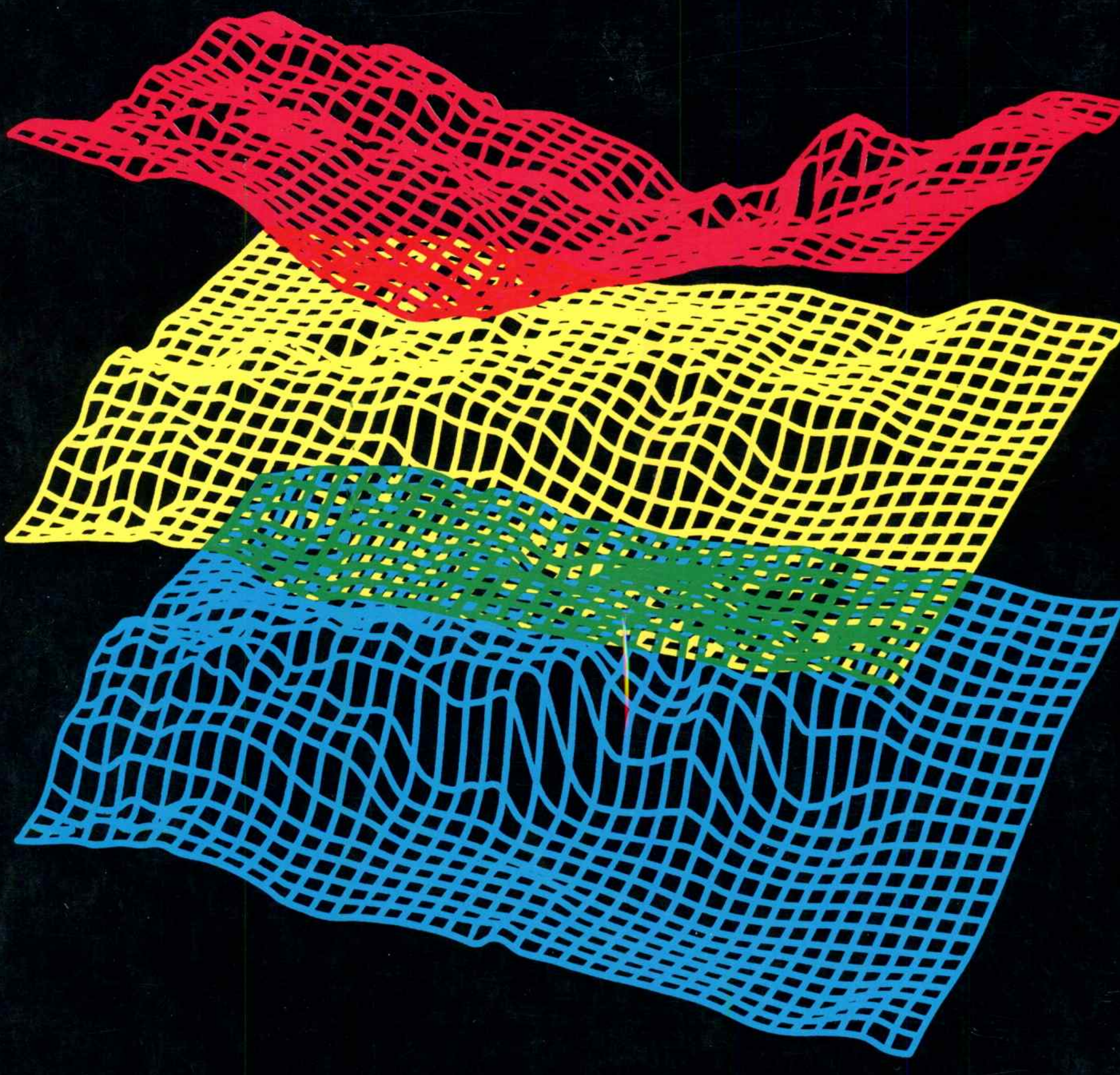
SURFACE II GRAPHICS SYSTEM

(REVISION ONE)

R. J. SAMPSON



Editor's Remarks

The new *Series on Spatial Analysis* will be devoted to longer contributions from the Kansas Geological Survey to the understanding of variation in geologic phenomena through time and space. The publications will encompass theoretical studies, methodology and algorithms, and case histories and demonstrations. The common thread running through the series will be concern with the manner in which geologic properties change from point to point.

The *Series on Spatial Analysis* should not be regarded as a continuation of the earlier Kansas Geological Survey *Computer Contributions.* The CC's were a highly successful series designed to serve as a publication outlet for geologically oriented computer programs at a time when no appropriate medium for their distribution existed. With time, regular mechanisms for publication of programs developed, such as the *Journal of the International Association for Mathematical Geology, Computers & Geosciences, Computer Applications,* and *Geocom Programs,* and the CC series was no longer necessary. The *Series on Spatial Analysis* will contain monographs which are too long or otherwise not appropriate for these publications. In addition, the series will be confined to contributions from the Kansas Geological Survey and associated individuals.

The first paper in this series is by Robert J. Sampson of the Operations Research Section of the Kansas Geological Survey. The *SURFACE II Graphics System* is a user's manual for the computer contouring and graphics display system developed by the Kansas Survey, as currently implemented at the Computation Center of The University of Kansas and at other facilities. It is appropriate that this is the initial paper in our new series, because SURFACE II has been the primary tool used by the Kansas Survey in its investigations of spatial variability. As a result, SURFACE II incorporates options and statistical procedures not ordinarily found in graphics software. Many of the succeeding papers in the *Series on Spatial Analysis* will describe investigations which extensively used SURFACE II, or algorithms and procedures implemented as adjuncts to SURFACE II.

Information concerning the availability of SURFACE II and the costs of licensing agreements for its use may be obtained by writing the Editor, *Series on Spatial Analysis.* Additional copies of this manual are available through campus bookstores at those universities where SURFACE II has been implemented, or directly from the Kansas Geological Survey. Suggestions or corrections to the manual will be appreciated, and should be sent to the Editor. Although every attempt has been made to insure that SURFACE II performs as described and that the instructions contained in this manual are correct, the Kansas Geological Survey can assume no responsibility for the use of the SURFACE II graphics system.

Dr. John C. Davis, Editor
Series on Spatial Analysis

SURFACE II GRAPHICS SYSTEM

BY

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I would like to thank Dr. John C. Davis for his efforts on my behalf and for his suggestions and continued support of my research. Special thanks are due to Ms. Jo Anne DeGraffenreid for editorial assistance and typing of this manual. Mr. Harold Cable ran all of the test problems and prepared hundreds of plotter-drawn illustrations. Many other persons at The University of Kansas used earlier versions of SURFACE II and offered their suggestions for correcting malfunctions and comments for the improvement of the system. The patience of all of these people during the long gestation period of SURFACE II is gratefully acknowledged.

This revision contains numerous suggestions and corrections provided by users of SURFACE II. I am especially appreciative of the suggestions of Mr. Chuck Buckley, formerly at the Kansas State University Computation Center; Mr. T.P.L. Lam and Peter Buttuls of the University of Alberta Computing Service; Mr. Paul Hibbert and his staff at the Computer Science Centre, Canadian Department of Energy, Mines and Resources; and Mr. Paul Schiller, formerly with the Atlantic Richfield Company.

CONTENTS

PAGE

SURFACE II GRAPHICS SYSTEM

BY

ROBERT J. SAMPSON

INTRODUCTION

SURFACE II is a computer software system for creation of displays of spatially distributed data. An easily understood example of such data are measurements of the elevation of the ground collected at points on the Earth's surface. The geographic coordinates of these points constitute two variables, X and Y, and the height of the ground above sea level at each point constitutes a third variable, Z. SURFACE II will produce diagrams that show the continuous form of the ground in the area containing the control points. The system, however, is general, and will display the form of any variable characterized by values "located" at coordinates defined by two other variables. The only inherent restrictions are that the coordinate variables must be orthogonal, and the mapped variable must be single-valued.

The basic form of graphic display produced by SURFACE II is a *contour map*, a plot of the two coordinates on which values of the third variable are defined by lines of equal values. A *contour* is a line which goes through all points on a surface that have the same value. The area between two successive contours contains only points having values which lie within the range defined by the enclosing lines. Although the term "contour" applies in a strict sense only to lines of equal ground elevation, it is more generally used to describe any display of this type. An excellent introduction to contour maps is given in the free booklet, *Topographic Maps*, issued by the U.S. Geological Survey.

Figure 1 is a contour map of topography in a portion of Graham County, Kansas. Data were obtained by surveying the ground elevation at the sites of oil wells. The contour lines

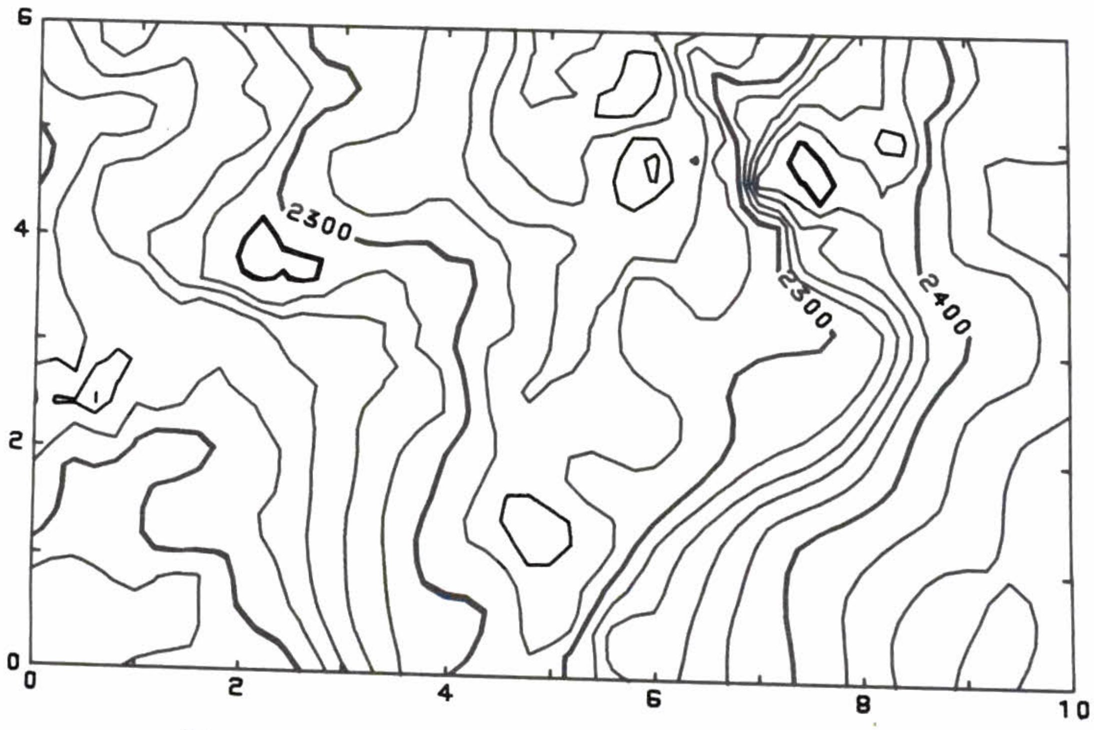


Figure 1.--Topography in a part of Graham Co., Kansas. Contour map prepared from 190 measurements of ground elevation. Horizontal distances are in miles. Contour interval is 20 feet.

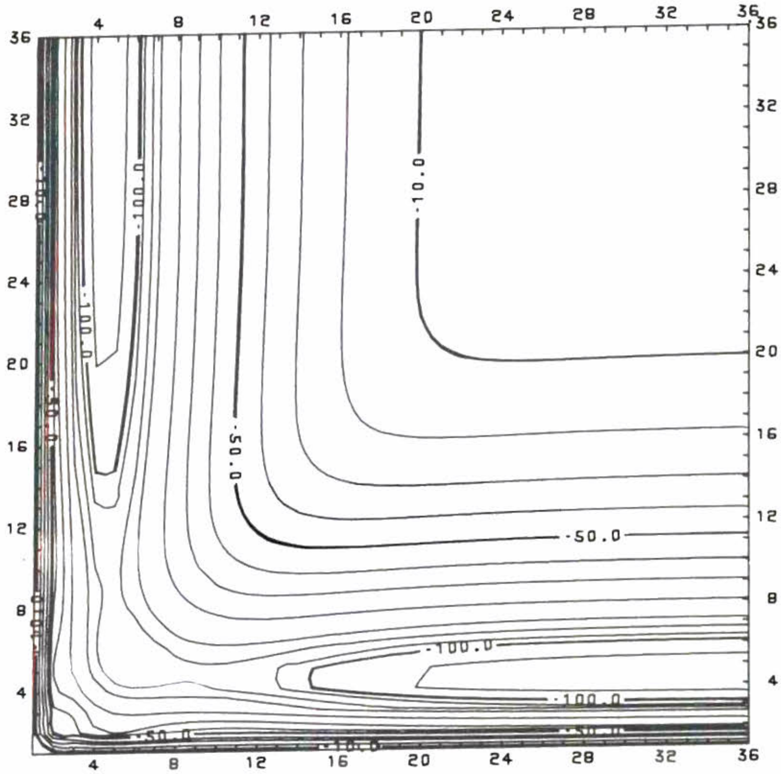


Figure 2.--Potential energy surface of a hydrogen molecule reacting with a hydrogen atom. X and Y coordinates are distances in Angstrom units between the molecule and atom. Contour interval is 10 kilocalories per mole.

provide an impression of the form of the Earth's surface in the map area. To demonstrate that other variables may be displayed in the same manner as geographic coordinates, Figure 2 is a contour map of the potential energy surface of a hydrogen molecule reacting with a hydrogen atom. The X and Y coordinates are the distance between the molecule and atom; the contours represent a measure of energy.

SURFACE II will also produce *perspective block diagrams*, sometimes called transect or "fishnet" plots. These can be envisioned as a deformed rectangular grid or mesh, where spacings between lines of the mesh correspond to equal increments of the variables X and Y. However, the mesh is pushed upward until it conforms to values of the third variable. The resulting form is displayed as it would appear to an observer at some specified viewpoint. Figure 3 is a perspective block diagram corresponding to the contour map of Figure 1.

In a perspective drawing, lines on the surface appear to converge as they become more distant. This effect becomes more pronounced as the viewpoint is moved closer to the block. SURFACE II allows the display to be viewed from any elevation, at any angle, and from any distance. If desired, contour lines may be drawn on the block diagram.

The block diagram shown in Figure 3 is a two-dimensional representation of a three-dimensional object. The illusion of three dimensions can be heightened by drawing the block as a *stereo pair* which can be viewed through special glasses to yield an apparently solid image. The effect is created by drawing two block diagrams, one representing the surface as seen by the right eye of the observer, the other representing the surface as seen by the left eye. The two blocks may be drawn side-by-side and viewed simultaneously using special glasses called stereoscopes, which insure that each eye perceives only the proper image. The separate images are automatically fused by the brain to create the illusion that the observer is looking at a single solid object. A stereo pair of the surface in Figure 1 is shown in Figure 4. The difference in appearance of the block diagrams in Figures 3 and 4 illustrates how the user can control the appearance of these diagrams by changing the viewing position and scaling the values to be plotted.

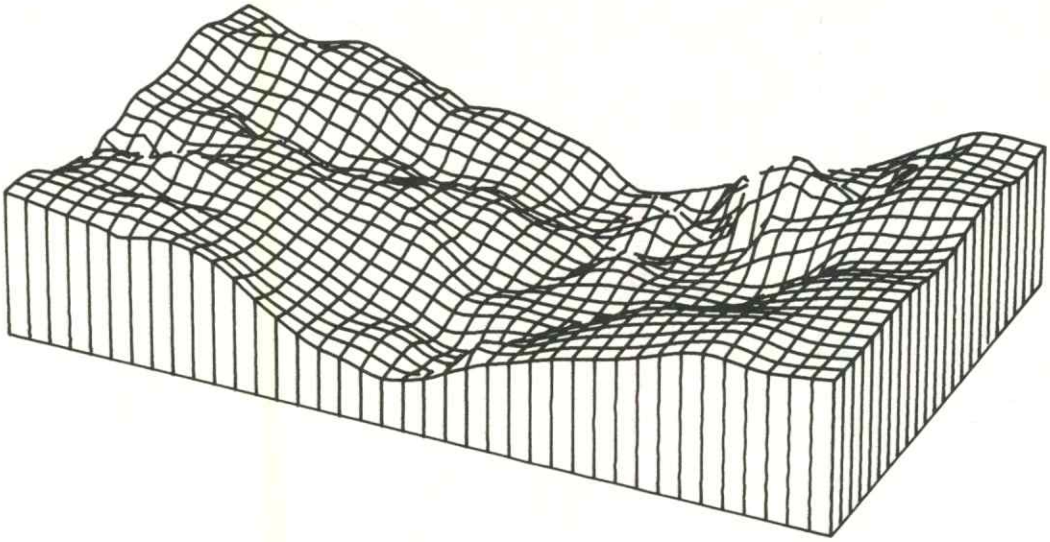


Figure 3.--Block diagram of topography, corresponding to Figure 1. Spacing between lines is 0.2 mile.

A third type of diagram is a *posting*, or plotting of symbols representing observations at their appropriate X and Y coordinates. SURFACE II will plot a specified symbol at the location of each data point and, if desired, will label each point with either an identification number or the value of Z associated with the point. Posting may be combined with a contour map, producing a map on which the original control points are located. Figure 5 shows a posting of the samples used to construct Figure 1. Postings may also be created using the line printer.

SURFACE II also generates displays of the spatial relationships between observations. Figure 6, for example, shows the distance from every point in the map area to the nearest control point. Such maps are useful for evaluating reliability of contour maps made from irregularly distributed data.

Spatial data may be transformed in many ways, leading to a great variety of derived maps and statistical displays. Numerous examples of such transformed maps are included with the appropriate commands in the Catalog section of this manual.

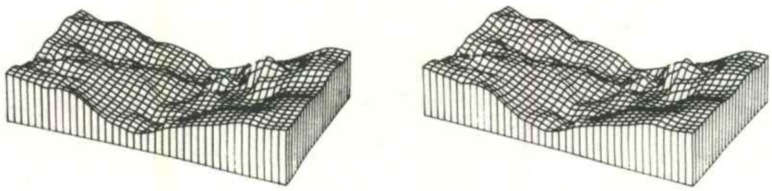


Figure 4.--Perspective block diagrams of topography in Graham Co., Kansas, plotted for stereoscopic viewing. Blocks were originally drawn twice finished size and photographically reduced to prevent line details from being obscured.

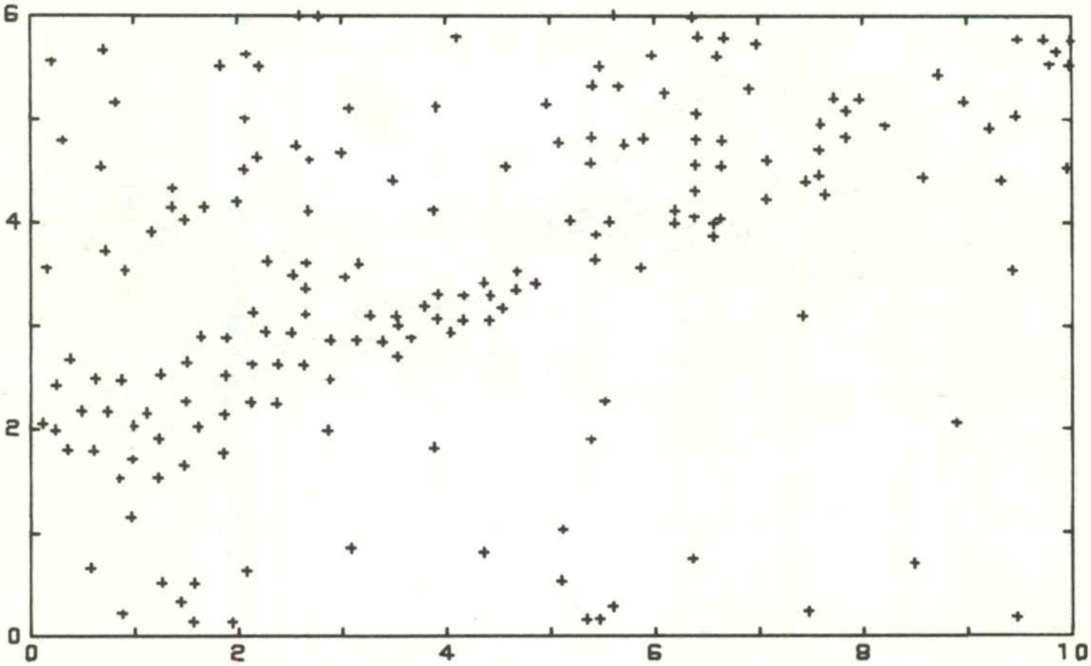


Figure 5.--Posting of control points used to prepare Figure 1.

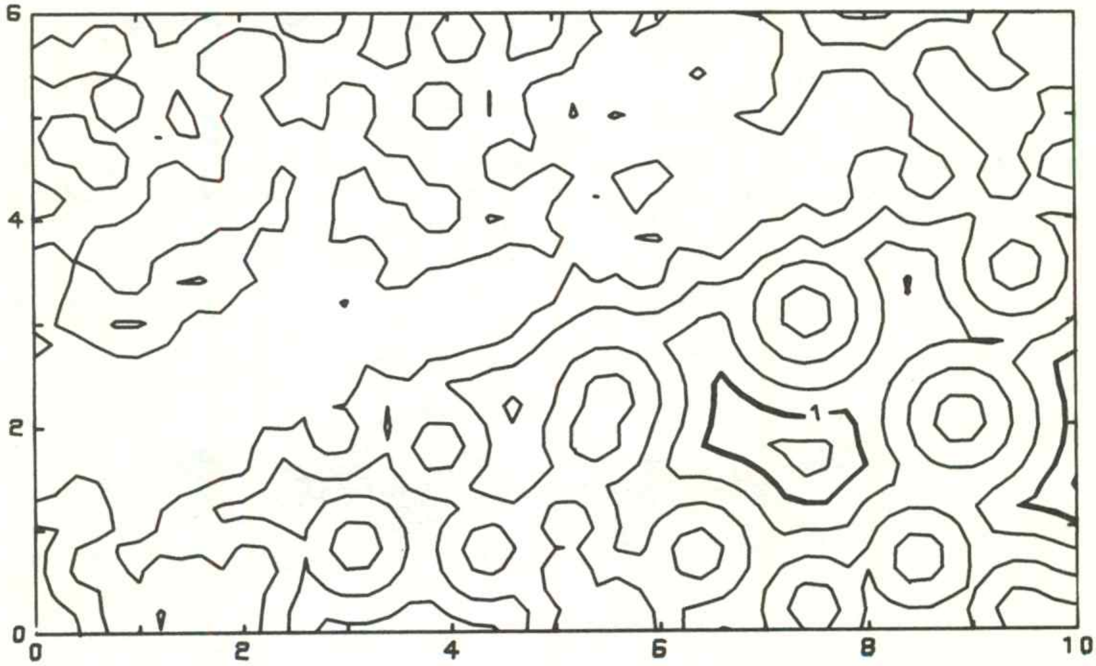


Figure 6.--Distance function map for Graham Co. area shown in Figure 1. Map gives distance from nearest control point to all points within map area. Contour interval is 0.25 mile distance.

GENERAL FEATURES OF SURFACE II

The basis for all operations in SURFACE II is a rectangular grid of values which is a numerical representation of the surface to be displayed. The grid is a numerical matrix whose elements are measurements of the Z variable made at points identified by the two geographic coordinates X and Y. The geographic coordinates are implicitly defined by the rows and columns in the matrix.

SURFACE II can display the grid matrix in two different ways. Contour lines may be laced through the grid, as shown in Figure 7. This is done by linearily interpolating between grid nodes to locate the points where a contour line of specified value will cross the edge of a grid cell. The string of successive X and Y coordinates of these intersections defines the contour line that will be drawn.

Alternatively, the grid may be drawn in perspective, with each grid node offset vertically an amount proportional to the Z-value. The result is a block diagram, as shown in Figure 8. This is more direct than contouring as a method of display, as it does not require interpolation. However, it is difficult for a viewer to extract quantitative information from a block diagram, which is easily done from a contour map.

Grid Element Manipulation.--Extensive capabilities for the numerical modification of grid matrices are built into SURFACE II. The Z elements in the array may be replaced by an average of their neighbors. That is,

$$\dot{Z}_{c,r} = \sum_{i=-k}^{k} \sum_{j=-m}^{m} \omega_{ij} Z_{c+i,r+j} / \sum_{i=-k}^{k} \sum_{j=-m}^{m} \omega_{ij} .$$

As an example, each element $Z_{c,r}$ might be replaced with a simple average of itself plus the eight nearest elements. This is illustrated in Figure 9, for the element in the rth row and cth column. SURFACE II allows the user to automatically assign a number of variable weighting functions that change with distance away from the point being calculated. The purpose of averaging is to smooth or reduce element-to-element variation in the grid matrix.

A closely related operation is filtering, in which the weighting function ω_{ij} may be explicitly defined by the user. This is done by providing a small matrix of filter weights

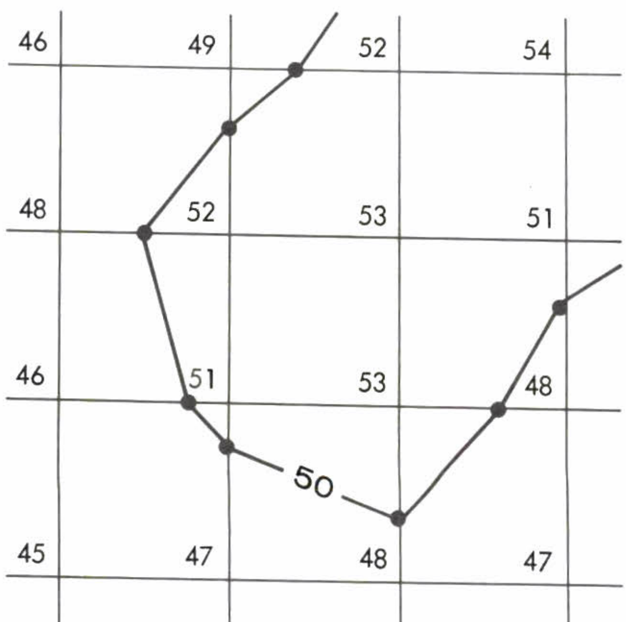


Figure 7.--Path of a contour line drawn through a regular grid. Value of the contour line is 50. (After Walden, 1972, fig. 1.4.)

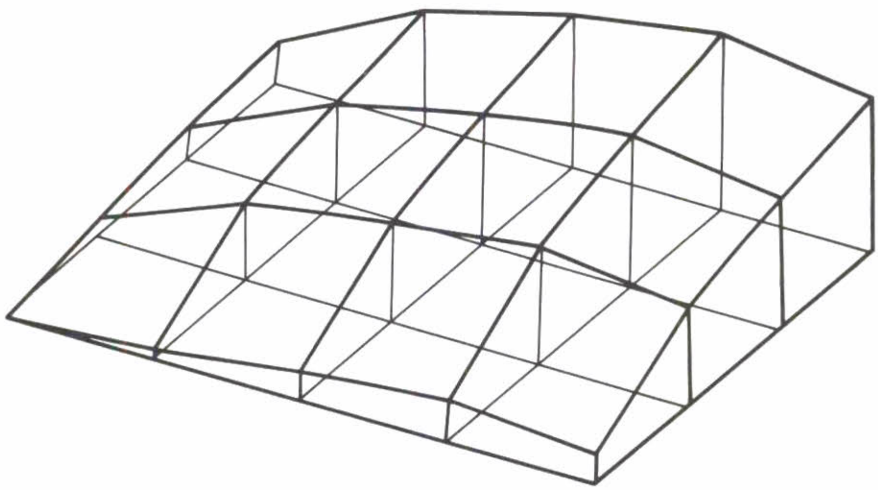


Figure 8.--Perspective block diagram constructed by vertically offsetting grid values an amount proportional to their value.

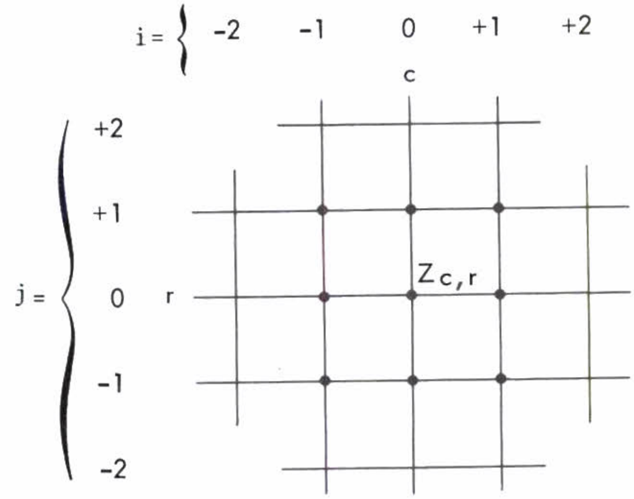


Figure 9.--Smoothing of a grid matrix by replacing the value $Z_{c,r}$ at a grid node with an average of the values at neighboring nodes.

which is cross-multiplied with successive areas of the grid. The products are summed and the result applied to the central value within the cross-multiplied area. The filter matrix is moved across the grid, repeating the operation until all Z elements in the matrix are replaced with filtered $\dot{Z}$ values. Note that in filtering the outer rows and columns of the grid matrix cannot be treated because the operations require elements that are beyond the edge of the grid. SURFACE II automatically blanks out untransformed rows and columns in the grid matrix so it includes only treated elements.

It is possible to differentiate the surface represented by the grid matrix. The derivative is taken with respect to a direction represented by an arbitrary geographic axis Q. The differentiation is $\tan\theta = \frac{dZ}{dQ}$ where Z is the mapped variable and Q is distance along the arbitrary axis. The differential equation is approximated by $\tan\theta = \frac{\Delta Z}{\Delta Q} = \frac{Z_2 - Z_1}{2D}$ where Z_2 and Z_1 are values of the mapped variable taken an arbitrarily small distance apart. These Z values are found, in turn, by double linear interpolation from the grid nodes. Z values in the grid matrix are replaced by $\dot{Z} = \tan\theta$, yielding maps of the slope of the surface (first derivative) in a specified direction. The bordering rows and columns are blanked out because the derivative cannot be calculated at the edges of the map.

For many operations, it is useful to remove the drift or linear trend from the Z value in the grid matrix. This transforms the surface so its values fluctuate around a mean of zero. The operation can be regarded as a rigid rotation and translation of the surface to a point where the regional dip becomes flat. Trend removal is accomplished by calculating the plane of best fit through the surface and then subtracting this plane from the surface. That is, $\dot{Z}_{c,r} = Z_{c,r} - (\beta_0 + \beta_1 X_c + \beta_2 Y_r)$ where the β's are the intercept and slope coefficients of the best-fit plane.

Values in the Z matrix may be scaled by various transformations to conform to a specified range. They also may simply be transformed by a specified operation without being forced into a set range. Transformations include $\dot{Z}_{c,r} = \log Z_{c,r}$, $\dot{Z}_{c,r} = \sqrt{Z_{c,r}}$, and $\dot{Z}_{c,r} = m\, Z_{c,r}$, where m is a constant. Constant values may be added or subtracted from the $Z_{c,r}$.

Scaling operations adjust all elements in the grid matrix. At times, however, it may be more meaningful to check the range of values in the matrix and adjust or delete only those which exceed set limits. This may be done in SURFACE II using a command in which the acceptable range can be specified.

A related operation checks the X and Y coordinates of grid nodes rather than Z values of the nodes. All grid elements satisfying a specified condition will be assigned an arbitrary Z value which will insure that they will not be represented on the finished graphics display. This operation is used to blank out areas of a map or block diagram.

Finally, the number of rows and columns in the grid matrix may be changed if desired. The new grid elements are calculated by interpolation from the original grid. The geographic extent of the new matrix may be changed if desired, and the map area represented by either more or fewer rows and columns. This allows two or more grids to be brought into coincidence.

Multiple Grid Operations.--The information contained in more than one grid matrix can be combined and displayed in various ways using SURFACE II. The only restriction on grid-to-grid operations is that the matrices being combined must have the same numbers of rows and columns. The simplest comparison between two grids is to find their difference; this yields an isopachous or equal thickness map which shows areas of equal difference between the two surfaces. The operation is $\dot{Z}_{c,r} = Z^1_{c,r} - Z^2_{c,r}$ where the superscript refers to the two grids.

Two grids may be added together to obtain their sum, $\dot{Z}_{c,r} = Z^1_{c,r} + Z^2_{c,r}$. If the two original matrices represent thicknesses, for example, the combined matrix represents total thickness of the two intervals.

An important application of the ability to subtract or add two surfaces is calculation of trend-surface residuals. Trend surfaces are polynomial regressions of the geographic coordinates of sample data points. Once a trend surface equation has been found, it can be used to evaluate the surface at every grid node, yielding a matrix of estimated trend values. Subtraction of this trend surface from the original grid matrix yields a matrix of the trend residuals.

Element-by-element multiplication of one grid matrix by another yields a product matrix, $\dot{Z}_{c,r} = Z^1_{c,r} \cdot Z^2_{c,r}$. The inverse operation $\dot{Z}_{c,r} = Z^1_{c,r} \cdot \frac{1}{Z^2_{c,r}}$, corresponding to element-by-element division of one matrix by the other, can also be performed. These operations are especially useful in the mapping of statistical quantities or econometric data. For example, a grid matrix representing a map of per capita income may be cross-multiplied by one of population to yield a total income map. If the two grids represent standardized statistical variables, their cross product is proportional to the local covariance. With appropriate scaling of the original grids, a combined grid can be created that closely approximates the point-by-point correlation between the two surfaces.

Creation of a Grid.--Grid matrices can be read into SURFACE II from external sources, but usually observations neatly spaced on a regular pattern are not available. In the natural sciences especially, it is more common to have data points scattered irregularly across the map area. Because graphic displays and transformations can only be performed with SURFACE II on regular grids, the system has several provisions for estimating such grids from irregularly spaced data. In fact, the "gridding" of scattered data points is the single most important use of this graphics display package.

The two general classes of techniques for estimating a regular mesh of points on a surface defined at other points are called "global fit" and "local fit" methods. As the names suggest, global estimates are based on all original data points on the surface and local estimates are made only from a selection of nearby data points. Trend surface analysis is the most widely used global method. It consists of fitting a polynomial expansion of the geographic coordinates to the Z values at the original data points using the method of least squares. Trend surface analysis is related to the statistical procedure of curvilinear regression. Each original observation is considered to be the sum of a deterministic polynomial function of the geographic coordinates plus a random error. That is,

$$Z_k = \beta_0 + \beta_1 X_k + \beta_2 Y_k + \beta_3 X_k^2 + \beta_4 Y_k^2 + \ldots + e_k \quad .$$

Here, the subscript k simply denotes an original control point at location $X_k Y_k$. The polynomial can be expanded to any arbitrary degree, within the limits of computational capability. The unknown β coefficients are found by solving a series of simultaneous linear equations which involve powers and cross products of the X, Y, and Z values. Once the coefficients are found, the polynomial function can be evaluated at any point within the map area. It is a simple matter to create a grid matrix of $\dot{Z}_{c,r}$ values by substituting the coordinates of the grid nodes into the polynomial and calculating an estimate of the surface for each point.

There are a number of disadvantages to a global fit procedure. The most obvious of these is the extreme simplicity of form of the polynomial surface as compared to most natural surfaces. A first degree polynomial trend surface is a dipping flat plane. A second degree surface may have a single maximum or minimum. In general, the number of possible inflections in a polynomial surface is one less than the number of coefficients. As a consequence, a trend surface does not generally pass through the data points, but has the characteristics of an average.

A second disadvantage of polynomial trend surfaces is that they tend to accelerate upward or downward without bounds in areas of no control, such as along the edges of maps. Admittedly, estimation in such areas is questionable using any method, but trend surfaces seem particularly inappropriate.

Computational difficulties can be encountered if an attempt is made to fit a function of great complexity. This will require solution of a large number of simultaneous equations containing very large elements. The matrix solution may become unstable, or rounding errors may result in incorrect coefficients.

Nevertheless, there are circumstances in which trend surface analysis is an appropriate method for estimating a grid matrix. If the raw data are random statistical variates, perhaps with more than one value at each observation point, trend surfaces will have certain statistically optimum properties. In addition, trend surfaces are used as an approximation of "regional structure" in geologic structure maps. Autocorrelated positive residuals from the regional structure are used as guides in petroleum exploration.

Local fit procedures are generally considered to be the most appropriate for estimating points on a complex surface. They are based on the intuitively appealing idea that a nearby observation is a better estimate of the value of a point on a surface than a more distant one, and that a small number of the nearest control points provides essentially all of the information that is relevant in an estimate. In other words, values at successive locations on a continuous surface are usually considered to be autocorrelated, but the degree of autocorrelation decreases with increasing distance between the locations.

There are many different ways in which the control points in a neighborhood can be combined to create an estimate. Unfortunately, little comparative work has been done on the relative merits of these alternatives. Some use all control points within a specified distance of the point to be estimated, others use the nearest n points regardless of how distant some might be. Most weight the points so the nearest have greatest influence on the estimate. However, some use an inverse distance weighting function, others use the inverse of the distance squared, still others use functions that drop off even more rapidly. Some place constraints on the manner in which the nearest neighbors are found, to insure an equitable distribution of control points around the estimated point. Others pay no attention to the radial distribution of the control points.

Because the relative merits of different local fit algorithms are unassessed at the present time, and because different methods may be superior for certain combinations of data point arrangements and surface forms, SURFACE II allows the user to select from among a large collection of estimating procedures in the construction of a grid. The standard method used is a two-part, weighted average of the projected slopes from the nearest neighboring data points around each grid node. In an initial pass, the slope of the surface is estimated at every data point. A search procedure finds the nearest n neighbors to the data point being considered and fits a weighted trend surface to these points. Weights inversely proportional to the distance from data point being evaluated are assigned to the other points. The constant of the fitted regression equation is adjusted so the plane passes exactly through the data point (Fig. 10). If the search procedure cannot find at least five points or if the

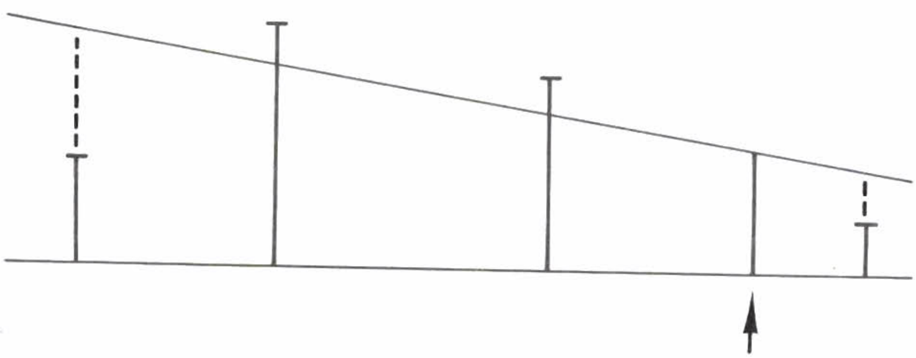


Figure 10.--Local dip at a data point (shown by arrow) is found by fitting a least-squares surface to surrounding data points, subject to the constraint that the plane passes through the point (Sampson, 1975, fig. 8).

simultaneous equations of the fitted plane do not have a solution, the coefficients of a global or regional trend are used as the local trend. The coefficients of the trend are saved for each data point.

The second part of the algorithm estimates the value of the surface at the grid nodes. A search procedure finds n' nearest neighboring data points around the node to be estimated. The X, Y coordinates of the grid node are substituted into each of the local trend-surface equations associated with these data points, in effect projecting these local surfaces to the location of the node (Fig. 11). A weighted average of these estimates is then calculated, weighting each slope by the inverse of the distance between the grid node and the data point associated with the slope. If a data point lies at or very near to a grid intersection, the value of the data point is used directly as the value of the grid node.

Slope projection may be disadvantageous in certain circumstances. For example, the method may tend to create spurious highs or lows in areas of low control if dips are projected from areas of tightly clustered control points. Also, the two-phase estimating algorithm obviously requires more computation time than a simple weighted averaging process. A gridding option is available to the user which in effect deletes the first phase of slope calculation from the

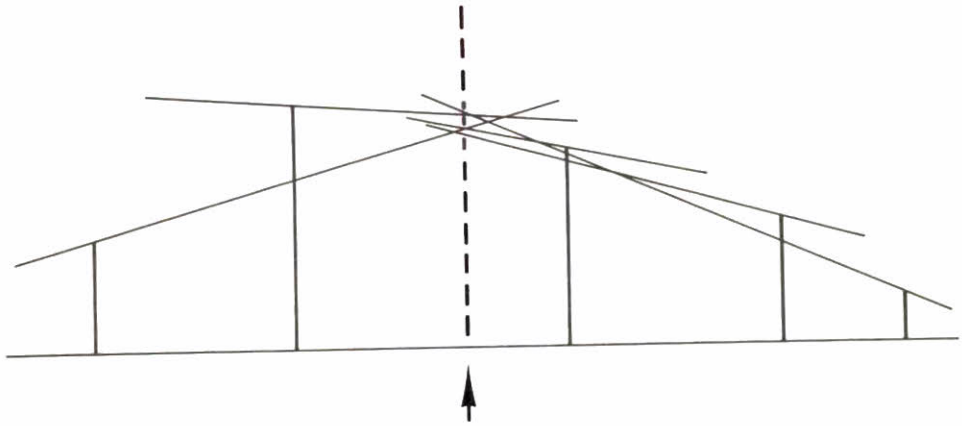


Figure 11.--Local dips at control points are projected to a grid node to be estimated (arrow). The value assigned to this node is a weighted average of the dip projections (Sampson, 1975, fig. 9).

gridding process. The grid estimates are then simply distance weighted averages of the surrounding control points.

One critical difference between various algorithms for interpolating to a regular grid is the way in which "nearest neighbors" are defined and found. Because some search techniques may be superior to others in certain situations (primarily reflecting the nature of the data point distribution), SURFACE II provides a variety of search patterns that may be selected by the user. The simplest method finds the n nearest neighboring data points, in a Euclidean distance sense, regardless of their angular distribution around the point being estimated. This method is fast and satisfactory if control points are distributed in a comparatively uniform pattern but provides poor estimates if the data are distributed at close intervals along widely spaced traverses. A quadrant search, which imposes the additional constraint that a minimum number of points must be taken from each of the four quadrants around the estimated point, is superior for highly irregular data distributions. A further elaboration is the octant search, which obtains specified numbers of nearest points (usually one or two) from each octant around the point being estimated. The procedures require finding and testing more neighbors than a simple search which increases search time. An entirely different type of search procedure finds all points within a radius r of the point being estimated.

The weights which are attached to the control points or the slopes at the points during the estimation procedure are weighted according to their distance away from the grid intersection being estimated. A number of different weighting functions can be selected. These include $\omega = \frac{1}{D}$, $\omega = \frac{1}{D^2}$, $\omega = \frac{1}{D^4}$, $\omega = \frac{1}{D^6}$, and $\omega = (1 - \frac{D}{1.1 \cdot D_{max}})^2 / (\frac{D}{1.1 \cdot D_{max}})^2$. The first four functions drop at increasing rates with distance. The more complex function is one widely used in some commercial contouring systems and drops off at a rate of approximately $\frac{1}{D^2}$.

A different approach to grid estimation is the use of universal Kriging, developed by Matheron and his associates. Kriging provides an optimal estimate of the surface at every point; that is, the interpolated surface will have minimum error. This is achieved by taking into account prior knowledge about the spatial autocorrelation between sample data points. The method requires a "structural analysis" to determine the form of the two-dimensional autocorrelation function of the surface before contouring can begin. The universal Kriging algorithm used in SURFACE II was developed by Olea (1972, 1975) in a joint research project of the Kansas Geological Survey and Empresa Nacional del Petroleo, Chile. Although universal

Kriging is more expensive than conventional interpolation procedures, it also provides a map of the expected error contained in the estimated surface. Theoretical and computational details on the method of Kriging used in SURFACE II are contained in the two articles by Olea, which also contain extensive references to the original works by Matheron and others.

An entirely different method of creating a regular grid of information from irregularly located control points is calculation of distance functions. These do not reflect the value of the surface at all, but rather the distance from any point on the map to nearby control points. The displayed grid is useful for assessing the reliability of maps of surface configuration made from the original data, as the maps will obviously be of lower reliability in areas where control is most distant. Grids can be constructed giving the distance to the nearest control point, average distance to a specified number of control points, or distance to the most distant of a specified number of points. Another application is the automatic definition of oil field boundaries by drawing a single contour line a specified distance around producing wells. Distance function maps may be useful in the examination of any phenomenon whose influence declines with distance.

EXAMPLE APPLICATIONS OF SURFACE II

Contour maps, block diagrams, and related forms of graphic displays are obviously useful in scientific fields such as geography, geology, and meteorology where maps provide the central means of scientific communication. Use of such displays is not as widespread in the other observational sciences, and they are even less appreciated in the physical sciences and mathematics. However, graphic displays can be extremely useful in these disciplines, especially as teaching or explanatory aids. The availability of voluminous demographic information from censuses has awakened the social sciences to the usefulness of graphics display techniques such as those in SURFACE II, particularly because these data are contained in large computer-managed files. Architecture and engineering, especially the fields of civil and aeronautical engineering, are areas of applied science where methods of graphic display and analysis are important tools.

This section contains selected examples of the use of SURFACE II with data from various disciplines. These applications are by no means exhaustive, but rather suggestive of the diverse possibilities of a generalized computer graphics system. Within this short space it is not feasible to include the data from which the examples are drawn, or to describe completely the command options used to make these particular illustrations. However, each example is accompanied by a general discussion of the particular application of SURFACE II, and any special graphic features of the illustrations are noted.

Locational Efficiency with Respect to Schools in Topeka, Kansas.--An example of the application of SURFACE II to the social sciences is shown in Figure 12. This map depicts the most and least locationally efficient residential areas in Topeka, Kansas, in terms of walking or travelling to junior high school locations. The best locations are shown as highs while the troughs indicate poorer locations. Schools are near the center of circular contours surrounded by the 24 distance unit locational benefit isoline.

The isoline values shown on Figure 12 are savings to students in walking or travel distance units as compared to the most distant residential area. The student assignment objective is to minimize the total aggregate distance students must walk or travel to neighborhood schools. In other words, the residential area most distant from a junior high school--near the east edge of the school district in East Topeka--receives zero locational benefits while residential areas near neighboring schools receive maximum locational benefits. Students living within the 24 distance unit isoline, for instance, receive at least this quantity of benefit from closeness to school.

The data used to draw the isoline map were obtained by linear programming. The linear program minimizes the distance students walk or travel to neighborhood schools, providing a tool for optimally assigning students.

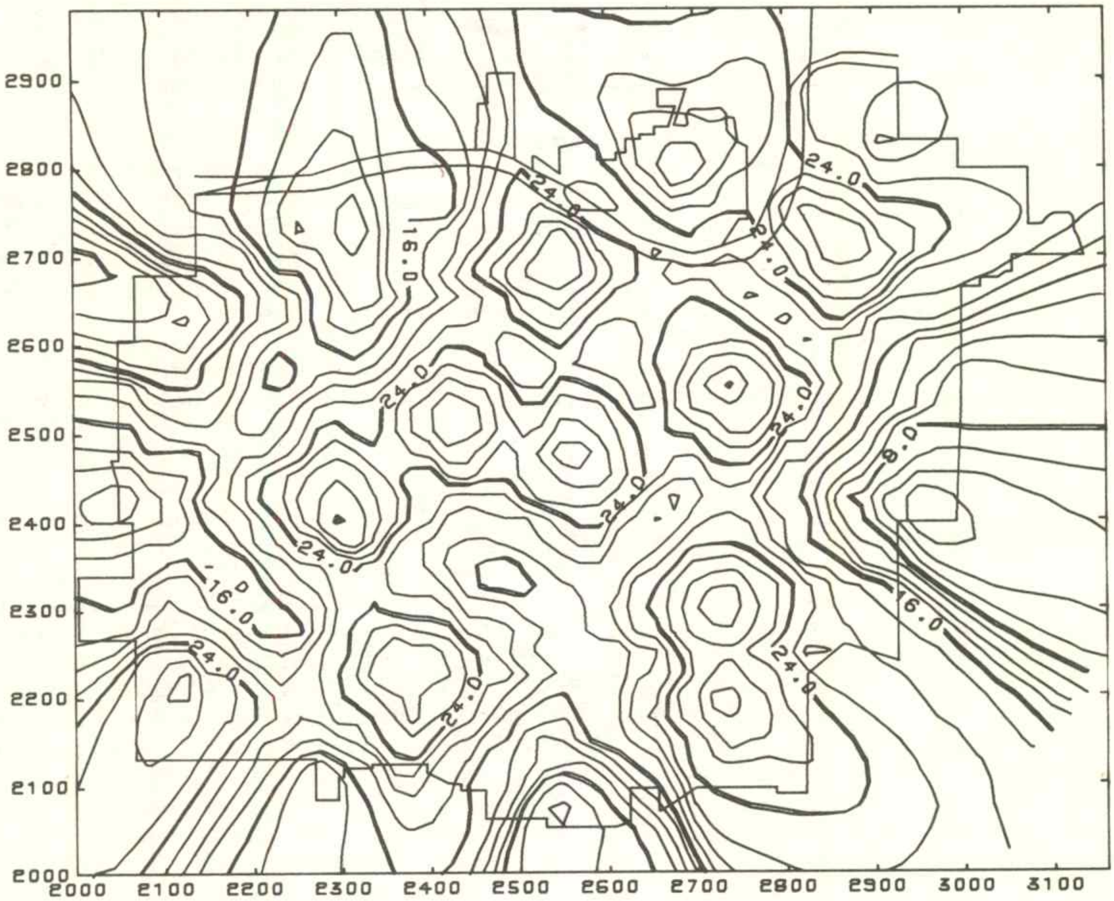


Figure 12.--Locational efficiency of residential areas in Topeka, Kansas, in terms of distances to junior high schools. Contours are in units of locational benefit. Geographic coordinates are in arbitrary units. The outline of the municipal boundary and the Kansas River has been digitized and plotted on the map.

The analysis was performed by D. E. Anderson. Original data were in the form of 389 locational benefit values for neighborhoods within the Topeka school district. These were used to create a 56 x 40 grid matrix which was then contoured. A digitized outline of the metropolitan boundaries of Topeka was read in and plotted on the map.

Optical Power Spectra of Images of Sandstones.--A two-dimensional Fourier transform of an image can be created optically by projecting the image through a simple lens. If monochromatic light is used and the image is placed in the front focal plane of the lens, the image's Fourier transform will appear at the back focal plane. All information originally present in the image is preserved in the transform, but rearranged according to spatial frequency and orientation rather than by spatial coordinates. Examination of the optical Fourier transform will reveal the relative contributions of different spatial wavelengths to the original image, emphasizing the presence of periodicities or oriented structures.

The example shown in Figure 13 is a digitized optical transform of a photomicrograph of sandstone. The pattern in the original image represents the contrast between sand grains and open pore space. The transform can be interpreted as reflecting the size distribution and orientation of pores and grains in the sample.

Data were obtained by photographing the transform at the focal plane of a laser optical bench, then digitizing the optical transmission of the photograph. An area one inch square was digitized on a 1024 x 1024 grid at 64 density levels. Areas 10 x 10 were then averaged by computer to yield a final matrix of 100 x 100 points. These were entered directly into SURFACE II and contoured at 32 logarithmically spaced contour intervals. X and Y coordinates on the diagram are rows and columns in the digitized matrix.

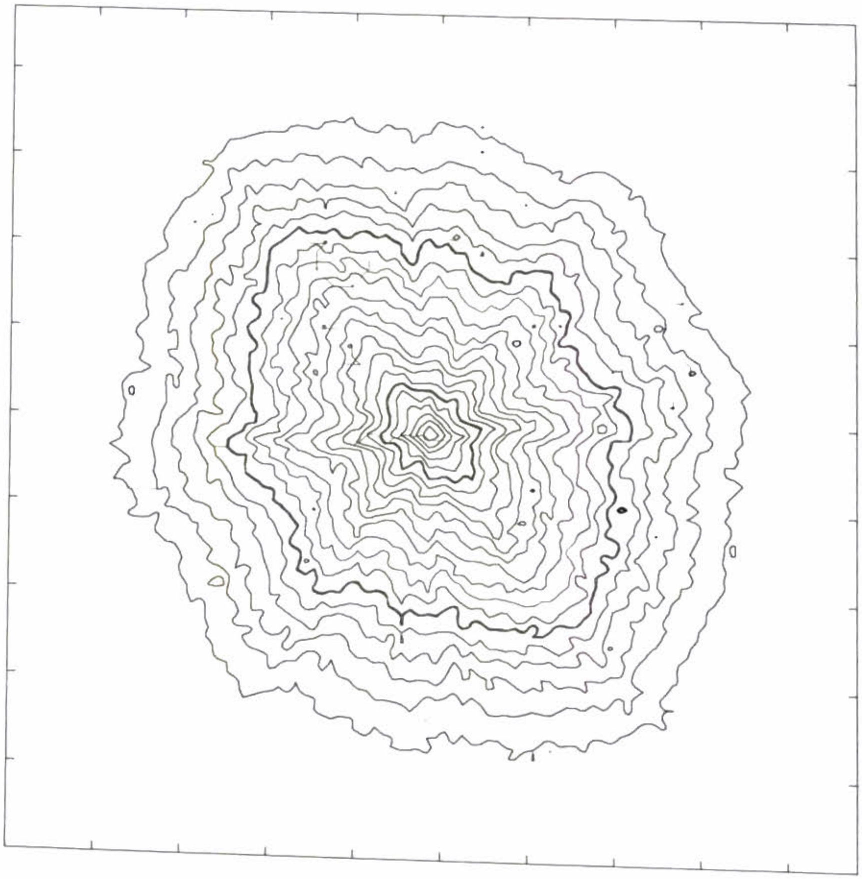


Figure 13.--Contour plot of a digitized optical transform of a sandstone photomicrograph. The contour interval is logarithmic, covering a range from 100% to 0.1% optical transmission. X and Y coordinates are rows and columns of the matrix of digitized points.

Gold and Silver Distribution in the Malvern Hills, England.--The maps in Figures 14 and 15 show the gold and silver distribution in the Malvern Hills of western England. The Malverns are a localized Precambrian inlier approximately 7 1/2 miles long and less than a mile wide. The geology of the inlier is extremely complex, consisting of a variegated suite of igneous rocks including granites, diorites, and tonolites, along with diabase dikes, pegmatites, and aplites. Anomalous concentrations of gold and silver have been reported in these rocks, although their association is obscure. Because bedrock is poorly exposed, 567 soil samples were analyzed for traces of gold and silver by atomic absorption spectrophotometry. The distribution pattern of these elements in the soil is believed to strongly reflect their abundance in the underlying rocks.

Samples were collected on a regular grid; locations were plotted as crosses on the accompanying maps. Distance between control points is 50 meters. The contour interval is 0.05 ppm on the gold map, and 0.10 ppm on the silver map. These maps show pronounced edge effects, because the contoured area is larger than the area covered by the sampling grid. These effects are especially pronounced along the lower edges. Gold and silver values are highly erratic within the sampled region, except for a band of high gold values that cross the map in Figure 14 approximately at its center.

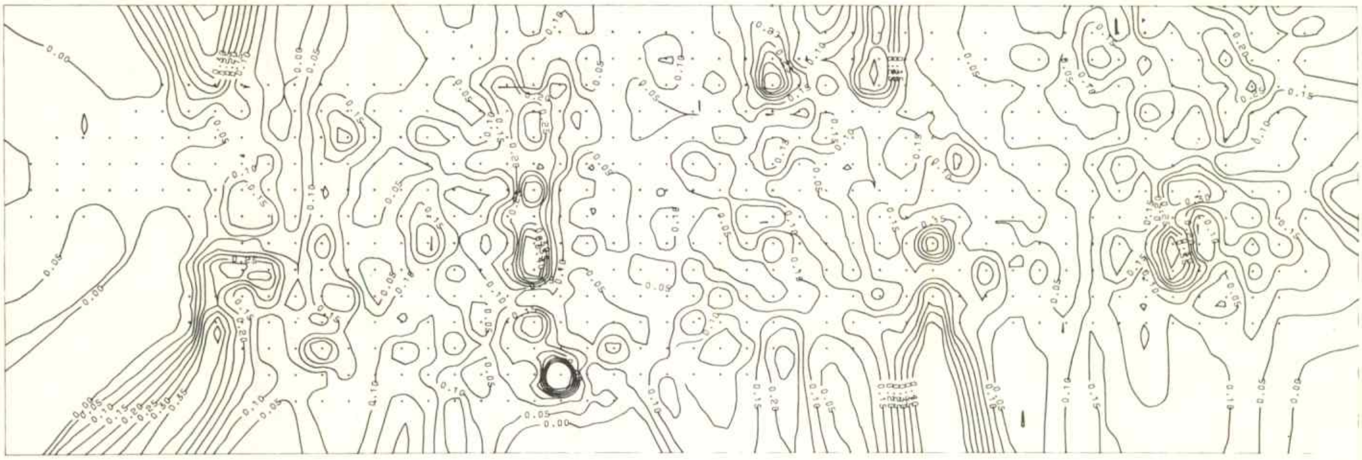


Figure 14.--Distribution of gold in soil samples from the Malvern Hills, England. Sample locations shown by crosses. Spacing between sample points is 50 meters, contour interval is 0.05 ppm.

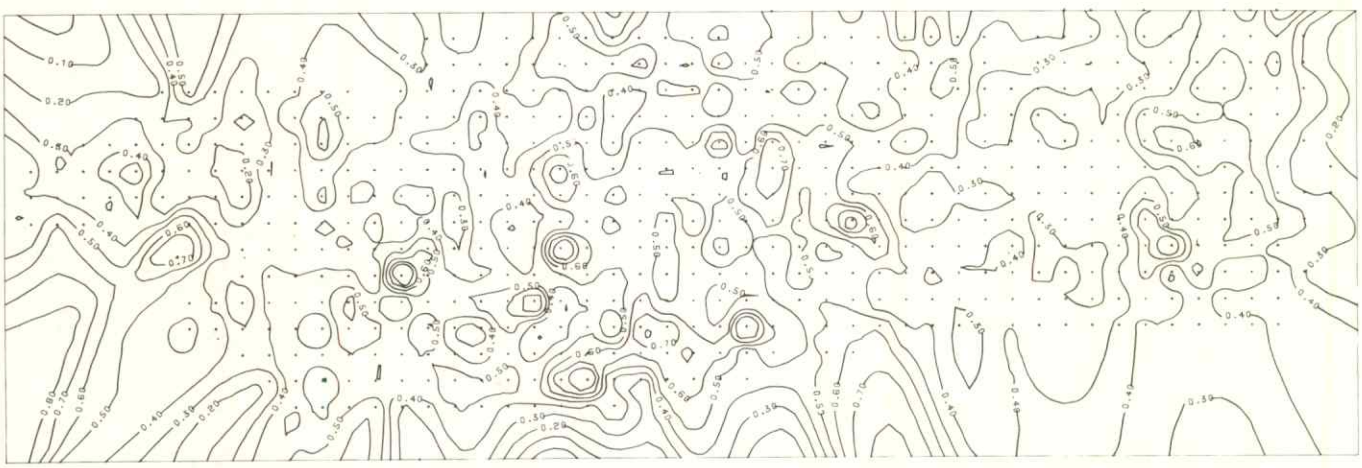


Figure 15.--Distribution of silver in soil samples from the Malvern Hills, England. Conventions are the same as in Figure 14, except the contour interval is 0.10 ppm.

These maps are part of a study of the statistical relationship between gold and silver values and rock type in the Malvern Hills, by J. H. Doveton, D. W. Bullard, and P. K. Harvey (1974).

Derivative Map of Subsurface Structure in Stafford County, Kansas.--Searching for favorable subsurface structures is one of the most successful and widely used techniques in oil and gas exploration. This is done by mapping the configuration of key horizons (measured directly as drill hole elevations or as seismic reflectors) and looking for closed structural highs. A key factor in evaluation of potential traps is the area or volume of closure, which indicates the maximum possible reserves that might be contained. It is difficult to estimate closure area from contour maps, because this requires a fortuitous coincidence of a contour line with the minimum closed elevation (spill-over point) of the trap.

If the structural contour map has been prepared by an automatic contouring program such as SURFACE II, it is possible to differentiate the surface with respect to the regional dip. This will produce a map showing slope components in the direction of the regional dip at all points in the map area. Reversals of regional dip appear as negative values while crests of anticlines and troughs of synclines appear as areas of zero slope. A differential map can be used in conjunction with a structural contour map to determine elevation of the spill-over point of anticlinal traps. Figure 16 is a subsurface structural contour map of the top of the Lansing Group (Pennsylvanian) in Stafford County, Kansas. The regional trend can be approximated by fitting a first order linear trend surface to values of the formation top in wells which penetrate the horizon (Fig. 17). The regional dip plunges approximately S30°W. If the structural contour map is differentiated with respect to this dip, the map shown in Figure 18 will be produced. Negative slopes show a strong coincidence with locations of known oil pools. Furthermore, oil migration paths can be traced manually across the map from the southwest by drawing flow lines that pass around areas of zero or negative slope.

The original data set consists of 1200 Lansing tops. The analysis was conducted as part of the Kansas Oil Exploration (KOX) Project of the Kansas Geological Survey, and was done by J. C. Davis and R. J. Sampson.

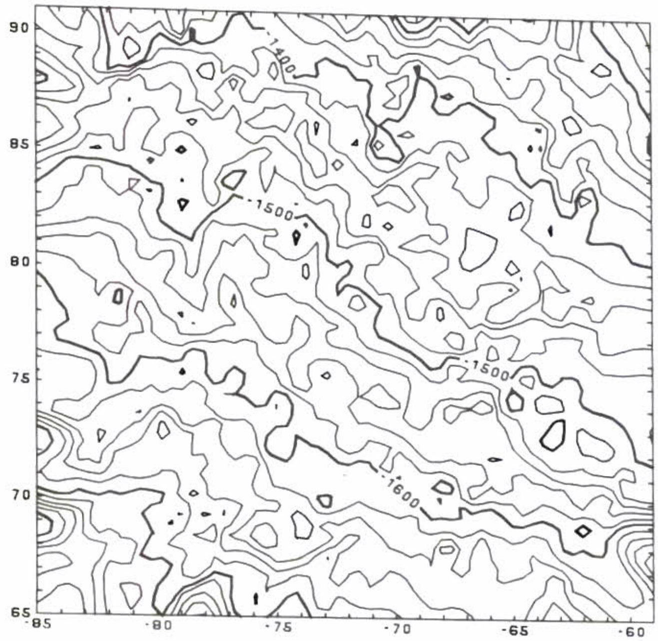


Figure 16.--Subsurface structural contour map of the top of the Lansing Group (Pennsylvanian) in Stafford Co., Kansas. Geographic coordinates are in miles, elevations in feet below sea level. Contour interval is 20 feet.

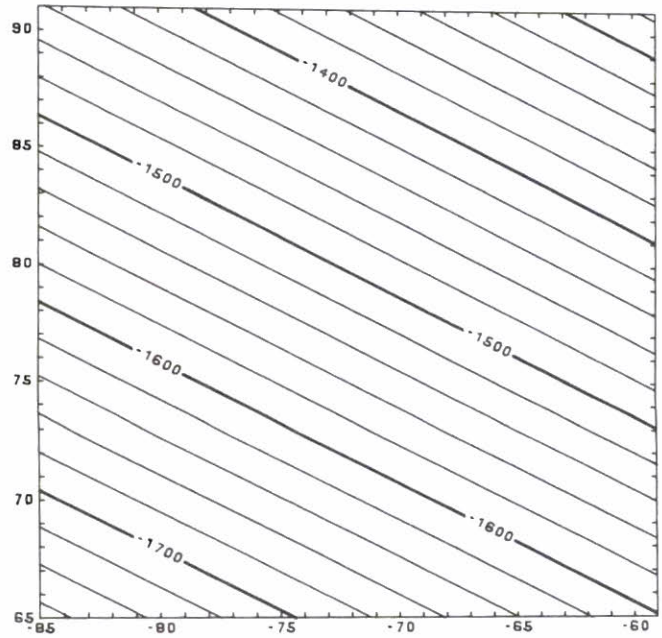


Figure 17.--First degree trend surface of the data used to construct Figure 16. The dip of the trend surface is an approximation of the regional dip.

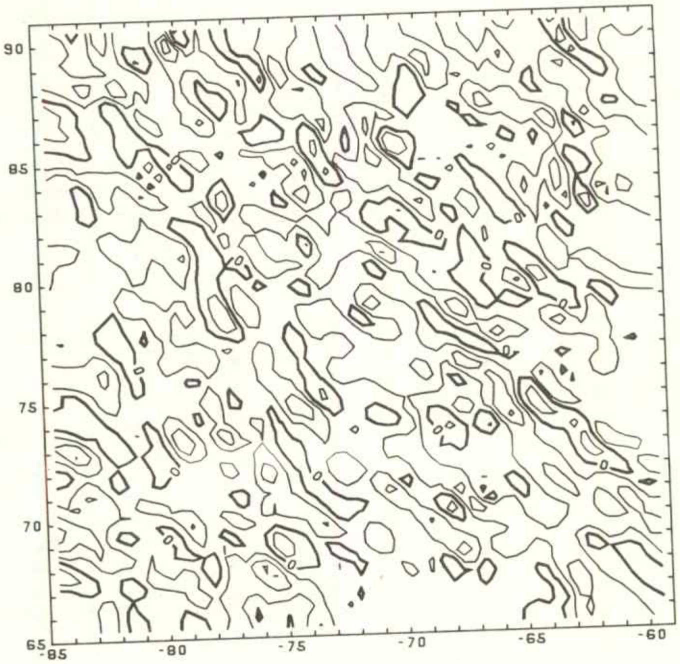


Figure 18.--First derivative of the top of the Lansing, taken with respect to the regional dip. The contour interval is in slope units of 20 feet/mile.

Average Annual Rainfall in Illinois.--Figure 19 shows average annual rainfall in inches recorded for each of the 102 counties of Illinois. Data were taken from tables in the Atlas of Illinois Resources (Section 6, "Agriculture in the Illinois Economy"). Geographic locations were obtained by measuring the approximate centers of counties on the Atlas base map. In addition, 595 points were digitized to form an outline of the state. Digitizing was done using a Hewlett-Packard digitizer.

Geographic coordinates are given in inches on the original base map, which is the recording scale on the Hewlett-Packard instrument. Although spatial resolution of the digitized map is low, it is sufficient to represent the generalized data of the agricultural tables. The original base map measured 16 inches in maximum length; when plotted at the scale of Figure 19 digitizing inaccuracies become acceptably small.

Contour lines outside the state boundaries were suppressed using the 'BLAN'K command, which sets all grid values outside a line read in by 'ROUT'LINE to a code value. No contours are drawn in areas containing code values. Note that contours within the state approach but do not touch the boundary in all instances. The width of the gap is a function of the location of the digitized line at the point of intersection and the coarseness of the grid matrix.

Original data were taken from the Atlas of Illinois Resources (p. 13, Sec. 6). Digitizing was done by Mrs. Mella Voellinger.

Newton Diagrams of Gas Phase Reactions.--Plots of the type shown in Figure 20 are called Newton diagrams because they are based on classical Newtonian mechanics; they are a common method of presenting results from reactive scattering studies of gas phase chemical reactions. Typical experimental conditions involve the crossing of two beams of reactant molecules in a background pressure of 10^{-6} to 10^{-7} torr. A small fraction of the molecules collide and react. The scattering angle and velocity of the products from these reactive encounters are measured; a Newton diagram is a convenient and informative way of presenting these results. The plot is a contour diagram showing the relative amount of product formed as a function of the product's velocity and scattering angle. The shape and position of the contours give information about the mechanism of the reaction. For example, if the reaction occurs through the formation of a complex which rotates several times before breaking up, the contours will show a plane of

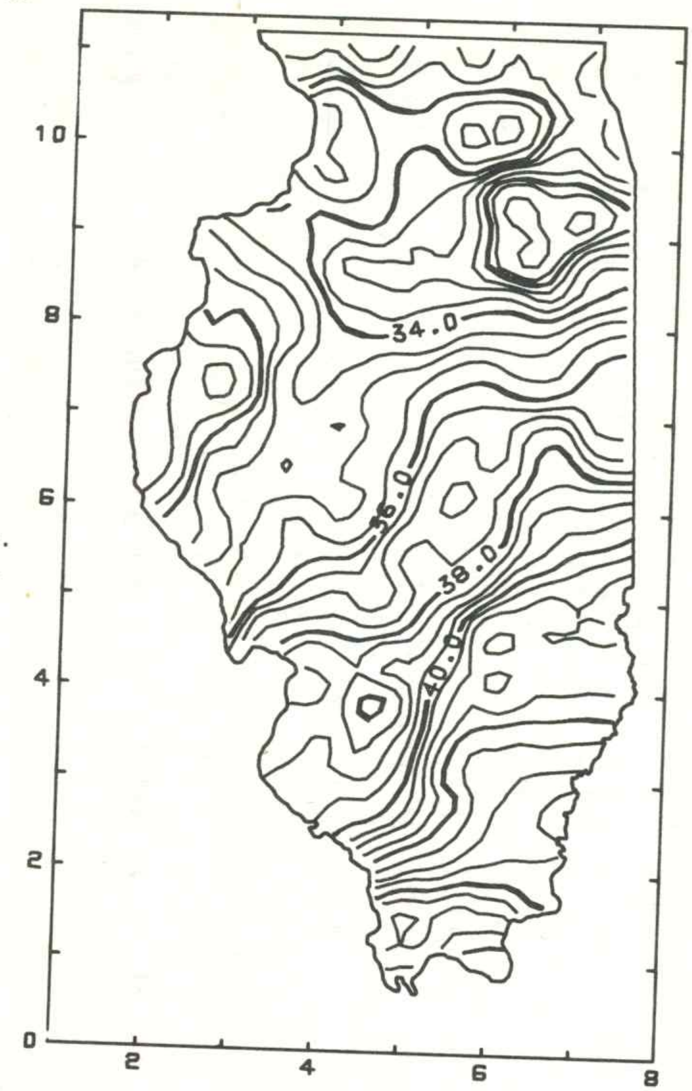


Figure 19.--Average annual rainfall in Illinois. Geographic coordinates in inches on original base map; contour interval is one-half inch.

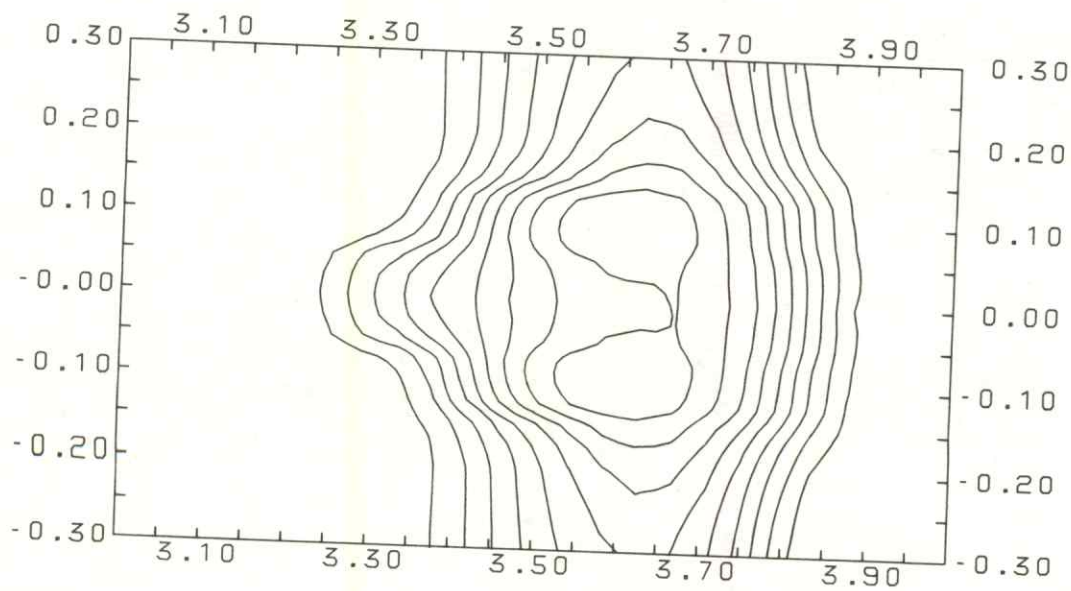


Figure 20.--Newton diagram of the reaction between Kr^+ and CH_4 to form $KrCH_3^+$. X and Y axes are orthogonal velocity vectors measured in units X 10^{-5} cm/sec. Contours are arbitrary relative intensities of $KrCH_3^+$ measured at the detector.

symmetry passing through the center of mass velocity of the system, and perpendicular to the relative velocity vector of the reactants. If on the other hand, the complex breaks up before completing one rotation, the products will be scattered forward of the center of mass velocity. The distance that a product is found from the center of mass velocity is a measure of the amount of internal energy which it possesses.

Figure 20 is a Newton diagram representing the reaction between a beam of ionized Krypton gas and a beam of methane gas, reacting to form the short-lived cation $KrCH_3^+$. The diagram was prepared from 174 measurements by L. W. Strattan.

Artifact Density in a Hopewell Indian Village Site.--Within an archaeological site, the proportions of different types of artifacts found within different areas provide a clue to the location of centers of activity when the site was inhabited. The internal structure of a site can be determined only by an intensive, systematic collection of materials.

The Young site is at the location of a Hopewell Indian village near Kansas City, in Platte County, Missouri. An 11 x 14 grid of 10-meter cells was superimposed over the area and all material lying on the surface within each cell was collected. Specimens were sorted according to type, such as waste flint flakes or debitage, pottery sherds, bone, etc. These data were converted to percent abundance within each cell. Two of the most commonly found materials in Hopewell sites are burned limestone, indicating fire hearths and debitage, reflecting flint tool manufacturing. Figures 21 and 22 are contour maps of the relative percent of these two types of artifacts found within the Young site.

The original data represent material collected within areas; for contour mapping purposes, the observations are considered to come from a point at the center of each area. These centers are on a regular grid which could be contoured directly. This was not done because adjacent

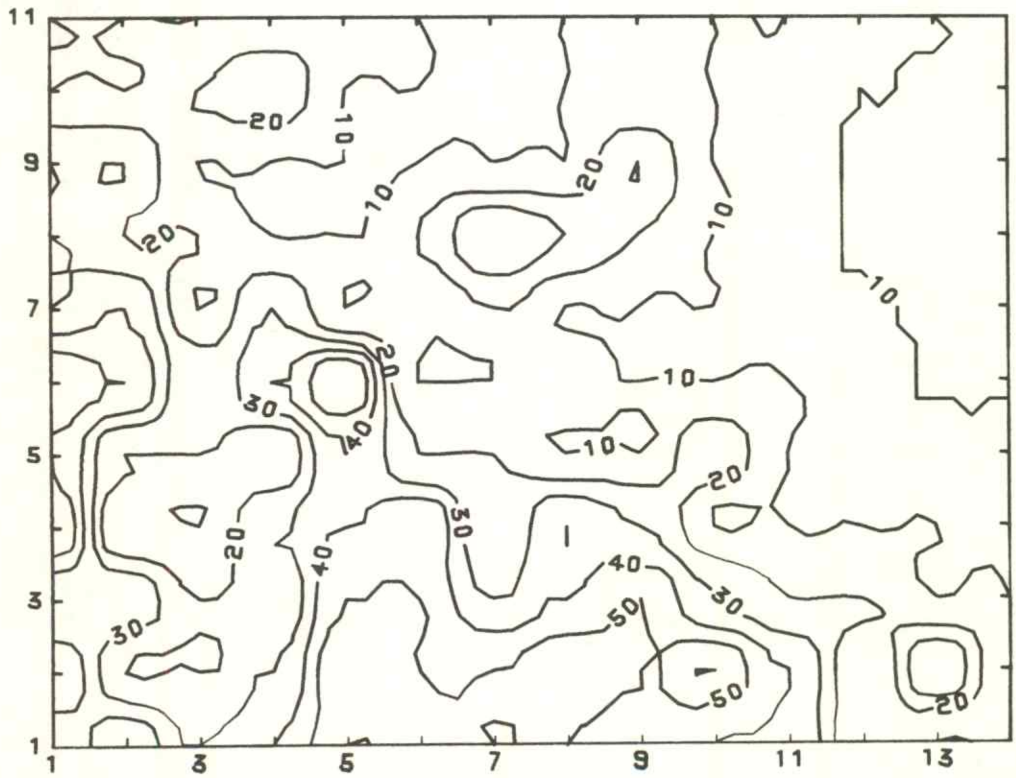


Figure 21.--Percentage of burnt limestone fragments within the Young Hopewell archaeological site, Platte Co., Missouri. Coordinates are measured in tens of meters from the southwest corner of the site. Contours are in percent.

values are so different that a highly erratic surface would result. Instead, the original values were entered as XYZ data and a much finer grid constructed, which allowed the interpolation of slopes between adjacent extreme values. It can be argued that contour mapping is inappropriate for such data, and a choroplethic technique should be used instead. A counterargument is that gradients in density of artifacts obviously must exist across the site so the continuous variation of a contour map is more realistic than the discontinuous changes of a choropleth map. Data for this example were supplied by P. E. Brockington.

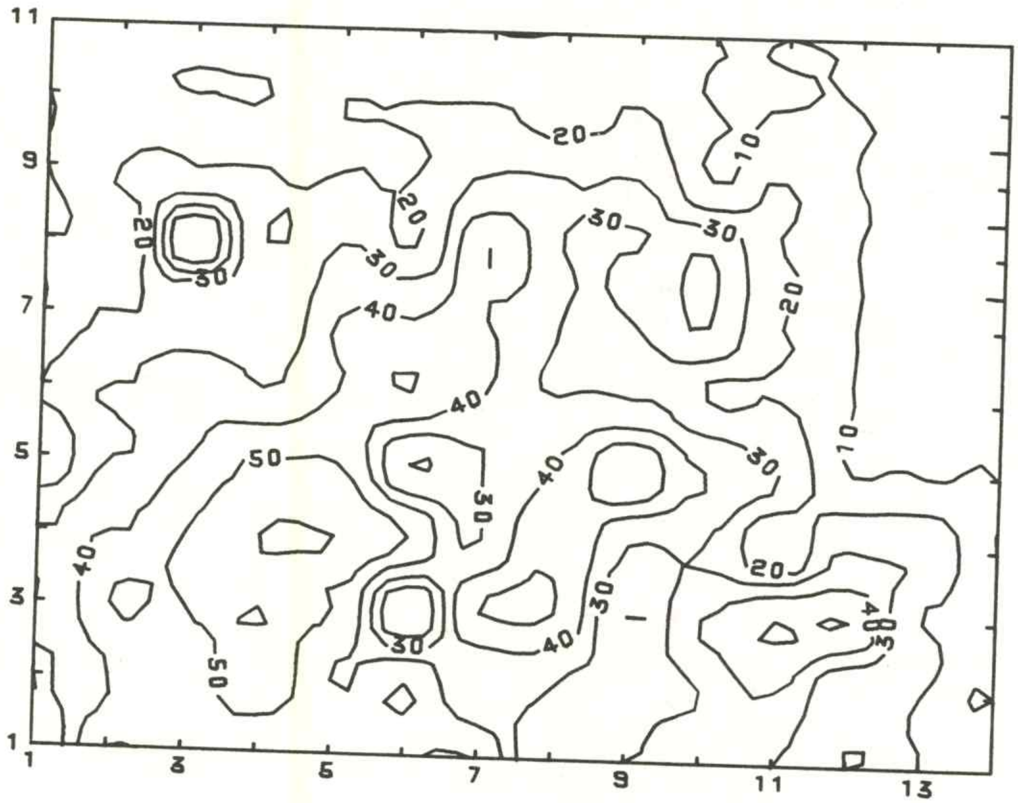


Figure 22.--Percentage of debitage within the Young site.

Magnetic Field Intensity in an Area of Northeastern Kansas.--The map in Figure 23 shows total magnetic field intensity in a portion of Douglas, Osage, and Shawnee counties, Kansas. The data were collected by an airborne proton magnetometer flown over the area at an altitude of 1000 feet. The area was covered with eight east-west flight lines and two north-south tie lines. Observations are closely spaced along the flight lines; only one-third of the observation points are plotted to avoid unnecessary clutter on the map.

Because observations are closely spaced along widely separated lines, the map grid was prepared using an octant search with two points per octant. The grid spacing is 1 mile in the X direction and 1/2 mile in the Y direction. Use of an octant search causes severe smoothing of the surface, but avoids creation of unconstrained slopes perpendicular to the flight lines where nearby lateral control is lacking. If a radially constrained search is not used, a "waffle-like" surface may be created solely because of the arrangement of the control points.

The X and Y axes in Figure 23 are measured in degrees of latitude and longitude. Magnetic intensity is in +50,000 gammas. That is, the contour labelled 6400 is actually 6,400 + 50,000 = 56,400 gammas. The magnetic data were gathered by H. L. Yarger and R. Avanessians of the Kansas Geological Survey.

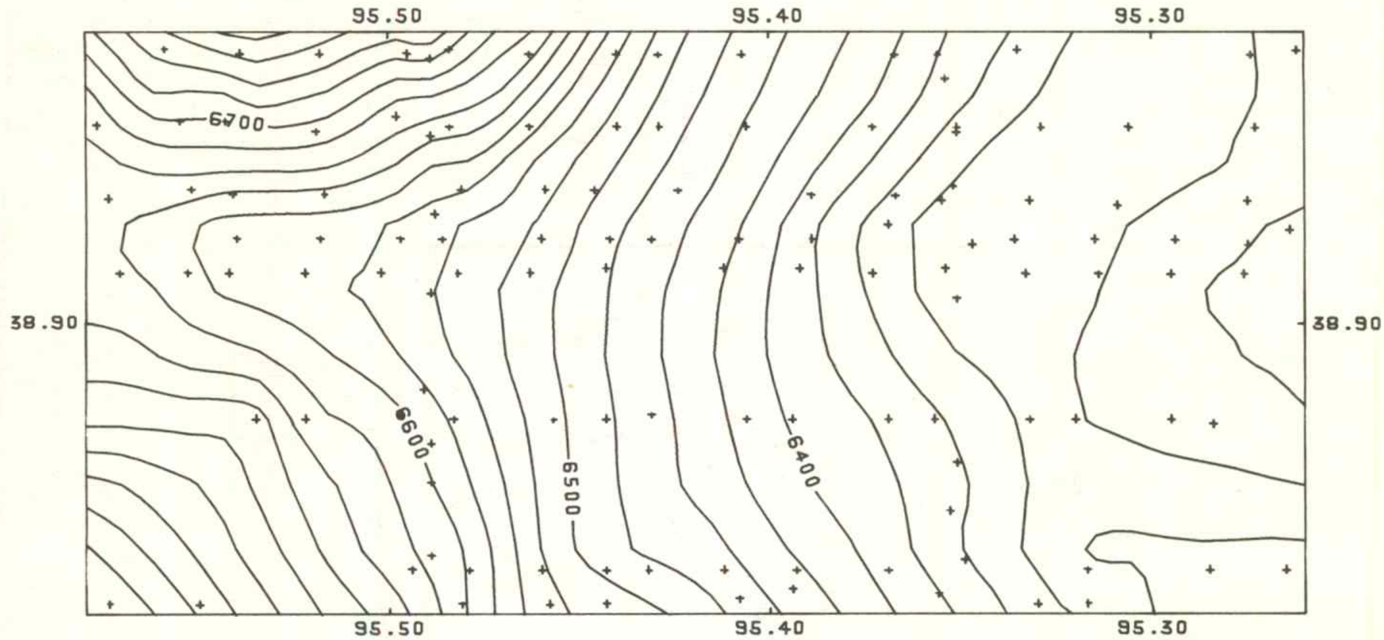


Figure 23.--Total magnetic field intensity as measured by an airborne proton magnetometer over parts of Douglas, Osage, and Shawnee counties, Kansas. X and Y axes are scaled in degrees of latitude and longitude. Contour interval is 25 gammas; annotation values should be increased by 50,000.

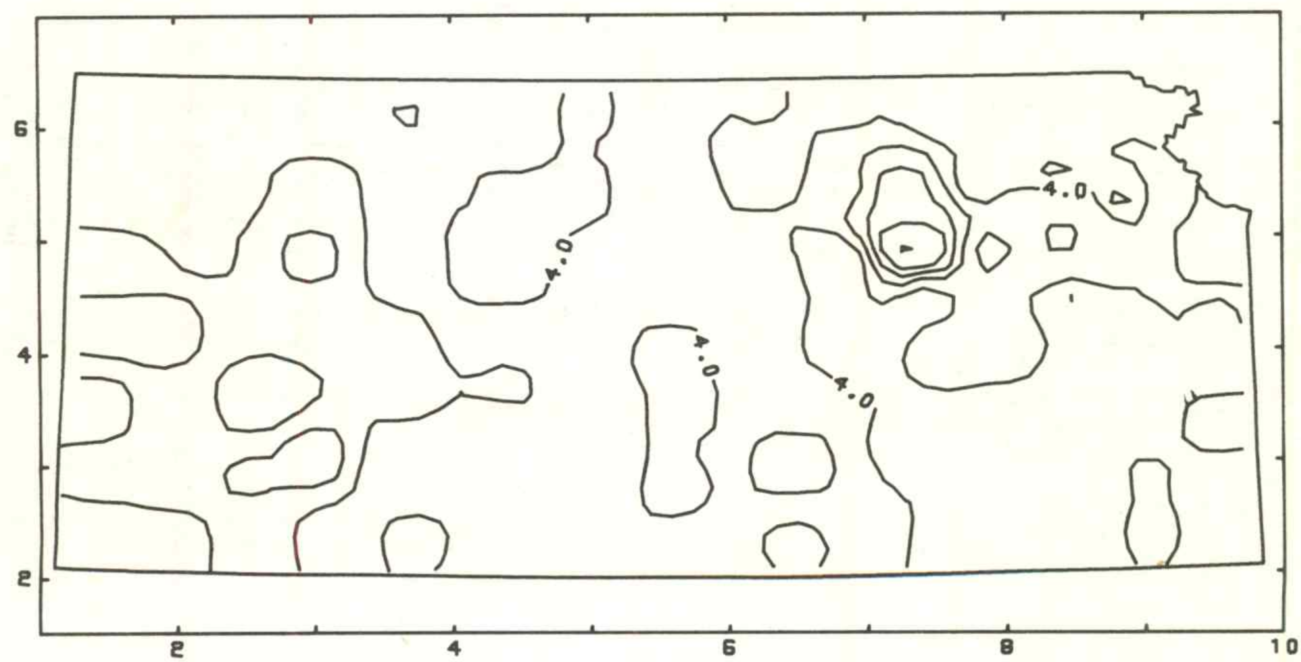


Figure 24.--Map of per capita income in Kansas for 1973. Contour interval in thousands of dollars. X and Y coordinates in inches on digitizer used to digitize State outline and county centers.

Per Capita Income in Kansas.--As part of a study of fuel consumption in Kansas, information was gathered on income in different economic sectors, agricultural variables, and demographic variables in the 105 counties of the State. A computer file of 17 variables for each of the counties was created, and each county keyed to the X and Y geographic coordinates of the county center. In addition, an outline map of the State was digitized at 79 points.

The 17 original variables were gridded using SURFACE II and the grid matrices stored for future manipulation. Because of the extreme ranges of some variables (population, for example, extends from approximately 2,000 to over 330,000 persons per county), the grids were calculated without dip projection. This causes smoothing, but avoids creation of spurious highs and lows in the grid matrix.

It was necessary to combine some grid matrices in order to generate displays of composite variables. For example, the map in Figure 24 shows per capita income, in thousands of dollars. It was created by adding together the grids representing farm income, government income, and business income to produce a grid matrix of total income. This grid was then divided by county population grid to yield per capita income. Grid combination was performed using the 'MADD' and 'MDIV'IDE commands.

FORMAT OF SURFACE II COMMANDS

In general, a sequence of three basic operations is performed by SURFACE II to create a map from sample data.

1. Input irregularly spaced sample data.
2. Construct a matrix or regular grid of estimated surface values.
3. Plot a map from the grid matrix.

User commands implement the SURFACE II routines which perform each of the basic operations. These commands allow the user to specify which plot option to perform, how large to make the display, how to calculate values in the grid matrix, where to find the input data, how to read the data, and so forth.

IMPORTANT NOTE: Throughout this manual, SURFACE II commands are indicated by upper case letters with the first four letters enclosed in single quotes, as for example 'AZIM'UTH. The quote marks identify that part of the command scanned by the computer and do not actually appear in the punched command.

Commands are punched on separate cards, beginning in column 1 and extending through column 72. Although the number of characters in the names of the commands vary, only the first four letters of a command are actually read by the computer. Parameters of the command, when required, may be typed in a free field format after the command name. The first parameter must be separated from the command name by one or more blanks. Succeeding parameters must be separated by commas. If a command and its required parameters cannot be punched between columns 1 and 72 on a single card, the parameters may be continued on a second card. If there are insufficient columns on the first card to punch a parameter (and a comma, if used), then the remaining columns should be left blank and the entire parameter should be punched on the second card. Column 1 of the second card must be blank.

Many parameters have assumed or preassigned values and it is not necessary to define them by a command unless the user wishes to change their preassigned values. If a parameter field is left blank, that parameter will be set equal to its assumed value. However, if the parameter has no predetermined value, the program will terminate if the required value is not supplied.

It should be noted that some parameters may contain alphanumeric characters. When this type of parameter is used, it must be enclosed in single quote marks. The only exceptions are the parameters used with the 'OFF ' and 'TITL'E commands.

With few exceptions, the order in which commands are given is not important. All command statements are internally rearranged into their proper operational sequence. No computing is done by SURFACE II until a 'PERF'ORM command is encountered, which initiates the execution of all prior commands. The entire sequence of operations specified will be executed, and SURFACE II will then accept a new sequence of commands which may contain different parameters. Upon encountering a new 'PERF'ORM command, the second sequence of operations will be executed.

Each command is individually described in the Catalog section of this manual, where the command's function and its associated parameters are outlined in detail. Certain SURFACE II commands require the presence of others, as noted. Some commands do not have to be explicitly given but will be assumed if they are omitted. For example, the assumed value of the parameters of the 'SIZC'ONTOUR command is 12 inches. If no 'SIZC'ONTOUR card appears among the string of SURFACE II commands, a map will be made at the assumed size of 12 inches in width. Therefore, it is necessary to include the 'SIZC'ONTOUR command only if a contour map having a width other than 12 inches is desired.

Parameters will be referred to by their position in the parameter string which follows one or more blanks after the name of the command. Successive parameter values are separated by commas. For example, a command card may have the following appearance:

```
XXXX  1.0,,35
```

The command name is XXXX, the first parameter of XXXX is assigned a value of 1.0, the second parameter is set to its assumed value, and the third parameter becomes 35. If additional parameters are associated with the command XXXX, they will be set to their assumed values. That is, the command has the same effect as:

```
XXXX  1.0,,35,,,,
```

Once the preassigned value of a parameter is altered, the new value of this parameter becomes the implied value that affects all succeeding commands in the instruction sequence, unless it is explicitly assigned another value. If the parameters of a command are to be reset to their preassigned or assumed values, the 'OFF ' command should be used. For example, if the viewing angle of a block diagram is set to 210° by the 'AZIM'UTH command, then all block diagrams made during the same run will also have an azimuth equal to 210° instead of the assumed value of 45°, unless the command OFF AZIM or a second 'AZIM'UTH command specifying a new viewing angle appears in the command sequence.

If a plotter is used as an off-line device, it is wise to examine the printed output produced by SURFACE II and check for possible mistakes in the specification of parameters before starting to plot. By carefully examining the printed output, the user can determine if the finished plot will have the desired form. This output includes a listing of commands that were read in, a description of parameters used in various phases of execution, and if requested by the user, a listing of any data read in, any matrix generated by SURFACE II, and statistics related to the form of the surface and the magnitudes of interpolation errors.

BRIEF DESCRIPTION OF SURFACE II COMMANDS

The Catalog of SURFACE II commands lists the commands in alphabetical order. However, it is also useful to categorize them according to function. Some commands cause a definite action to be taken. Examples are 'GRID', 'CONT'OUR, and 'ECHO'. Other commands cause secondary effects; that is, they define conditions that are used in executing the first set of (active) commands. Examples are 'AZIM'UTH, 'CINT'ERVAL, 'LINE'S, and 'SIZC'ONTOUR. The "active" commands must be present in the list of commands if the desired action is to take place. In many instances, the secondary commands that may affect these actions need not be explicitly listed if the assumed value of their parameters will produce the desired results. Below is an outline of all the active commands (underlined) as they are related to the operation of SURFACE II. Listed with them are the secondary commands (not underlined) which affect execution of active commands.

Commands to input data:

1. <u>'IDXY'</u> - reads in X, Y, Z sample data points.

   Execution is affected by:

   'ECHO' - lists X, Y coordinates of data points.
   'RTXY' - rotates X, Y coordinates of data points.
   'SUBS'ET - specifies which data points, if any, are not to be stored by SURFACE II.

2. <u>'ROUT'LINE</u> - reads in digitized map boundaries.

   Execution is affected by:

   'ECHO' - lists X, Y coordinates of digitized outline.
   'RTXY' - rotates X, Y coordinates of digitized outline.

3. 'LEVE'LS - reads in desired contour levels and their annotation code.

   Execution is affected by:

   'ECHO' - lists levels and annotation codes.

Commands used to create a grid matrix:

A. Generate a grid matrix from sample data points.

1. <u>'DMAP'</u> - creates a grid matrix that is a function of the distance from a grid node to data points selected by a search algorithm.

   Execution is affected by:

   'EXTR'EMES - defines X and Y limits of the grid.
   'NEAR' - nearest n neighbors search.
   'OCTA'NT - octant search.
   'QUAD'RANT - quadrant search.
   'VRAD'IUS - variable radius search.

2. <u>'GRID'</u> - creates a grid matrix by interpolating from irregularly spaced control points, using a local weighted averaging technique.

Execution is affected by:

'EXTR'EMES - defines X and Y limits of the grid.
'NEAR' - nearest n neighbors search.
'OCTA'NT - octant search.
'QUAD'RANT - quadrant search.
'VRAD'IUS - variable radius search.

3. 'KRIG'E - generates a grid matrix by interpolation from irregularly spaced control points, using the process of universal Kriging.

   Execution is affected by:

   'EXTR'EMES - defines X and Y limits of the grid.

4. 'TREN'D - creates a grid matrix based on an n-th degree polynomial regression of values of Z on the X and Y coordinates.

   Execution is affected by:

   'EXTR'EMES - defines X and Y limits of the grid.

B. Read a matrix into core from an external file.

1. 'MATR'IX - reads a matrix written in BCD format into memory.

   Execution is affected by:

   'ECHO' - lists $\dot{Z}$ values in matrix.
   'INCR'EMENT - specifies which rows and columns of an external matrix will be stored.

2. 'REST'ORE - reads a matrix written in binary format into memory.

   Execution is affected by:

   'ECHO' - lists $\dot{Z}$ values in matrix.
   'INCR'EMENT - specifies which rows and columns of an external matrix will be stored.

C. Modify an existing matrix.

1. 'BLAN'K - sets specified areas of a grid matrix to a "blank" code level.

2. 'DERI'VATIVE - replaces the grid matrix with an approximation of its first derivative.

3. 'FILT'ER - multiplies a grid matrix by a spatial filter or weighted moving average.

4. 'ISOP'ACH - subtracts elements of one grid matrix from corresponding elements in another grid matrix.

5. 'MADD' - adds elements of one grid matrix to corresponding elements of another grid matrix.

6. 'MDIV'IDE - divides elements of one grid matrix by corresponding elements of another grid matrix.

7. 'MLEV'EL - subtracts a linear trend from a grid matrix so values of the matrix fluctuate around a mean of zero.

8. 'MMUL'TIPLY - multiplies elements of one grid matrix by corresponding elements of another grid matrix.

9. 'MSMO'OTH - smooths the values in a grid matrix by averaging each element with its nearest neighbors.

10. 'RANG'E - replaces elements in a grid matrix that lie outside a specified range with a code value.

11. 'REGR'ID - changes the number of rows and columns in a grid matrix.

12. 'SCAL'E - scales the values in a grid matrix into a new range.

Commands to plot a map:

1. 'CONT'OUR - displays a grid matrix by drawing contour lines on the surface defined by values in the matrix.

   Execution is affected by:

   'BOX ' - labels map boundaries.
   'BXEX'TREMES - establishes dimensions of map border.
   'CINT'ERVAL - establishes contour interval and labels contour lines.
   'LEVE'LS - specifies unequally spaced contour lines.
   'OVER'LAY - superimposes two or more plots.
   'POUT'LINE - draws an outline or boundary within the map area.
   'SIZC'ONTOUR - specifies the size of the map.

2. 'ECON'TOUR - displays a grid matrix as a perspective block diagram with contour lines.

   Execution is affected by:

   'AZIM'UTH - observer's viewing angle.
   'DIST'ANCE - distance between the observer and the surface.
   'ECIN'TERVAL - establishes contour interval on a block diagram.
   'ELEV'ATION - elevation of the observer above the X-Y plane.
   'LINE'S - defines the number of lines drawn on the surface.
   'SIZC'ONTOUR - defines the size of the block diagram.
   'STER'EO - produces two block diagrams properly spaced and tilted for viewing through a stereoscope.

3. 'POST' - plots data points on an X-Y diagram.

   Execution is affected by:

   'BOX' - labels map boundaries.
   'BXEX'TREMES - establishes dimensions of posting border.
   'OVER'LAY - superimposes two or more plots.
   'POUT'LINE - draws an outline or boundary within the map area.
   'SIZC'ONTOUR - defines the size of the posting.

4. 'TRAN'SECT - displays a grid matrix as a perspective block diagram with form lines.

   Execution is affected by:

   'AZIM'UTH - observer's viewing angle.
   'DIST'ANCE - distance between the observer and the surface.
   'ELEV'ATION - elevation of the observer above the X-Y plane.
   'LINE'S - defines the number of lines drawn on the surface.
   'SIZT'RANSECT - defines the size of the block diagram.
   'STER'EO - produces two block diagrams to be viewed through a stereoscope.

Commands to print a map using the line printer:

1. 'PCON'TOUR - prints a contour map using the line printer.

   Execution is affected by:

   'SIZP'CONTOUR - defines the size of the printed map.

2. 'PPOS'T - prints a posting of data points on an X-Y diagram, using the line printer.

   Execution is affected by:

   'EXTR'EMES - defines the X and Y limits of the posting.
   'SIZP'CONTOUR - defines the size of the printed map.

Commands to print other output:

1. 'ERAN'ALYSIS - prints an error analysis of a contouring operation.

2. 'HIST'OGRAM - prints histograms of data and errors.

3. 'MOUT'PUT - prints a listing or punches a card deck of any generated grid matrix, after any specified modifications have been performed.

4. 'NNA ' - performs and prints a nearest-neighbor analysis of the data point distribution.

5. 'ODXY' - prints a listing or punches a card deck of X, Y, Z data points.

6. 'SAVE' - stores a modified grid matrix in binary format on a file.

ASSUMED ORDER OF EXECUTION OF SURFACE II COMMANDS

The order of appearance of SURFACE II commands in the control card sequence is not necessarily the order in which the commands will be executed. There is an assumed order of execution which can be controlled by the user by using the 'PERF'ORM command. SURFACE II reads all commands in the control deck until it encounters a 'PERF'ORM command. The active commands are read and executed in the following order:

Input commands:

1. 'IDXY'
2. 'LEVE'LS
3. 'MATR'IX
4. 'REST'ORE
5. 'ROUT'LINE

Matrix modification/creation commands:

6. 'GRID'
7. 'KRIG'E
8. 'TREN'D
9. 'DMAP'
10. 'REGR'ID
11. 'MLEV'EL
12. 'FILT'ER
13. 'DERI'VATIVE
14. 'ISOP'ACH
15. 'MADD'
16. 'MDIV'IDE
17. 'MMUL'TIPLY
18. 'MSMO'OTH
19. 'RANG'E
20. 'SCAL'E
21. 'BLAN'K

Output commands:

22. 'MOUT'PUT
23. 'ODXY'
24. 'SAVE'
25. 'PCON'TOUR
26. 'PPOS'T
27. 'NNA '
28. 'ERAN'ALYSIS
29. 'HIST'OGRAM

Plotting commands:

30. 'TRAN'SECT
31. 'ECON'TOUR
32. 'CONT'OUR
33. 'POST'

SURFACE II control operations:

1. 'CLEA'R - clears memory of all previous data and commands.
2. 'DEVI'CE - turns on a specified plotting device.
3. 'FINI'SH - turns off a plotting device.
4. 'OFF ' - negates the effect of a previously specified command.
5. 'PERF'ORM - executes the preceding string of SURFACE II commands.
6. 'STOP' - halts all execution.
7. 'TITL'E - labels the top of each page of output.

CATALOG OF SURFACE II COMMANDS

The following pages contain, in alphabetical order, explanations of all SURFACE II commands. A brief statement of the purpose of each command is given, followed by a listing of all parameters associated with the command. Next is more detailed discussion of the use of the command and explanatory material about its operation. Most commands are illustrated with one or more examples of graphic output that show the effect of changes in the parameters. The sequence of SURFACE II commands used to generate the illustrations is also given.

Most of the examples are maps or diagrams of the data set listed in Appendix A. These are subsea elevations of the top of the Lansing Group (Pennsylvanian) in a part of Graham County, Kansas, as measured in wells drilled for petroleum exploration. Geographic coordinates of the wells are given in miles from an arbitrary origin. Z-values are in feet below sea level.

Some plots were made using other data sets that more clearly illustrate the operation of a particular command. These data are described where they are used.

'AZIM'UTH - defines the observer's viewing angle of a block diagram. The parameter is expressed in degrees of rotation from south.

Field Number	Parameter Description	Assumed Value
1	Azimuth of observation point in degrees.	45°

The parameter specifies the angle to a point from which a perspective block diagram is to be viewed. The angle is measured in degrees counterclockwise from south (Fig. 25). "South," as defined in SURFACE II, may not necessarily be the compass direction south. Rather, the edge of the block represented by the first (bottom) row of the $\dot{Z}$ matrix is considered to be the southern edge, as this is the bottom of a corresponding contour map. As the azimuth is increased from 0° to 90°, more of the eastern (right) edge of the block (represented by the last column of the matrix) becomes visible. The viewer appears to be travelling around the block in a counterclockwise direction, or equivalently, the block appears to rotate clockwise. The 'AZIM'UTH parameter may be given as a real or integer number. Specification of negative degrees rotates the block in a counterclockwise direction. If more than 360° are specified, the surface is rotated to the proper position, assuming more than a complete revolution.

Figures 26 through 29 show a perspective block diagram rotated to various viewing angles by 'AZIM'UTH. The SURFACE II commands which produced these plots are listed below:

Grid original data	TITLE	AZIMUTH TEST FOR SURFACE MANUAL
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	GRID	1,0.2,0.2
	EXTREMES	0,10,0,6
	DEVICE	1,'SAMPSON',60,40,3,3
	PERFORM	
Establish dimensions and draw first diagram (Fig. 26)	TRANSECT	0,20,0
	SIZTRANSECT	6
	LINES	1,40,24
	DISTANCE	100
	ELEVATION	30
	AZIMUTH	25
	PERFORM	
Rotate to Figure 27	AZIMUTH	115
	TRANSECT	0,20,0
	PERFORM	
Rotate to Figure 28	AZIMUTH	190
	TRANSECT	0,20,0
	PERFORM	
Rotate to Figure 29	AZIMUTH	-25
	TRANSECT	0,20,0
	PERFORM	
	STOP	

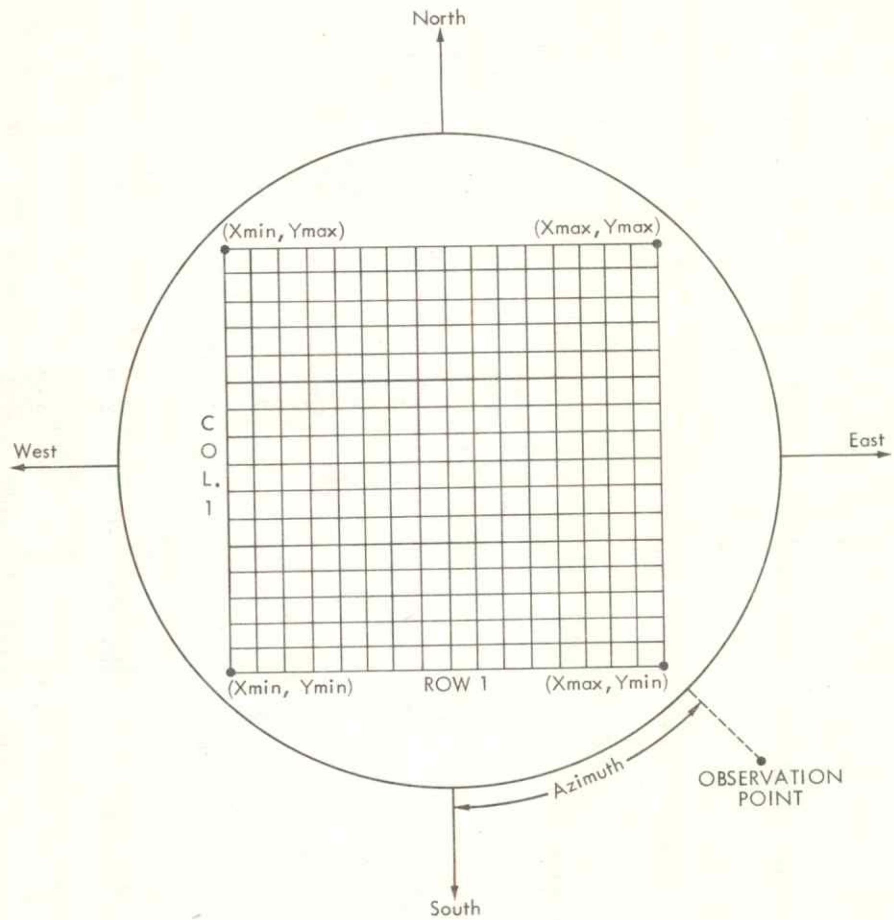


Figure 25.--Relationship of viewing position to the grid matrix in a block diagram. Azimuth is measured in degrees counterclockwise from "south."

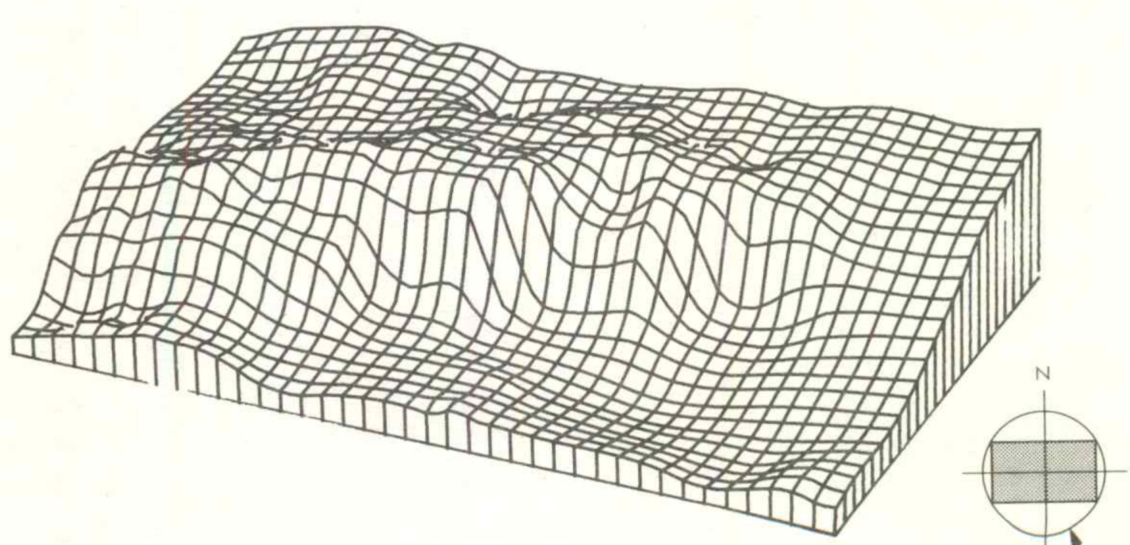


Figure 26.--Perspective block diagram of subsurface geologic structure in part of Graham Co., Kansas. Azimuth of viewpoint is 25°, or from the southeast.

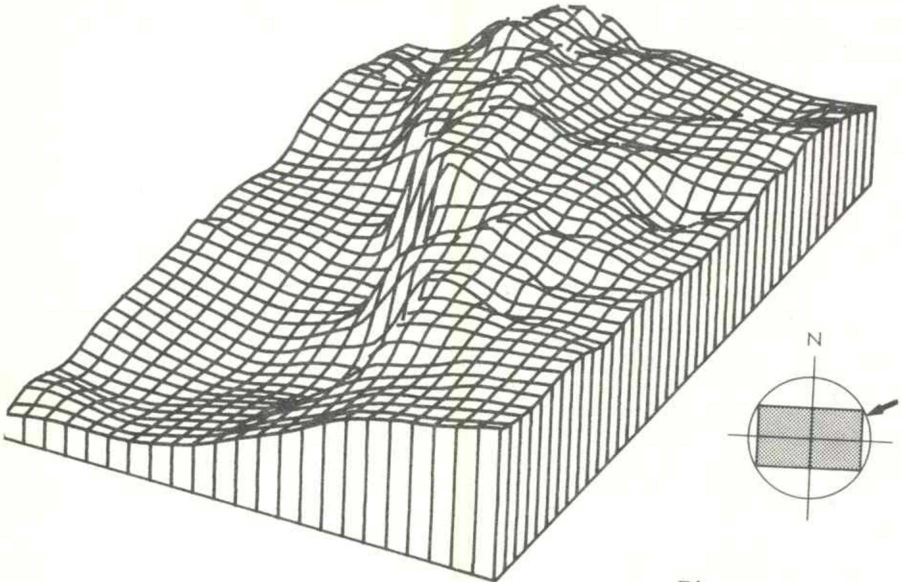


Figure 27.--Block diagram rotated to an azimuth of 115° or from the northeast.

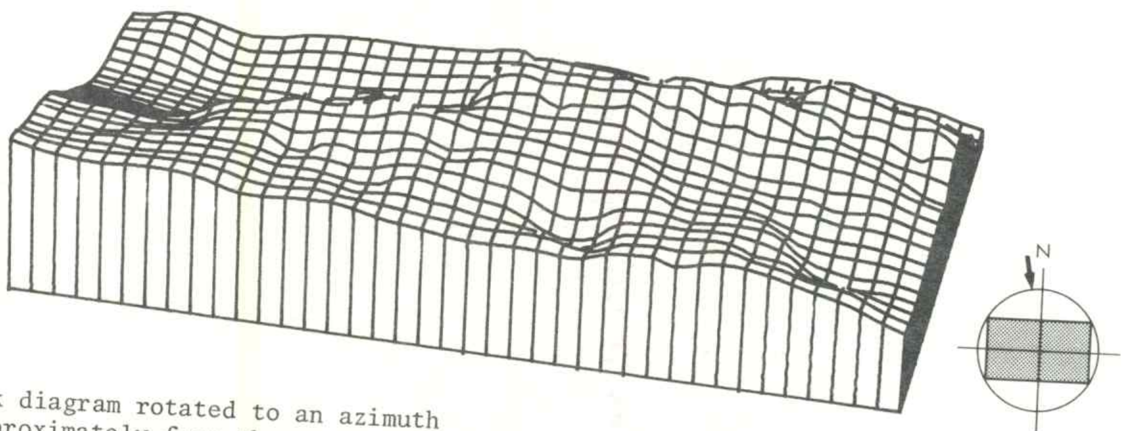


Figure 28.--Block diagram rotated to an azimuth of 190° or approximately from the north.

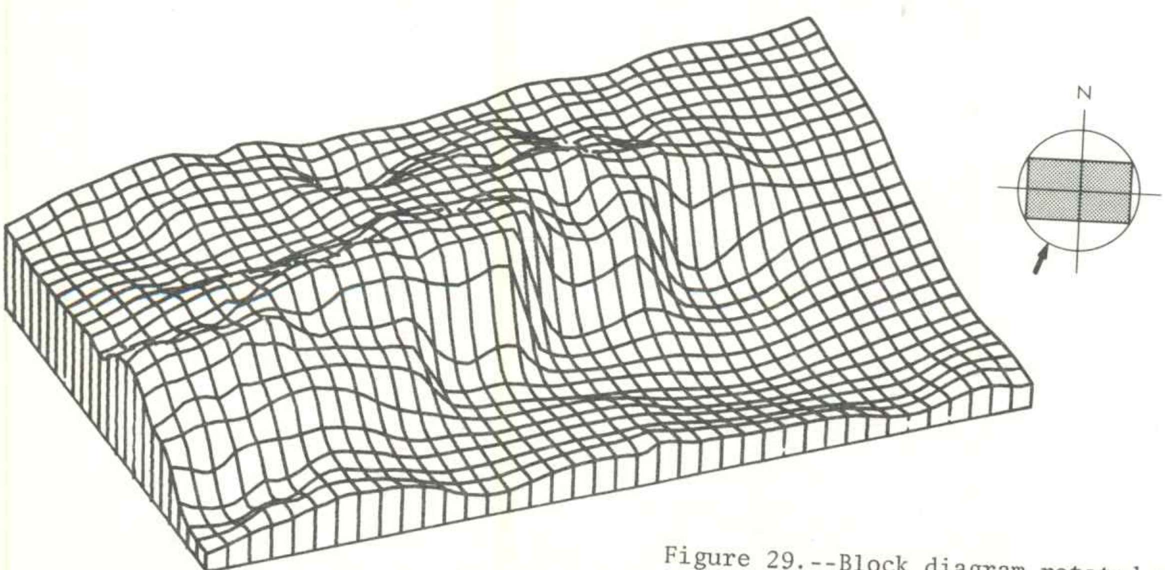


Figure 29.--Block diagram rotated clockwise to an azimuth of -25° or from the southwest.

'BLAN'K - sets all grid values within a specified area to an internal code value.

NO PARAMETERS.

The 'BLAN'K command allows the user to assign the code value $-1*10^{+30}$ to certain elements in the grid matrix. The modified grid nodes lie in an area defined by coordinates read in by the 'ROUT'LINE command. Grid elements which are assigned the code value will be ignored during execution of the 'CONT'OUR command so no contour lines will pass through the blanked area. If a perspective block diagram is made, the blanked area will appear as a low, flat region.

Figure 30 shows the effect of 'BLAN'K on a contour map. The state outline of Illinois was read in by 'ROUT'LINE. Contours show average annual inches of rainfall. Figure 31 is a perspective block diagram of the same data, illustrating the effect of 'BLAN'K on this type of display.

Read in XYZ data and outline; create grid	TITLE	ILLINOIS MAP TEST FOR BLANK
	DEVICE	1,'DAVIS'
	IDXY	102,14,6,2,3,4,1,,,,'(F3.0,17X,5F10.0)'
	ROUTLINE	13,1,'(10X,2F10.0)'
	GRID	1,0.15,0.15
	EXTREMES	1,8,0,11.40
	PERFORM	
Blank grid	BLANK	
	PERFORM	
Draw Figure 30	CONTOUR	
	CINTERVAL	0,0,0.5,0,4,0.1,1,,4
	POUTLINE	
	SIZCONTOUR	1,3.5,6
	BOX	1,2,1,2,0,0,0,1,0.1
	PERFORM	
Draw Figure 31	TRANSECT	0,20,0
	SIZTRANSECT	6
	AZIMUTH	335
	ELEVATION	40
	DISTANCE	1000
	LINES	1,20,40
	PERFORM	
	STOP	

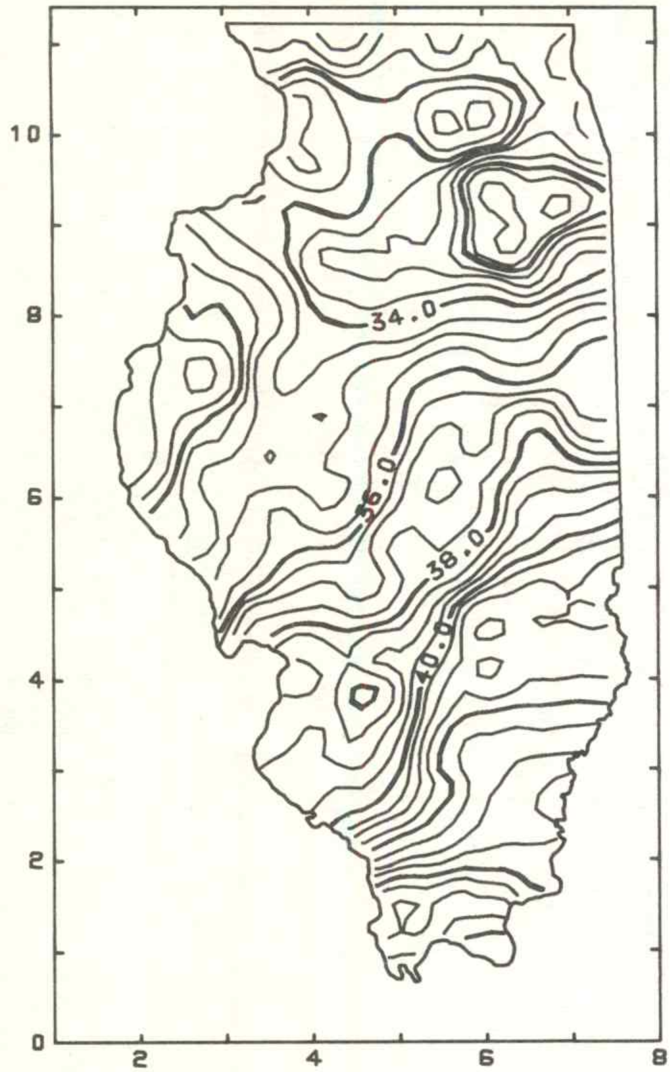


Figure 30.--Average annual rainfall in Illinois, in inches. All contours outside the digitized state boundaries were suppressed by 'BLAN'K.

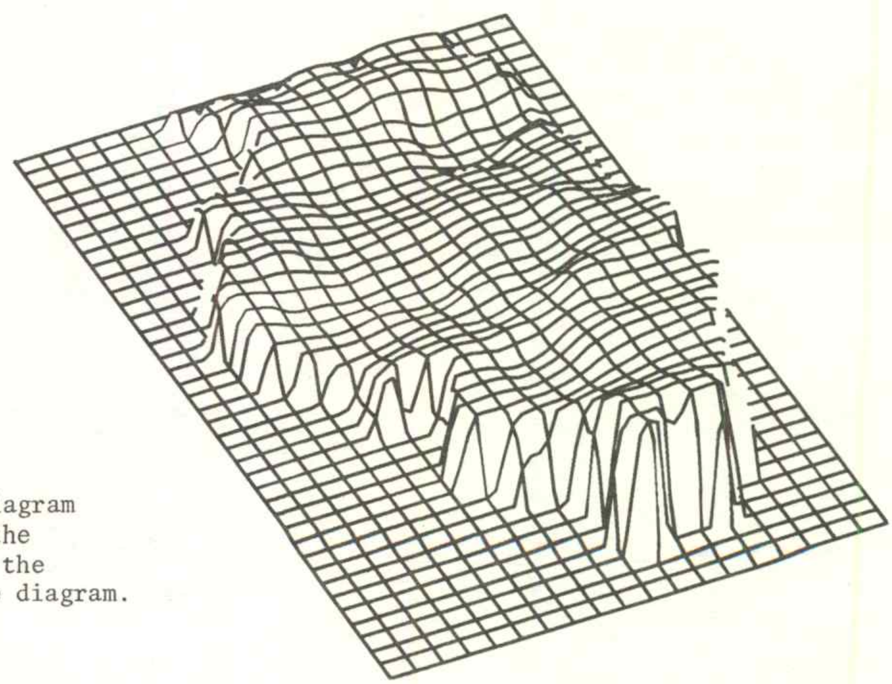


Figure 31.--Perspective block diagram of Figure 30. Areas set to the 'BLAN'K code value appear at the same level as the base of the diagram.

'BOX ' - draws and labels index or tick marks around the border of a posting or a contour map. If this command does not appear, no tick marks or labels will appear on the border of the plot.

Field Number	Parameter Description	Assumed Value
1	Distance between tick marks in X-direction. Distance is specified in units of the X-dimension, not in inches on the plot.	1
2	Frequency of labeling of tick marks in the X-direction. Assumed value specifies that every fifth tick mark will be labeled.	5
3	Distance between tick marks in Y-direction. Distance is specified in units of the Y-dimension, not in inches on the plot.	1
4	Frequency of labeling of tick marks in the Y-direction.	5
5	Number of characters to the right of the decimal point.	0
6	Reference value for tick marks and labels on X-axis.	0
7	Reference value for tick marks and labels on Y-axis.	0
8	Indicates which edges of the plot border will be labeled. If 0, none. If 1, bottom and left edges only. If 2, all edges.	2
9	Height of plotted numbers, in inches.	0.1

The 'BOX ' command labels the coordinates of the X and Y axes along the borders of a contour map or posting. The units used to determine the distance between tick marks are defined by the parameters of the 'EXTR'EMES command.

The 'BOX ' command used to create Figure 32 is

BOX 1,2,1,2,0,0,0,1,0.1

Using the assumed values in the command, the same effect could also be obtained by

BOX ,2,,2,,,,2,

Because the reference values for the X and Y axes are 0, tick marks corresponding to 0, 2, 4, 6, ... are annotated.

Figure 33 uses the same 'BOX ' parameters, except six and seven which specify that the reference values for the two axes are 1 and 1. Because every other tick mark is annotated, labels will be placed at 1, 3, 5, 7 .... The 'BOX ' command for Figure 33 is

BOX 1,2,1,2,0,1,1,2,0.1

Parameter eight is set to option 2, specifying labels on all edges of the map.

In these two examples, scales in both X and Y were annotated in the same fashion. Although this is the usual manner of annotation, it is possible to tick the X and Y scales at different intervals and to annotate them at different frequencies. It is also possible to specify distances along the axes and reference values that are not whole numbers. Figure 34 shows some alternative parameter specifications and the resulting annotation. Although only the X-axis is described, equivalent results may be specified for the Y-axis. Note that in the last example in Figure 34 the reference value is outside the range of the plot. Only those labels which are within the range specified by the 'EXTR'EMES command will actually be plotted.

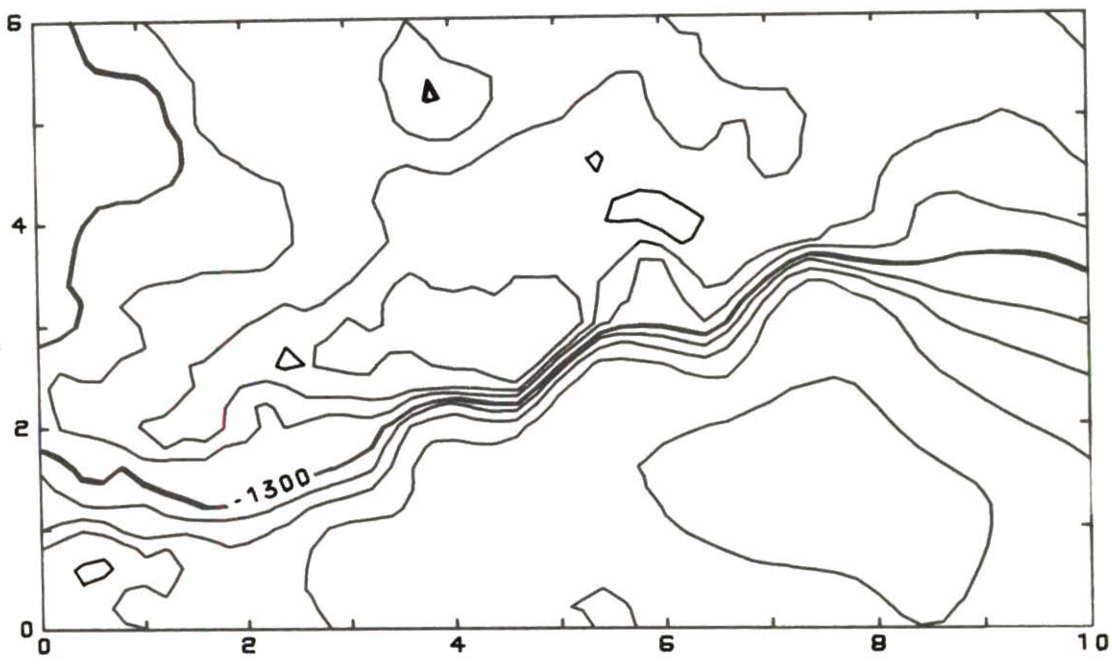


Figure 32.--Structure contour map of part of Graham Co., Kansas. Annotation around margin of map is controlled by 'BOX ' command, which specifies labeling of alternate tick marks spaced at one mile intervals from zero.

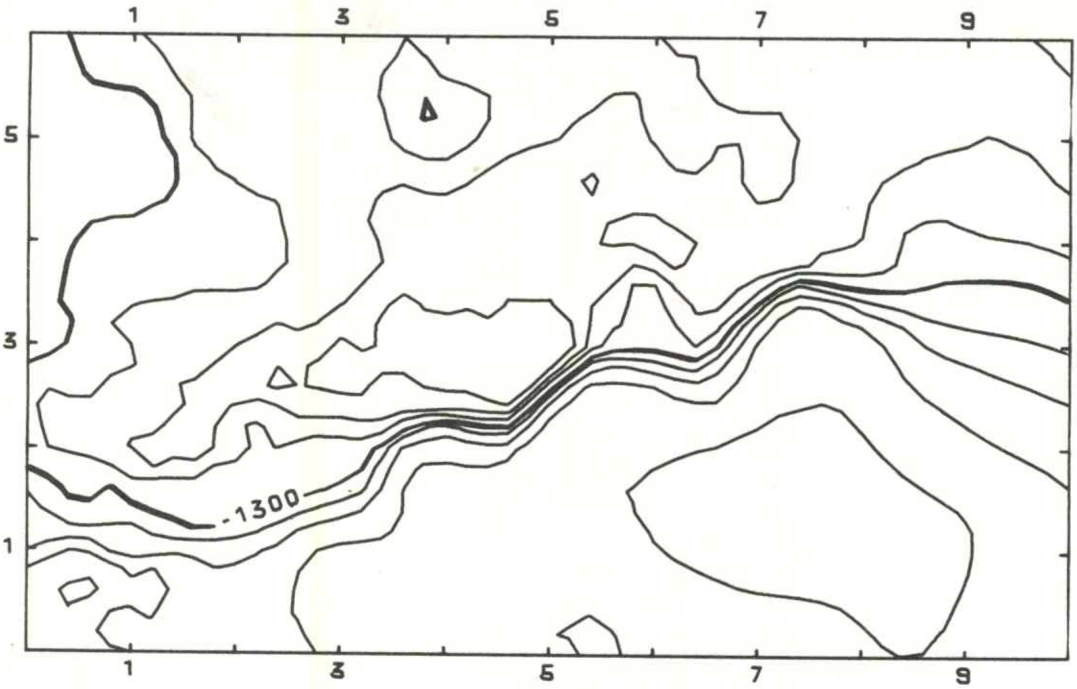


Figure 33.--Same map as in Figure 32, but with margin labeled at alternate tick marks originating at one.

BOX 1.5,2,1.5,2,1,0,0,1,0.1

BOX 1.5,2,1.5,2,1,1.5,1.5,1,0.1

BOX 1.5,2,1.5,2,1,1,1,1,0.1

BOX 1,2,1,2,1,1.5,1.5,1,0.1

BOX 1,2,1,2,1,0.5,0.5,1,0.1

BOX 1,2,1,2,1,0,0,1,0.1

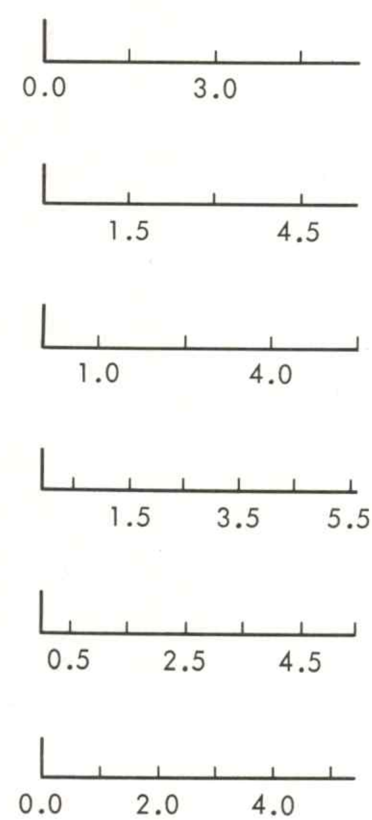


Figure 34.--Examples of different labeling conventions that can be created using the 'BOX ' command.

'BXEX'TREMES - defines and X and Y limits of the map border and neat line.

Field Number	Parameter Description	Assumed Value
1	X-coordinate of the left edge of the map border.	Varies; see text
2	X-coordinate of the right edge of the map border.	Varies; see text
3	Y-coordinate of the bottom edge of the map border.	Varies; see text
4	Y-coordinate of the top edge of the map border.	Varies; see text
5	Width in inches between left border and left neat line.	0
6	Width in inches between right border and right neat line.	0
7	Width in inches between bottom border and bottom neat line.	0
8	Width in inches between top border and top neat line.	0

'BXEX'TREMES establishes the dimensions of the border of a map or posting and the dimensions of an enclosing neat line. The border, or line defining the edge of the map, cannot be smaller than the dimensions of the grid matrix of the map. Note that 'BXEX'TREMES cannot be used to invert the axes of a map.

The assumed values of 'BXEX'TREMES will cause a border to be drawn around the map or posting which corresponds to the outer limits of the map area as defined by the 'EXTR'EMES command. Map dimensions controlled by parameters of the 'BXEX'TREMES command are shown in Figure 35.

Assumed values of the 'BXEX'TREMES parameters

1. For 'CONT'OUR and 'POST' with a grid matrix:

   parameter one: X-coordinate of the left edge of the grid matrix
   parameter two: X-coordinate of the right edge of the grid matrix
   parameter three: Y-coordinate of the bottom edge of the grid matrix
   parameter four: Y-coordinate of the top edge of the grid matrix.

2. For 'POST' without a grid matrix:

   parameter one: minimum X-coordinate of sample data minus 1% of range of X
   parameter two: maximum X-coordinate of sample data plus 1% of range of X
   parameter three: minimum Y-coordinate of sample data minus 1% of range of Y
   parameter four: maximum Y-coordinate of sample data plus 1% of range of Y.

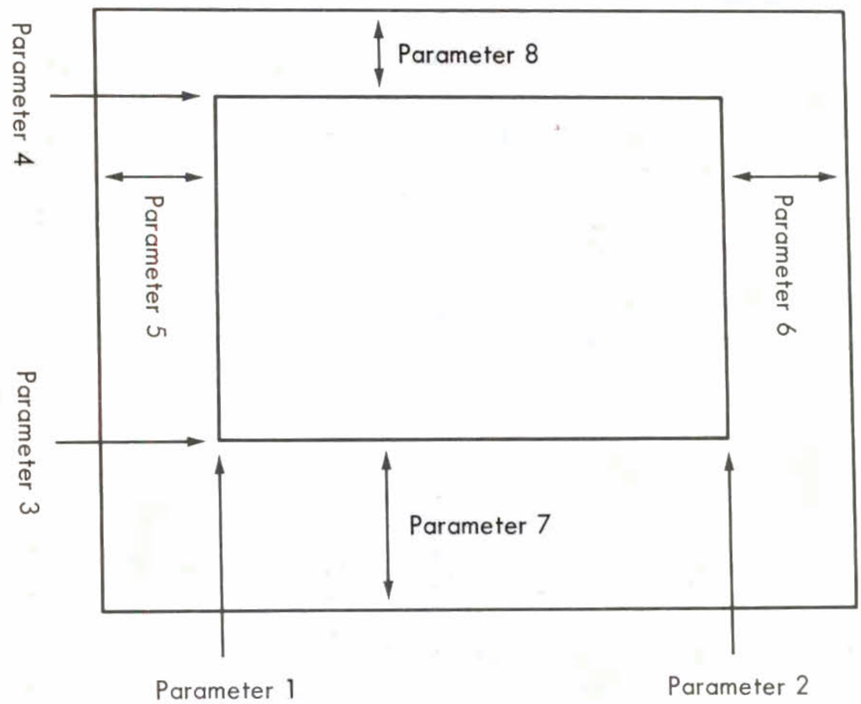


Figure 35.--Border and neat line dimensions controlled by parameters of the 'BXEX'TREMES command.

'CINT'ERVAL - specifies the spacing, annotation, and labeling of contour lines.

Field Number	Parameter Description	Assumed Value
1	Source of contour level reference table. If 0, table based on parameter 2, 3, and 4. If 1, use reference table plus 'LEVE'LS command. If 2, use 'LEVE'LS only.	0
2	Elevation of the base contour level, from which other contour levels will be calculated.	0
3	Increment between each successive level.	Variable
4	Maximum number of contour levels to be generated. If 0, a sufficient number of contours will be generated to cover the entire range of data.	0
5	Label every Nth contour line.	5
6	Height of numerals in label, in inches.	0.1
7	Number of characters to the right of the decimal point that are to be included in label.	Variable
8	Minimum distance, in inches, between successive labels on contour lines.	40% of map size, measured in the longest dimension
9	Plot every Nth contour as a heavy line.	5

The 'CINT'ERVAL command specifies the nature of contour lines to be drawn on a map. Contour intervals defined by 'CINT'ERVAL are equally spaced. If intervals of differing sizes are to be used, the values of individual contour levels must be read in with the 'LEVE'LS command. The assumed value of parameter three is variable and depends upon the physical dimensions of the map. If the smallest map dimension is less than 10 inches, the increment between successive contour levels will be adjusted to a rational value that will yield a maximum of fifteen contour intervals covering the range of the original data. If the smallest map dimension is less than 20 inches, a maximum of thirty contour intervals will be generated. If the smallest map dimension exceeds 20 inches, up to sixty contour intervals will be used (Fig. 36).

Parameter three cannot be 0 or negative. Only those contour levels that fall within the range of values in the grid matrix will be used. If none of the specified contour levels are found within the range of the grid matrix, the contour map will not be drawn.

If parameter four is larger than 0, contour levels are generated by adding successive integer multiples of parameter three to the base contour level. For example, CINT 0,560,5,6

indicates that the lowest contour level is 560 feet, the contour interval is 5 feet, and a total of 6 contour lines will be drawn. Contour lines would be drawn at elevations of 560, 565, 570, 575, 580, and 585 feet.

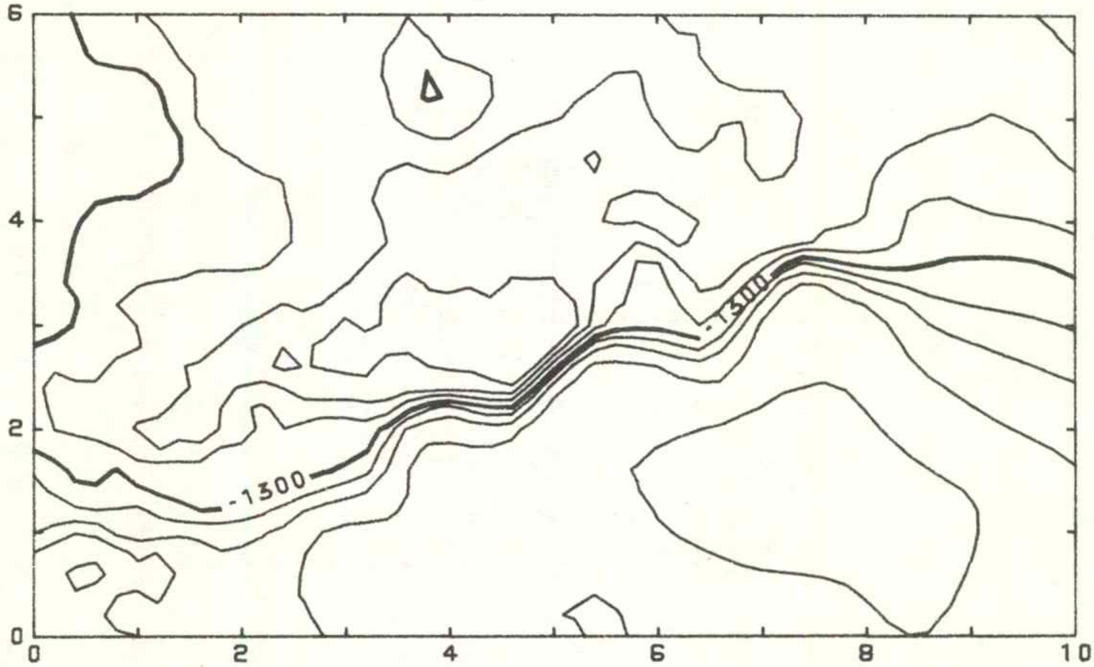


Figure 36.--Structure contour map of the top of the Pennsylvanian Lansing Group in part of Graham Co., Kansas. Contours have been drawn at the levels calculated under the assumed values of the 'CINT'ERVAL command.

By proper selection of parameters two, three, and four, it is possible to represent only values which fall within a specified range on a map. As an example, Figure 37 shows third order trend surface residuals from Lansing structure in a part of Graham Co., Kansas. Only positive residuals have been contoured. Compare this illustration with Figure 167.

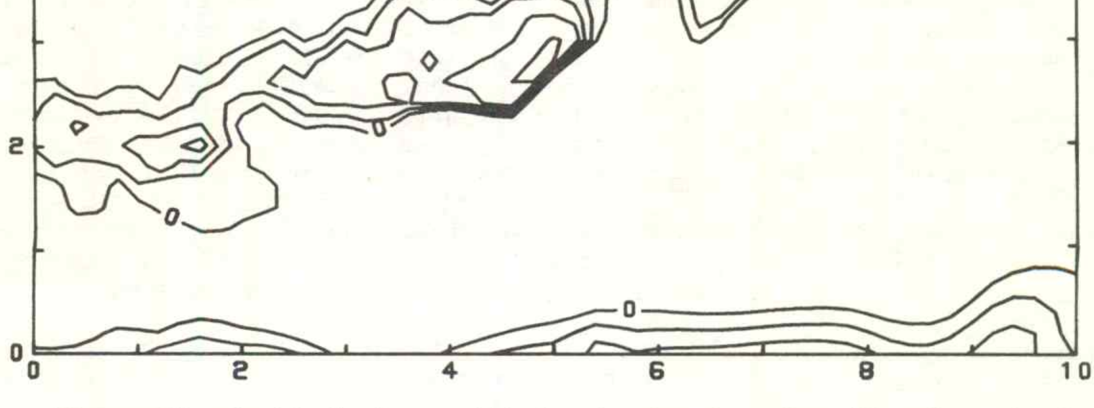


Figure 37.--Residuals from a third order trend surface fitted to the data shown in Figure 36. Twenty contour lines have been specified covering the range 0 to +200 feet, so only positive residuals are shown.

If parameter four is set to 0, the contour levels are defined by adding and/or subtracting successive integer multiples of the contour interval to or from the base contour level. Only those contour levels that are within the range of values in the grid matrix are used. As an example, consider the command

CINT 0,0,25,0

where the range of values in the grid matrix extends from 745 to 903. The base value is 0 and the contour interval is 25. The contour table would be: 0,25,50,75,...,700,725,750,..., 875,900,925,.... However only the values that are in the range of the grid matrix will be used: 700,725,750,775,800,825,850,875, and 900. The same results could have been obtained using the command

CINT 0,1000,25,0

In this case the contour interval is subtracted from the base value to form the table: 1000,975,950,...,750,725,700,.... Only the values between 700 and 900 will be used.

By setting parameter four to 0, the user has the greatest flexibility in defining the contour levels to be used on a map. It is not necessary to know the range of values in the grid matrix; only the contour interval is required.

Parameters five through nine control labelling of the contour lines. If all contour lines are labelled, the map may become cluttered and difficult to read. Parameter five specifies the number of lines to be annotated. The assumed value, for example, will cause every fifth line to be labelled. The physical size, in inches, of the characters used for annotation is given by parameter six. Parameter seven specifies the number of characters to the right of the decimal point in each label. The assumed value is adjusted so contours of fractional Ż data will be labeled. Parameter eight allows control of the frequency with which labels are repeated along a contour line. The distance is measured in inches along the line itself. Labels are automatically oriented and are placed on the line only at locations where they can be easily read. SURFACE II begins searching for a suitable location for the next label after moving the minimum distance specified by the eighth parameter. The next label is not written, however, until an approximately straight segment of the necessary length is found on the contour line.

Parameter nine controls the drawing of bold or heavy contour lines. Every Nth line above and below the base contour line will be bold. These lines are not necessarily the same lines selected for annotation. Figures 38 and 39 demonstrate some of the available options of 'CINT'ERVAL. The commands used to operate these two illustrations are given below:

```
                        TITLE       CINTERVAL TEST FOR SURFACE MANUAL
                      { DEVICE      1,'DAVIS'
                      { IDXY        200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
Read XYZ data,        { EXTREMES    0,10,0,6
calculate and         { GRID        1,0.2,0.2,1
plot Figure 38        { CONTOUR
                      { CINTERVAL   0,0,10,0,5,0.1,0,2.0,0
                      { SIZCONTOUR  1,6,3.6
                      { BOX         1,2,1,2,0,0,0,1,0.1
                        PERFORM
Plot Figure 39        { CINTERVAL   0,0,10,0,4,0.1,0,2.0,2
                      { CONTOUR
                        PERFORM
                        STOP
```

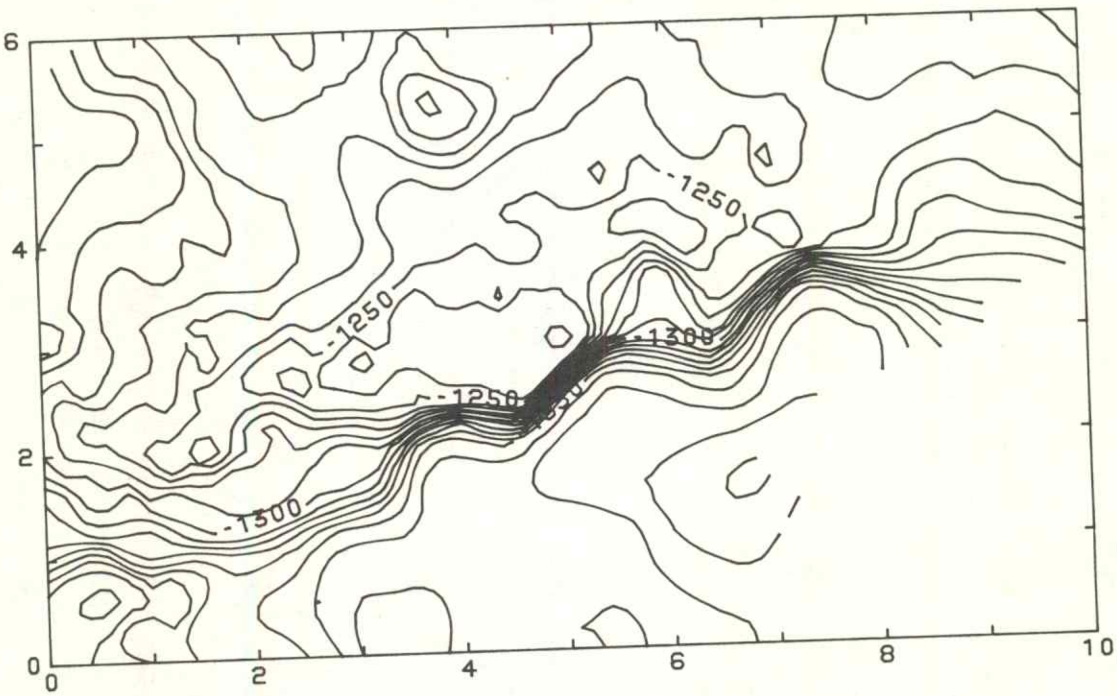


Figure 38.--Map of data shown in Figure 36 contoured at 10 foot intervals, with every fifth line annotated.

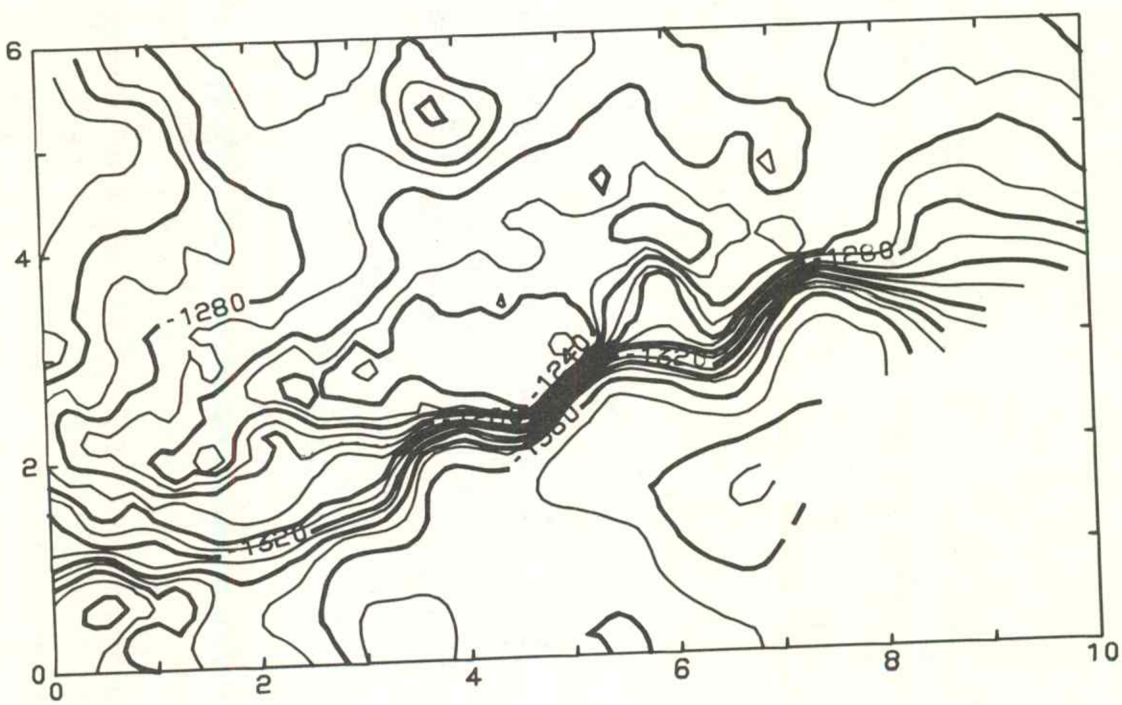


Figure 39.--Map of data shown in Figure 36 contoured at 10 foot intervals with every fourth line annotated and every second line drawn bold.

'CLEA'R - resets the parameters of all SURFACE II commands to their assumed values and clears the grid matrix, the filter matrix, sample data points, contour levels table, and outlines from memory.

NO PARAMETERS.

'CLEA'R removes all previous commands and clears memory. It has the effect of starting a new SURFACE II job, except that the 'DEVI'CE command remains as initially defined. The command allows the user to execute multiple runs using different data sets without submitting each as separate jobs. 'CLEA'R should not be used if previously set parameters or values in the grid matrix will be used in the new plot.

IMPORTANT NOTE: 'CLEA'R is executed immediately at the point where it is encountered in the command sequence. Therefore, a 'CLEA'R command should immediately follow a 'PERF'ORM command. Any commands between a 'PERF'ORM and a 'CLEA'R will be removed by 'CLEA'R.

'CONT'OUR - generates the instructions used by the plotting device to make a contour map from the grid matrix.

Field Number	Parameter Description	Assumed Value
1	Controls smoothing of contour lines. If 0, no contour line smoothing will be done. If 1, contour lines will be smoothed by piecewise Bessel interpolation.	1
2	Controls annotation of closed depressions on the map. If 0, no annotation. If 1, all closed contour lines in depressions are hatchured. If 2, only bold contour lines are hatchured.	0
3	Size of tick marks on hatchured line, in inches.	1/2 height of labels
4	Contour lines spaced closer together than the specified distance will be suppressed for clarity. If 0, all contours will be drawn regardless of crowding.	0.10 inches
5	Controls mode of drawing bold lines. If 0, bold lines are drawn by retracing in reverse direction. This option minimizes pen-up time. If 1, bold lines are drawn by returning to line origin and retracing in original direction of pen travel. This option is slower but may yield superior line quality on certain plotters.	0
6	Inoperative - Reserved for future use.	
7	Tangent or maximum slope at end-points of line segments to be smoothed.	2.0
8	Maximum length, in inches, of line segment to be retained as a straight line without smoothing.	0.07

The 'CONT'OUR command generates a set of plotting instructions from the $\dot{Z}$ matrix which is used by the plotting device to create a contour map. The instructions consist of a series of X-Y coordinates defining the path along which the pen is to move. Associated with each pair of coordinates is a command which causes the pen to be raised (no line is drawn) or lowered (a line is drawn) while it is moving from its current position to the next location. The pen always moves in a straight line from one coordinate to another. Figure 7 shows the path of a contour line passing through the rectangular grid. The point at which the contour line intersects the side of a grid cell is determined by simple linear interpolation.

Smoothing, if specified, is done by piecewise Bessel interpolation within the grid cell. First, a line is calculated at the point of intersection of the contour line with the edge of a grid cell so that the angles between the line and the contour segments are equal, as shown by shading in Figure 40. If the slope of the contour line (or tangents of these angles) exceeds the value specified in parameter seven, it is set to the specified value. Once slopes are established at both end-points of a segment within a grid cell, intermediate values can be calculated by a Bessel algorithm devised by L. Mansfield (1977, personal communication). Contour line segments shorter than the value specified by parameter eight are left as straight lines.

Parameter two of the 'CONT'OUR command specifies the placement of hatchures (small tick marks) on contour lines which enclose depressions. These tick marks point into the depression; their size is controlled by parameter three. The distance between tick marks is four times the length of the tick marks. Figures 43 and 44 show different annotations of contour lines as specified by parameter two. Note that parameter six is not used in the current release of SURFACE II. If parameters seven or eight are to be set to values other than those assumed, the parameter string should contain an extra comma to denote the sixth parameter.

Before a matrix of estimated $\dot{Z}$ values can be contoured, it must be placed into memory using 'REST'ORE or 'MATR'IX. Alternatively, the grid of $\dot{Z}$ values may be generated from sample data points using 'GRID', 'DMAP', 'TREN'D, or 'KRIG'E. The command 'CONT'OUR instructs SURFACE II to prepare contour vectors through this grid.

The following auxiliary commands provide parameters which are necessary to create a contour plot. If their assumed values are not appropriate for the map to be created, these commands, with the desired parameters, should be included in the command sequence.

AUXILIARY COMMANDS used with 'CONT'OUR: 'BOX '
'BXEX'TREMES
'CINT'ERVAL
'OVER'LAY
'POUT'LINE
'SIZC'ONTOUR

'BOX ' labels the values of X and Y on the border of the plot. 'BXEX'TREMES establishes the X and Y limits of the map border. 'CINT'ERVAL designates the elevations at which contour lines are to be plotted and which lines, if any, are to be drawn heavy. 'CINT'ERVAL also specifies which lines are to be labeled. 'LEVE'LS may be used with 'CINT'ERVAL to specify unequally spaced contour intervals. 'OVER'LAY allows more than one plot to be superimposed. 'POUT'LINE causes an outline (read in by 'ROUT'LINE) to be drawn on the map. 'SIZC'ONTOUR defines the physical dimensions of the finished map.

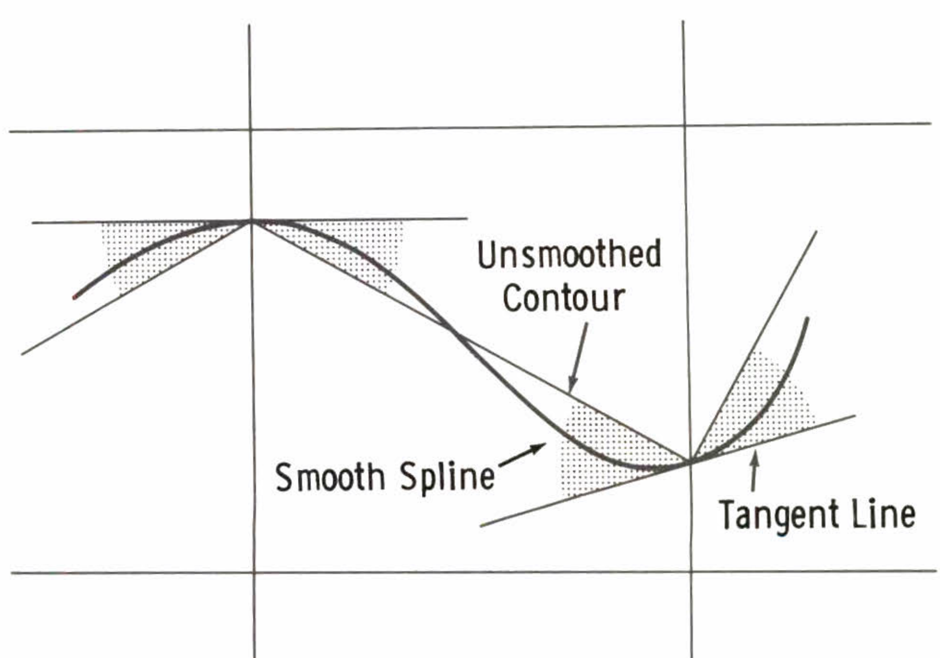


Figure 40.--Path of contour line through grid, calculated by spline fitting.

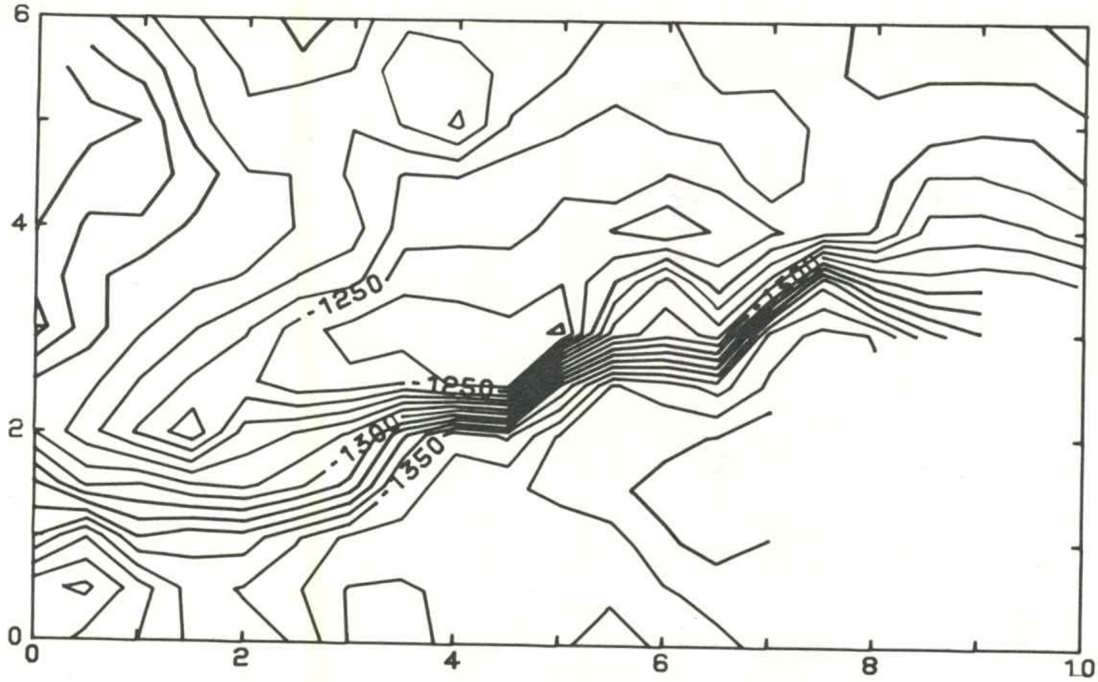


Figure 41.--Contour map of subsurface geologic structure in part of Graham Co., Kansas, drawn with an extremely coarse grid. Grid coarseness causes excessive angularity in the contour lines.

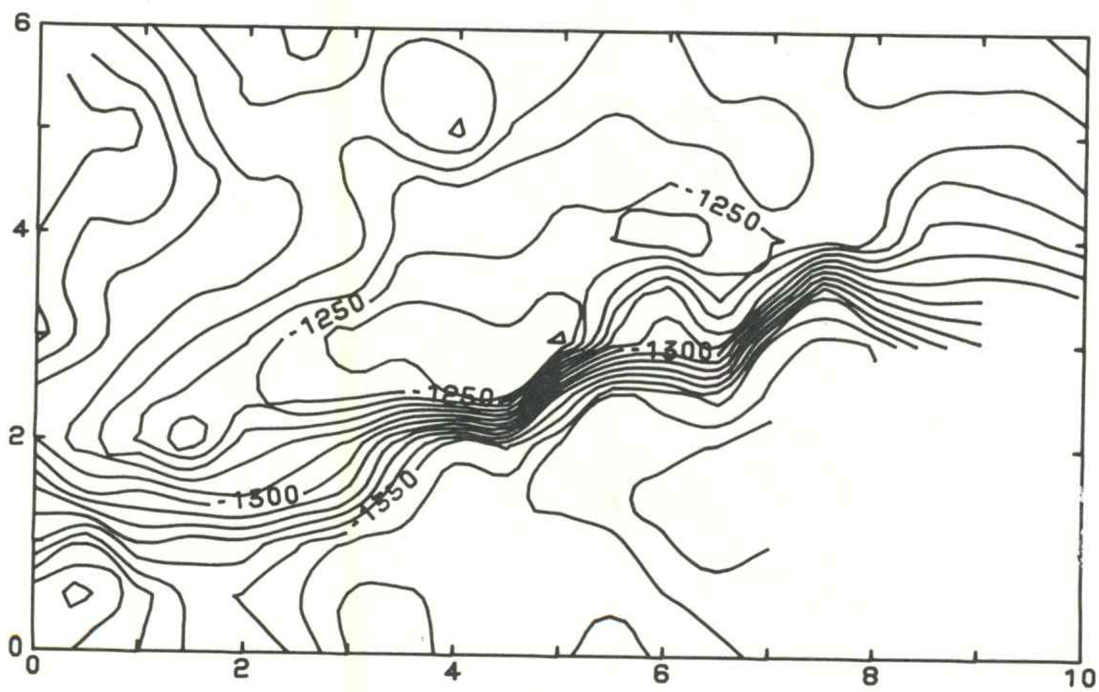


Figure 42.--Contour lines in Figure 41 smoothed by piecewise Bessel interpolation within each grid cell. Note that smoothing may cause contour lines to cross in certain circumstances. Unlike the 'MSMO'OTH command, smoothing of contour lines does not affect the Z values in the grid matrix.

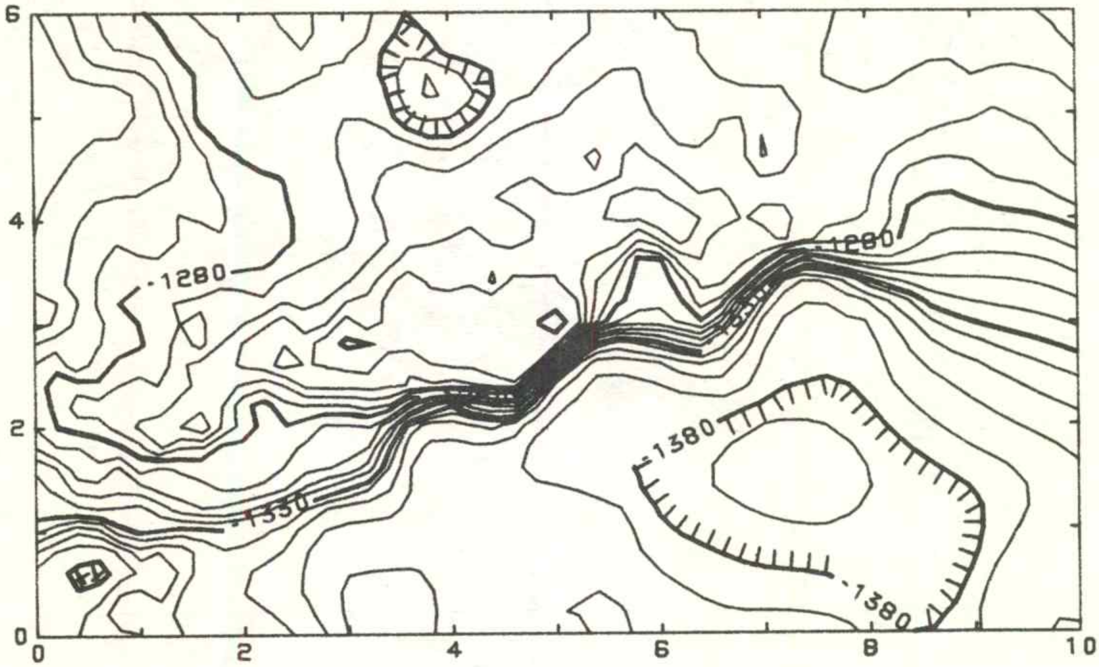


Figure 43.--Surface with closed depressions indicated by hatchuring of enclosing bold contour lines.

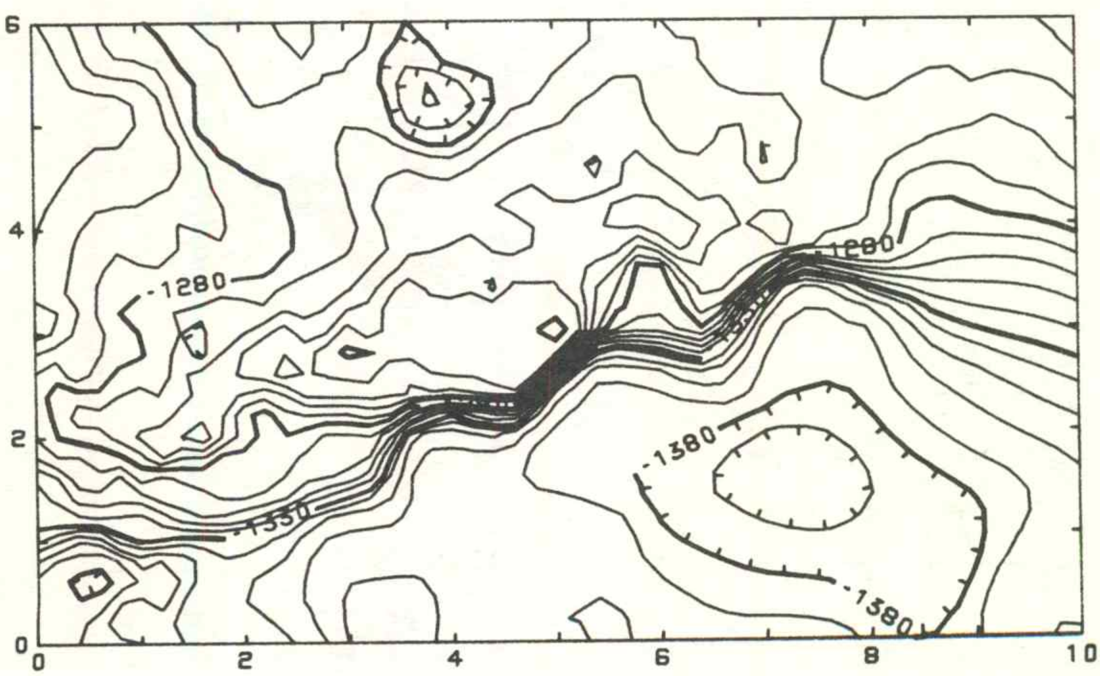


Figure 44.--Surface with closed depressions indicated by hatchuring of all enclosing contour lines.

'DERI'VATIVE - calculates a new grid matrix which contains an approximation of the first derivative of the original grid.

Field Number	Parameter Description	Assumed Value
1	Angle of the line along which the derivative is calculated. The angle should be given in degrees from the X-axis.	0°

A contour map of a derivative matrix shows changes in slope of the surface over the map area. The diagram in Figure 45 illustrates the method used by SURFACE II to approximate the first derivative of each element in the grid matrix. First, two imaginary lines are extended from the grid node (X_c, Y_r) in opposite directions. The length of each line is equal to 1/4 the diagonal length of a grid cell. Values for the surface, Z^1 and Z^2, are estimated by double linear interpolation from the grid values in the cells containing the imaginary lines. The derivative for the element $\dot{Z}_{c,r}$ is computed from the following formula:

$$\dot{Z}_{c,r} = \frac{Z^2 - Z^1}{2d} \quad .$$

Note that derivatives cannot be calculated for the outer rows and columns of the grid matrix. These are automatically set to the blank code value, so contour lines on a derivative map will not extend to the edges of the mapped area. This is shown in Figure 46, a map of the derivative of the surface in Figure 32, taken at 85°. Commands used to create this plot are:

```
TITLE         DERIVATIVE TEST FOR SURFACE MANUAL
DEVICE        1,'DAVIS'
IDXY          200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
GRID          1,0.2,0.2
EXTREMES      0,10,0,6
DERIVATIVE    -85
CONTOUR
CINTERVAL     0,0,20,0,5,0.1,0,2,5
SIZCONTOUR    1,6,3.6
BOX           1,2,1,2,0,0,0,1,0.1
PERFORM
STOP
```

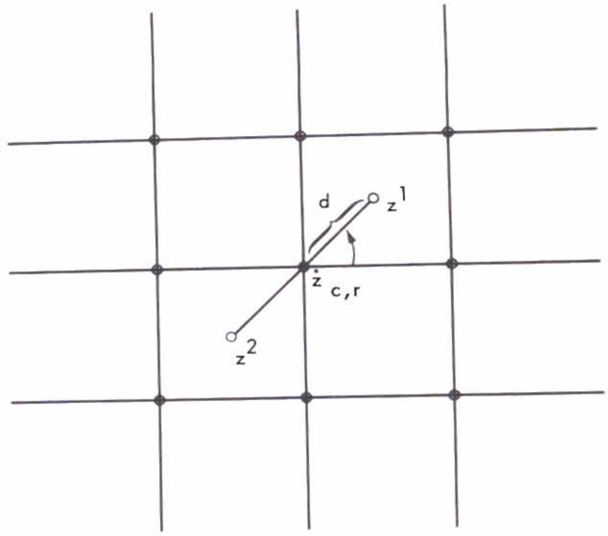


Figure 45.--Calculation of the first derivative of the surface at grid location (X_c, Y_r). The value of the derivative becomes the new value of $\dot{Z}_{c,r}$. The length of the line that is extended from the grid node is represented by d.

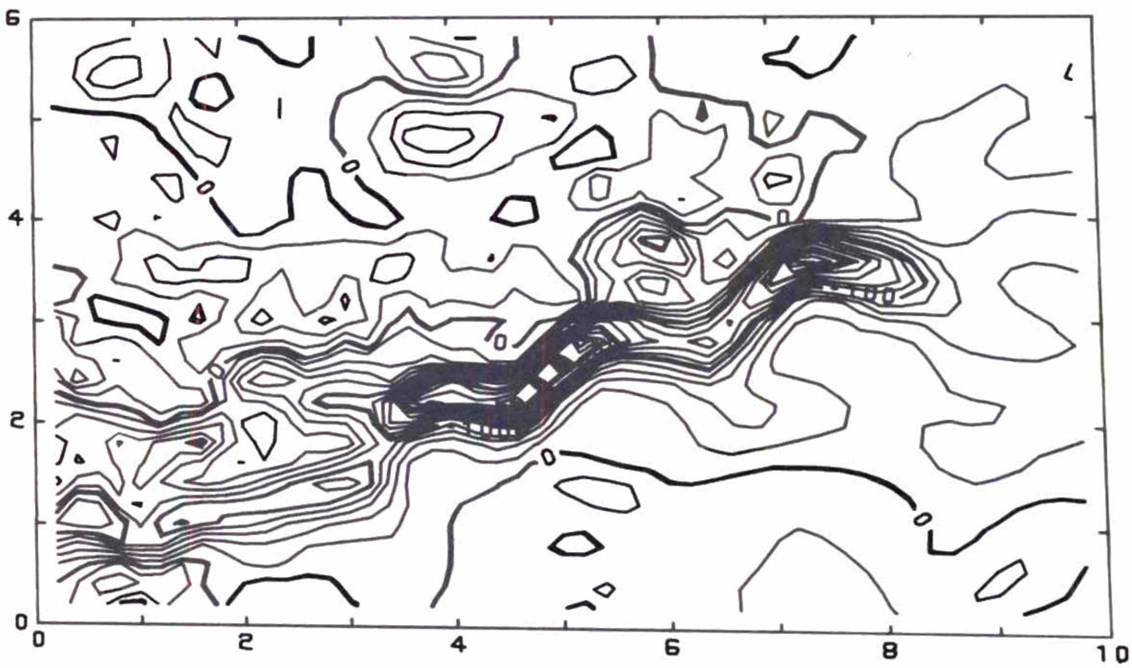


Figure 46.--Derivative of subsurface geologic structure map of part of Graham Co., Kansas. Derivative taken at 85°, a line approximately perpendicular to the greatest change in surface slope.

'DEVI'CE - prepares the plotting device to accept instructions.

Field Number	Parameter Description	Assumed Value
1	Code for individual plotting device.	Required
2	User's name; must be enclosed in single quotes.	Required
3	Size of plotter in X-direction.	Varies; see below
4	Size of plotter in Y-direction.	Varies; see below
5	Distance between plots in X-direction.	4
6	Distance between plots in Y-direction.	4

'DEVI'CE is required to initialize the plotting device. Parameter one identifies the device to be used. The 'DEVI'CE command can be used only once in a SURFACE II job; therefore, only one plotting device can be used during any one execution of SURFACE II commands. A device remains active until a 'FINI'SH or 'STOP' command is given. Once a device has been turned off it cannot be reactivated during that job.

Parameters three and four define the physical size of the plotting medium. In the case of flatbed plotters, it defines the paper size being used; in the case of a drum plotter, it defines the width of a roll of paper. For plots that exceed the size of the plotter, SURFACE II segments the plots into pieces that will fit onto the plotting medium. Parameters five and six define the amount of separation between plots, in inches, as illustrated in Figure 47.

Plotting devices and assumed values for each device.

Device code	Device name	Maximum size in X-direction	Maximum size in Y-direction
1	Gerber flatbed	60 in.	50 in.
2	Omega-T	15 "	10 "
3	Benson-Lehner	9999 "	29 "
4	Intermediate output	9999 "	9999 "

The intermediate output option allows the user to store the plotting instructions on a temporary or permanent file assigned the file code 9. This file may be subsequently accessed and plotted on any device for which the user has a plotting routine.

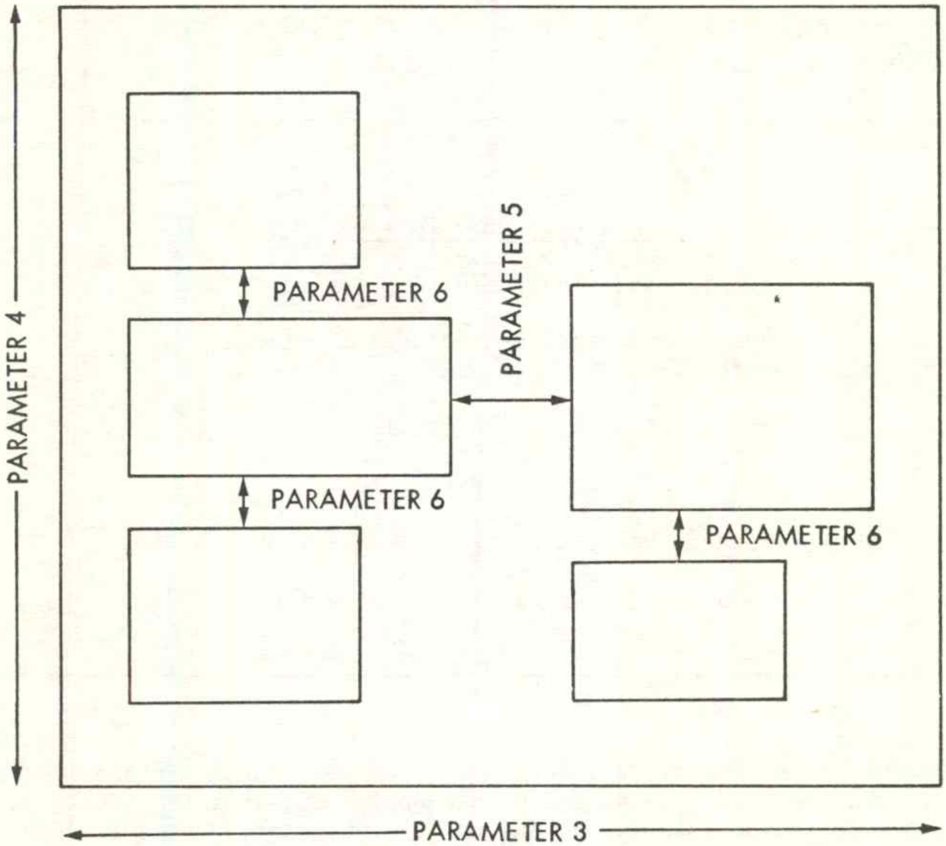


Figure 47.--Layout of plots on a sheet of paper, showing how parameters of 'DEVI'CE affect spacing.

'DIST'ANCE - defines the distance from the point of observation to the center of a block diagram.

Field Number	Parameter Description	Assumed Value
1	The distance, in units of X and Y, from the center of the matrix to the point of observation.	10000

The appearance of a block diagram changes as the observer's viewpoint is moved farther away from the block. 'DIST'ANCE specifies the distance between the viewpoint and the center of the block or grid matrix. If the command is not given, the point of observation will be assumed to be 10,000 map units distant from the center of the grid.

At very great viewing distances, the diagram will appear as a mechanical construction; that is, receding lines will not converge and the width of the block along its back edge will be the same as the width along the front edge. From closer viewpoints, receding lines converge toward vanishing points and the block appears in perspective. From a very close viewpoint, the convergence will be severe and the block may appear distorted. The distance cannot be so small that the viewpoint is within the block. If such a distance is specified, SURFACE II will automatically move the viewpoint back until it is immediately outside the block. Figures 48-51 show a surface viewed from increasingly greater distances. SURFACE II commands used to produce these illustrations are:

Grid original data	TITLE	DISTANCE TEST FOR SURFACE MANUAL
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	GRID	1,0.2,0.2
	EXTREMES	0,10,0,6
	DEVICE	1,'SAMPSON',60,40,3,3
	PERFORM	
Establish dimensions and draw Figure 48	TRANSECT	0,20,0
	SIZTRANSECT	6
	LINES	1,40,24
	DISTANCE	7
	ELEVATION	30
	AZIMUTH	25
	PERFORM	
Move back and draw Figure 49	DISTANCE	20
	TRANSECT	0,20,0
	PERFORM	
Move back and draw Figure 50	DISTANCE	100
	TRANSECT	0,20,0
	PERFORM	
Move back and draw Figure 51	DISTANCE	10000
	TRANSECT	0,20,0
	PERFORM	
	STOP	

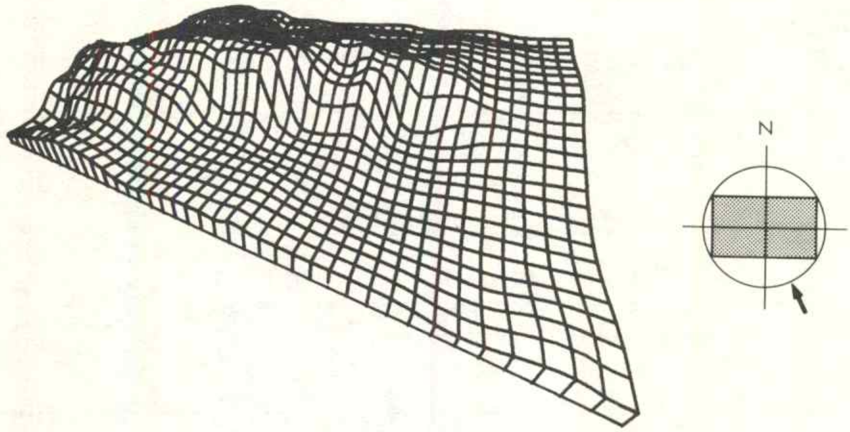


Figure 48.--Perspective block diagram of subsurface geologic structure in part of Graham Co., Kansas. Distance to viewpoint is 7 map units. Severe convergence of lines causes compression of the block so its overall size is reduced.

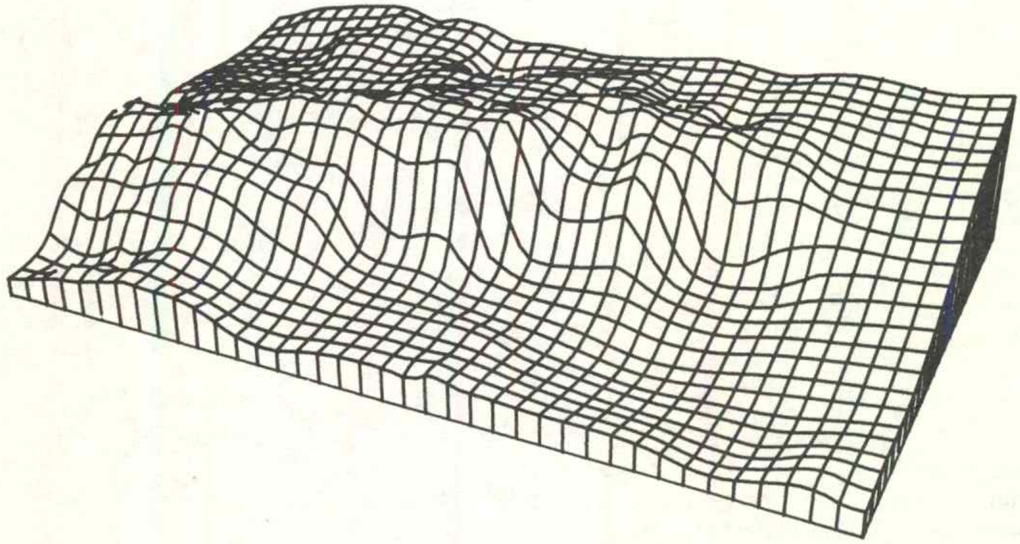


Figure 49.--Block diagram viewed from a point 20 map units away. Note slight downward convergence at this close viewing distance.

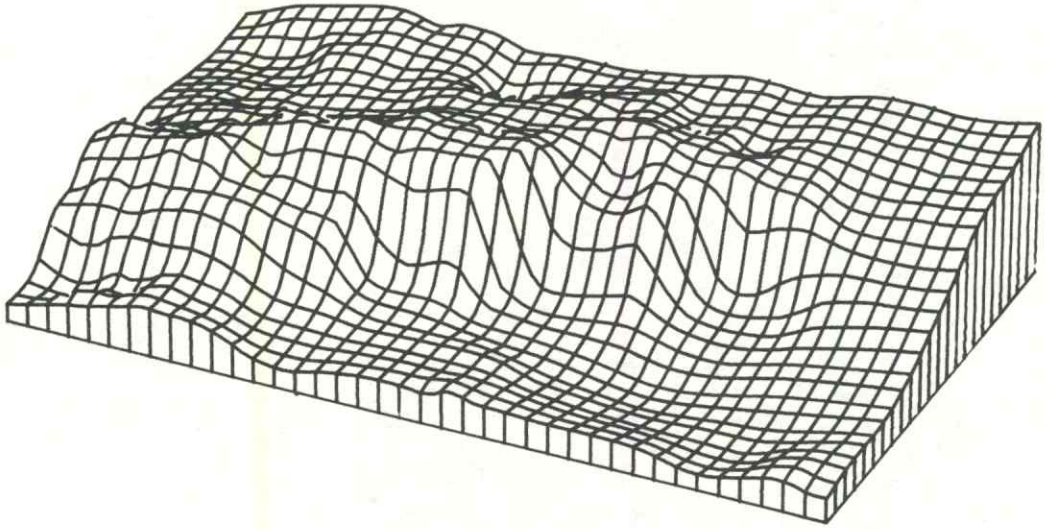


Figure 50.--Block diagram viewed from a point 100 map units away. Block has moderate front-to-back convergence and no perceptible downward convergence.

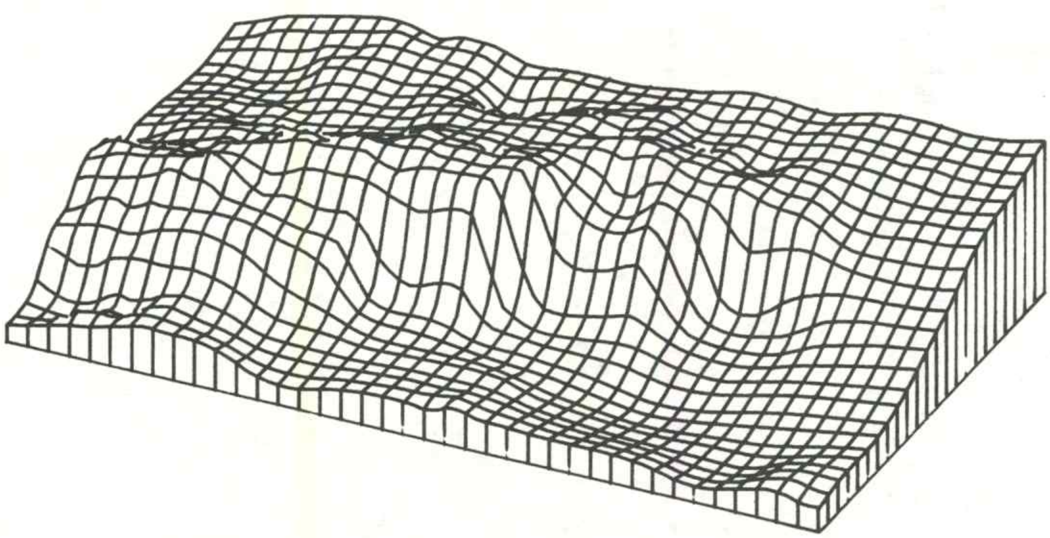


Figure 51.--Block diagram viewed from 10,000 map units away. This is the view created by the assumed value of the 'DIST'ANCE command. There is no measurable convergence of receding lines.

'DMAP' - generates a matrix of values representing some function of the distance of each grid node from the sample data points.

Field Number	Parameter Description	Assumed Value
1	Method of determining the grid size. If 0, the number of columns and rows in the grid matrix will be specified. If 1, the number of columns and rows in the grid matrix will be calculated. The desired distance between columns and rows must be given.	0
2	Either the number of columns in the grid matrix, or the distance between columns, depending upon the specification of parameter one.	25/1
3	Either the number of rows in the grid matrix, or the distance between rows, depending upon the specification of parameter one.	25/1
4	Type of distance function to be calculated. The codes and corresponding functions are listed below.	0
5	If parameter four is set to 7, 8, or 9, a weighting function can be specified as listed below.	0
6	Specifies whether or not to release the memory occupied by the array of sample data points for subsequent use. If 0, retain the sample data. If 1, delete the sample data.	0
7	Method of handling duplicate data points (two or more data points having the same X and Y coordinates and possibly different Z values). If 0, compute $\dot{Z}$ = average value of duplicate data points. If 1, delete duplicate data points. If 2, where more than one data point is present in a grid cell, replace all points within that cell by their centroid location.	0

The 'DMAP' command generates a grid matrix which may subsequently be used to produce a distance contour map or block diagram. Unlike grids which contain estimates of the Z-variable, the elements in a 'DMAP' matrix are functions of the distance of each grid node from nearby sample data points.

'DMAP' is an analytical tool which can be used to study the effectiveness of various search methods on particular data sets. Areas of high values in a distance map (assuming distance from samples rather than number of samples found is the value being calculated) indicate areas in which estimates of surface values would be poorly controlled and hence of low reliability.

The user may define the size (i.e., the number of columns and rows) of the matrix in two different ways. By setting parameter one to 0, the number of columns and rows in the matrix may be given explicitly. Then, the distance between columns is

$$\frac{X_{max} - X_{min}}{NC - 1}$$

and the distance between rows is

$$\frac{Y_{max} - Y_{min}}{NR - 1}$$

where X_{min}, X_{max}, Y_{min}, and Y_{max} are determined by 'EXTR'EMES, and NC and NR are given by parameters two and three.

When parameter one is set to 1, the user defines the distance between columns and rows, and NC and NR are calculated by dividing these distances into the ranges of X and Y, as specified by 'EXTR'EMES. If there is any remainder, the ranges of X and Y are expanded so the distances between all rows and columns are uniform. For example, if

$X_{min} = 1$ $Y_{min} = 1$ parameter two = 3

$X_{max} = 25$ $Y_{max} = 20$ parameter three = 3

the number of columns in the matrix will be

$$\frac{25 - 1}{3} + 1 = 9$$

and the number of rows in the matrix will be

$$\frac{20 - 1}{3} + 1 = 7\ 1/3\ .$$

To avoid fractions, the number of rows will be increased to 8, and the value of Y_{max} automatically expanded to 22.

Codes and functions of parameter four, which specifies the method of calculation of a grid in 'DMAP'.

Value of parameter four	Function
0	$\dot{Z}_{c,r}$ = distance from grid node (X_c, Y_r) to the nearest sample data point. Figure 52 is a nearest-neighbor distance map of control points in part of Graham Co., Kansas.
1	$\dot{Z}_{c,r}$ = distance from grid node (X_c, Y_r) to the farthest data point found by the specified search procedure. If no data points are found the grid value is blanked out. Figure 53 is a map of distance to "farthest nearest-neighbor" of the data in Figure 52.

2 $\dot{Z}_{c,r}$ = average distance of all data points found by the specified search pattern around the grid node (X_c, Y_r). If no points are found the grid value is blanked out.

3 $\dot{Z}_{c,r}$ = standard deviation of the distances of data points found by the specified search pattern around grid node (X_c, Y_r). If no points are found the grid node is blanked out. Figure 54 shows an example of a map made using this option.

4 $\dot{Z}_{c,r}$ = distance from the grid node to the centroid of the data points found by the specified search pattern around grid node (X_c, Y_r). If no points are found the value is blanked out. See Figure 55 for a map of distance to the centroids of control points.

5 $\dot{Z}_{c,r}$ = number of data points found around grid node (X_c, Y_r) by the specified search procedure.

6 $\dot{Z}_{c,r}$ = number of quadrants or octants filled with the specified number of control points.

7 $\dot{Z}_{c,r}$ = percent contribution of the nearest sample data point to the estimate of the Z-variable at grid node (X_c, Y_r).

8 $\dot{Z}_{c,r}$ = percent contribution of the most distant sample point found by the specified search procedure to the estimate of the Z-variable at grid node (X_c, Y_r).

9 $\dot{Z}_{c,r}$ = standard deviation of percent contribution of all sample data points used to estimate the Z-variable at grid node (X_c, Y_r).

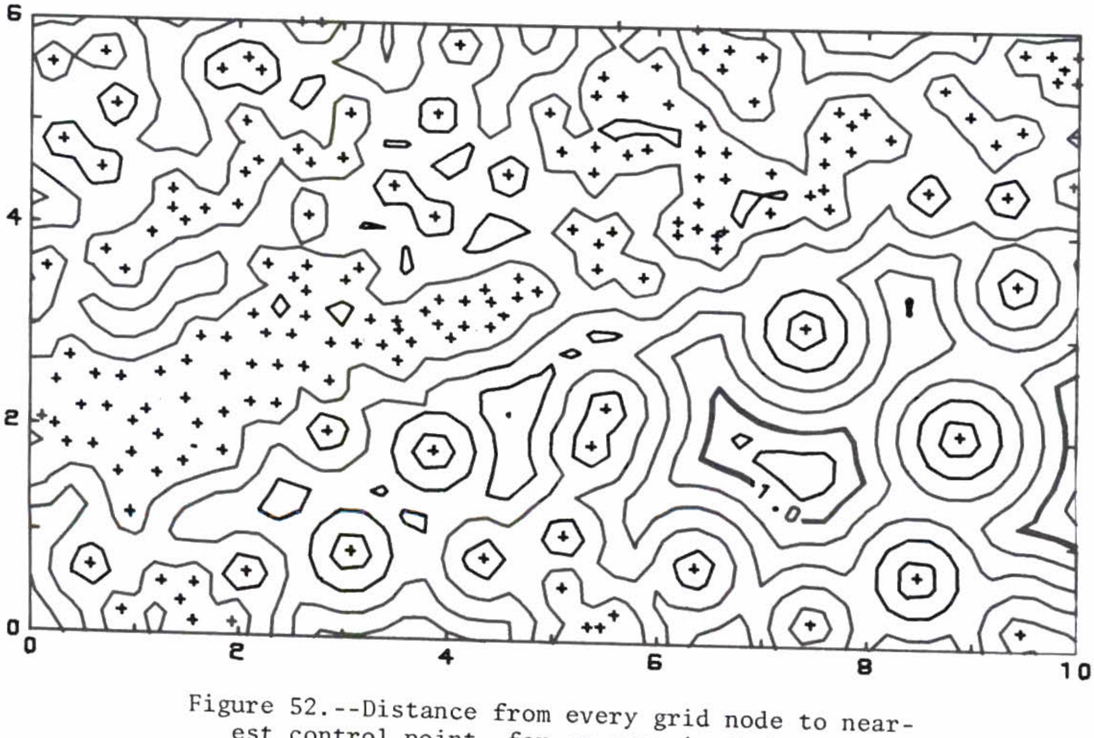


Figure 52.--Distance from every grid node to nearest control point, for an area in Graham Co., Kansas. Control points (oil well locations) are shown by +. Contour interval is 0.25 miles distance away from nearest control.

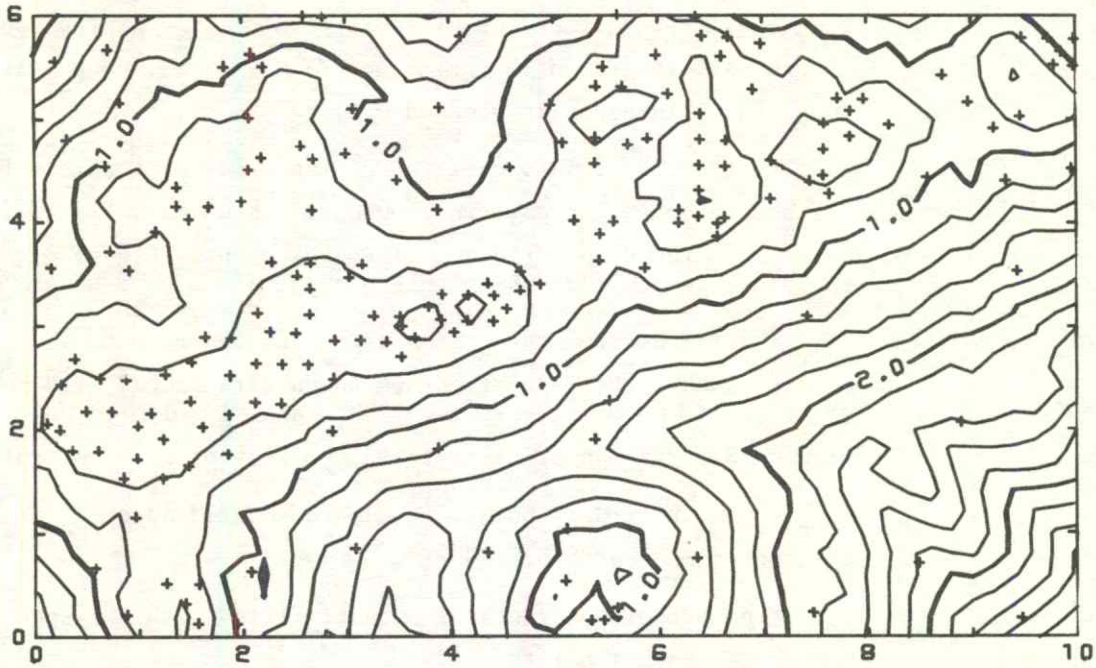


Figure 53.--Distance from every grid node to the farthest of the control points used in its estimation. Data are the same as in Figure 52. Contour interval is 0.25 miles distance away from farthest estimating point found by a nearest-neighbors search for eight points.

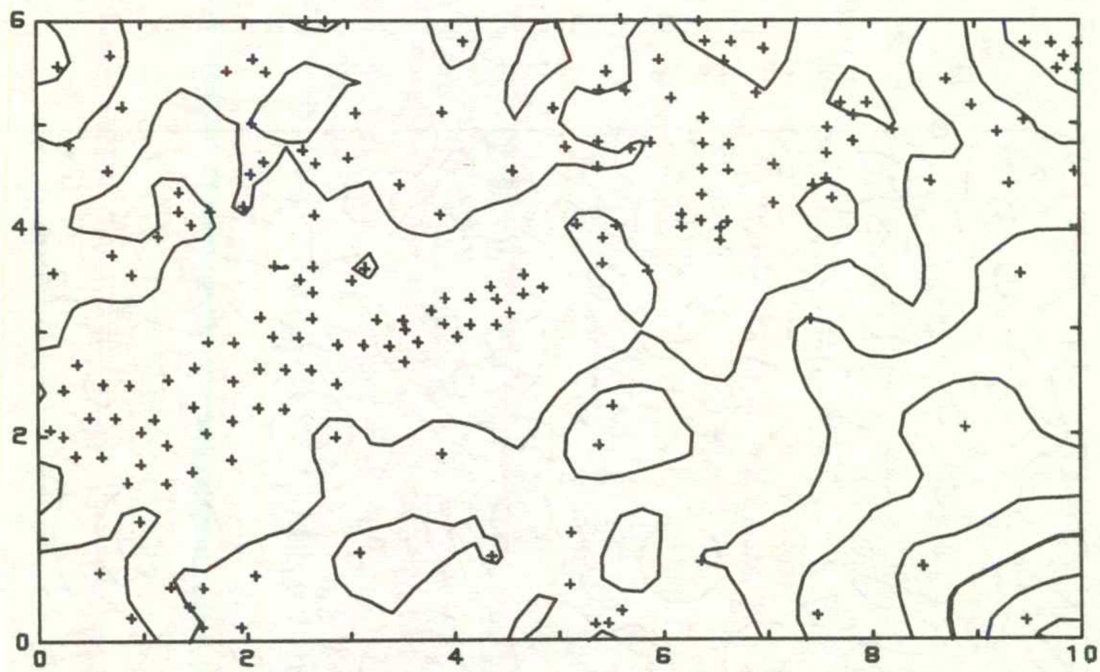


Figure 54.--Standard deviation of distances from a grid node to the points used in its estimation. Data are the same as in Figure 52. Contour interval is 0.25 miles standard deviation. Standard deviations are calculated for the eight points found by the specified nearest-neighbor search.

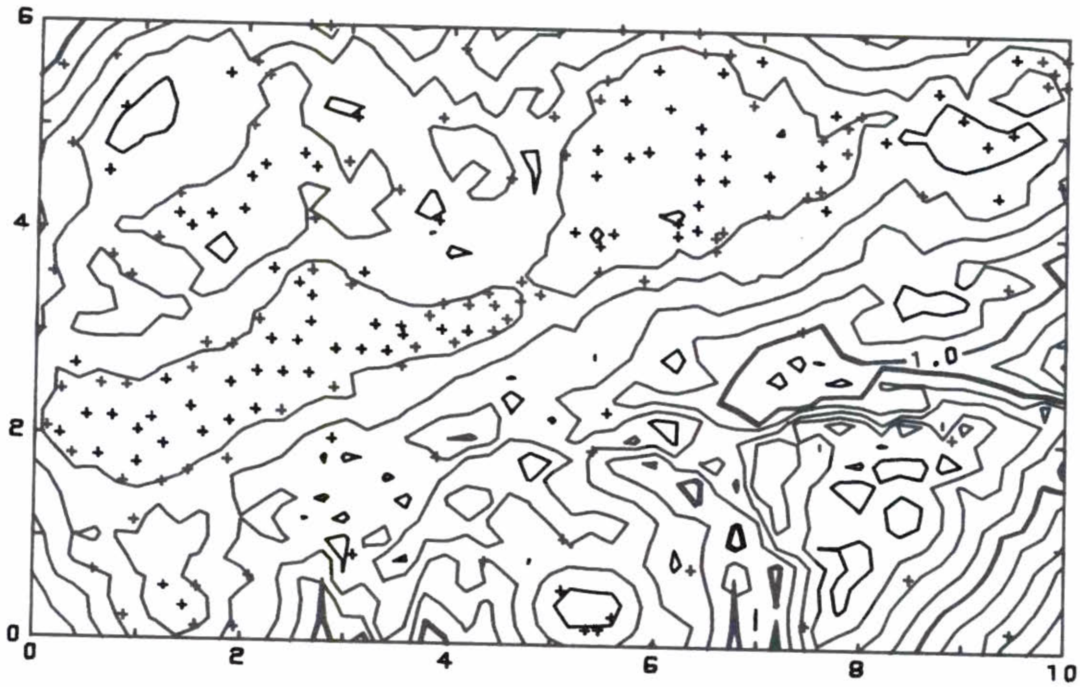


Figure 55.--Distance from every grid node to the centroid of the control points used in its estimation. Data are the same as in Figure 52. Contour interval is 0.25 miles distance away from the centroid of eight estimating points found by a nearest-neighbor search.

Codes and functions of parameter five, which specifies the weighting functions used in gridding routines to estimate $\dot{Z}_{c,r}$ values.

Value of parameter five	Function
0	Scaled $1/D^2$ weighting function, $\omega = (1 - \frac{D}{1.1 \times D_{max}})^2 / (\frac{D}{1.1 \times D_{max}})^2$
1	Inverse distance weighting function, $\omega = \frac{1}{D}$
2	Inverse distance-squared weighting function, $\omega = \frac{1}{D^2}$
3	Inverse D^4 weighting function, $\omega = \frac{1}{D^4}$
4	Inverse D^6 weighting function, $\omega = \frac{1}{D^6}$

Figure 56 is a plot of the weighting function specified by option 0. Figure 57 shows the weighting function given in option 1.

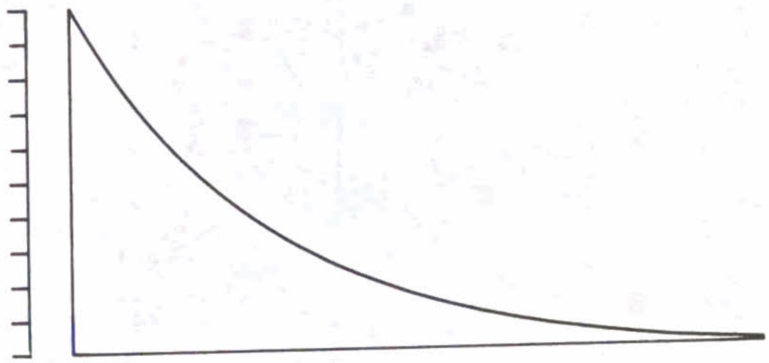


Figure 56.--Decline of scaled $\frac{1}{D^2}$ weighting function with distance away from estimated point.

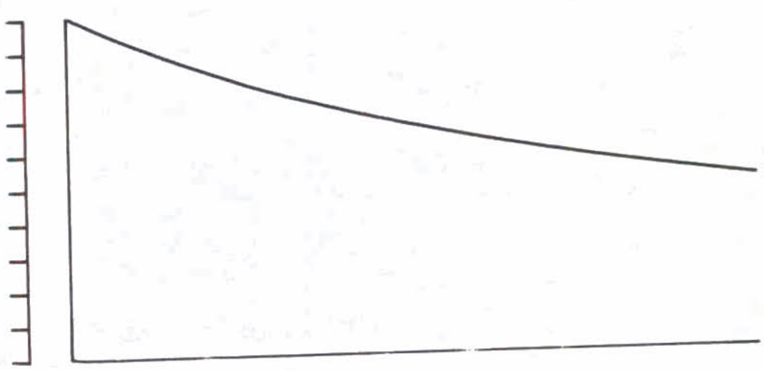


Figure 57.--Decline of $\frac{1}{D}$ weighting function with distance away from estimated point.

AUXILIARY COMMANDS used with 'DMAP':

'EXTR'EMES
'NEAR'
'OCTA'NT
'QUAD'RANT
'VRAD'IUS

The 'EXTR'EMES command establishes the X, Y limits of the map. The next four commands allow the user to specify the search procedure which finds the nearest data points which will be used in the distance calculations. The search is conducted around each grid node to be estimated. If the search around a grid node does not find an acceptable number of sample data points for calculation purposes, the grid intersection is assigned a code value for missing data. Contour lines will be omitted in grid cells containing a node that has been assigned this code value.

The sample data points near each grid node are selected by the search procedure specified. If no search method is specified, a nearest neighbor search ('NEAR') is used with the assumed values for the command controlling the number of nearest neighbors, the maximum allowable distance to the nearest data point, and the maximum search radius.

There is a certain compromise involved in selecting the search radius and the number of points to be sought. If these values are selected so a large number of search failures occur, the map will contain numerous incomplete contour lines. On the other hand, specification of a large search radius or a large number of data points to be included in each search may introduce excessive averaging and loss of detail in the grid matrix.

'ECHO' - creates a printed listing of all input data read by SURFACE II.

NO PARAMETERS.

When this command is specified, all input data will be printed as it is read during the execution of an input command. If the input is a set of data points (read by 'IDXY'), the 'ECHO' output is a list of all points read in. The first column in the 'ECHO' list contains the sequential identification number of each data point. The next three columns contain the X and Y coordinates and the Z-value of the data points. If the input is a matrix (read by 'REST'ORE or 'MATR'IX), the 'ECHO' output is the matrix read in, listed by rows and columns. The 'ECHO' list can be used to confirm the validity of input data. Values read by 'LEVE'LS or 'ROUT'LINE are also printed by 'ECHO'.

'ECIN'TERVAL - specifies the spacing of elevated contour lines on a block diagram made using the 'ECON'TOUR command.

Field Number	Parameter Description	Assumed Value
1	Source of contour level reference table. If 0, table based on parameter 2, 3, and 4. If 1, use reference table plus 'LEVE'LS command. If 2, use 'LEVE'LS only.	0
2	Elevation of the base contour level, from which other contour levels will be calculated.	0
3	Increment between each successive level.	Variable
4	Maximum number of contour levels to be generated. If 0, a sufficient number of contours will be generated to cover the entire range of data.	0

The 'ECIN'TERVAL command specifies the nature of contour lines to be drawn on a block diagram. Contour intervals defined by 'ECIN'TERVAL are equally spaced. If intervals of differing sizes are to be used, the values of individual contour levels must be read in with the 'LEVE'LS command.

The assumed value of parameter three is variable and is adjusted to a rational value that will yield a maximum of fifteen contour intervals covering the range of the original data. Parameter three cannot be 0 or negative. Only those contour levels that fall within the range of values in the grid matrix will be used. If none of the specified contour levels are found within the range of the grid matrix, the block diagram will not be drawn.

If parameter four is larger than 0, contour levels are generated by adding successive integer multiples of parameter three to the base contour level. For example,

```
ECIN 0,560,5,6
```

indicates that the lowest contour level is 560 feet, the contour interval is 5 feet, and a total of 6 contour lines will be drawn on the block. Elevated contour lines would be drawn at elevations of 560, 565, 570, 575, 580, and 585 feet.

If parameter four is set to 0, the contour levels are defined by adding and/or subtracting successive integer multiples of the contour interval to or from the base contour level. Only those contour levels that are within the range of values in the grid matrix are used. As an example, consider the command

```
ECIN 0,0,25,0
```

where the range of values in the grid matrix extends from 745 to 903. The base value is 0 and the contour interval is 25. The contour table would be: 0,25,50,75,...,700,725,750,..., 875,900,925,.... However only the values that are in the range of the grid matrix will be used: 700,725,750,775,800,825,850,875, and 900. The same results could have been obtained using the command

ECIN 0,1000,25,0

In this case the contour interval is subtracted from the base value to form the table: 1000,975,950,...,750,725,700,.... Only the values between 700 and 900 will be used.

By setting parameter four to 0, the user has the greatest flexibility in defining the contour levels to be used on a map. It is not necessary to know the range of values in the grid matrix; only the contour interval is required.

Examples of block diagrams with elevated contour lines are given with the 'ECON'TOUR command. Operation of 'ECIN'TERVAL parallels that of 'CINT'ERVAL: refer to that section for additional examples which use a contour map.

'ECON'TOUR - creates a perspective block diagram with elevated contour lines.

Field Number	Parameter Description	Assumed Value
1	If 0, the block diagram will have a base. If 1, only the surface will be displayed. If 2, vertical grid lines will not be drawn on base.	0
2	Percent of range in X- or Y-direction (whichever is greater) into which the range of Z will be scaled. If 0, no scaling is done.	50%
3	Determines the directions of lines across the surface. If 0, only elevated contour lines will be drawn. If 1, elevated contour lines and form lines parallel to the X-axis are drawn. If 2, elevated contour lines and form lines parallel to the Y-axis are drawn. If 3, elevated contour lines and form lines perpendicular to the line of sight between the observer and the block diagram are drawn.	0
4	Scales X and Y axes with respect to each other. If 0, one unit in X equals one unit in Y. If 1, Y is scaled to a percentage of the range of X. If 2, X is scaled to a percentage of the range of Y.	0
5	Percent scaling to be used if parameter four is 1 or 2.	100%
6	Check to determine if specified size of plot is reasonable. If 0, check will be made. If 1, no check will be made.	0

The shape of a block diagram is determined by the relative length, width, and range of heights of the surface. The range of the surface in the Z-direction is the difference between the smallest and largest values in the grid matrix. If the numerical range of Z is much larger than the range of X and Y, the block diagram may appear as a spike, and the plot may be useless. The 'SCAL'E command allows the user to scale the values of Z in the grid matrix to within a specified range; this operation permanently destroys the original Z values. In contrast, 'ECON'TOUR allows scaling without altering the original values in the grid matrix. Parameter two of 'ECON'TOUR specifies degrees of scaling as a percent of the X- or Y-range; a value of 40 to 60% usually produces a block diagram which has acceptable proportions. If too much scaling is specified, low features on the surface may be lost. If the vertical range is specified as a large percentage of the horizontal scale, surface features may appear exaggerated and the elevated contour lines may have excessive separation.

Parameter three controls how contour and form lines will be drawn across the surface of the block. Figures 58-61 illustrate the four options.

Parameters four and five can severely affect the appearance of a block plot. These are illustrated in Figures 161 and 162, under the 'TRAN'SECT command.

AUXILIARY COMMANDS used with 'ECON'TOUR:

'AZIM'UTH
'DIST'ANCE
'ECIN'TERVAL
'ELEV'ATION
'LINE'S
'SIZC'ONTOUR
'STER'EO

The 'SIZC'ONTOUR command determines the physical size of the finished plot in inches. The length, width, and height of the surface are scaled to the dimensions defined by 'SIZC'-ONTOUR when the plotting instructions are generated. The matrix is not affected by this command.

'LINE'S defines the number of form lines that will appear on the block to represent the surface. It has no effect on the size or shape of the plot.

The 'SIZC'ONTOUR, 'ECIN'TERVAL and 'LINE'S commands control the appearance of a perspective block diagram with elevated contour lines. If the assumed values of their parameters are not appropriate for displaying a specific matrix, they should appear with the 'ECON'TOUR command. Other commands used in conjunction with 'ECON'TOUR are 'DIST'ANCE, 'AZIM'UTH, and 'ELEV'ATION. These determine the observer's point of view with respect to the block diagram and control the perspective effect. 'STER'EO specifies that the block diagram will be drawn as a stereo pair.

This option of 'ECON'TOUR is not implemented in the initial release of SURFACE II.

Figure 58.--Block diagram with elevated contour lines, showing subsurface geologic structure in part of Graham Co., Kansas. Parameter three is set to 0, so only elevated contours are shown.

This option of 'ECON'TOUR is not implemented
in the initial release of SURFACE II.

Figure 59.--Block diagram drawn with elevated contour lines and form lines parallel to the X-axis. Parameter three is set to 1.

This option of 'ECON'TOUR is not implemented
in the initial release of SURFACE II.

Figure 60.--Block diagram drawn with elevated contour lines and form lines parallel to the Y-axis. Parameter three is set to 2.

This option of 'ECON'TOUR is not implemented
in the initial release of SURFACE II.

Figure 61.--Block diagram drawn with elevated contour lines and form lines perpendicular to the line of sight between the observation point and the block. Parameter three is set to 3.

'ELEV'ATION - defines the elevation of the observer's viewpoint above a block diagram.

Field Number	Parameter Description	Assumed Value
1	Angle of the observation point above the horizon, in degrees.	30°

The parameter specifies the angle above the X-Y plane at which a block diagram is to be viewed, as indicated in Figure 62. For most surfaces, angles of elevation between 10° and 30° produce the most effective block diagrams. If an excessively high viewing angle is used, the appearance of surface relief is lost, as in Figure 63. A maximum elevation of 90° may be specified, which places the observer's viewpoint directly above the center of the block. If the 'ELEV'ATION command is not given, an angle of 30° is assumed.

Figures 63-66 show a block diagram viewed from different elevations. In these illustrations, other commands which affect the location of the viewpoint ('AZIM'UTH, 'DIST'ANCE) are held constant. See Figure 51 for a view of this diagram from the assumed elevation of 30°.

The following commands produced the examples shown:

Grid original data	TITLE	ELEVATION TEST FOR SURFACE MANUAL
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	GRID	1,0.2,0.2
	EXTREMES	0,10,0,6
	DEVICE	1,'SAMPSON',60,40,3,3
	PERFORM	
Establish dimensions and draw first block (Fig. 63)	TRANSECT	0,20,0
	SIZTRANSECT	6
	LINES	1,40,24
	DISTANCE	100
	ELEVATION	5
	AZIMUTH	25
	PERFORM	
Elevate to Figure 64	ELEVATION	15
	TRANSECT	0,20,0
	PERFORM	
Elevate to Figure 65	ELEVATION	45
	TRANSECT	0,20,0
	PERFORM	
Elevate to Figure 66	ELEVATION	75
	TRANSECT	0,20,0
	PERFORM	
	STOP	

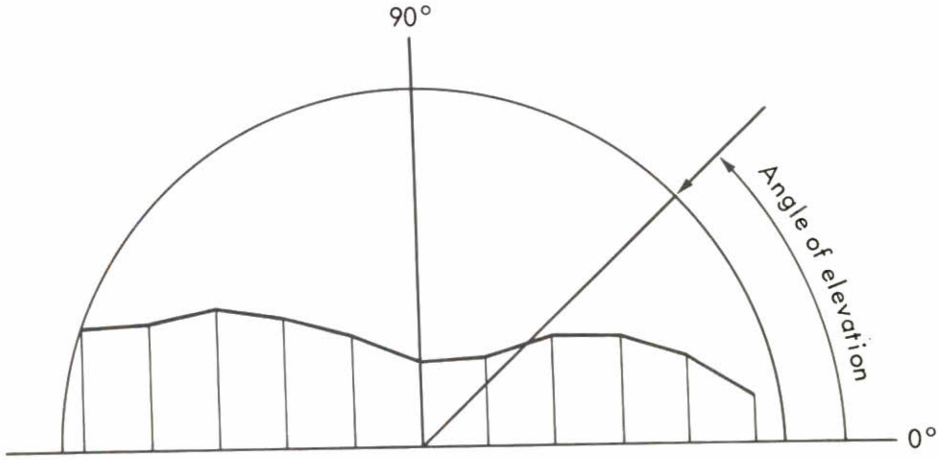


Figure 62.--Angle of elevation of viewpoint is measured in degrees from the horizon, along a vertical plane defined by the viewing angle.

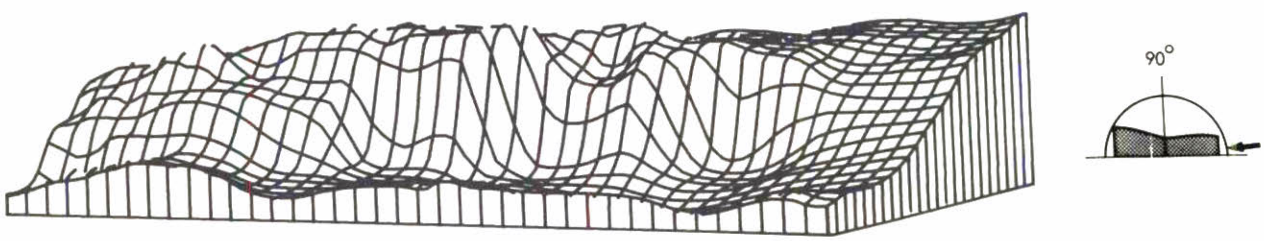


Figure 63.--Perspective block diagram of subsurface geologic structure in part of Graham Co., Kansas. Block viewed from an elevation of 5°.

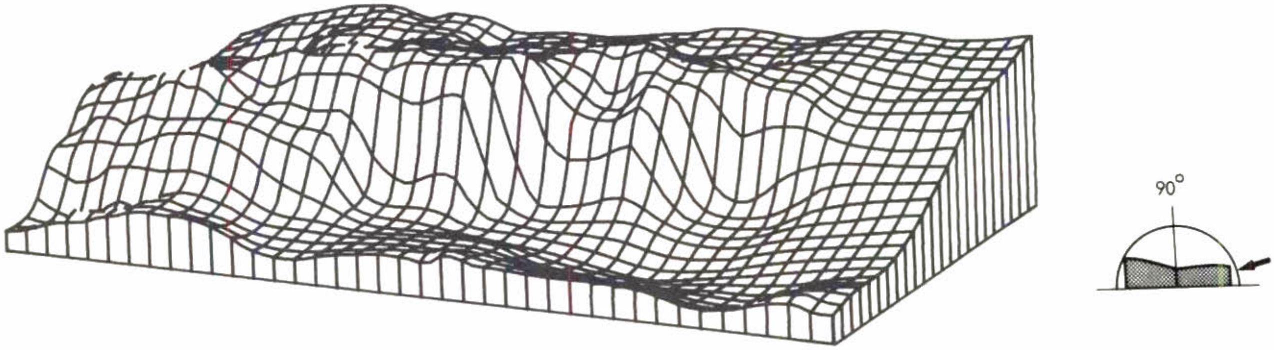


Figure 64.--Block diagram viewed from an elevation of 15°.

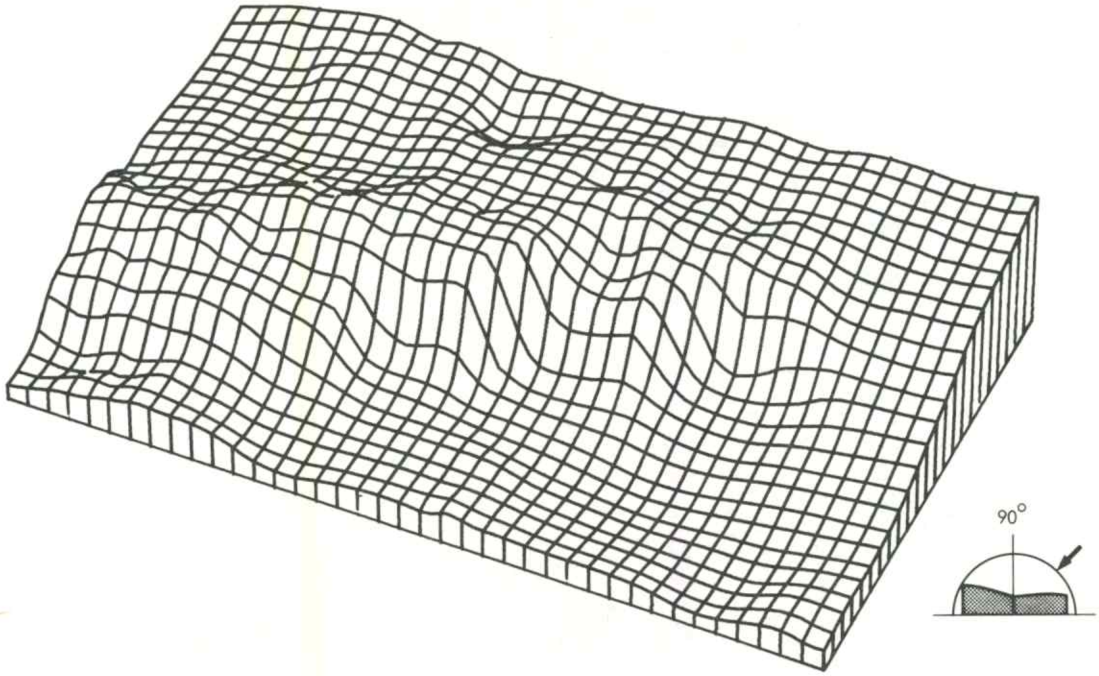


Figure 65.--Block diagram viewed from an elevation of 45°. With this particular surface, the appearance of relief is subdued at this viewing angle.

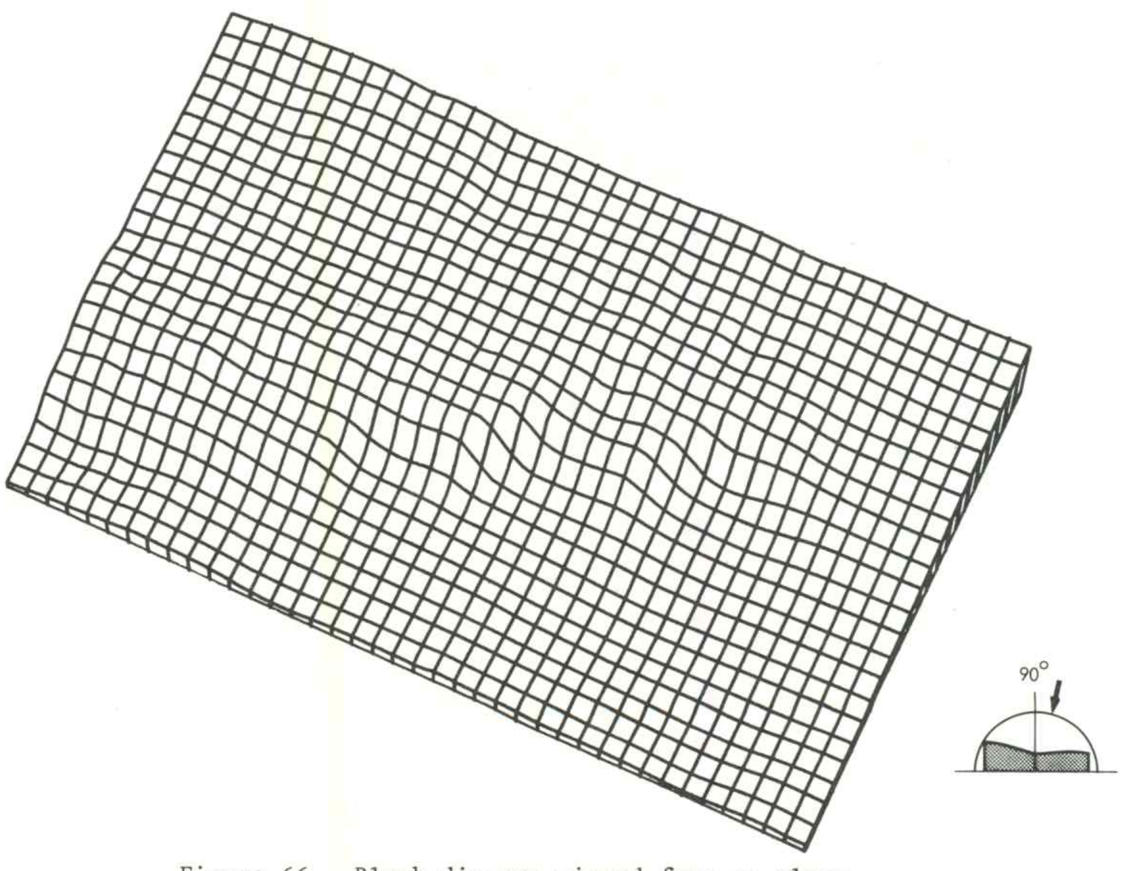


Figure 66.--Block diagram viewed from an elevation of 75°. Because of the extreme angle of elevation, the sense of relief is almost completely lost.

'ERAN'ALYSIS - generates statistics describing the error in a map at the control points.

Field Number	Parameter Description	Assumed Value
1	If 0, error at data points is not printed. If 1, error at data points is printed.	0
2	Class interval for histogram of errors.	Variable[1]

Because the gridding process involves averaging in the estimation of grid nodes, a computed map may fail to exactly honor the original data points. The degree of error may be assessed by back-calculating values at control point locations from the grid matrix, and comparing these values with the original. A variety of statistics are calculated for assessment of these errors, as is a histogram showing the error distribution, and cross-plots of estimated versus original control point values. The back-calculated values at control points are found by double linear interpolation from the grid nodes which enclose the locations being evaluated.

The 'ERAN'ALYSIS command may be used in conjunction with 'GRID' or 'KRIG'E to evaluate the control-point error in a map grid, or to perform an error analysis of an independently generated grid compared to a sequence of X-Y-Z values. By providing an assessment of the error in a gridded surface, the appropriate density of a grid matrix may be determined in a series of runs. Also, the relative performance of various gridding algorithms may be objectively compared.

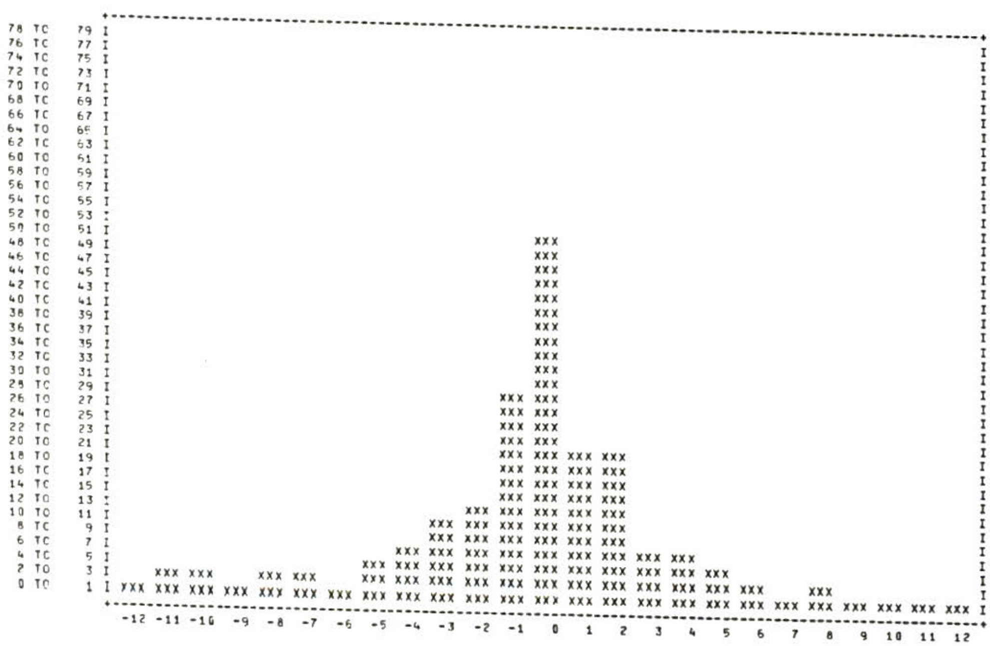


Figure 67.--Histogram of errors at control points.

[1]The range of errors is divided into 25 categories whose boundaries are adjusted to rational limits.

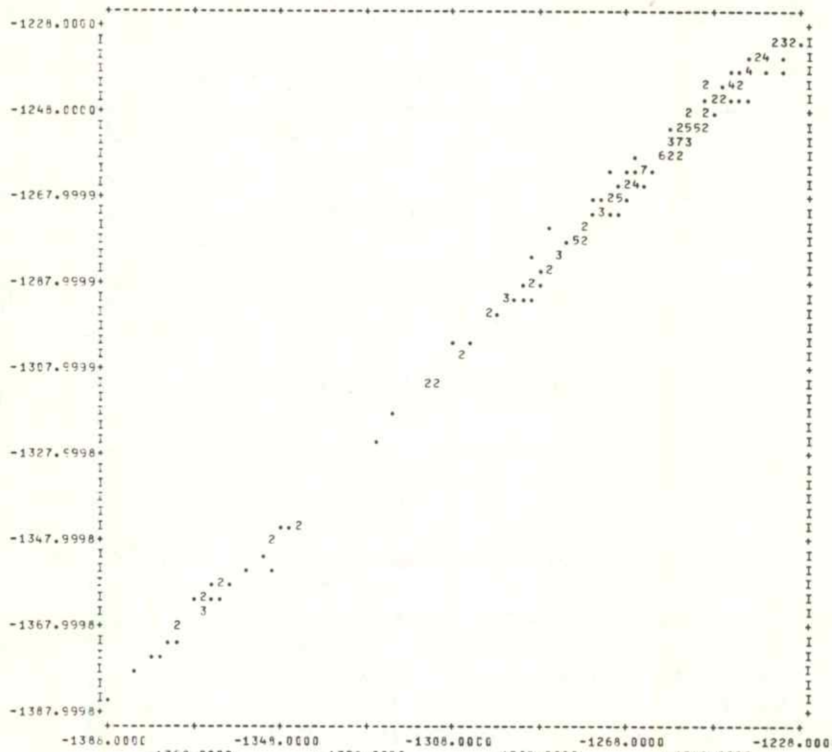


Figure 68.--Scatter diagram of original Z data values (horizontal axis) versus estimated Ż values (vertical axis).

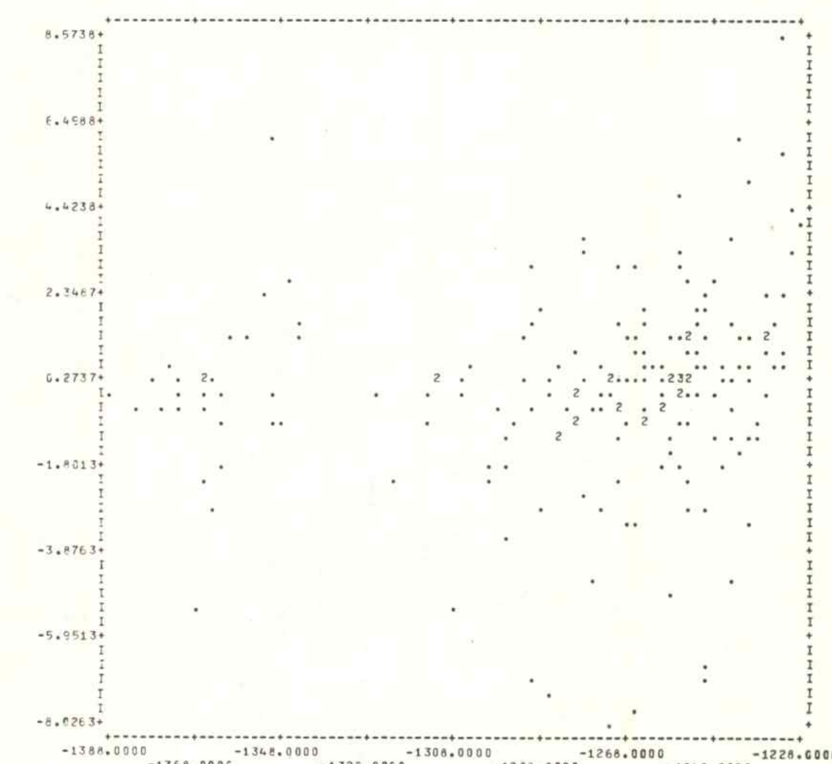


Figure 69.--Scatter diagram of original Z data values (horizontal axis) versus difference between original and estimated Ż values (vertical axis).

'EXTR'EMES - defines the X and Y limits of a grid matrix, or the boundaries of a posting.

Field Number	Parameter Description	Assumed Value
1	X-coordinate of the first column in a grid matrix, or the left edge of a posting.	Varies; see text
2	X-coordinate of the last column in a grid matrix, or the right edge of a posting.	Varies; see text
3	Y-coordinate of the first row in a grid matrix, or the bottom edge of a posting.	Varies; see text
4	Y-coordinate of the last row in a grid matrix, or the top edge of a posting.	Varies; see text

The 'EXTR'EMES command defines the coordinate system in which the sample data points are located. The X and Y limits established by this command are used as the boundaries for any grid matrices subsequently generated by SURFACE II during a run.

'EXTR'EMES specifies the geographic limits of a grid matrix. The assumed values of this command are a function of the location of the most distant points, but 'EXTR'EMES can be used to define a grid matrix which is either larger or smaller than the geographic range of the data. However, if a grid matrix much larger than the minimum area that contains the sample points is specified, $\dot{Z}$ values calculated near the edge of the grid matrix may be inaccurate.

IMPORTANT NOTE: The ranges of X and Y established in a grid matrix by 'EXTR'EMES cannot be changed by a second 'EXTR'EMES command. If the previously defined parameters of 'EXTR'EMES are not appropriate for a subsequent map, the grid matrix must be recreated using the appropriate sequence of commands.

Assumed values of the 'EXTR'EMES parameters

1. For the following commands and conditions:

'DMAP'
'GRID'
'KRIG'E
'TREN'D
'MATR'IX, with sample data points in memory
'REST'ORE, using Option 0

assumed parameters are

parameter one: minimum X-coordinate of sample data minus 1% of range of X.

parameter two: maximum X-coordinate of sample data plus 1% of range of X.

parameter three: minimum Y-coordinate of sample data minus 1% of range of Y.

parameter four: maximum Y-coordinate of sample data plus 1% of range of Y.

Expanding the map by 1% beyond the limits of the data points insures that posted points will fall within the map rather than on the boundary line.

2. For the following commands and conditions:

'MATR'IX, with no sample data present
'REST'ORE, with no sample data present and Option 0

assumed parameters are

parameter one: 1.

parameter two: number of columns in matrix.

parameter three: 1.

parameter four: number of rows in matrix.

3. For the following command and condition:

'REST'ORE, with Option 1

assumed parameters are

parameter one: minimum X-coordinate value saved with the grid matrix.

parameter two: maximum X-coordinate value saved with the grid matrix.

parameter three: minimum Y-coordinate value saved with the grid matrix.

parameter four: maximum Y-coordinate value saved with the grid matrix.

Figures 70 through 73 show the effect on the finished plot of different parameters in the 'EXTR'EMES command. These were generated by the following sequence of SURFACE II commands.

Read in data and post Figure 70 using assumed 'EXTR'EMES parameters	TITLE	EXTREMES TEST FOR SURFACE MANUAL
	DEVICE	1,'DAVIS'
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	POST	2,0,0,0.1
	SIZCONTOUR	0,1.667
	BOX	1,2,1,2,0,-2,-2,1,0.1
	PERFORM	
Post Figure 71	POST	2,0,0,0.1
	EXTREMES	0,10,0,6
	PERFORM	
Post Figure 72	POST	2,0,0,0.1
	EXTREMES	2,8,2,4
	PERFORM	
Post Figure 73	POST	2,0,0,0.1
	EXTREMES	-2,12,-2,8
	PERFORM	
	STOP	

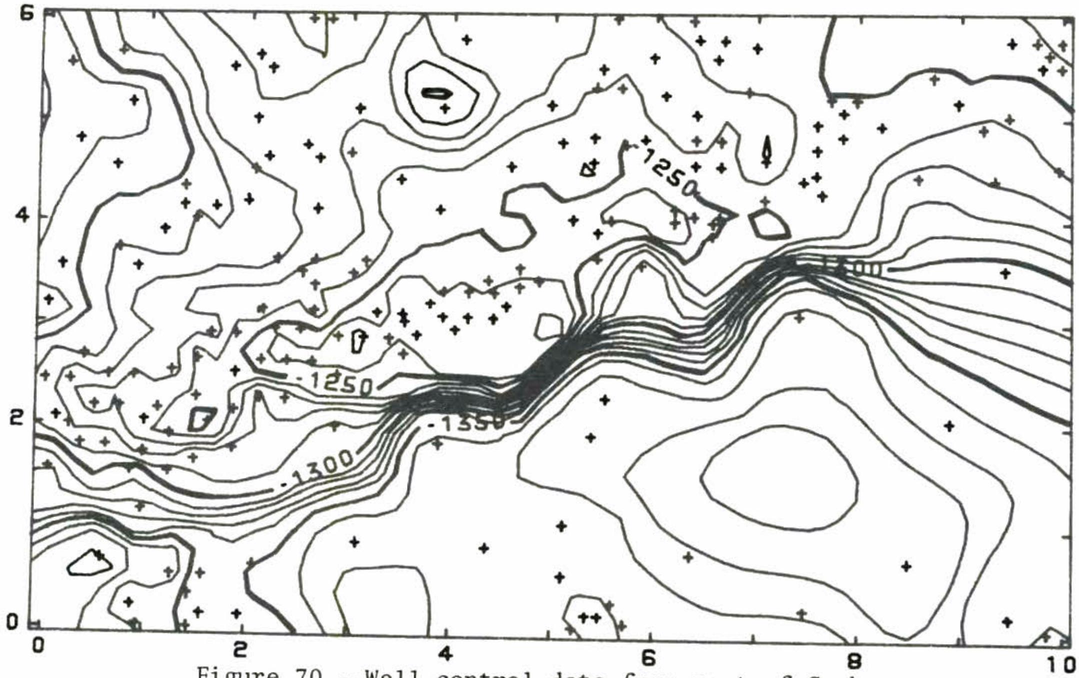


Figure 70.--Well control data from part of Graham Co., Kansas, posted using assumed values of the 'EXTR'EMES command.

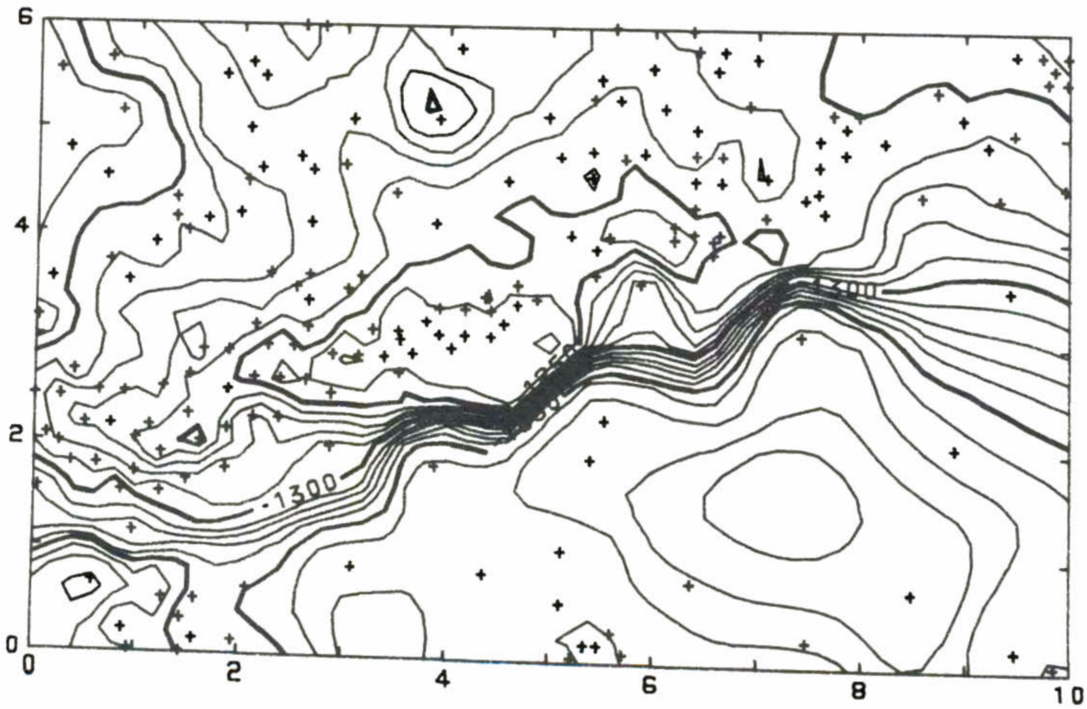


Figure 71.--Same data as in Figure 70, but posted using an 'EXTR'EMES command that specified limits of 0 to 10 in the X-direction, and 0 to 6 in the Y-direction. These are the parameters used to produce most illustrations with this data set in this manual.

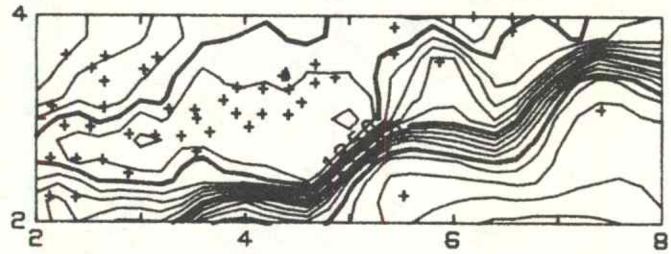


Figure 72.--Same data as in Figure 70, but posted using an 'EXTR'EMES command with limits of 2 to 8 in the X-direction and 2 to 4 in the Y-direction.

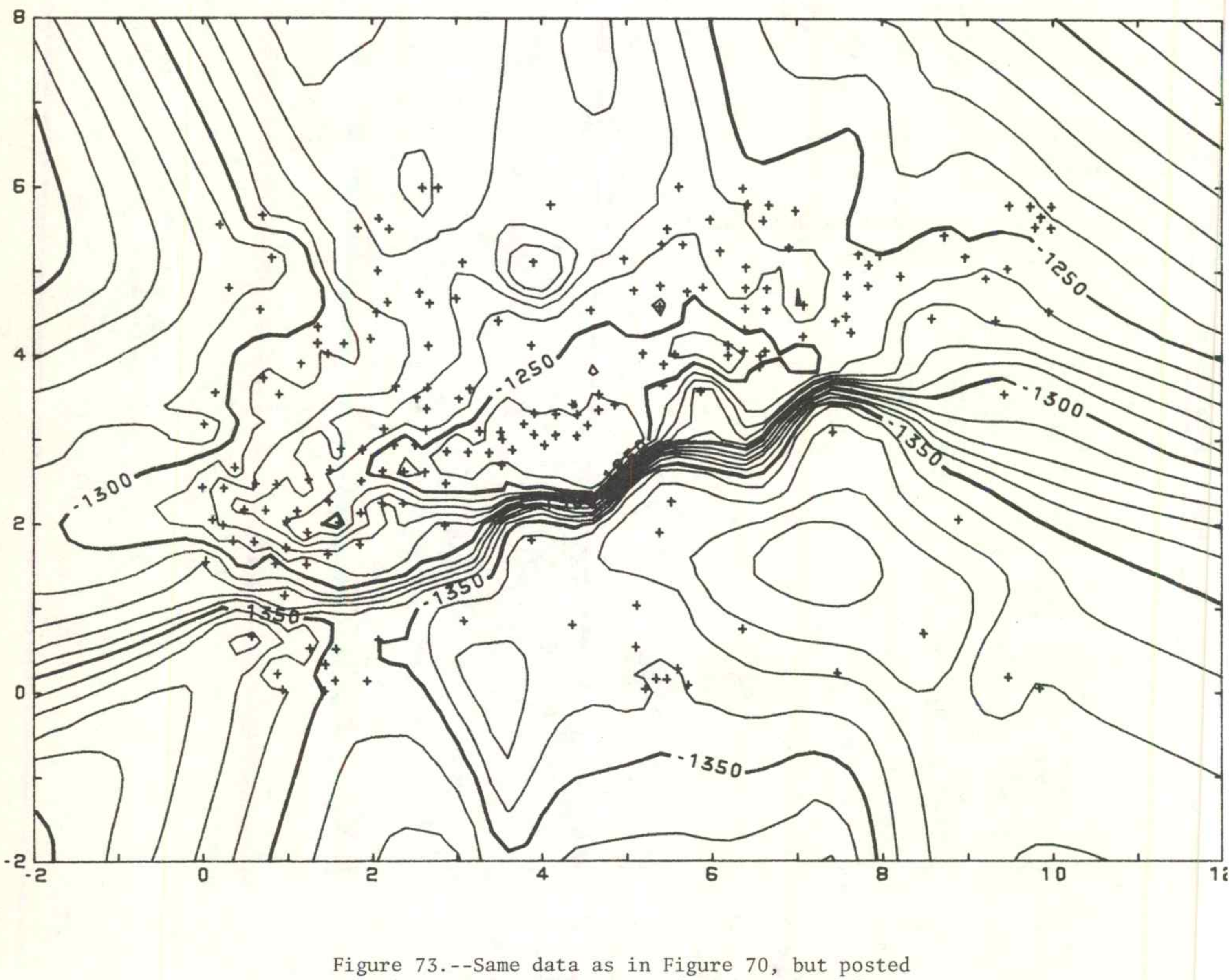


Figure 73.--Same data as in Figure 70, but posted using an 'EXTR'EMES command with limits of -2 to 12 in the X-direction and -2 to 8 in the Y-direction.

'FILT'ER - filters a grid matrix by a weighted two-dimensional moving average.

Field Number	Parameter Description	Assumed Value
1	If 0, blank out rows and columns along the margin of the grid matrix which cannot be filtered. If 1, delete rows and columns along the margin of the grid matrix which cannot be filtered.	0

A filter is a small matrix containing an odd number of rows and columns, and whose elements are weights that sum to zero or one. It is moved to successive positions on the grid matrix, and element-by-element multiplication of the two matrices performed. The products are summed and become the new value of the grid element that corresponds to the center element in the filter. The filter is then offset one grid element and the operation repeated. By moving the filter back and forth across the entire grid matrix, the grid is replaced by a weighted moving average of its original values. The weights assigned to elements in the filter determine its effect; it can be used to emphasize features in the original surface that are characterized by specific spatial frequencies, while subduing other features. Design of two-dimensional filters is discussed by Robinson and Ellis (1971).

The margins of a grid matrix cannot be filtered because the filter matrix would lap over the edge of the grid. If a filter matrix contains r rows and c columns, (r-1)/2 rows will be lost off the top and bottom edges of the filtered grid, and (c-1)/2 columns will be lost off the right and left margins. Under control of parameter one, these unfiltered marginal rows and columns may either be blanked out or deleted from the grid.

If all elements in the filter matrix are identical (0.04 in a 5 x 5 filter) the filter acts as a simple moving average. By making some of the elements larger and others smaller or negative, the filter will selectively enhance features whose form and size correspond with the area of the larger elements. For example,

-0.001	-0.001	-0.010	-0.026	-0.034	-0.035	-0.034	-0.026	-0.010	-0.001	-0.001
-0.001	-0.016	-0.034	-0.040	-0.038	-0.035	-0.038	-0.040	-0.034	-0.016	-0.001
-0.010	-0.034	-0.039	-0.028	-0.009	-0.001	-0.009	-0.028	-0.039	-0.034	-0.010
-0.026	-0.040	-0.028	0.011	0.058	0.082	0.058	0.011	-0.028	-0.040	-0.026
-0.034	-0.038	-0.009	0.058	0.140	0.167	0.140	0.058	-0.009	-0.038	-0.034
-0.035	-0.035	-0.001	0.082	0.167	0.204	0.167	0.082	-0.001	-0.035	-0.035
-0.034	-0.038	-0.009	0.058	0.140	0.167	0.140	0.058	-0.009	-0.038	-0.034
-0.026	-0.040	-0.028	0.011	0.058	0.082	0.058	0.011	-0.028	-0.040	-0.026
-0.010	-0.034	-0.039	-0.028	-0.009	-0.001	-0.009	-0.028	-0.039	-0.034	-0.010
-0.001	-0.016	-0.034	-0.040	-0.038	-0.035	-0.038	-0.040	-0.034	-0.016	-0.001
-0.001	-0.001	-0.010	-0.026	-0.034	-0.035	-0.034	-0.026	-0.010	-0.001	-0.001

is a filter designed to emphasize features whose average width is six grid units. It will pass features as small as three grid units; anything smaller will be suppressed.

Figure 74 is an original contour map of subsurface structure in part of Graham County, Kansas. Figure 75 is the same map filtered by the filter matrix given above. Because of the size of the grid spacing, the filter emphasizes features whose average size is approximately three miles.

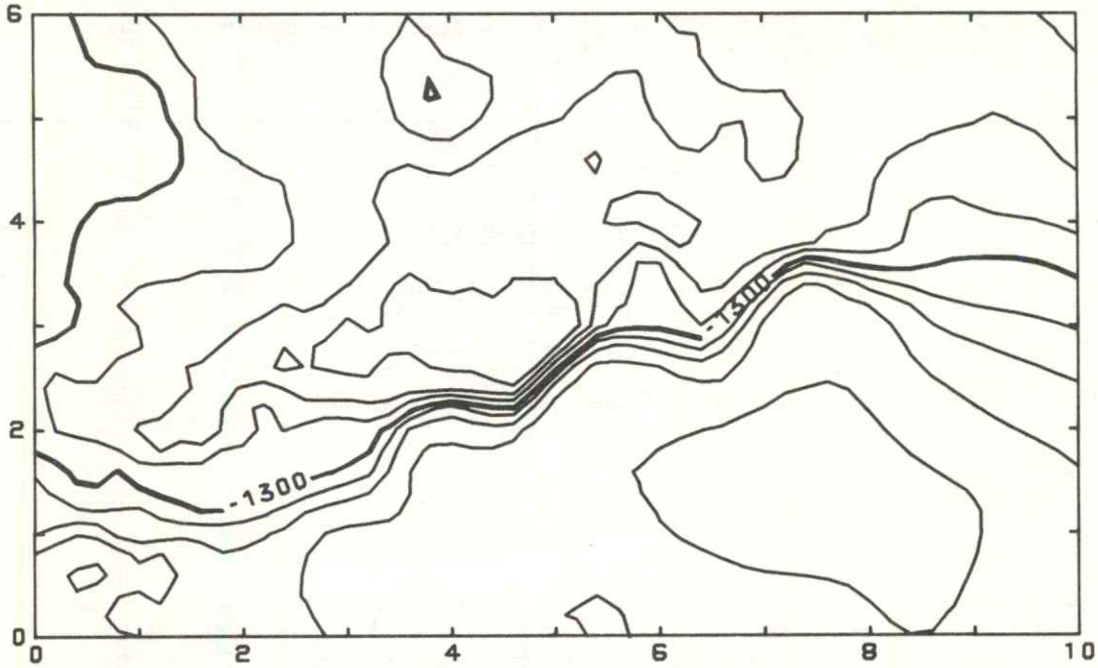


Figure 74.--Subsurface structural contour map of the top of the Lansing Group (Pennsylvanian) in part of Graham Co., Kansas. Elevations are in feet below sea level. Grid spacing is one-half mile.

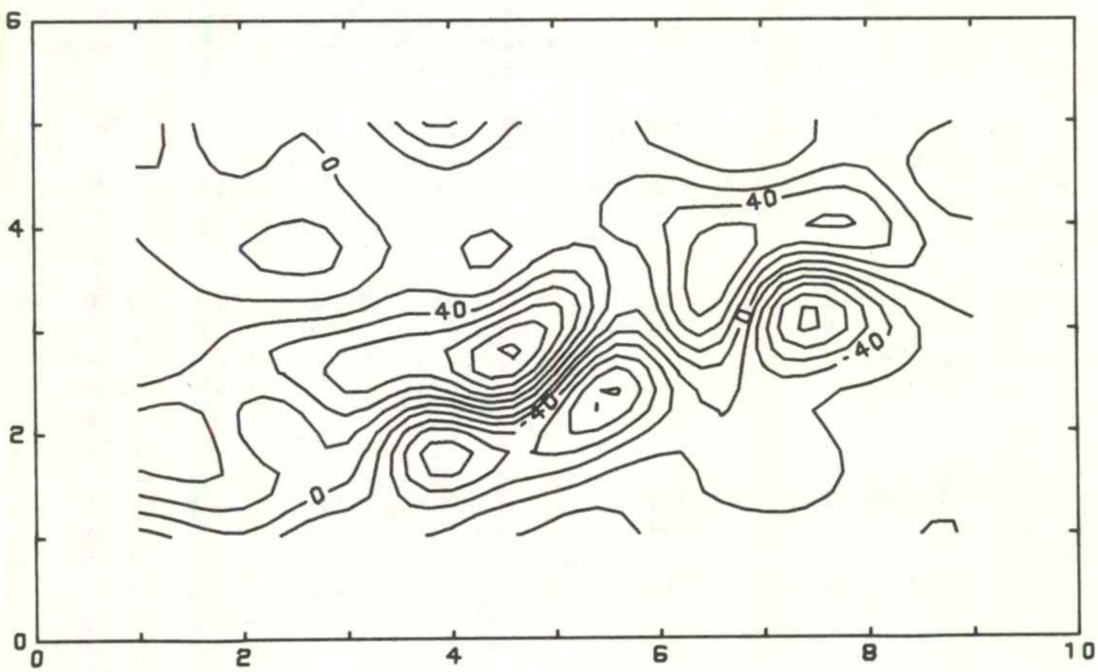


Figure 75.--Map shown in Figure 74 filtered using filter matrix listed in text. The filter emphasizes features having a spatial wavelength of six grid units, or three miles. Unfiltered marginal rows and columns have been blanked.

'FINI'SH - stops all plotting activity of the plotting device previously activated by the 'DEVI'CE command.

NO PARAMETERS

This command may be used to terminate plotting on a particular device. It causes the appropriate wrap-up routines to be called so the plot instruction file is properly closed. If used, this command must appear before 'STOP', but is not necessarily the next-to-last SURFACE II command.

'FINI'SH releases tape drives back to the operating system but does not terminate a SURFACE II job as does the command 'STOP'.

'GRID' - generates a grid matrix of estimated $\dot{Z}$ values from irregularly spaced X, Y, Z sample data points.

Field Number	Parameter Description	Assumed Value
1	Method of determining grid size. If 0, the number of columns and rows in the grid matrix will be specified. If 1, the number of columns and rows in the grid matrix will be calculated. The desired distance between columns and rows must be given.	0
2	Either the number of columns in the grid matrix, or the distance between columns; the interpretation depends on parameter one.	25/1
3	Either the number of rows in the grid matrix, or the distance between rows; the interpretation depends on parameter one.	25/1
4	Method of estimating grid elements. If 0, estimate at grid node is a distance-weighted average of nearby sample data points. The first phase of gridding is not performed. If 1, estimate at grid node is a distance-weighted average of projection of dips of the surface at nearby sample data points. Gridding involves a two-phase procedure. If 2, estimates are calculated in the same manner as option 1, and in addition coefficients of the surface dips at sample data points are printed.	0
5	Weighting function to be used in the averaging process. Options are given below.	0
6	Specifies whether or not to release for subsequent use the memory occupied by the array of sample data points. If 0, retain the sample data. If 1, delete the sample data.	0
7	Method of handling duplicate data points (two or more data points having the same X and Y coordinates and possibly different Z values). If 0, compute $\dot{Z}$ = average value of duplicate data points. If 1, delete all duplicate data points. If 2, replace all data points within a grid cell by their X, Y, Z centroid.	0

The user may define the size (i.e., the number of columns and rows) of the matrix in two different ways. By setting parameter one to 0, the number of columns and rows in the matrix may be given explicitly. Then, the distance between columns is

$$\frac{X_{max} - X_{min}}{NC - 1}$$

and the distance between rows is

$$\frac{Y_{max} - Y_{min}}{NR - 1}$$

where X_{min}, X_{max}, Y_{min}, and Y_{max} are determined by 'EXTR'EMES, and NC and NR are given by parameters two and three.

When parameter one is set to 1, the user defines the distance between columns and rows, and NC and NR are calculated by dividing these distances into the ranges of X and Y, as specified by 'EXTR'EMES. If there is any remainder, the ranges of X and Y are expanded so the distances between all rows and columns are uniform. For example, if

$$X_{min} = 1 \quad Y_{min} = 1 \quad \text{parameter two} = 3$$

$$X_{max} = 25 \quad Y_{max} = 20 \quad \text{parameter three} = 3$$

the number of columns in the matrix will be

$$\frac{25 - 1}{3} + 1 = 9$$

and the number of rows in the matrix will be

$$\frac{20 - 1}{3} + 1 = 7\ 1/3 \ .$$

To avoid fractions, the number of rows will be increased to 8, and the value of Y_{max} automatically expanded to 22.

The number of rows and columns in the grid matrix has a direct influence on the finished appearance of a contour map. As the number of rows and columns is increased, the lengths of straight-line segments in the contour lines are reduced and the contours become smoother in appearance. However, estimation of additional grid intersections increases computation time. Figures 76 and 77 show a contour map made with a coarse and a fine grid array.

If option 0 of parameter four is specified, each grid value is estimated by a distance-weighted average of the sample data points found in the specified search around that grid intersection. Because an average cannot lie outside the range of the values from which it was calculated, the sample data points will define the extreme high and low values on the surface, and the interpolated grid nodes will be intermediate in value.

It is possible, under options 1 or 2 of parameter four, to calculate grid values beyond the range of the sample data. At each sample data point, a first-order trend surface is fit to the nearby sample data points found by the specified search routine. The trend surface is constrained so it passes through the control point being evaluated, and so is a least-squares estimate of the dip of the surface at that point. Coefficients of this trend surface are then evaluated for the X, Y location of the grid node being estimated, in effect projecting the dip of the surface from the sample data point to that grid intersection. A distance-weighted average is then made of the projected dips from the sample data points found in the specified search around the grid point (Fig. 78). Option 2 is identical to option 1, except a listing is printed of the coefficients of the local trend surfaces at the sample data points. Note that grid calculation is a two-phase procedure under options 1 and 2 of parameter four, as separate searches must be made for points from which to calculate dips at the data points, and then again for points to calculate the surface values at grid intersections. If option 0 of parameter four is selected, only the second search is performed because dips are not calculated.

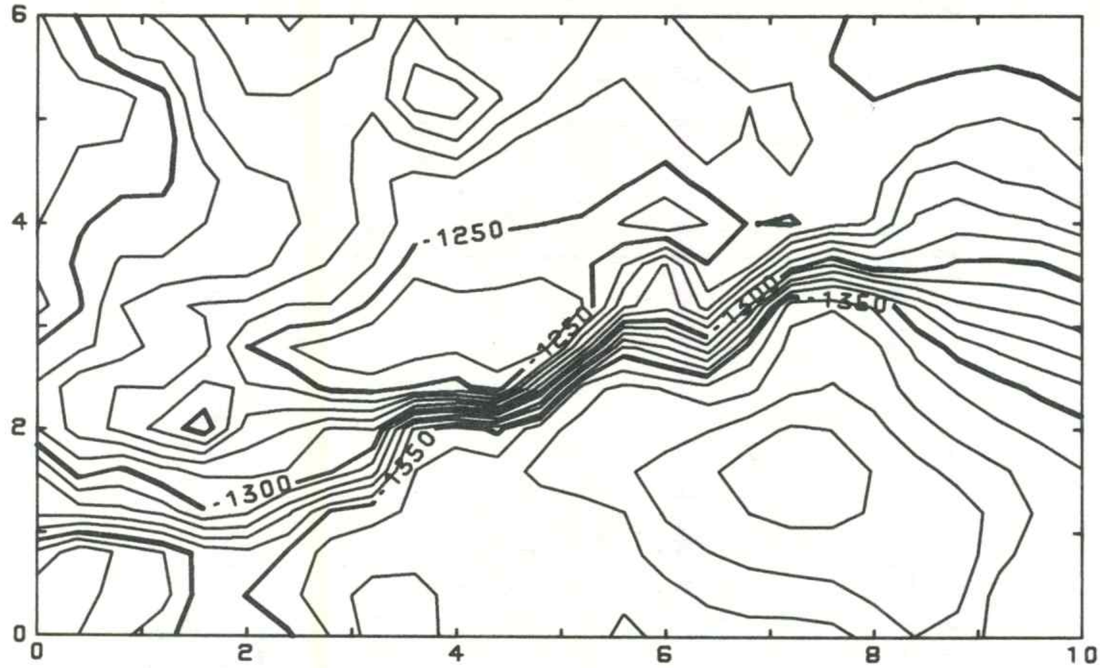


Figure 76.--Contour map showing subsurface structural elevation of the top of the Lansing Group in part of Graham Co., Kansas. Grid matrix contains 16 rows and 26 columns.

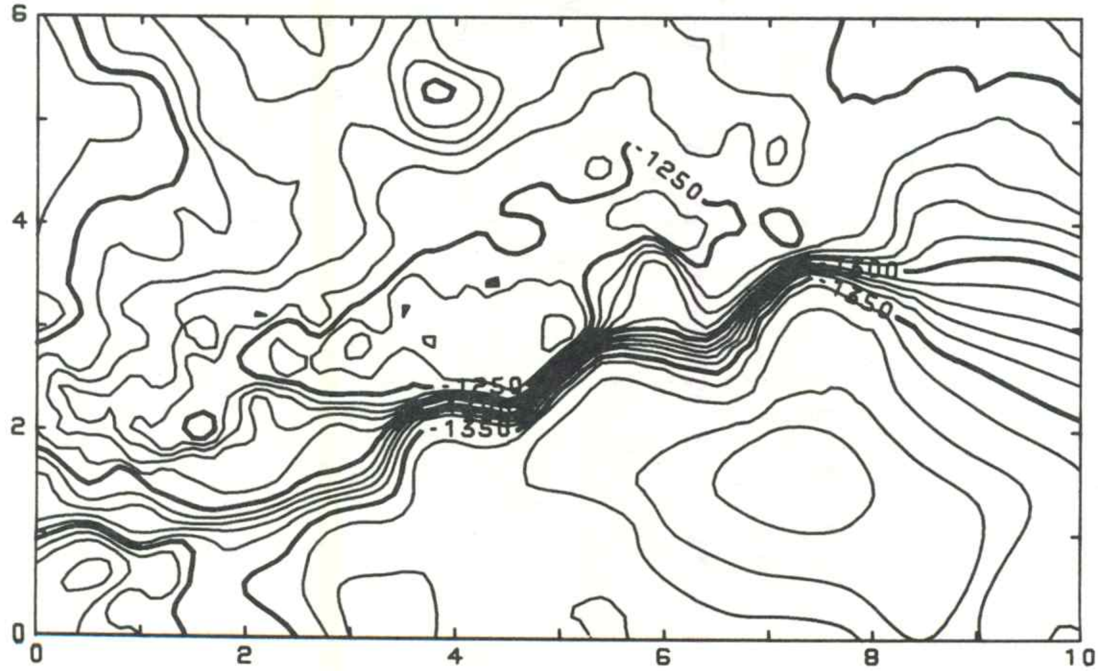


Figure 77.--Contour map of data from Figure 76, gridded with 61 rows and 101 columns.

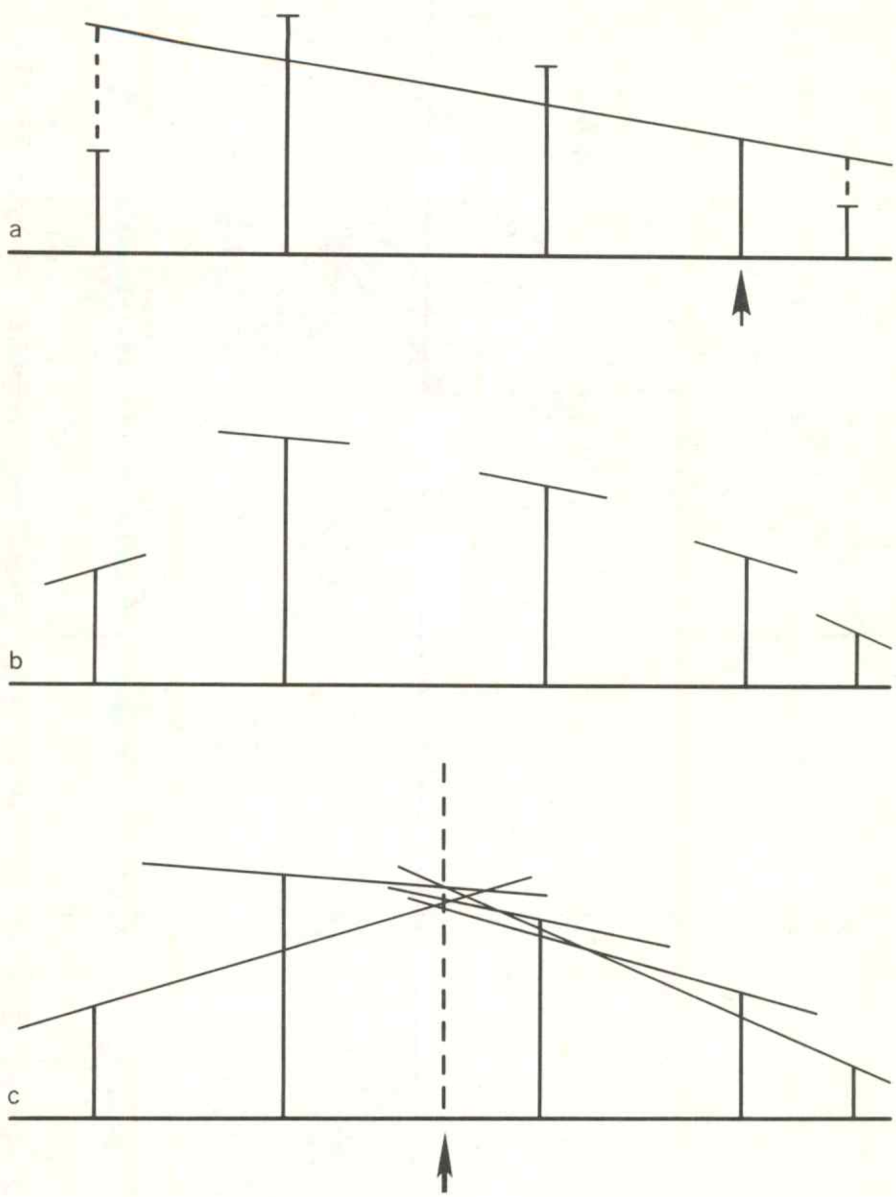


Figure 78.--Projection of surface dips to point being estimated. (a) Dip of surface at control point (arrow) is found by least-squares fit of plane to surrounding control points. (b) Dips are found for all control points in map area. (c) Dips are projected from control points to grid node (arrow) and their average calculated.

Sample data points used in the estimation procedure are weighted so their influence declines with distance from the point being estimated. A weighting function which declines slowly with distance will produce heavily averaged estimates, resulting in a surface with slowly changing gradients. A rapidly declining weighting function places great emphasis on the values of nearest points in the estimation procedure, and may yield a rapidly changing surface. Available weighting options of parameter five are listed below and shown in Figure 79. A contour map prepared using a weighting function of $1/D^6$ is shown in Figure 80. A map of the same data set, using 1/D weighting, is shown in Figure 81. Figure 82 is a map made using the assumed weighting function which is scaled $1/D^2$; Figure 83 is made using $1/D^2$ weighting without scaling (option 2).

Distance weighting functions available under parameter five

option	function
0	$\omega = (1 - \frac{D}{1.1 \times D_{max}})^2 / (\frac{D}{1.1 \times D_{max}})^2$
1	$\omega = 1/D$
2	$\omega = 1/D^2$
3	$\omega = 1/D^4$
4	$\omega = 1/D^6$

ω is the weight attached to a sample data point a distance D from the grid intersection being estimated. D_{max} is the distance from the grid intersection to the most distant sample point in the set being used in the estimation.

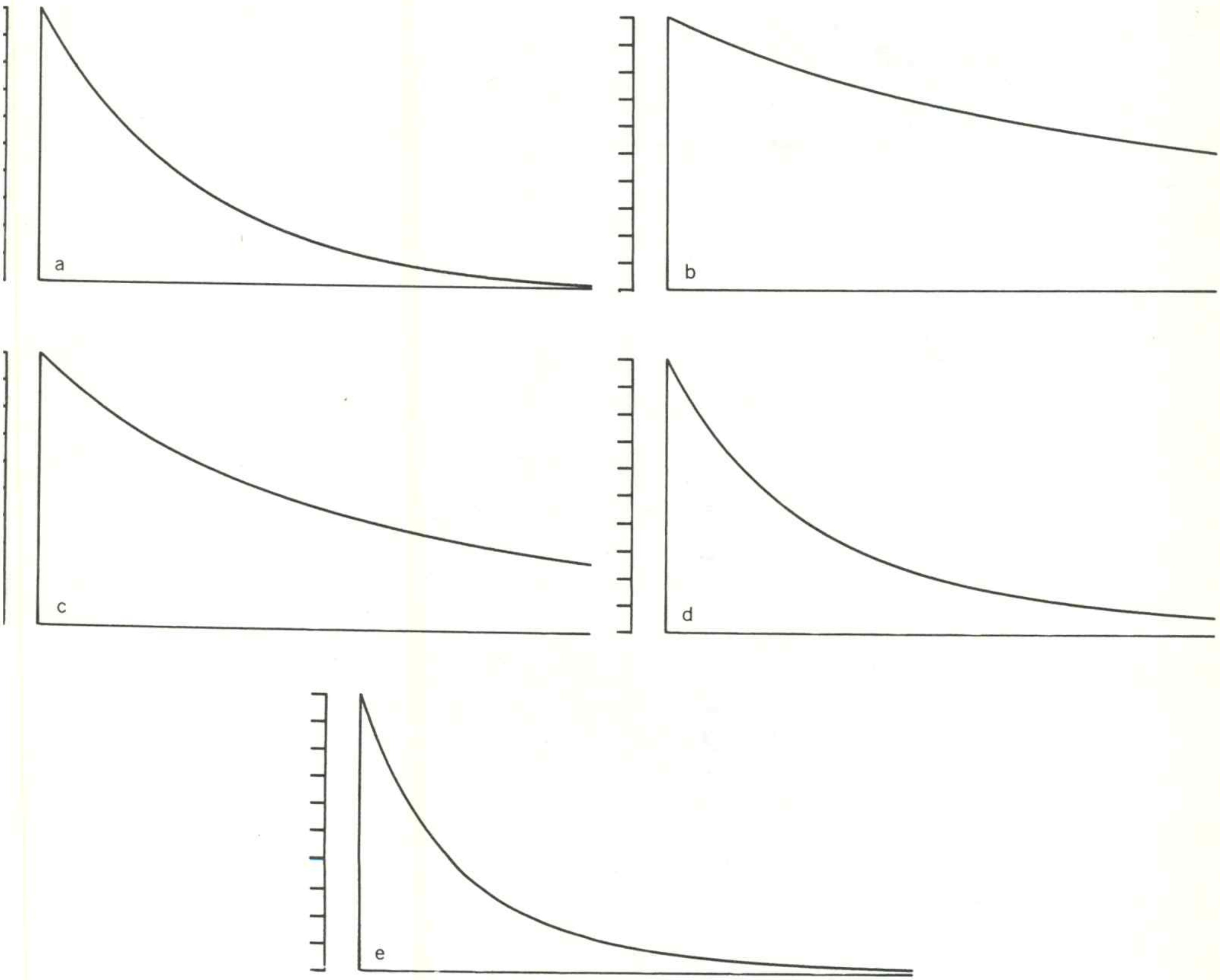


Figure 79.--Generalized plot of weighting functions used in averaging. (a) Constrained distance-squared weighting function. (b) 1/D weighting function. (c) $1/D^2$ weighting function. (d) $1/D^4$ weighting function. (e) $1/D^6$ weighting function.

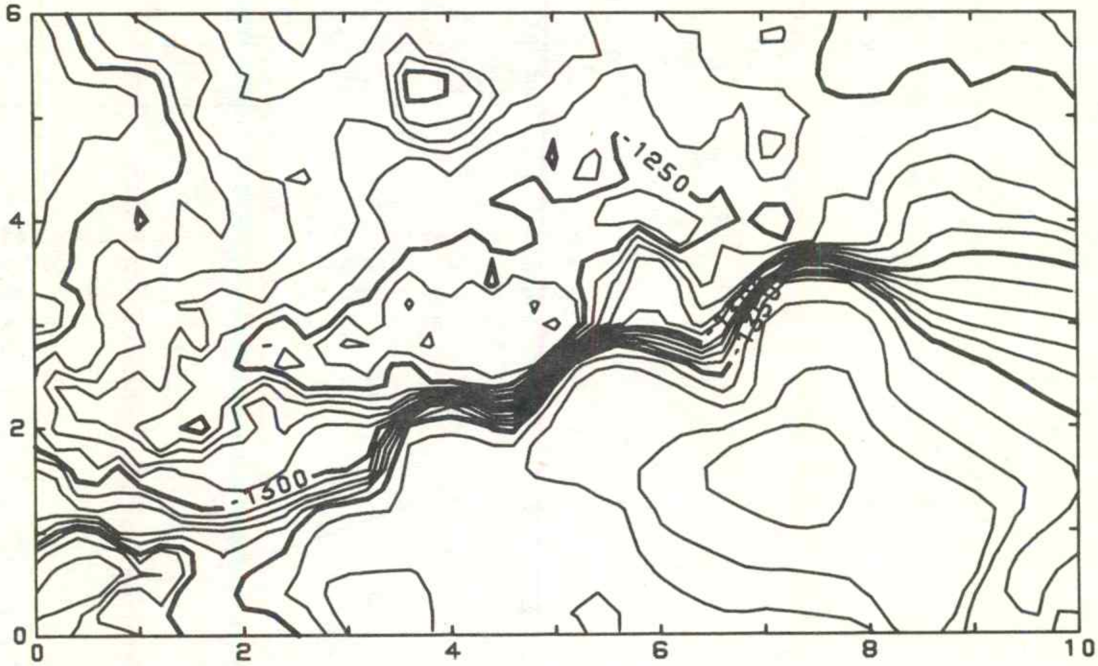


Figure 80.--Contour map of subsurface structure in Graham Co., Kansas, made using $1/D^6$ weighting function and dip projection.

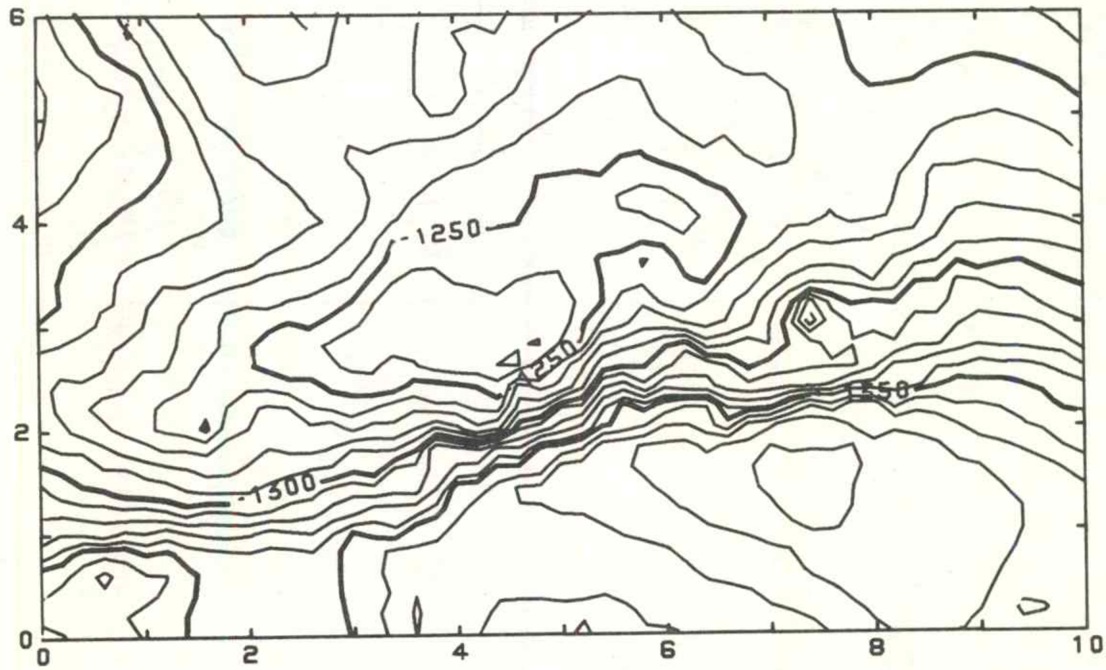


Figure 81.--Contour map of subsurface structure in Graham Co., Kansas, made using 1/D weighting function and dip projection.

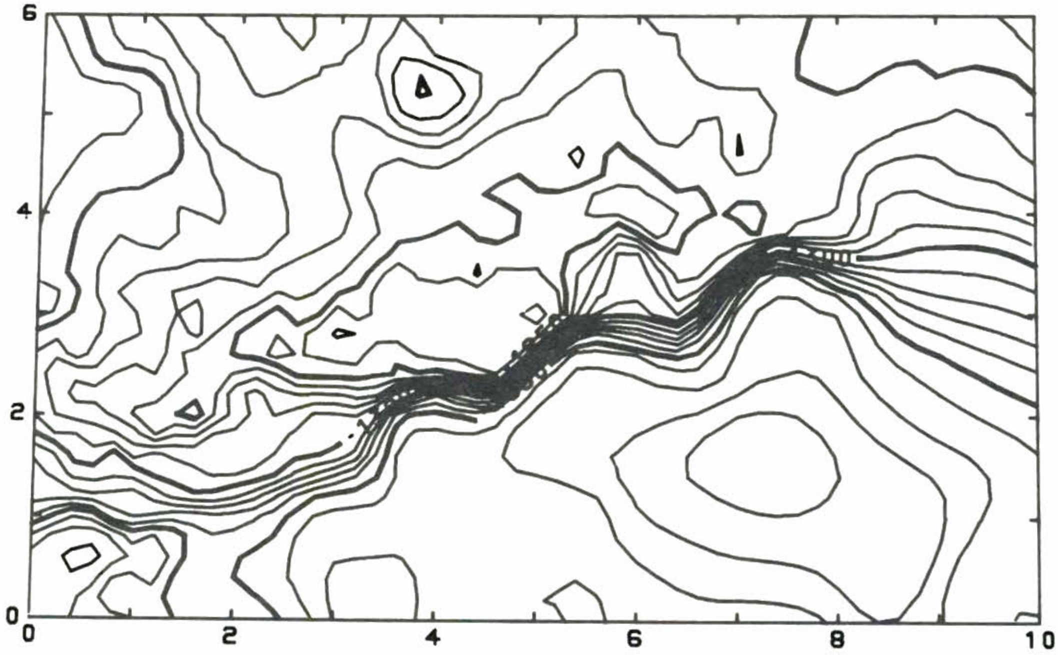


Figure 82.--Contour map of subsurface structure in Graham Co., Kansas, made using scaled $1/D^2$ weighting function and dip projection. This is the assumed option of parameter five.

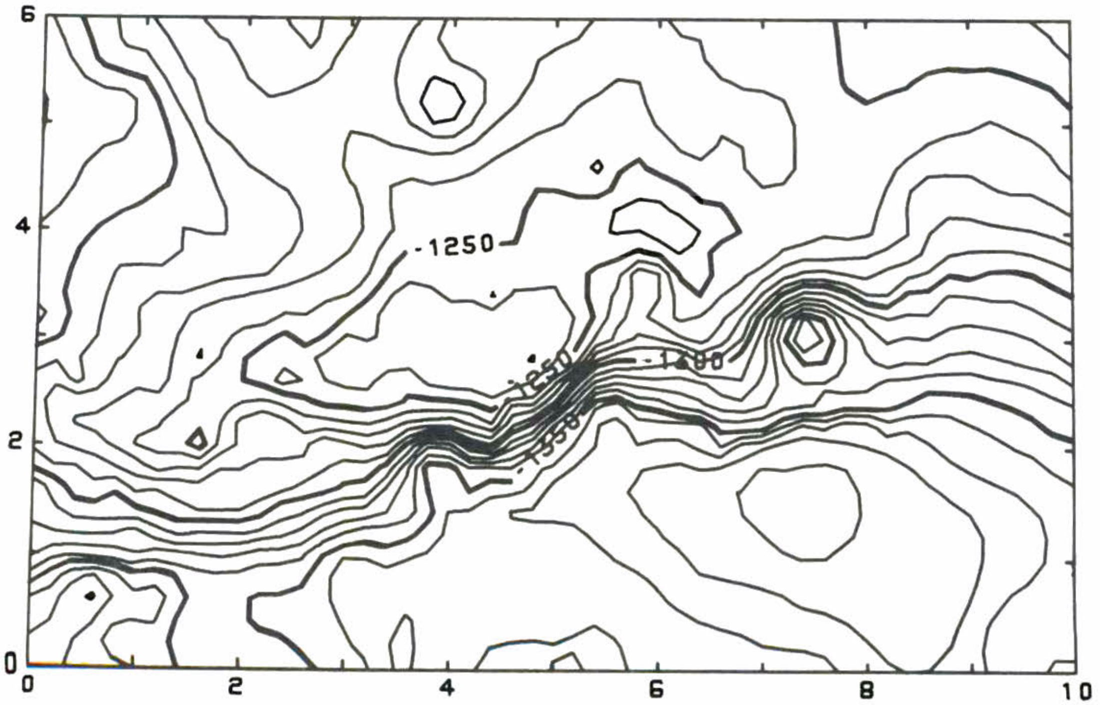


Figure 83.--Contour map of subsurface structure in Graham Co., Kansas, made using $1/D^2$ weighting function and dip projection.

AUXILIARY COMMANDS used with 'GRID':

'EXTR'EMES
'NEAR'
'OCTA'NT
'QUAD'RANT
'VRAD'IUS

'EXTR'EMES defines the X, Y limits of the map. The next four commands allow the user to specify the search procedure which finds the nearest data points which will be used in the estimation procedure. The search is conducted around each grid node to be estimated. If dips are to be calculated and projected, a search is also conducted around each sample data point.

If the search around one grid node does not find an acceptable number of sample data points for estimation purposes, the grid intersection is assigned a code value for missing data. Contour lines will be omitted in grid cells containing a node that has been assigned this code value.

A search procedure should be specified for each of the two phases involved in the gridding procedure, if dip projection is to be used. It is possible to use a different search method for each of the two phases. An example would be to use an octant search ('OCTA'NT) for calculation of the dips at the control points and a radius search ('VRAD'IUS) for estimation of the grid nodes. If no search method is specified, a nearest neighbor search ('NEAR') is used with the assumed values for the command controlling the number of nearest neighbors, the maximum allowable distance to nearest data point, and the maximum search radius.

There is a certain compromise involved in selecting the search radius and the number of points to be sought. If these values are selected so a large number of search failures occur, the map will contain numerous incomplete contour lines. On the other hand, specification of a large search radius or a large number of data points to be included in each search may introduce excessive averaging and loss of detail in the grid matrix.

'HIST'OGRAM - plots histograms of the distributions of X, Y, and Z control values or of the Ż values in the grid matrix.

Field Number	Parameter Description	Assumed Value
1	Specifies variable to be plotted as histogram. If 0, histogram is made of Ż values in grid matrix. If 1, histogram is made of X-variable of X-Y-Z control points. If 2, histogram is made of Y-variable of X-Y-Z control points. If 3, histogram is made of Z-variable of X-Y-Z control points.	0
2	Middle value of central class on histogram.	Variable[1]
3	Class interval width.	Variable[2]

'HIST'OGRAM produces a frequency distribution of the specified variable, and calculates the first four moments of the distribution. These statistics and plots are useful for analysis of the uniformity and nature of the spatial arrangement of control points, the distribution of the mapped variable, or the distribution of estimated values calculated by the gridding operation. Figure 84 shows the table of statistics printed by 'HIST'OGRAM under option three of parameter one. The accompanying histogram of Z values is shown in Figure 85.

---

[1] Set to approximate mean of distribution, adjusted to rational value.

[2] The range of values is divided into 25 categories whose boundaries are adjusted to rational limits

TEST OF HISTOGRAM

STATISTICS OF HISTOGRAM

NUMBER OF SAMPLES ****	190
MINIMUM VALUE ********	-1388.00000000
MAXIMUM VALUE ********	-1228.00000000
MEAN OF SAMPLES ******	-1278.63157654
STANDARD DEVIATION ***	40.93860721
VARIANCE *************	1675.96955872
SKEWNESS *************	-1.17781314
KURTOSIS *************	3.29627880

****

***** HISTOGRAM FREQUENCY TABLE *****

CLASS	CLASS LIMITS	STD. CLASS LIMITS	COUNT	PERCENT
-12	-1386.0000 TO -1377.0000	-2.7480 TO -2.5282	2	1
-11	-1377.0000 TO -1368.0000	-2.5282 TO -2.3083	5	2
-10	-1368.0000 TO -1359.0000	-2.3083 TO -2.0885	12	6
-9	-1359.0000 TO -1350.0000	-2.0885 TO -1.8687	2	1
-8	-1350.0000 TO -1341.0000	-1.8687 TO -1.6488	7	3
-7	-1341.0000 TO -1332.0000	-1.6488 TO -1.4290	0	0
-6	-1332.0000 TO -1323.0000	-1.4290 TO -1.2091	1	0
-5	-1323.0000 TO -1314.0000	-1.2091 TO -0.9893	1	0
-4	-1314.0000 TO -1305.0000	-0.9893 TO -0.7694	5	2
-3	-1305.0000 TO -1296.0000	-0.7694 TO -0.5496	6	3
-2	-1296.0000 TO -1287.0000	-0.5496 TO -0.3298	12	6
-1	-1287.0000 TO -1278.0000	-0.3298 TO -0.1099	12	6
0	-1278.0000 TO -1269.0000	-0.1099 TO 0.1099	16	8
1	-1269.0000 TO -1260.0000	0.1099 TO 0.3298	24	12
2	-1260.0000 TO -1251.0000	0.3298 TO 0.5496	37	19
3	-1251.0000 TO -1242.0000	0.5496 TO 0.7694	20	10
4	-1242.0000 TO -1233.0000	0.7694 TO 0.9893	18	9
5	-1233.0000 TO -1224.0000	0.9893 TO 1.2091	9	4
6	-1224.0000 TO -1215.0000	1.2091 TO 1.4290	0	0
7	-1215.0000 TO -1206.0000	1.4290 TO 1.6488	0	0
8	-1206.0000 TO -1197.0000	1.6488 TO 1.8687	0	0
9	-1197.0000 TO -1188.0000	1.8687 TO 2.0885	0	0
10	-1188.0000 TO -1179.0000	2.0885 TO 2.3083	0	0
11	-1179.0000 TO -1170.0000	2.3083 TO 2.5282	0	0
12	-1170.0000 TO -1161.0000	2.5282 TO 2.7480	0	0

Figure 84.--Statistical table of the distribution of Z values of subsurface structural elevations in Graham Co., Kansas.

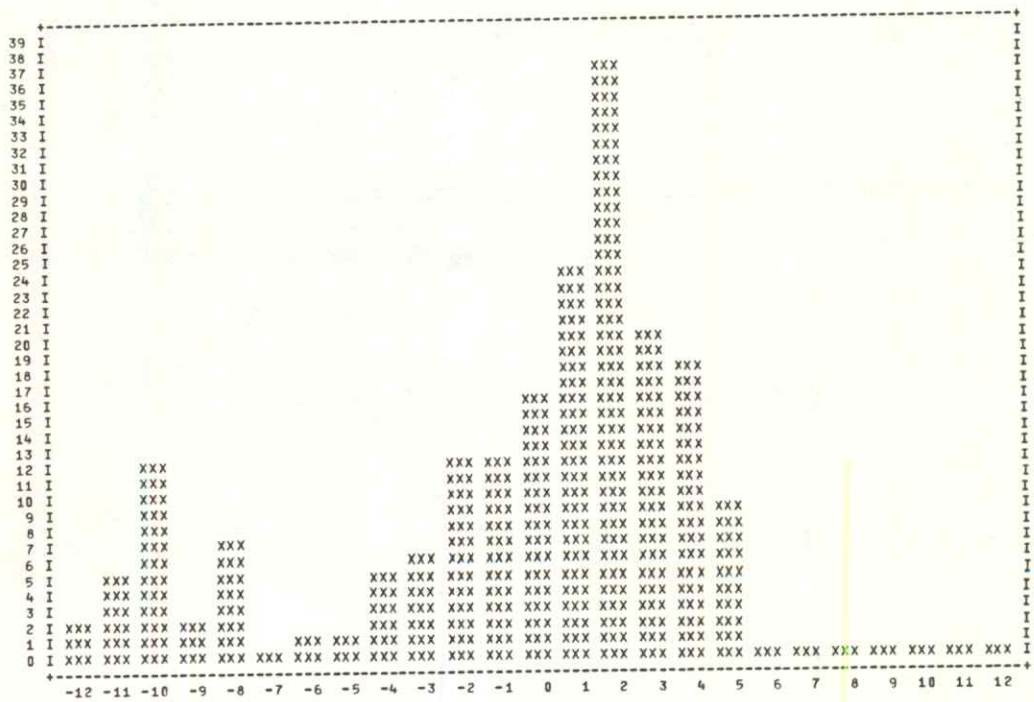


Figure 85.--Histogram of Z values of subsurface structural elevations in Graham Co., Kansas.

'IDXY' - reads sample data points, ID labels, and posting symbols into an array in memory.

Field Number	Parameter Description	Assumed Value
1	Maximum number of data points to be read in. This number can be greater than the number of samples actually on the file. SURFACE II reads in only the number of samples specified by this parameter, even though the file may contain more data points.	Required
2	File code on which the data points are located.[1]	Required
3	Total number of fields in each record of the input file. The minimum number of fields is three. A fourth field may be used for identification purposes. A fifth field, which must be integer, may be used to specify the map symbol to be used to represent the data points in a posting. The symbols available for a posting are listed in the 'POST' command.	Required
4	Identifies which field of the input record contains the X-variable.	1
5	Identifies which field of the input record contains the Y-variable.	2
6	Identifies which field of the input record contains the Z-variable.	3
7	Identifies which field of the input record contains identification numbers. If the parameter is 0, or parameter three is 3, the samples will be sequentially numbered. If the parameter is negative, there is no identifier, so storage requirements will be reduced.	0
8	Identifies which field of the input record contains the data point symbol code.	0
9	If 0, no check is made for missing data. Any positive value will cause SURFACE II to check each Z-observation against the missing value code given as parameter ten.	0
10	Code value for missing data.	Required if field 9 contains a positive number
11	Format of data.[2]	Required

[1] See Appendix C.
[2] See Appendix B.

The 'IDXY' command reads in sample data points from which the grid matrix is to be calculated. The ID-variable allows the user to designate data points by numerical identifiers. If identification numbers are not supplied, each sample may be assigned a sequential identification number by setting parameter seven to 0 and setting parameter three to 3.

Parameter fields four through eight are necessary to distinguish one variable from another. For example, if six variables appear on the input file, it is possible that the third one is the X-value, the second one is Y, and the sixth one is Z. The ID-variable might be the first on the file. Thus, it is necessary to specify which variables on the input file correspond to X, Y, Z, and ID.

On occasion, some of the Z values in the sample data may be missing. Usually missing data are assigned a code number which is unlikely to occur as a real value of Z (such as 9999). SURFACE II will check for missing data if parameter field eight contains a number greater than 0. Any sample point with a Z-value identically equal to the code value specified in field nine is ignored.

AUXILIARY COMMANDS used with 'IDXY':

'ECHO'
'RTXY'
'SUBS'ET

The 'ECHO' command can be used to list X, Y, Z identification numbers, and map symbol codes. A set of data point coordinates read in by 'IDXY' may be rotated, translated, and scaled to some other coordinate configuration using the 'RTXY' command. By the use of 'SUBS'ET, specific data points may be identified and selected out to make separate maps from a single file. An example is distinction between dry and producing wells in a subsurface data file by means of a code number.

IMPORTANT NOTE: In the current version of SURFACE II, it is impossible to read more than one data set from a single file. Successive data sets must be read, using separate 'IDXY' commands, from different files.

'INCR'EMENT - specifies which columns and rows of an externally stored matrix are to be loaded into memory. 'INCR'EMENT may be used when reading in a matrix by the 'MATR'IX or 'REST'ORE commands.

Field Number	Parameter Description	Assumed Value
1	First column to be stored.	1
2	The increment between each column to be stored.	1
3	Last column to be stored.	Number of columns in the input matrix
4	First row to be stored.	1
5	The increment between each row to be stored.	1
6	Last row to be stored.	Number of rows in the input matrix

The assumed values cause the entire matrix on a file to be read. However, if an entire matrix is to be stored, this command is not necessary.

As an example of the use of 'INCR'EMENT, suppose a matrix on an input file is 60 x 60. If values of 20,4,52,10,2,40 are specified in the parameter fields of the 'INCR'EMENT command, the matrix actually stored will have 16 rows and 9 columns. The first row of the stored matrix will contain the elements corresponding to those in $\dot{Z}_{20,10}$, $\dot{Z}_{24,10}$, $\dot{Z}_{28,10}$, ..., $\dot{Z}_{48,10}$, $\dot{Z}_{52,10}$ of the original matrix. The second row will contain elements $\dot{Z}_{20,12}$, $\dot{Z}_{24,12}$, ..., $\dot{Z}_{48,12}$, $\dot{Z}_{52,12}$, and so forth. All rows of the new matrix are determined in this manner. Note that subscripts are used here in a different convention than in matrix algebra. The first subscript indicates the column and the second subscript indicates the row of the matrix in which an element is located. Columns and rows of the matrix are arranged in the same manner as a grid matrix when it is plotted; that is, the first column is the leftmost edge of the map and the first row is the bottom edge.

'ISOP'ACH - calculates the element-by-element difference between a grid matrix and a matrix stored on an external file.

Field Number	Parameter Description	Assumed Value
1	File code on which external matrix is is stored.[1]	Required
2	Defines the subtraction procedure. If 0, the external matrix is subtracted from the grid matrix. If 1, the grid matrix is subtracted from the external matrix.	0

The difference matrix, sometimes referred to as a residual or isopach matrix, replaces the original grid matrix in memory. The external matrix and the grid matrix must have the same number of rows and columns.

The operation of 'ISOP'ACH may be symbolically represented as

$$\begin{bmatrix} a_{12} & a_{22} \\ a_{11} & a_{21} \end{bmatrix} \text{ (ISOP) } \begin{bmatrix} b_{12} & b_{22} \\ b_{11} & b_{21} \end{bmatrix} = \begin{bmatrix} a_{12}-b_{12} & a_{22}-b_{22} \\ a_{11}-b_{11} & a_{21}-b_{21} \end{bmatrix}$$

original grid matrix   second matrix   new grid matrix

If parameter two is 0, the operation is [A] - [B]; if parameter two is 1, the operation is [B] - [A].

The external matrix may be generated by some program other than SURFACE II, but it must be stored in the same format as a file created by the 'SAVE' command. These FORTRAN instructions are included with the description of 'SAVE'. A discussion of the file codes used in parameter one is given in Appendix C.

Figure 86 is a contour map of the subsurface structural configuration of the top of the Permian Stone Corral Formation in Graham County, Kansas. Figure 87 is a subsurface structure map of the top of the Pennsylvanian Lansing Group in the same area. Figure 88 is an isopach or map of the thickness of rock between the two units, obtained by subtracting the grid matrix for Figure 87 from the grid matrix for Figure 86.

The commands used to create Figures 86-88 are given on the following page.

[1] See Appendix C.

```
                    TITLE         ISOPACH TEST FOR SURFACE MANUAL
                    DEVICE        1,'DAVIS'
Read in             IDXY          200,11,5,2,3,4,1,0,1,9999,'(F6.0,2F12.5,2F7.0)'
data and            GRID          1,0.2,0.2
contour             EXTREMES      0,10,0,6
top of              SAVE          12
Lansing             CONTOUR
(Fig. 87)           CINTERVAL     0,0,10,0,5,0.1,0,2,5
                    SIZCONTOUR    1,6,3.6
                    BOX           1,2,1,2,0,0,0,1,0.1
                    PERFORM
Contour top         IDXY          200,11,5,2,3,5,1,0,1,9999,'(F6.0,2F12.5,2F7.0)'
of Stone            GRID          1,0.2,0.2
Corral              CONTOUR
(Fig. 86)           PERFORM
Create isopach      ISOPACH       12,0
(Fig. 88)           CONTOUR
                    PERFORM
                    STOP
```

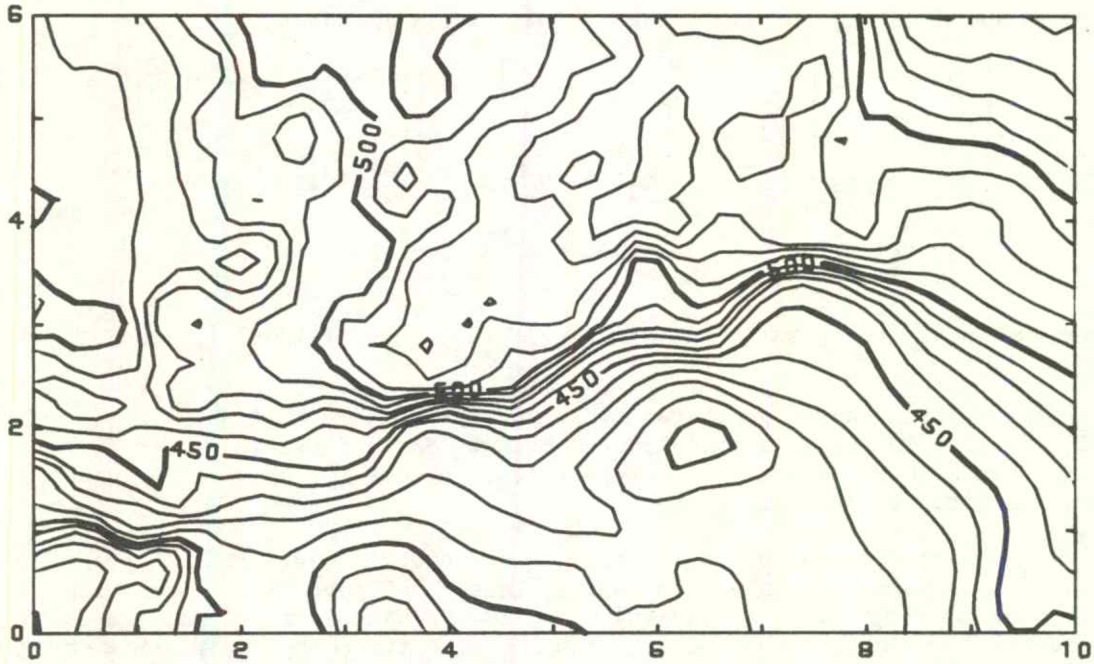


Figure 86.--Subsurface structural configuration of the top of the Permian Stone Corral Formation in part of Graham Co., Kansas. Elevations are in feet above sea level.

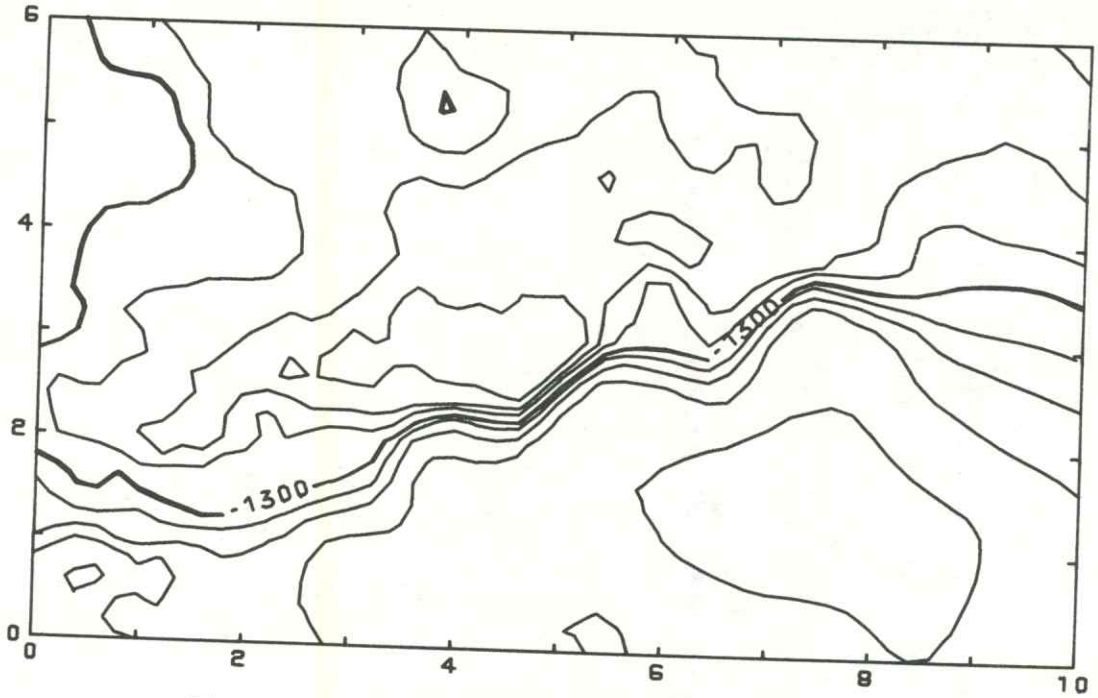


Figure 87.--Subsurface structural configuration of the top of the Pennsylvanian Lansing Group in the same area as Figure 86. Elevations are in feet below sea level.

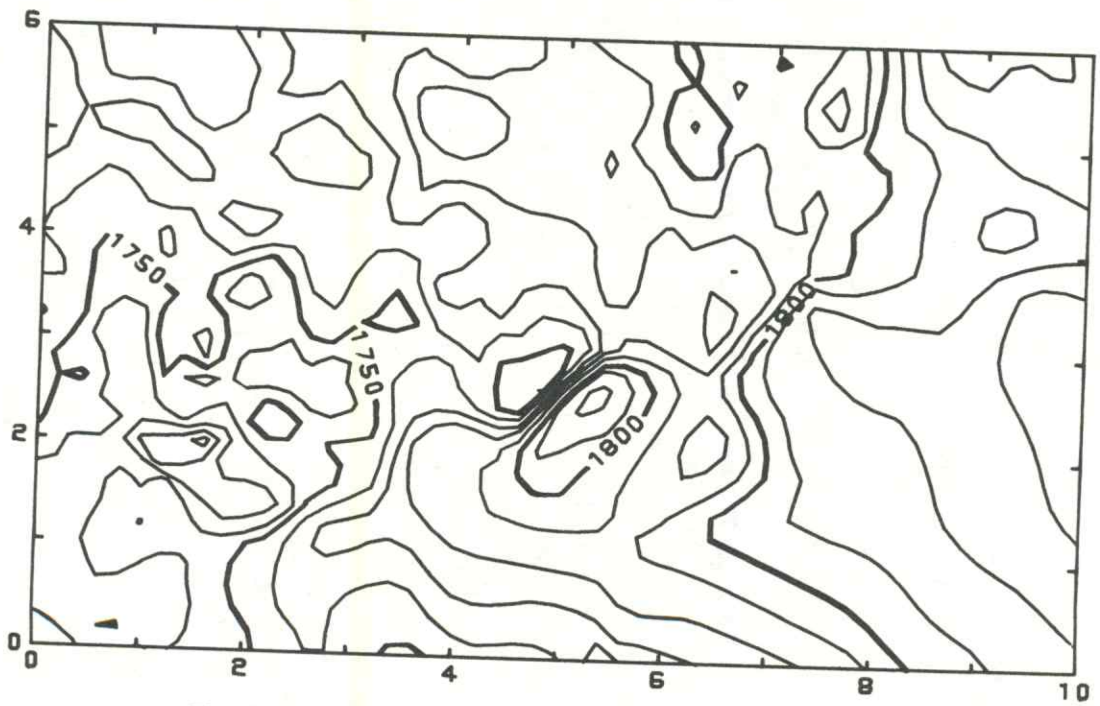


Figure 88.--Isopach map of the thickness of the interval between the top of the Stone Corral and the top of the Lansing. Thicknesses are in feet.

'KRIG'E - generates a grid matrix by Universal Kriging or drift estimation.

Field Number	Parameter Description	Assumed Value
1	Method of determining grid size. If 0, the number of columns and rows in the grid matrix will be specified. If 1, the number of columns and rows in the grid matrix will be calculated. The desired distance between columns and rows must be given.	0
2	Either the number of columns in the grid matrix, <u>or</u> the distance between columns; the interpretation depends on parameter one.	25/1
3	Either the number of rows in the grid matrix, <u>or</u> the distance between rows; the interpretation depends on parameter one.	25/1
4	Method of estimating grid elements. If 0, grid contains Universal Kriging estimates. If 1, grid contains drift estimates.	0
5	Degree of polynomial drift (0,1, or 2).	2
6	Slope of the semivariogram within the standard neighborhood.	1
7	Slope of the semivariogram within the wide neighborhood.	1
8	File-code on which the error grid is stored.[1]	Required
9	Form of error values. If 0, errors are given in standard deviations. If 1, errors are given in variances.	0
10	*A priori* variance for residuals (used only if parameter four is 1).	10000.0
11	Specifies whether or not to release for subsequent use the memory occupied by the array of sample data points. If 0, retain the sample data. If 1, delete the sample data.	0
12	Method of handling duplicate data points (two or more data points having the same X and Y coordinates and possibly different Z values). If 0, compute Z = average value of duplicate data points. If 1, delete all duplicate data points. If 2, replace all data points within a grid cell by their X, Y, Z centroid.	0

[1]Refer to Appendix C.

Field Number	Parameter Description	Assumed Value
13	Maximum permissible standard deviation of estimation error. If the calculated standard exceeds this value, the grid node is set to the blank value.	½ range of data points

Universal Kriging is used in SURFACE II to estimate values of a surface at the nodes of a regular grid from irregularly spaced sample data points. Unlike the distance-weighted averaging methods used in 'GRID', Kriging makes optimum use of the autocorrelation between point on the surface. It requires the prior determination of a semivariogram, which is a function relating the covariance of the difference between points to the distance between the points. In general, the semivariance increases with increasing distance. 'KRIG'E uses the form of this function to calculate estimates of the surface which are best linear unbiased estimates, provided the correct form of the semivariogram has been found. 'KRIG'E also estimates the likely error (as standard deviations or variances) at every estimated point in the grid. This can be mapped to give a direct assessment of the reliability of the contoured surface. As an example, Figure 89 is a map of the subsurface structural configuration in part of Graham County, Kansas, prepared by Universal Kriging. Figure 90 is a map of the associated error, given in feet of standard deviation.

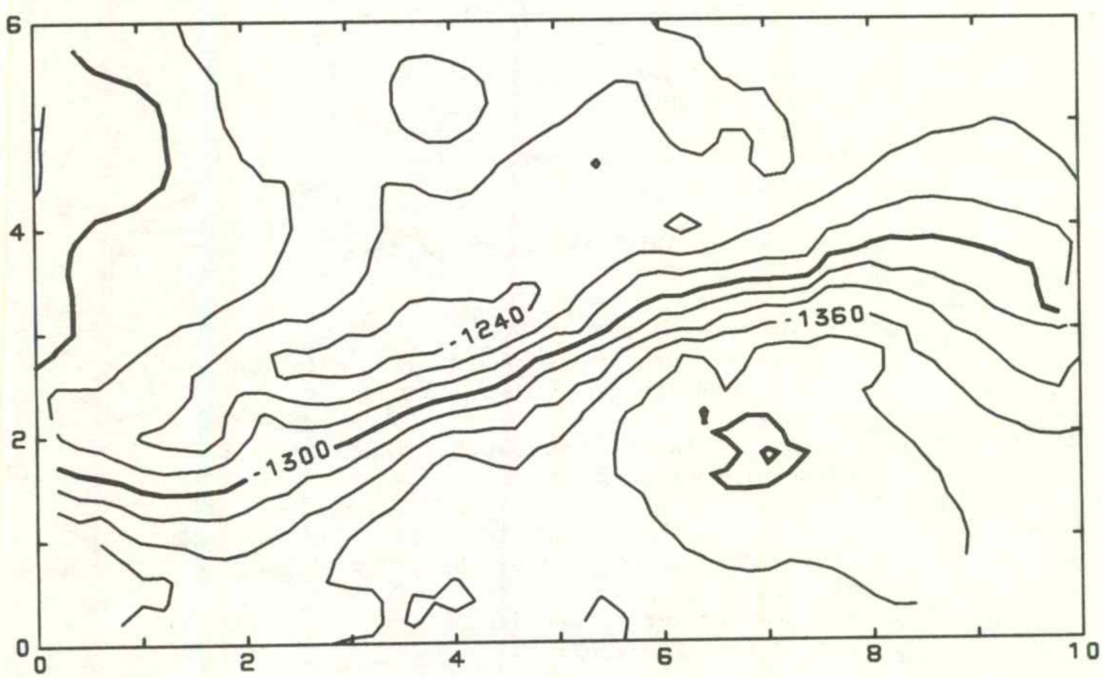


Figure 89.--Subsurface structure of the top of the Pennsylvanian Lansing Group in part of Graham Co., Kansas, mapped using the 'KRIG'E gridding command.

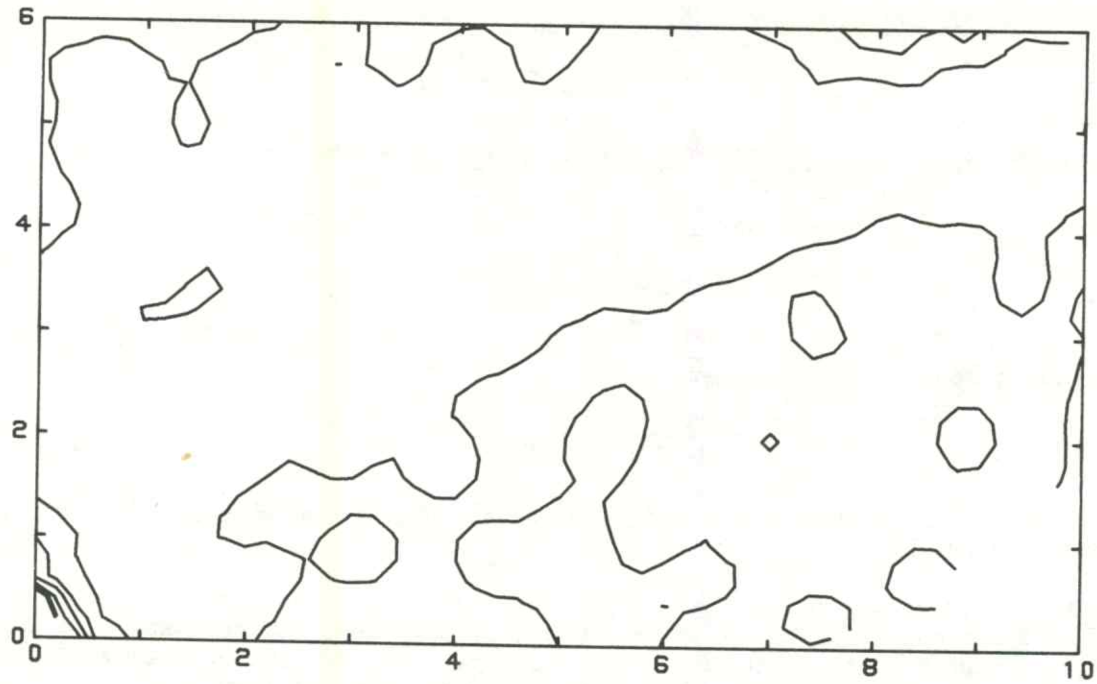


Figure 90.--Map of the standard deviation of estimation for the surface shown in Figure 89. Each contour interval defines an integral of ± one standard deviation about the surface.

In theory, no other method of grid generation can produce more accurate estimates of the form of a mapped surface. In practice, the effectiveness of Kriging depends upon the proper selection of several parameters, including the slope of the semivariogram. However, even with naive estimates of these parameters, Kriging will do no worse than arbitrary estimating procedures such as those in 'GRID'.

The price that must be paid for optimality is computational complexity. A large set of simultaneous equations must be solved for every point estimated by Kriging. Therefore, run times will be approximately one order of magnitude greater for a given map using 'KRIG'E rather than 'GRID'. In addition, an extensive prior examination of the data must be made to find the slope of the semivariogram and to select the proper order of the drift. These two parameters are not independent, so experimentation may be necessary to determine the best combination. For these reasons, Kriging probably should be applied in those instances where the best possible estimate of the surface is essential, and the data are of sufficient quality to warrant the additional costs of analysis and processing.

The user may define the size (i.e., the number of columns and rows) of the matrix in two different ways. By setting parameter one to 0, the number of columns and rows in the matrix may be given explicitly. Then, the distance between columns is

$$\frac{X_{max} - X_{min}}{NC - 1}$$

and the distance between rows is

$$\frac{Y_{max} - Y_{min}}{NR - 1}$$

where X_{min}, X_{max}, Y_{min}, and Y_{max} are determined by 'EXTR'EMES, and NC and NR are given by parameters two and three.

When parameter one is set to 1, the user defines the distance between columns and rows, and NC and NR are calculated by dividing these distances into the ranges of X and Y, as specified by 'EXTR'EMES. If there is any remainder, the ranges of X and Y are expanded so the distances between all rows and columns are uniform. For example, if

$$X_{min} = 1 \quad Y_{min} = 1 \quad \text{parameter two} = 3$$

$$X_{max} = 24 \quad Y_{max} = 20 \quad \text{parameter three} = 3$$

the number of columns in the matrix will be

$$\frac{25 - 1}{3} + 1 = 9$$

and the number of rows in the matrix will be

$$\frac{20 - 1}{3} + 1 = 7\ 1/3.$$

To avoid fractions, the number of rows will be increased to 8, and the value of Y_{max} automatically expanded to 22.

The number of rows and columns in the grid matrix has a direct influence on the finished appearance of a contour map. As the number of rows and columns is increased, the lengths of straight-line segments in the contour lines are reduced and the contours become smoother in appearance. However, estimation of additional grid intersections increases computation time. This is especially significant with 'KRIG'E.

Under the statistical theory which includes Kriging, a single-valued, continuous, mappable variable is called a "regionalized variable" and is considered to consist of two parts, a drift or regional tendency, and a residual or local fluctuation. The drift may be estimated by a polynomial function analogous to a trend surface (see 'TREN'D). If the drift is removed, the surface can be regarded as stationary in the statistical sense. The spatial relationship between residuals from the drift are expressed in the semivariogram. Parameter four selects either values of the drift or (drift + residual = surface) to be stored in the grid matrix. Parameter five is used to specify the order of the drift to be used. A zero-order drift corresponds to subtraction of the mean value of $\bar{Z}$ from every data point. If no drift is specified, a second order polynomial drift will be assumed.

The semivariogram is a continuous function, similar to an autocorrelation, which relates values at point on the surface to the values at other points as a function of the distance between them. (The semivariance is simply half the variance of the differences between the points). In 'KRIG'E, it is assumed that the semivariogram has the form

$$\gamma_d = \omega d$$

which is a straight line through the origin with a slope of ω. γ_d is the semivariance over distances d. Furthermore, the function is assumed to be the same for all directions across the mapped area.

At some distance d_k the semivariance will become approximately equal to the variance of the entire surface. This distance is called the range and is the greatest distance over which the value at a point on the surface is related to the value at another point. The range defines the maximum neighborhood over which control points can be selected to estimate a grid node. However, because the Kriging calculations become increasingly costly with larger number of points, 'KRIG'E uses a smaller "standard" neighborhood wherever possible. The radius of the standard neighborhood and the larger maximum neighborhood are specified in the 'OCTA'NT command. The slope of the semivariogram within these two neighborhoods is specified by parameters six and seven of the 'KRIG'E command. Calculation of the semivariogram can be performed using the FORTRAN program SEMIVAR written by R. A. Olea (1977).

Because 'KRIG'E creates both an estimate of the surface and the associated error, the error grid must be placed on an external file for later recall and contouring. Parameter eight specifies the code of this external file. It may be recalled using the 'REST'ORE command. The error map may be calculated in either standard deviations or variances, as specified by parameter nine.

A linear semivariogram of the type used by 'KRIG'E implies that the error increases without bounds with increasing distance from control. This, of course, is not true, as the error at a point within the map cannot exceed the variance in the original data points. Parameter ten specifies the total variance of the map residuals. The default value is a large number appropriate for subsurface structural contour maps where the variable is depth in feet below sea level.

AUXILIARY COMMANDS used with 'KRIG'E:

'EXTR'EMES
'OCTA'NT

The 'EXTR'EMES command specifies the X, Y limits of the map.

IMPORTANT NOTE: Two 'OCTA'NT commands are necessary when performing Kriging. The first 'OCTA'NT command, in which parameter one is set to 4, specifies the search pattern for the standard neighborhood. The second 'OCTA'NT command, in which parameter one is set to 5, specifies the search pattern for the wide neighborhood. No other search command may be used with 'KRIG'E.

Extensive discussions of both theoretical and practical aspects of Universal Kriging as applied to contour mapping are contained in Olea (1975) and in a shorter review article (Olea, 1974). Both of these include references to the basic literature, much of which is in French. The 'KRIG'E module of SURFACE II is adapted from the computer program "MAPPING" by R. A. Olea, and developed by Empresa Nacional del Petroleo, Chile. The contribution of Ing. Olea and ENAP is gratefully acknowledged.

'LEVE'LS - allows the user to specify unequal contour intervals.

Field Number	Parameter Description	Assumed Value
1	File code on which the contour levels are stored.[1]	Required
2	Total number of contour levels to be generated. This number must agree with the number of levels read.	Required
3	Format of data which specifies the contour levels and annotation code.[2]	Required

The user may specify the value of each contour level that will be plotted on a contour map instead of using values calculated by the 'CINT'ERVAL command. The contour levels to be used are read into memory from a file. Each record on the data file must contain information for only one contour level. The first value read from each record is the contour level (elevation), and must be read in real format. The second value on the record is the annotation code which must be read in integer format.

Annotation codes are:

0 - light line without annotation (labels)
1 - light line with labels
2 - heavy line with labels
3 - heavy line without labels.

If any other value is used it will be treated as an annotation code of 0. Labeling of contour lines under options 1 or 2 is controlled by 'CINT'ERVAL parameters six through eight.

Figures 91 and 92 show two examples of the use of the 'LEVE'LS command. SURFACE II commands and the levels file used to create these illustrations are given below.

Read in data, grid, and plot Figure 91	TITLE	LEVELS TEST FOR SURFACE MANUAL
	DEVICE	1,'DAVIS'
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	GRID	1,0.2,0.2
	EXTREMES	0,10,0,6
	CONTOUR	
	LEVELS	12,9,'(F7.0,I2)'
	CINTERVAL	2,,,,,0.1,0,2
	SIZCONTOUR	1,6,3.6
	BOX	1,2,1,2,0,0,0,0,1,0.1
	PERFORM	
Plot Figure 92	CONTOUR	
	LEVELS	13,10,'(F7.0,I2)'
	PERFORM	
	STOP	

[1]See Appendix C.

[2]See Appendix B.

Levels table for Figure 91

Contour level	Annotation code
-1373.	2
-1343.	0
-1323.	2
-1313.	0
-1308.	2
-1303.	0
-1293.	2
-1273.	0
-1243.	2

Levels table for Figure 92

Contour level	Annotation code
-1388.	0
-1382.	1
-1372.	0
-1352.	3
-1322.	2
-1292.	2
-1262.	3
-1242.	0
-1232.	1
-1228.	0

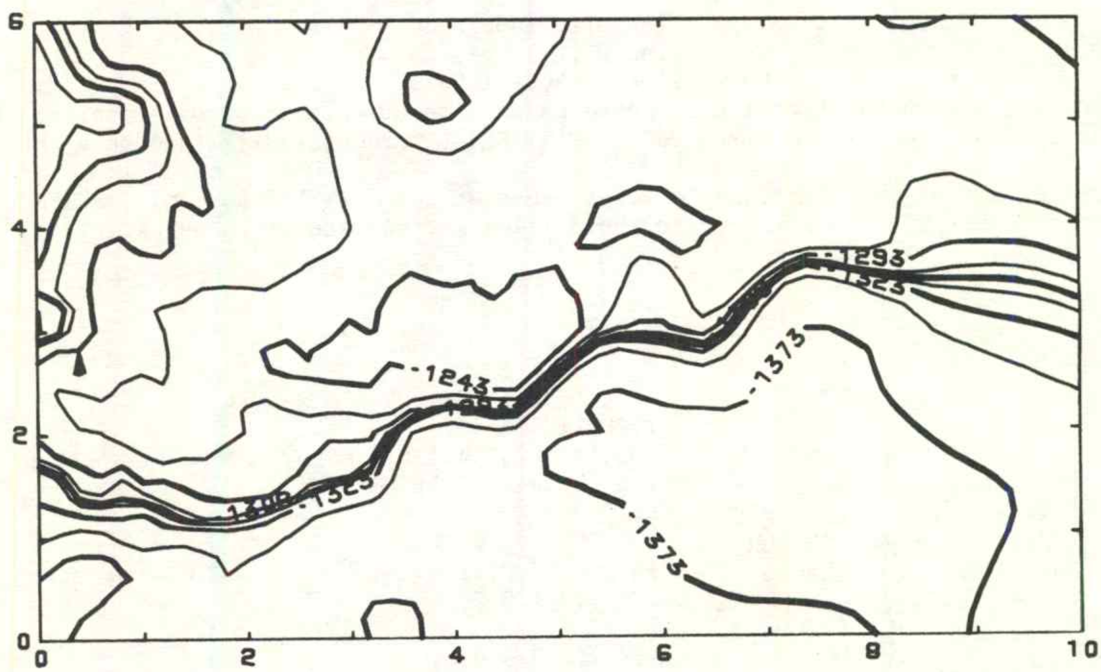


Figure 91.--Subsurface structure of the top of the Pennsylvanian Lansing Group in part of Graham Co., Kansas. The range of elevations has been divided into unequal contour intervals with the greatest number of lines in the middle of the range.

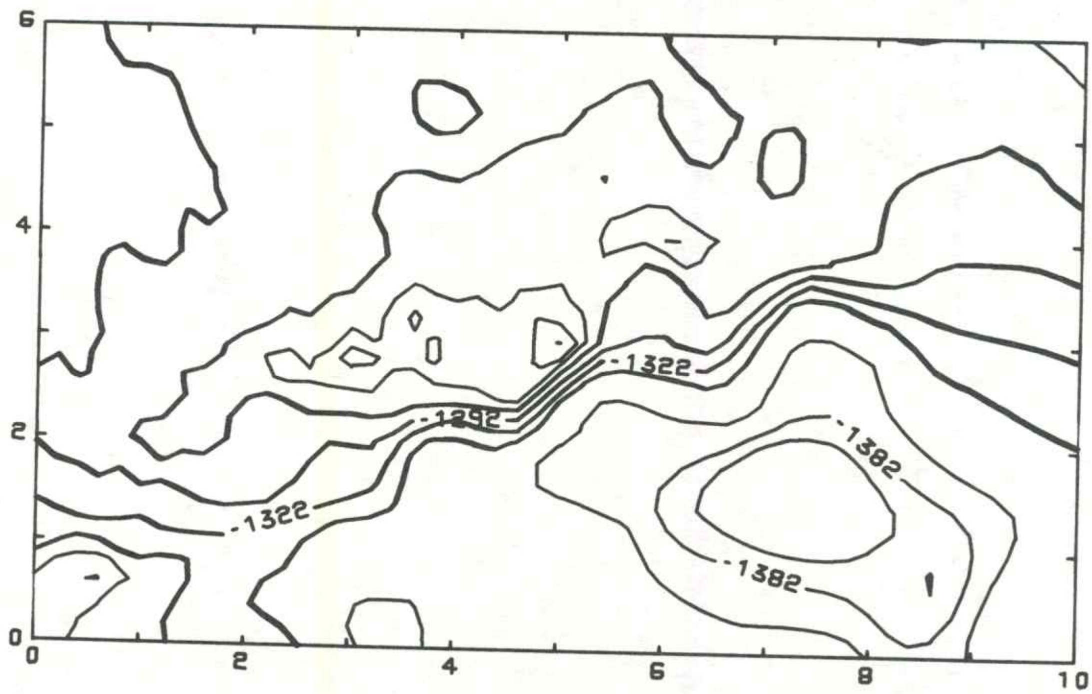


Figure 92.--Same data as in Figure 91 contoured at unequal intervals so the greatest number of lines are at the high and low extremes of the range.

'LINE'S - determines the number of lines to be drawn on a perspective block diagram.

Field Number	Parameter Description	Assumed Value
1	Defines operation of parameters two and three. If 0, parameters two and three specify number of grid intervals between lines on the surface. If 1, parameters two and three specify total number of lines on surface.	0
2	Number of lines to be drawn perpendicular to the X-axis.	2
3	Number of lines to be drawn perpendicular to the Y-axis.	2

The total number of lines appearing on a transect plot may be specified directly by the user (by setting parameter one to 1) or may be expressed as a function of the number of rows and columns in the grid matrix (parameter one = 0). If the desired number of lines is greater than the number of columns or rows in the grid matrix, SURFACE II will interpolate values between the grid values and draw the additional lines.

The assumed number of lines to be drawn is one-half the number of columns and rows. Thus, if the user does not include a 'LINE'S command, the perspective block diagram of a 40 x 40 matrix will have only 20 lines in the X and Y directions. If the surface is highly irregular, more lines may be necessary to adequately display the surface features. For many purposes, the assumed values of the 'LINE'S command may not be appropriate if the grid matrix is relatively small. On the other hand, the user should avoid specifying an excessive number of lines because the cost of producing the plot is directly proportional to the number of lines drawn.

Figures 93-96 show a block diagram constructed using different numbers of lines on the surface. Commands used to construct these illustrations are:

```
                    TITLE        LINES TEST FOR SURFACE MANUAL
                  { DEVICE       1,'DAVIS'
                  { IDXY         200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
                  { GRID         1,0.2,0.2
Read XYZ          { EXTREMES     0,10,0,6
data, grid,       { TRANSECT     0,20,0
plot              { LINES        1,10,10
Figure 93         { SIZTRANSECT  6
                  { DISTANCE     100
                  { ELEVATION    30
                  { AZIMUTH      25
                    PERFORM
Plot              { TRANSECT     0,20,0
Figure 94         { LINES        0,2,2
                  { PERFORM
```

```
Plot         TRANSECT    0,20,0
Figure 95    LINES       1,40,24
             PERFORM
Plot         TRANSECT    0,20,0
Figure 96    LINES       1,80,48
             PERFORM
             STOP
```

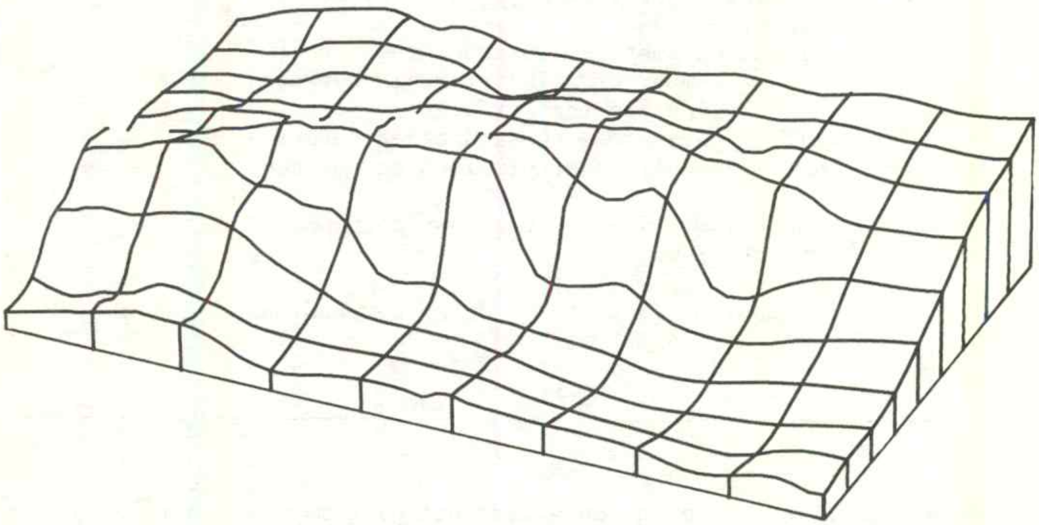


Figure 93.--Block diagram of subsurface geologic structure in part of Graham Co., Kansas, using only ten lines in X and ten lines in Y to display the surface.

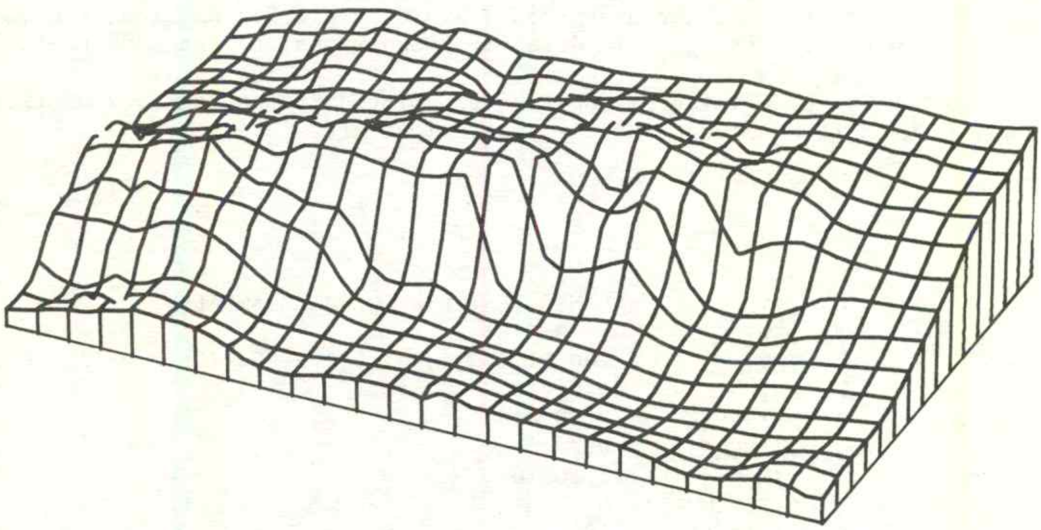


Figure 94.--Block diagram drawn with assumed values of the parameters of the 'LINE'S command (two grid intervals between lines).

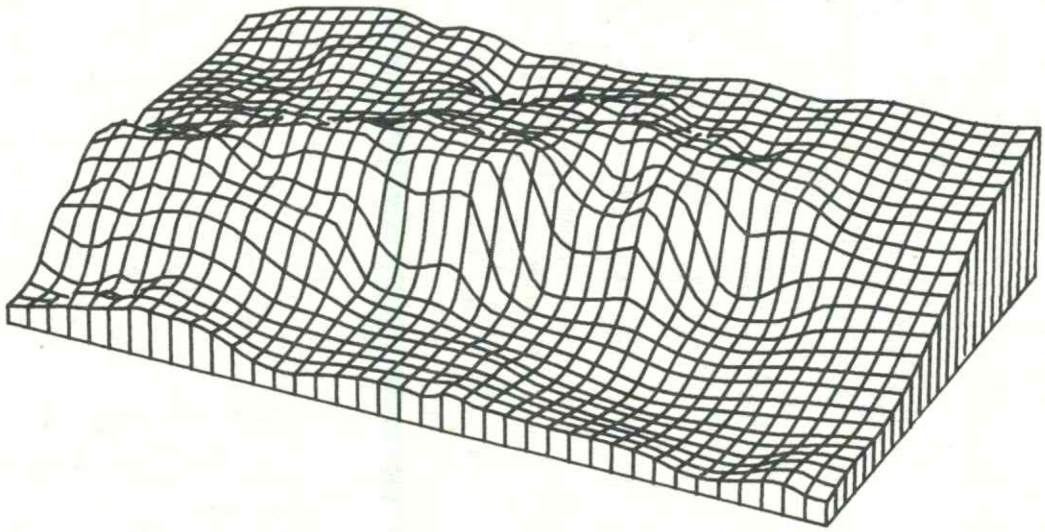


Figure 95.--Block diagram drawn with 40 lines parallel to Y-axis and 24 lines parallel to X-axis.

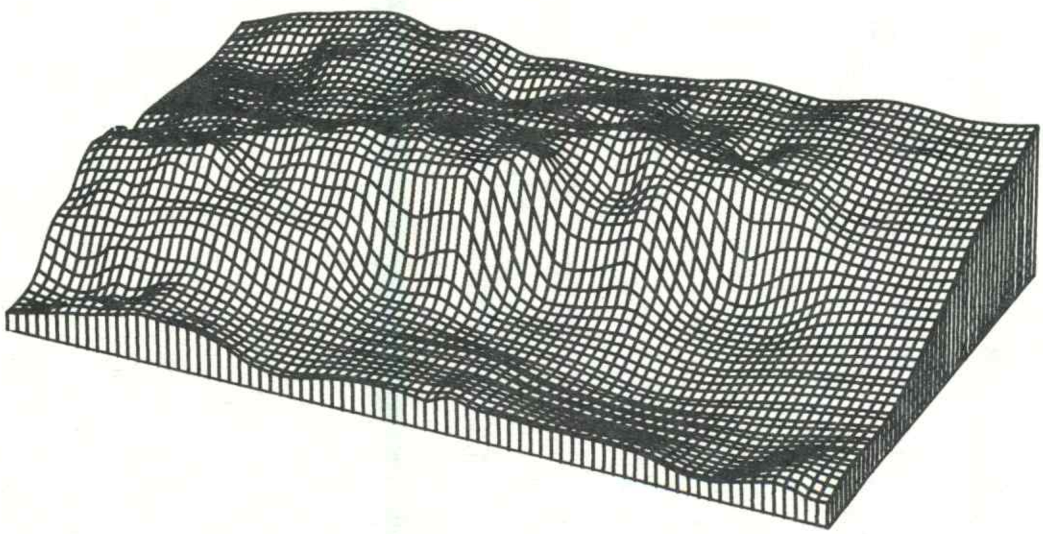


Figure 96.--Block diagram drawn with 80 lines parallel to Y-axis and 48 lines parallel to X-axis.

'MADD' - performs element-by-element addition between a grid matrix and a matrix stored on an external file.

Field Number	Parameter Description	Assumed Value
1	File code on which second matrix is stored.[1]	Required

The sum of the elements in the grid matrix and the external matrix replaces elements of the original grid matrix. The second matrix must be stored on an external file by the 'SAVE' command or in the same format (binary) as a 'SAVE'd matrix. The external matrix must have the same number of rows and columns as the grid matrix.

The operation of 'MADD' may be symbolically represented as

$$\begin{bmatrix} a_{12} & a_{22} \\ a_{11} & a_{21} \end{bmatrix} \text{ 'MADD' } \begin{bmatrix} b_{12} & b_{22} \\ b_{11} & b_{21} \end{bmatrix} = \begin{bmatrix} a_{12}+b_{12} & a_{22}+b_{22} \\ a_{11}+b_{11} & a_{21}+b_{21} \end{bmatrix}$$

original grid matrix — second matrix — new grid matrix

Note that subscripts are used in a different convention than in matrix algebra. The first subscript indicates the column and the second subscript indicates the row of the matrix in which an element is located. Columns and rows of the matrix are arranged in the same manner as a grid matrix when it is plotted; that is, the first column is the leftmost edge of the map and the first row is the bottom edge.

Figures 97 through 99 show the result of adding grid matrices representing farm income and non-farm income in the 105 counties of Kansas, to produce a map of total income within the State.

[1] See Appendix C.

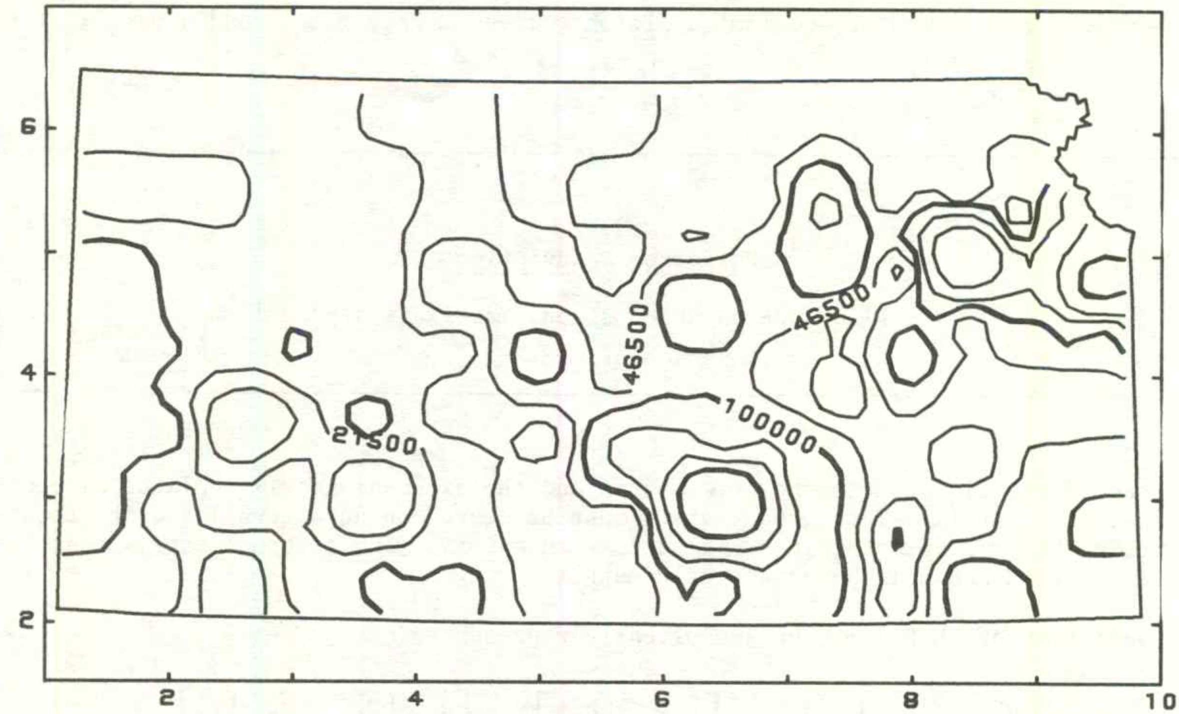


Figure 97.--Non-farm income in Kansas for 1973, by counties. Contour intervals are logarithmically spaced over the range 1000 to 4,650,000.

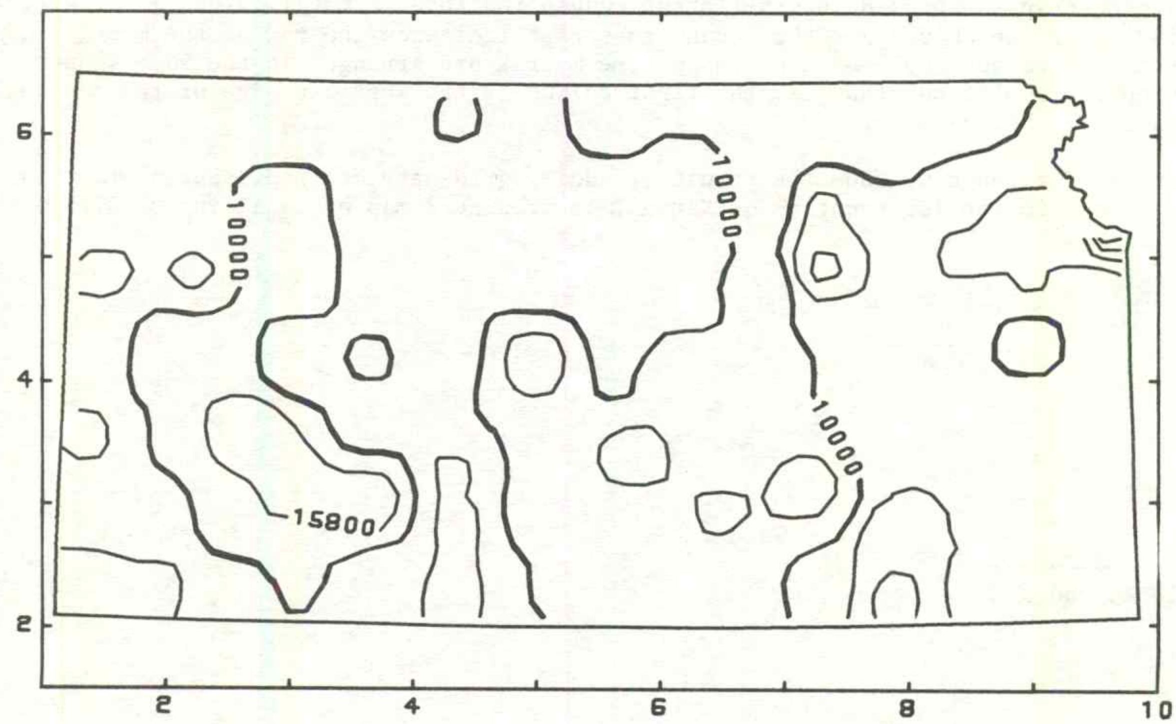


Figure 98.--Farm income in Kansas for 1973, by counties. Contour intervals are logarithmically spaced.

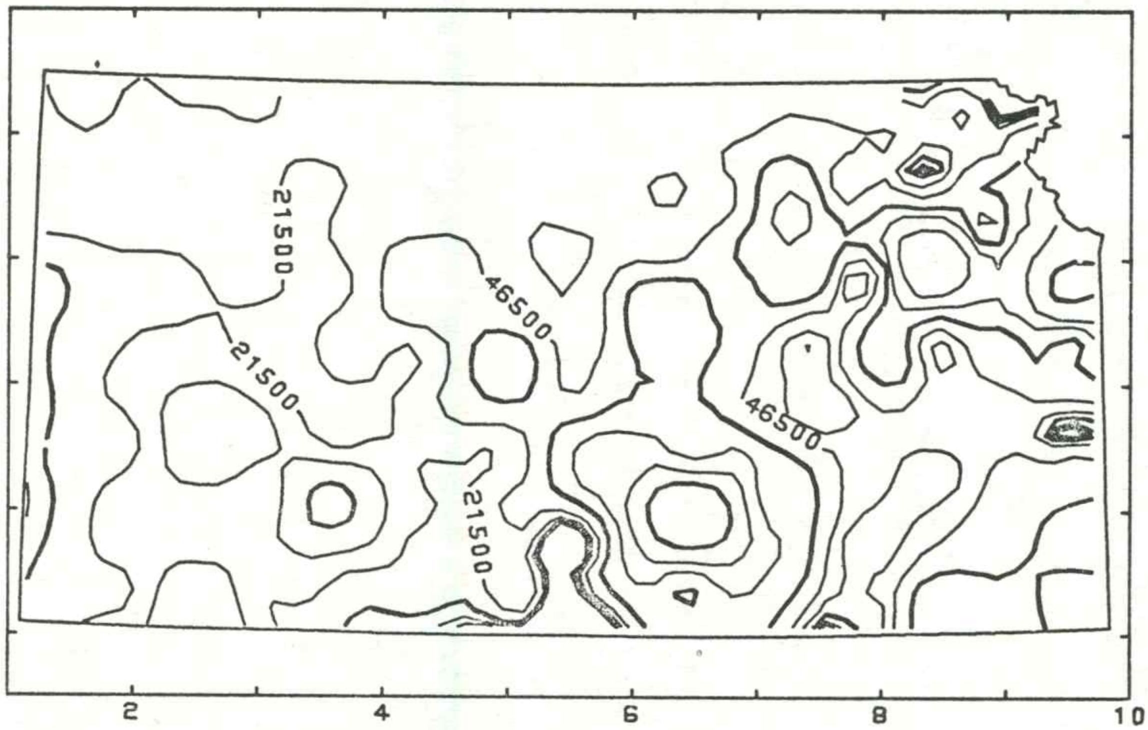


Figure 99.--Total income in Kansas, produced by adding the grid matrices from Figures 97 and 98. Contour intervals are logarithmically spaced.

'MATR'IX - reads a matrix in formatted form (BCD) into memory from an external file. Using this command, a matrix of surface values may be read in, rather than using SURFACE II to compute a matrix from raw data.

Field Number	Parameter Description	Assumed Value
1	Code number of the file from which the matrix is to be read.[1]	Required
2	Number of columns in the matrix.	Required
3	Number of rows in the matrix.	Required
4	Directs SURFACE II to store the matrix as grid matrix (1) or filter matrix (2).	1
5	If 0, the first column read from the file will be stored as the left edge of the matrix. If 1, the first column read is stored as the right edge of the matrix.	0
6	If 0, the first row read from the file is stored as the bottom row of the matrix. If 1, the first row read from the file is stored as the top row of the matrix.	0
7	Format of the input data;[2] elements of the matrix must be read in floating point (real) format with one row per record.	Required

The matrix may appear in any BCD format but must be read in by rows (one row per logical record) and not by columns. The 'INCR'EMENT command may be used to eliminate any elements on the file that are not to be stored. However, the same results can be achieved by use of an appropriate format specification in parameter seven. Once stored, the grid matrix may be scaled, smoothed, plotted, and manipulated in exactly the same manner as a matrix generated by a SURFACE II command. Values read in by 'MATR'IX may be listed by using 'ECHO'.

The 'MATR'IX command reads values for $\dot{Z}$ only. The values of the coordinate variables X and Y associated with elements in the matrix are defined by the 'EXTR'EMES command. If this command is not present and no sample data points have been previously read in, the range of the map in the X-direction will be set equal to the number of columns in the grid matrix (X_{min} = 1, X_{max} = NC) and the range in the Y direction will become the number of rows in the matrix (Y_{min} = 1, Y_{max} = NR). Values of X and Y associated with $\dot{Z}_{c,r}$, which is the element in column c and row r of the grid matrix, are (X_c, Y_r). These coordinates are calculated by

[1]See Appendix C.

[2]See Appendix B.

$$X_c = X_{min} + (c-1)\ dx \qquad Y_r = Y_{min} + (r-1)\ dy$$

where dx is the distance in the X-direction between columns in the grid matrix and dy is the distance in the Y-direction between rows of the grid matrix.

$$dx = \frac{X_{max} - X_{min}}{NC - 1} \qquad dy = \frac{Y_{max} - Y_{min}}{NR - 1}$$

Parameters five and six determine the placement of the rows and columns in the grid matrix. If the columns read from the external file are to be stored from the left edge of the grid to the right, parameter five should be 0. If the columns read from the file should be stored from right to left in the grid, parameter five should be set to 1. Similarly, if the rows read from the file are to be stored from the bottom to the top, parameter six should be 0. To store the rows starting at the top of the grid, parameter six should have a value of 1.

'MDIV'IDE - performs element-by-element division between a grid matrix and a second matrix.

Field Number	Parameter Description	Assumed Value
1	File code on which second matrix is stored.[1]	Required
2	Defines the dividend and divisor. If 0, each element in the grid matrix is divided by the corresponding element of the second matrix. If 1, each element of the second matrix is divided by the corresponding element of the grid matrix.	0

A quotient matrix replaces the original grid matrix. The second matrix is stored externally in the same format as a matrix written by a 'SAVE' command; it must have the same number of rows and columns as the grid matrix.

Below is an example of the operation of 'MDIV'IDE on a 2 by 2 grid matrix, with parameter two set to 0.

$$\begin{bmatrix} a_{12} & a_{22} \\ a_{11} & a_{21} \end{bmatrix} \text{ 'MDIV' } \begin{bmatrix} b_{12} & b_{22} \\ b_{11} & b_{21} \end{bmatrix} = \begin{bmatrix} a_{12}/b_{12} & a_{22}/b_{22} \\ a_{11}/b_{11} & a_{21}/b_{21} \end{bmatrix}$$

original grid matrix — second matrix — new grid matrix

Note that subscripts are used in a different convention than in matrix algebra. The first subscript indicates the column and the second subscript indicates the row of the matrix in which an element is located. Columns and rows of the matrix are arranged in the same manner as a grid matrix when it is plotted; that is, the first column is the leftmost edge of the map and the first row is the bottom edge.

Figure 100 is a contour map of total income for the 105 counties of Kansas. Figure 101 is a map of the populations of these counties. By dividing the elements of the first map by elements of the second, a map of per capita income is produced (Fig. 102).

[1] Refer to Appendix C.

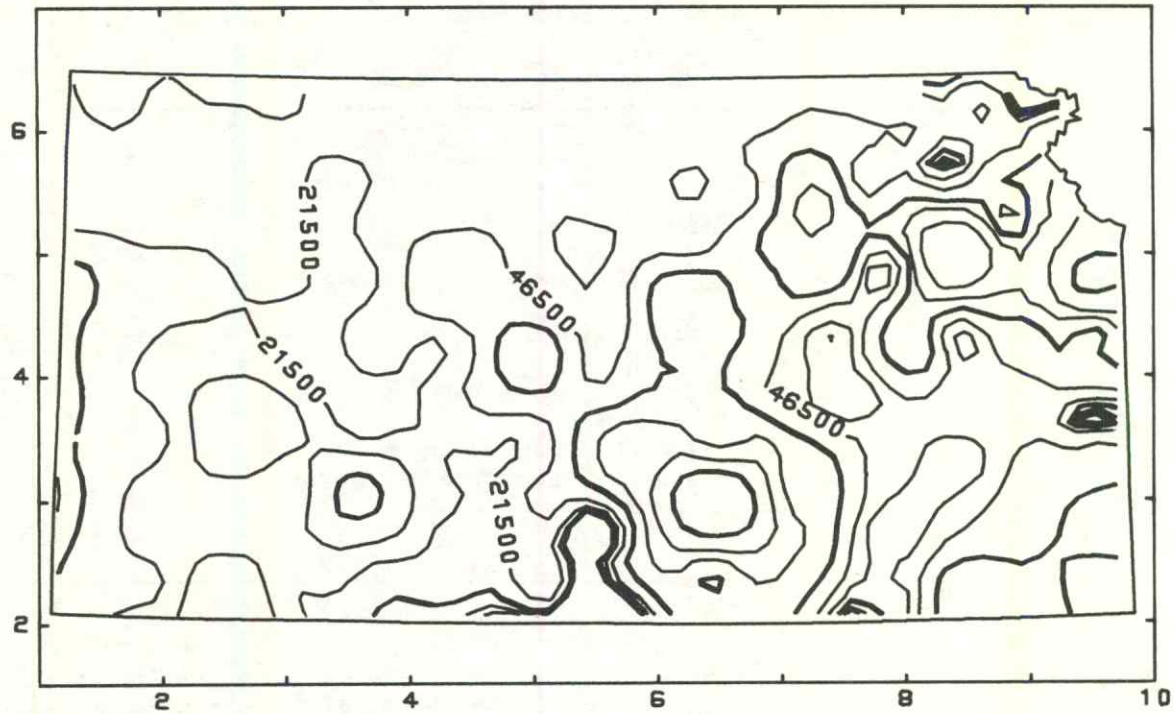


Figure 100.--Total income in Kansas for 1973, by counties. Contours are logarithmically spaced over the range $1000 to $4,650,000. This map is drawn from a grid matrix created using the 'MADD' command (see Figs. 97-99).

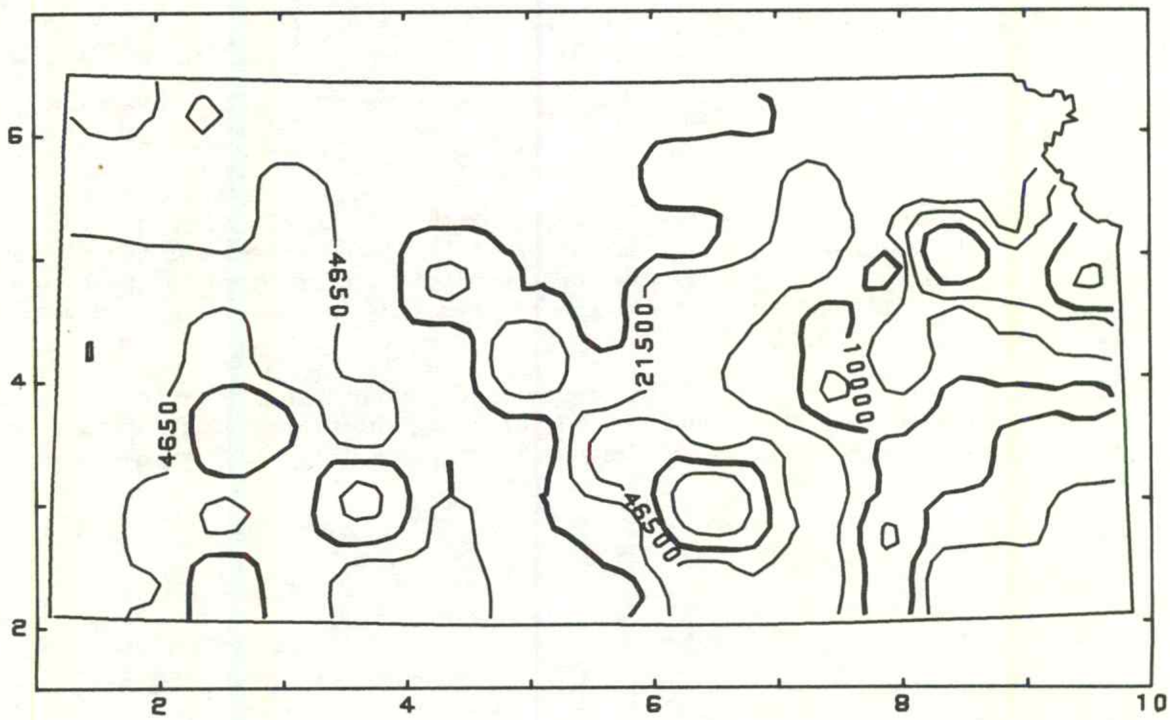


Figure 101.--Population in Kansas by county for 1973. Contours are logarithmically spaced.

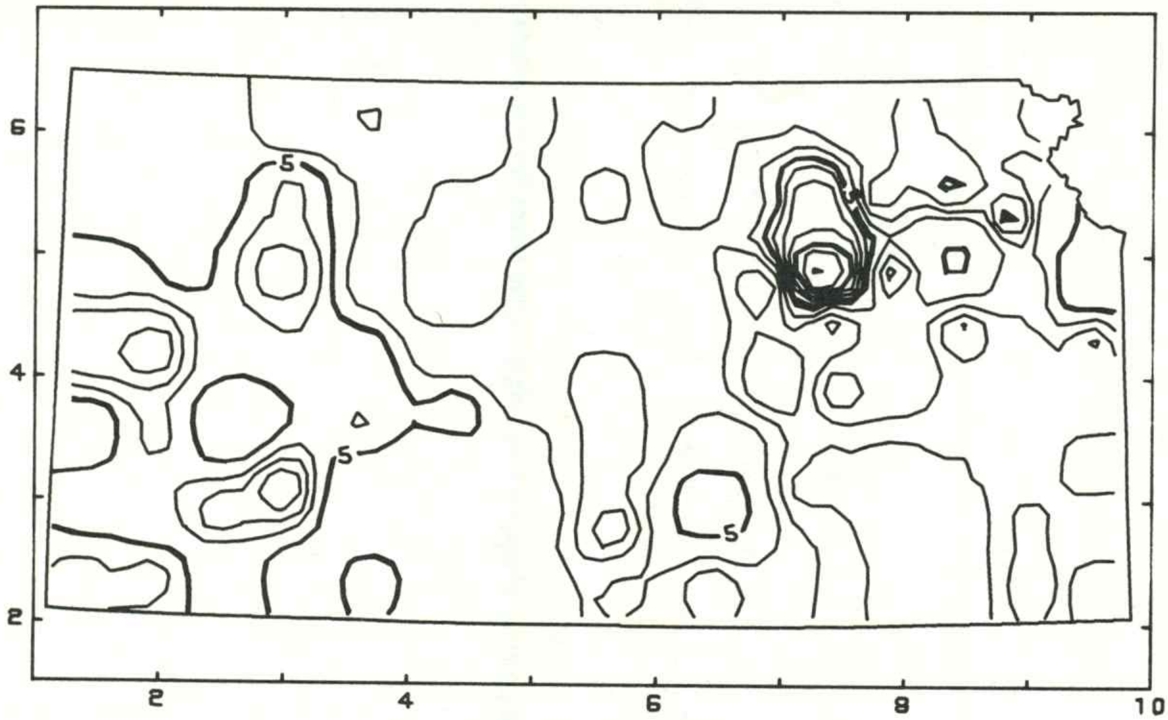


Figure 102.--Per capita income in Kansas, obtained by dividing elements in the grid matrix of Figure 100 by elements in the grid matrix of Figure 101. Contour interval is $500. The $5000 contour level is annotated.

'MLEV'EL - subtracts a linear trend surface from a grid matrix, replacing the matrix with the residuals.

Field Number	Parameter Description	Assumed Value
1	If 0, subtract linear trend from grid values only. If 1, subtract linear trend from grid values and from sample data points.	0

This command fits a linear least squares regression of the form $Z' = b_0 + b_1X_c + b_2Y_r$ to the estimated values $\dot{Z}_{c,r}$, c = 1, ..., NC, r = 1, ..., NR, rather than to the original sample data points as does 'TREN'D. The values for X_c and Y_r are calculated from parameters of the 'EXTR'EMES command:

$$X_c = \frac{X_{max} - X_{min}}{NC - 1} * (c-1) + X_{min} \quad ,$$

$$Y_r = \frac{Y_{max} - Y_{min}}{NR - 1} * (r-1) + Y_{min} \quad ,$$

where c and r are the column and row coordinates of a given matrix element.

If parameter one is set to 1, the regression equation is evaluated at the sample data points from which the grid was originally created. The Z values of the sample data points are replaced by the residual value (Z - Z') and are available for subsequent posting. The X and Y values of the sample data are not altered.

Because the linear trend is computed from $\dot{Z}$ values in the grid matrix, a grid must have been previously generated from sample data or read from an external file.

The purpose of 'MLEV'EL is to transform the surface to a statistically stationary form. The process is sometimes referred to as "leveling" the data. Figures 103-106 show a surface as both a contour map and block diagram before and after leveling. The commands which produced the leveled plot in Figure 105 are:

```
TITLE        MLEVEL TEST FOR SURFACE MANUAL
DEVICE       1,'DAVIS'
IDXY         200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
GRID         1,0.2,0.2
EXTREMES     0,10,0,6
MLEVEL
CONTOUR
CINTERVAL    0,0,10,0,5
SIZCONTOUR   1,6,3.6
BOX          1,2,1,2,0,0,0,1,0.1
PERFORM
STOP
```

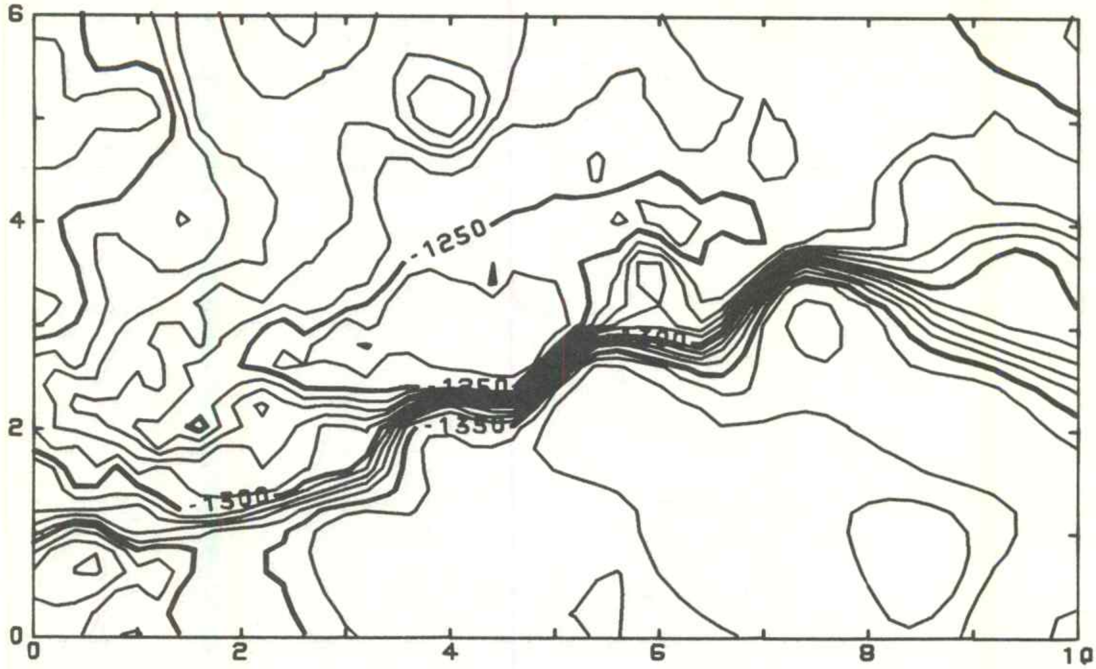


Figure 103.--Contour map of subsurface geologic structure in part of Graham Co., Kansas. Contours represent subsea elevations of the top of the Lansing group, and are given in feet below sea level.

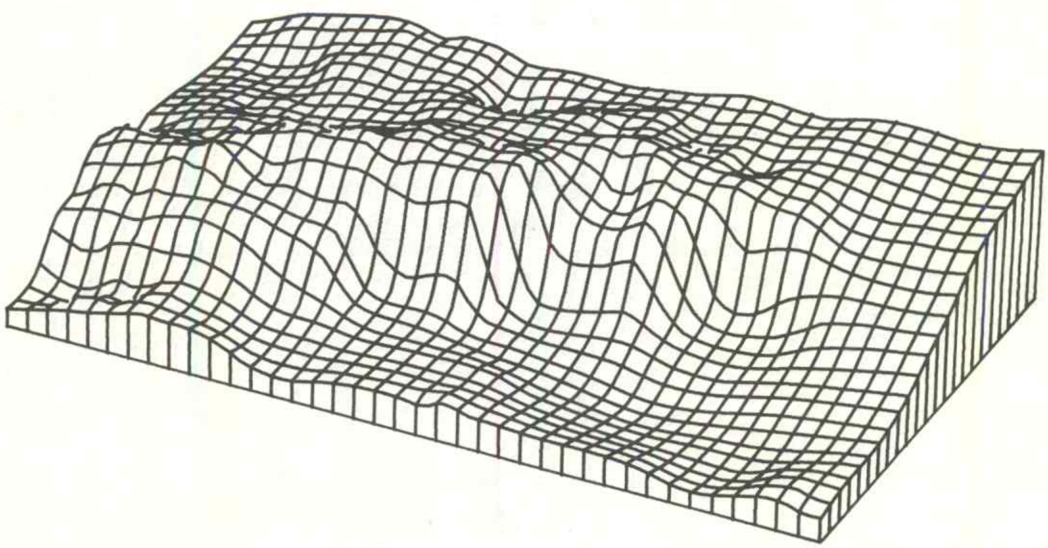


Figure 104.--Block diagram of the surface shown in Figure 103. Note pronounced slope of the surface from back to front of the diagram.

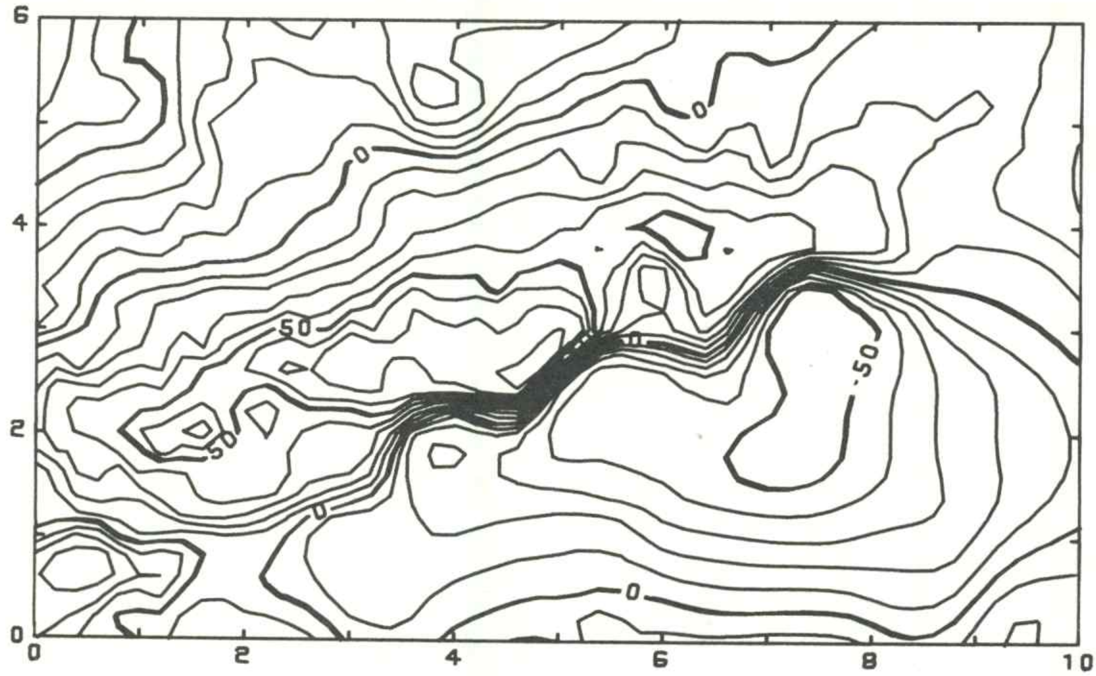


Figure 105.--Contour map of the surface shown in Figure 103 after leveling using the 'MLEV'EL command. Contours are in feet of deviation from the fitted trend.

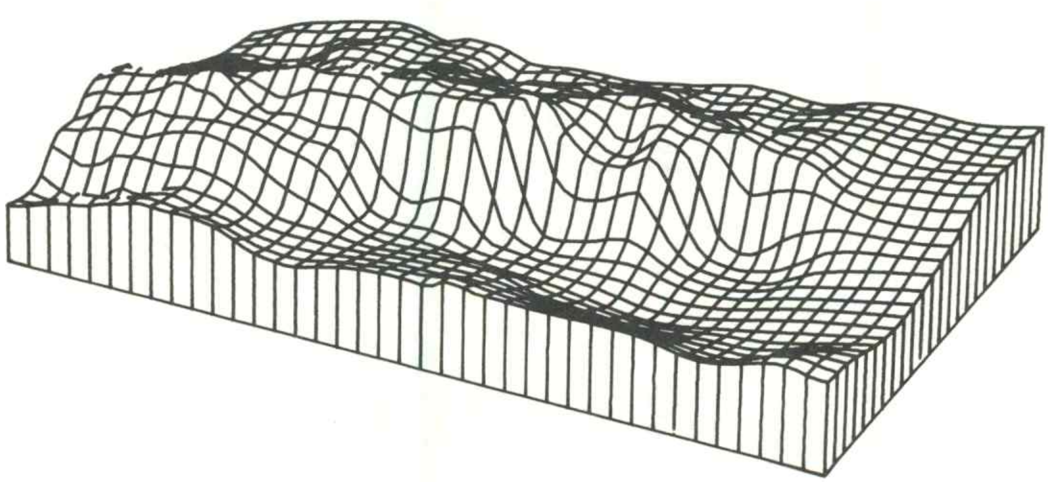


Figure 106.--Block diagram of the leveled surface shown in Figure 105. Note that the back-to-front slope apparent in Figure 104 is not present. The surface fluctuates around a middle value.

'MMUL'TIPLY - multiplies each element in a grid matrix by the corresponding element in a second matrix.

Field Number	Parameter Description	Assumed Value
1	File code on which second matrix is stored.[1]	Required

The product matrix replaces the original grid matrix. The second matrix must be stored on an external file by the 'SAVE' command or in the same (binary) format as a matrix created by 'SAVE'. The external matrix must have the same number of rows and columns as the grid matrix.

Below is an example of the operation of 'MMUL'TIPLY on a 2 by 2 grid matrix.

$$\begin{bmatrix} a_{12} & a_{22} \\ a_{11} & a_{21} \end{bmatrix} \text{ 'MMUL' } \begin{bmatrix} b_{12} & b_{22} \\ b_{11} & b_{21} \end{bmatrix} = \begin{bmatrix} a_{12}b_{12} & a_{22}b_{22} \\ a_{11}b_{11} & a_{21}b_{21} \end{bmatrix}$$

original grid matrix — second matrix — new grid matrix

Note that subscripts are used in a different convention than in matrix algebra. The first subscript indicates the column and the second subscript indicates the row of the matrix in which an element is located. Columns and rows of the matrix are arranged in the same manner as a grid matrix when it is plotted; that is, the first column is the leftmost edge of the map and the first row is the bottom edge.

Figure 107 is an isopach map of the 'B' division of the Mississippian Osage Series in Stafford County, Kansas. This unit is a zone of weathered rock composed of a mixture of chert fragments in a clay matrix. In some areas, natural gas is trapped in pores within the chert. The ratio of clay matrix to chert may be a critical control on gas accumulation. Figure 108 is a map of the shale ratio derived from the average intensity of gamma rays emitted by potassium 40 in clay minerals, as measured on radioactivity logs of wells drilled through the interval. These two maps can be combined by 'MMUL'TIPLY to yield a map of equivalent shale thickness, shown in Figure 109. This is the total thickness of the shale fraction of the Mississippian 'B' division, if all the constituent clay materials were segregated into a single unit. Because this map indicates areas of relatively high shale concentrations, it may be useful in future exploration for natural gas in the region.

[1] Refer to Appendix C.

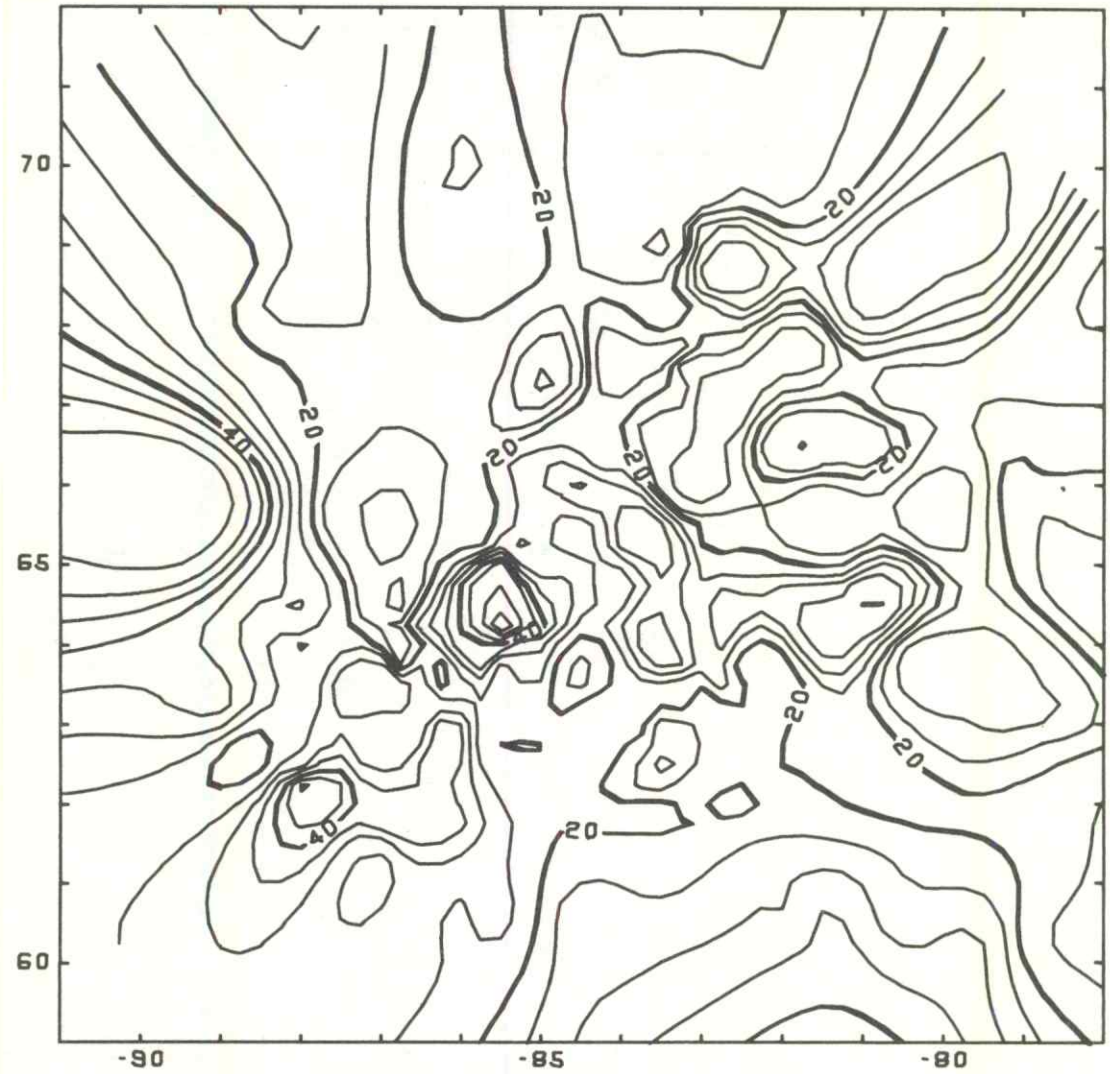


Figure 107.--Thickness of 'B' division of Mississippian Osage Series in Stafford Co., Kansas. Contour interval is 10 feet. Tick marks are at 1-mile intervals. Coordinates are measured from an arbitrary origin.

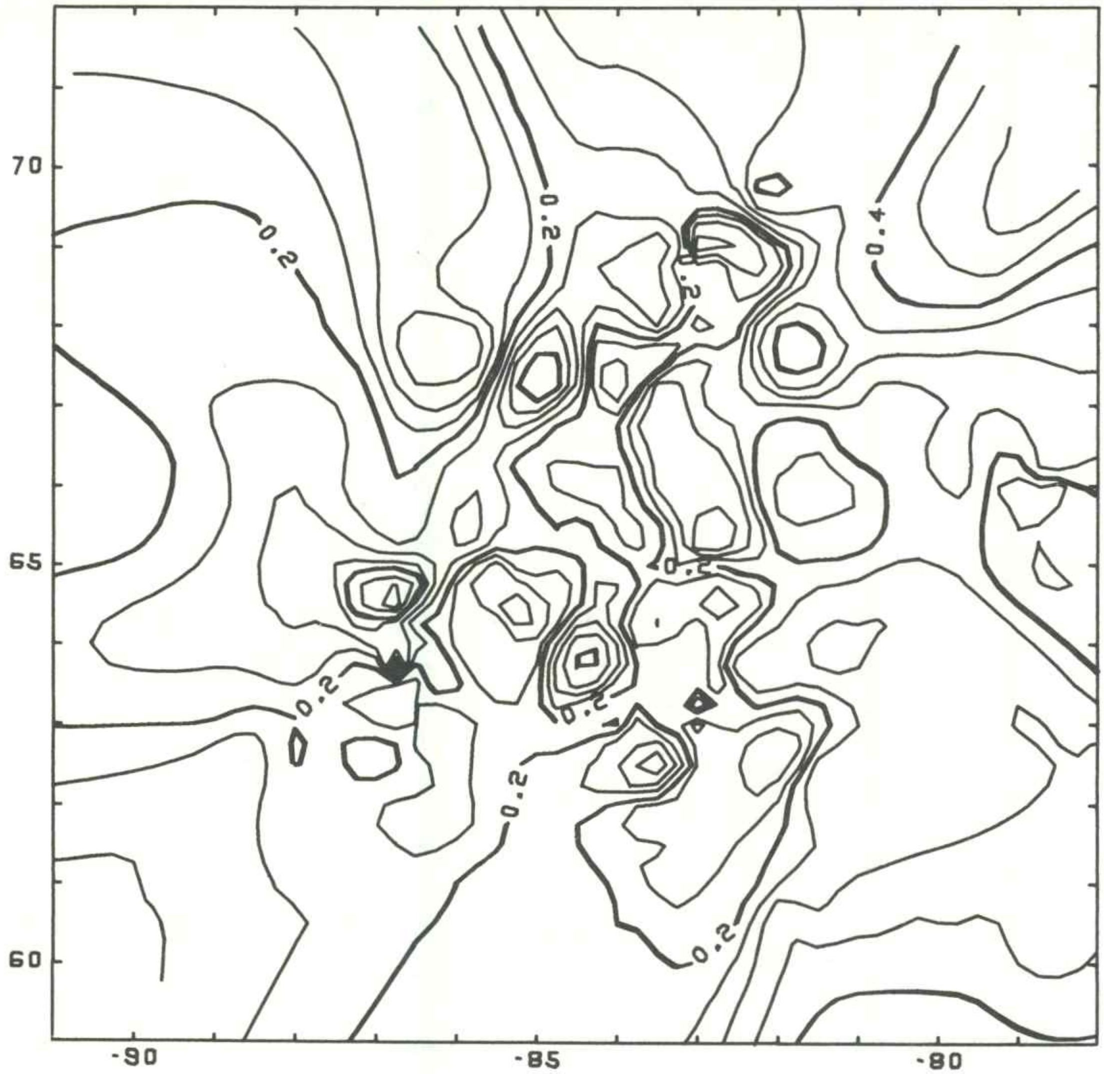


Figure 108.--Gamma ray shale ratio of Mississippian 'B' interval, based on average gamma ray intensity measured in wells. Contour interval is 0.1 shale ratio.

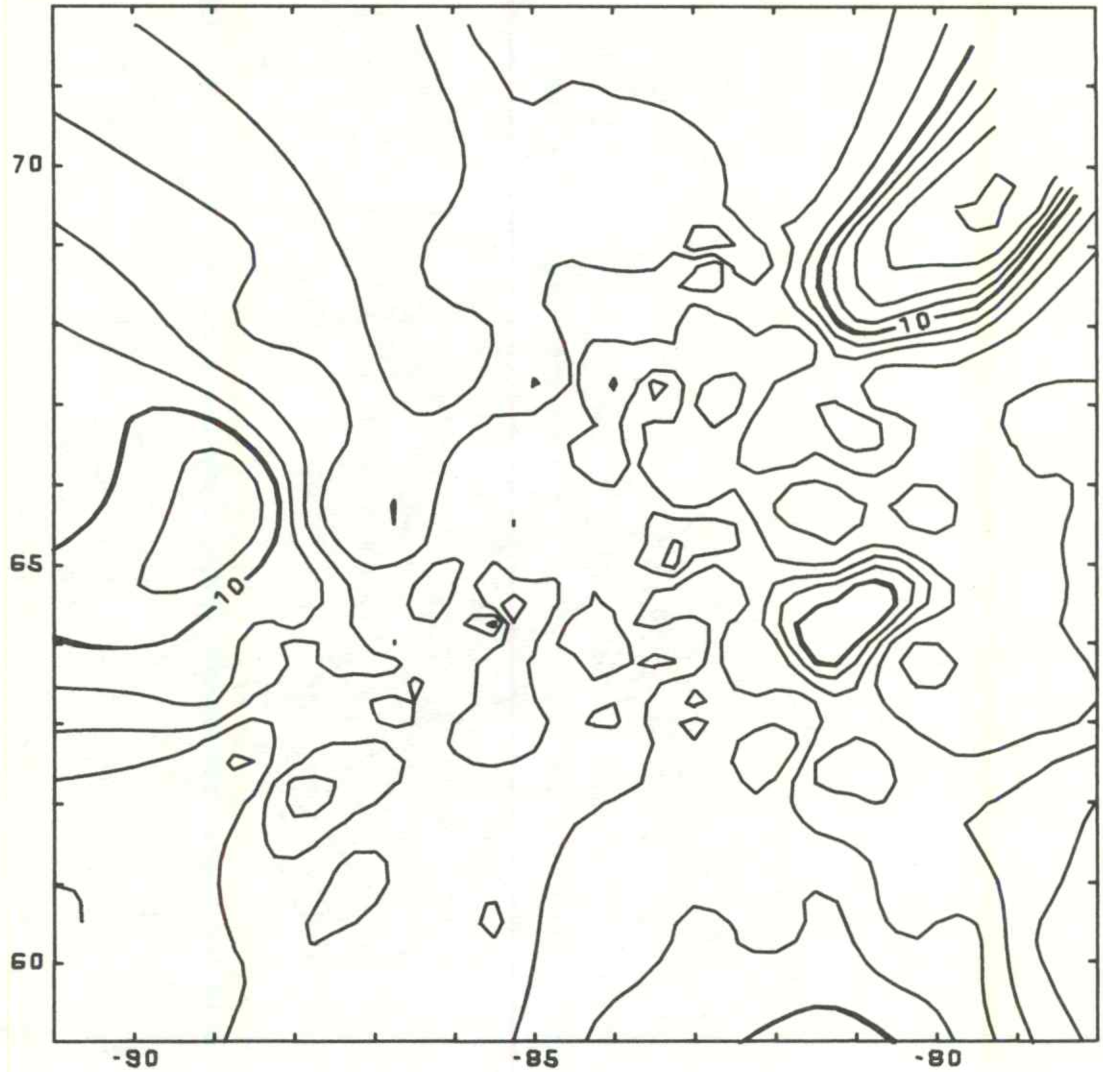


Figure 109.--Total thickness of shale fraction of Mississippian 'B' interval. The grid matrix for this map was created by using the 'MMUL'-TIPLY command to combine Figures 107 and 108.

'MOUT'PUT - prints or punches the grid matrix.

Field Number	Parameter Description	Assumed Value
1	Type of output desired. If 0, the grid matrix will be printed by rows. If 1, the grid matrix will be printed by columns. If 2, the grid matrix will be punched by rows. If 3, the grid matrix will be punched by columns.	1
2	Format of punched output.[1]	Required only for punched output

A matrix must have been previously read or generated before this command can be executed. If a matrix is read in, the 'ECHO' command can be used to print it as it is read. 'MOUT'PUT, on the other hand, prints the matrix after alterations, if any, have been made. For example, it may be used to display the results of commands such as 'MSMO'OTH, 'SCAL'E, 'ISOP'ACH, 'RANG'E, 'DERI'VATIVE, 'FILT'ER, or 'MLEV'EL which modify values of the grid matrix. SURFACE II prints the matrix in strips of eight columns.

The second parameter is required only for punched output. A standard format is used if the matrix is printed.

---

[1] See Appendix B.

'MSMO'OTH - performs "smoothing" or arithmetic averaging of adjacent $\dot{Z}$ values in the grid matrix. One purpose of smoothing is to eliminate undesired "noise" or small-scale variability that may be present in the original grid.

Field Number	Parameter Description	Assumed Value
1	Number of times the smoothing operation is to be performed.	1
2	Specifies type of smoothing. If 0, neighboring values used in the smoothing equation are not weighted. If 1, neighboring values in the smoothing equation are weighted by the inverse of their squared distance from the grid value being smoothed. If 2, neighboring values in the smoothing equation are weighted by the inverse of their distance from the grid value being smoothed.	0
3	Weight factor of center point. Must be greater than 0.	1
4	Number of columns on either side of the grid point being modified to be included in the smoothing equation (maximum = 5).	2
5	Number of rows on either side of the grid point being modified to be included in the smoothing equation (maximum = 5).	2

This command causes arithmetic smoothing of the grid matrix, using those grid values nearest the $\dot{Z}$ value being smoothed. In unweighted smoothing (parameter two is 0), the center point is multiplied by a factor specified by parameter three and averaged with the unweighted values of the nearest specified number of points in the matrix to produce a new value for $\dot{Z}$. In weighted smoothing, each neighboring point is assigned a weight factor. When parameter two is set to 1, $\omega = 1 - d/d_{max}$, where d is the distance from the point being smoothed to the neighboring grid point and d_{max} is the distance to the most distant of the neighboring points used in the smoothing process. If parameter two is set to 2, $\omega = (1 - d/d_{max})^2$.

The smoothed matrix replaces the original grid matrix. If parameter one is greater than 1, the averaging process will be repeated the indicated number of times using the values in the previously modified matrix. If the original grid is to be retained, it must be saved using the 'SAVE' command before smoothing is done.

Figure 110 is a structural contour map of the top of the Lansing Group in part of Graham County, Kansas. The grid matrix was then smoothed using various options of the 'MSMO'OTH command to produce the maps shown in Figures 111 through 120. Figures 111-113 show the effect of different distance weighting options. The most severe smoothing is accomplished by an unweighted average (Fig. 111) and the least smoothing is done by a weighted average in which the weights drop off by the square of their distance away from the point being smoothed (Fig. 112). If the central point among those averaged is heavily weighted, as in Figure 114, the smoothing effect is reduced. Figures 115-118 show the effect of smoothing over increasingly greater numbers of grid points. Figure 115, for example, was smoothed using a weighted average of nine points (one row and one column on either side of the point being averaged). Smoothing, of course, increases as the number of points used in the average is increased. The most severe smoothing in this sequence was done using 121 points (five rows and columns on either side of the point being averaged), shown in Figure 118 and as a block diagram in Figure 120. The block diagram may be compared to Figure 119, which shows the surface before smoothing.

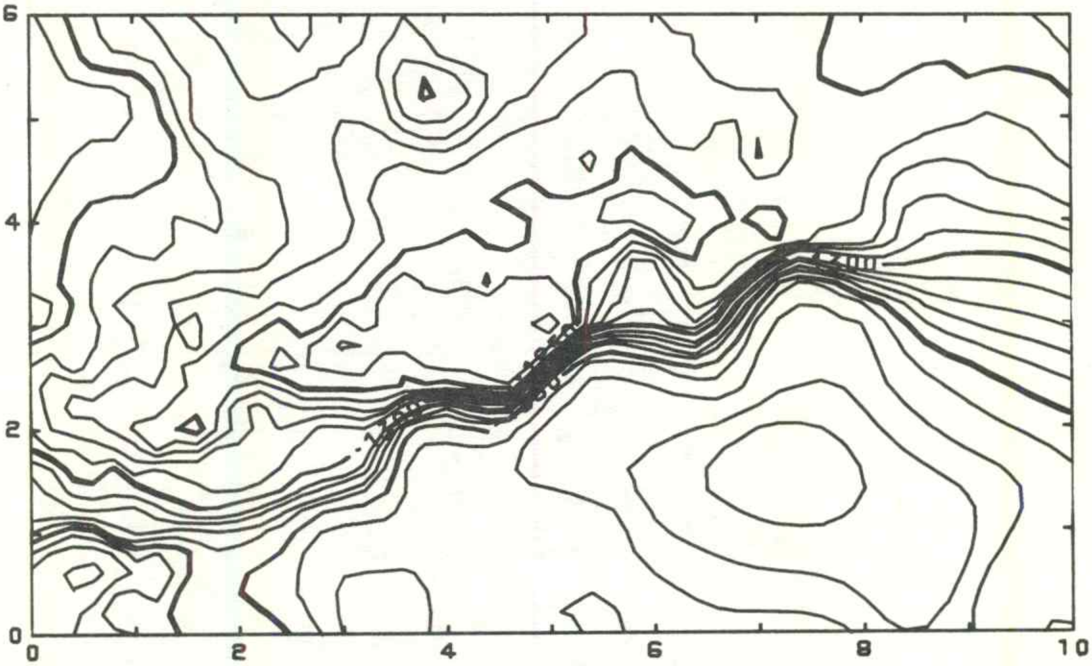


Figure 110.--Contour map showing subsurface structural elevation of the top of the Lansing Group in part of Graham Co., Kansas. Contour interval is 10 feet. Geographic coordinates are in miles from an arbitrary origin.

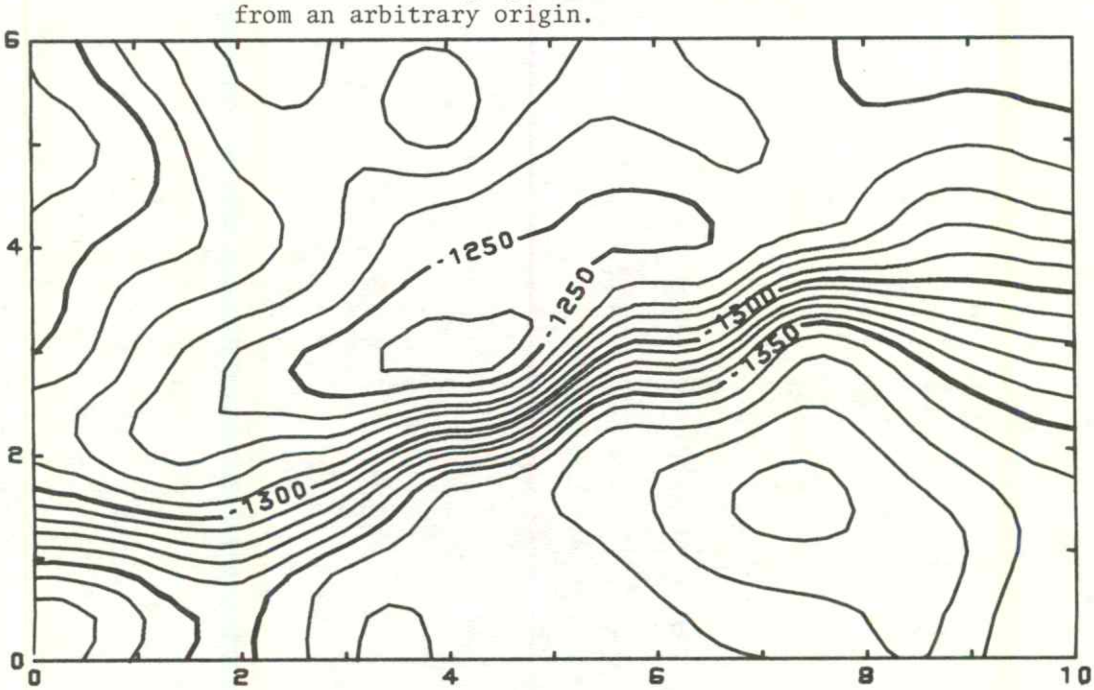


Figure 111.--Grid from Figure 110 smoothed by an unweighted average of two rows and two columns on either side of each grid node. Parameters of 'MSMO'OTH are 1, 0, 1, 2, 2.

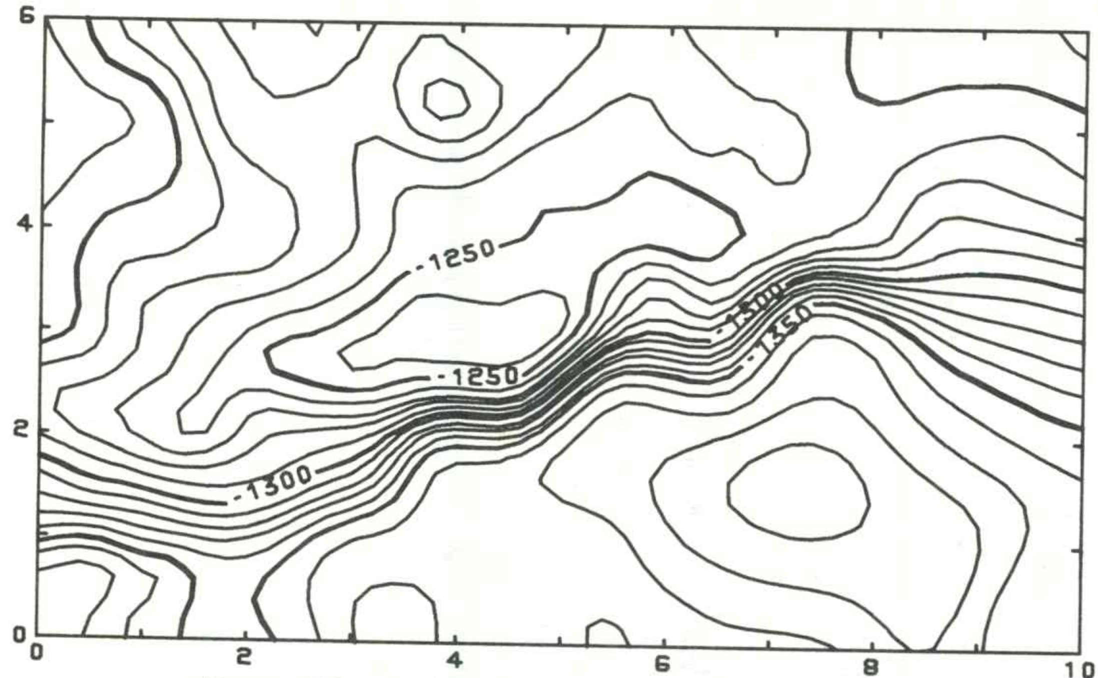


Figure 112.--Grid from Figure 110 smoothed by a weighted average of two rows and two columns on either side of each grid node. Weighting is inversely proportional to the square of the distance between points. Parameters of 'MSMO'OTH are 1, 1, 1, 2, 2.

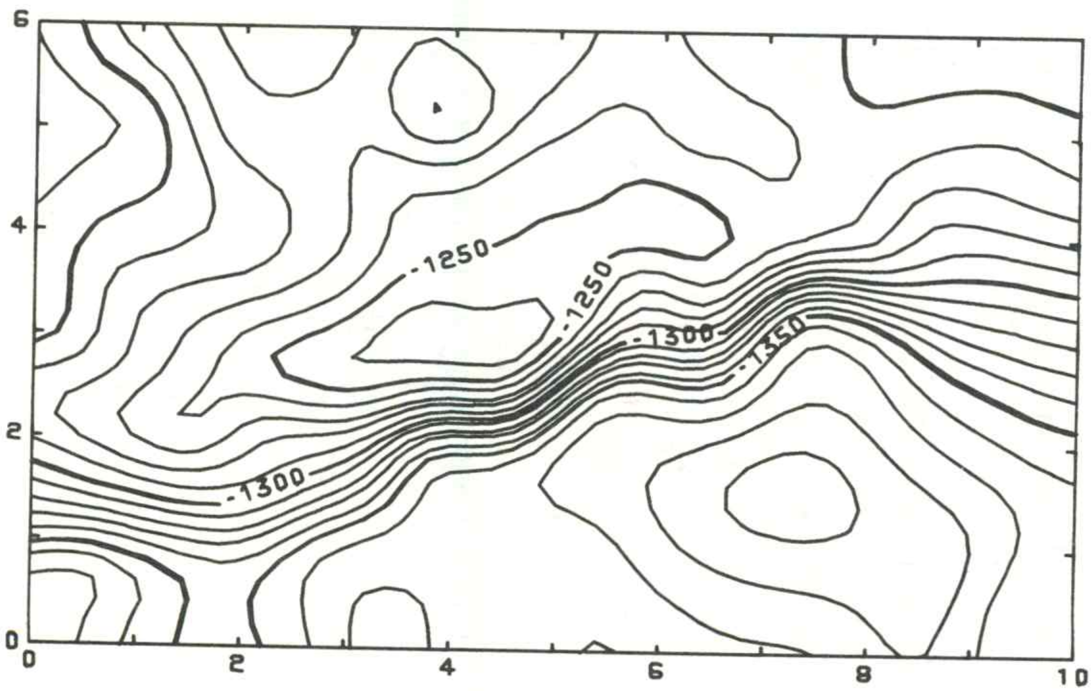


Figure 113.--Grid from Figure 110 smoothed by a weighted average of two rows and two columns on either side of each grid node. Weighting is inversely proportional to the distance between points. Parameters of 'MSMO'OTH are 1, 2, 1, 2, 2.

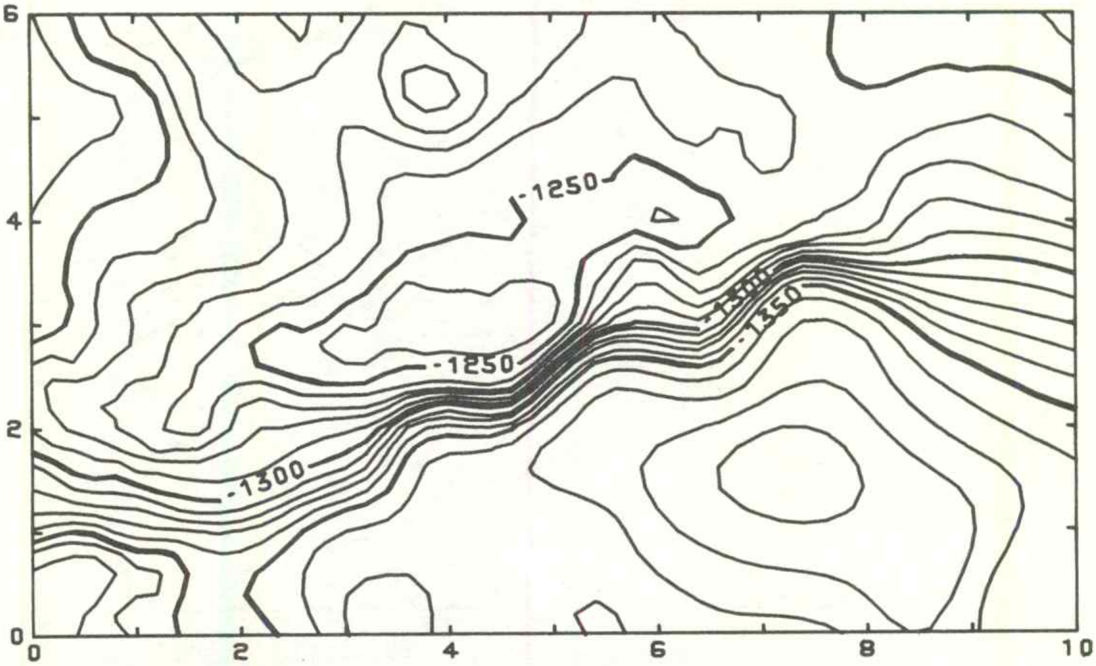


Figure 114.--Grid from Figure 110 smoothed by a weighted average of two rows and two columns on either side of each grid node. Weighting is inversely proportional to the distance between points, except the central value is weighted eight times as much as other points. Parameters of 'MSMO'OTH are 1, 2, 8, 2, 2.

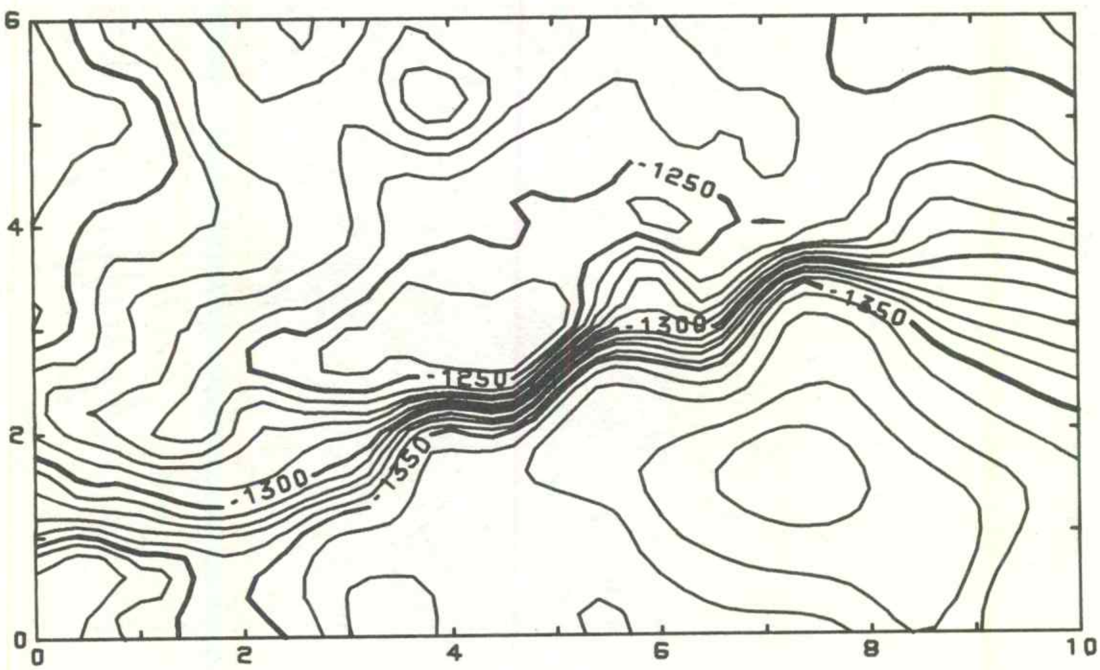


Figure 115.--Grid from Figure 110 smoothed by a weighted average of one row and one column on each side of each grid node. Weighting is inversely proportional to the distance between points. Parameters of 'MSMO'OTH are 1, 2, 1, 1, 1.

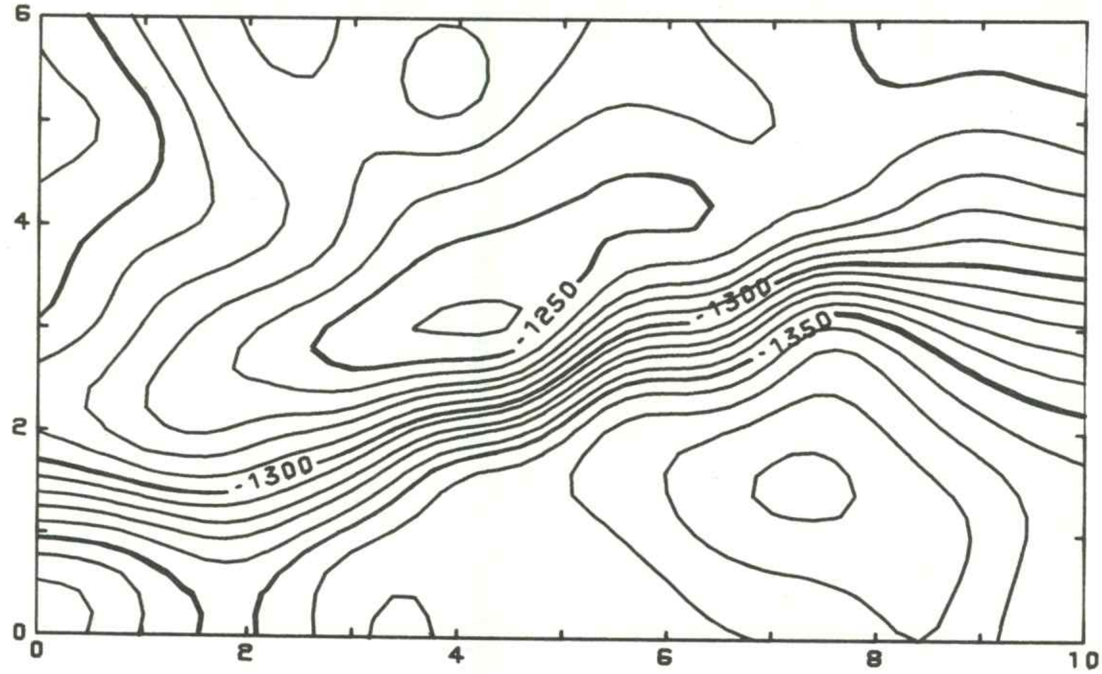


Figure 116.--Grid from Figure 110 smoothed by a weighted average of three rows and three columns on either side of each grid node. Weighting is inversely proportional to the distance between points. Parameters of 'MSMO'OTH are 1, 2, 1, 3, 3.

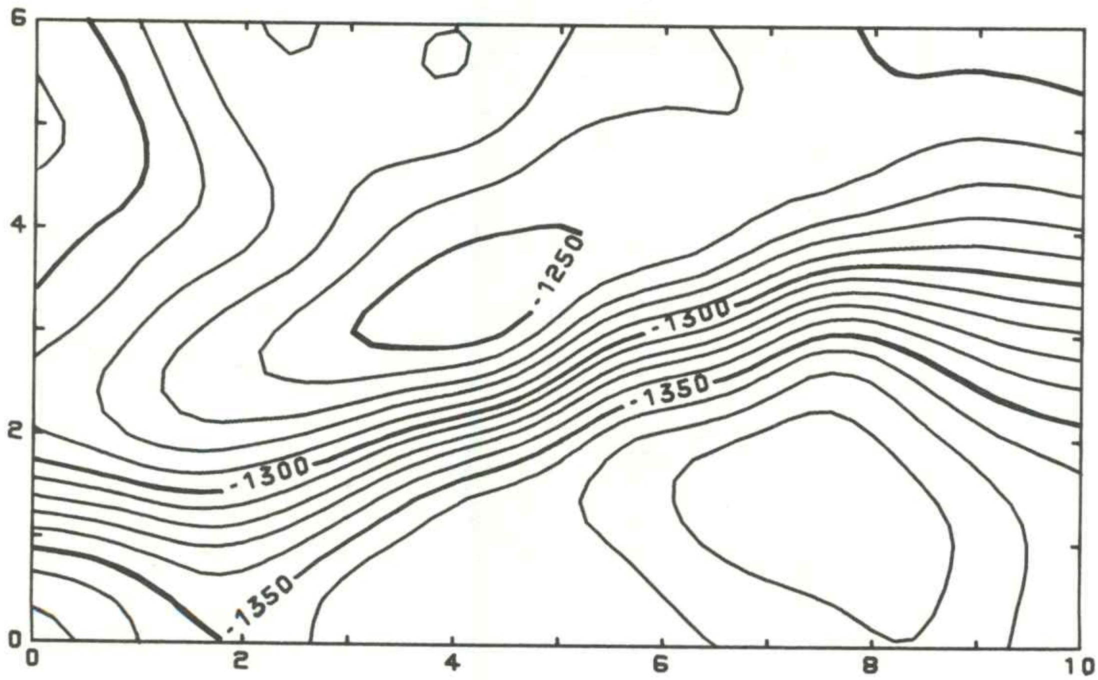


Figure 117.--Grid from Figure 110 smoothed by a weighted average of four rows and four columns on either side of each grid node. Weighting is inversely proportional to the distance between points. Parameters of 'MSMO'OTH are 1, 2, 1, 4, 4.

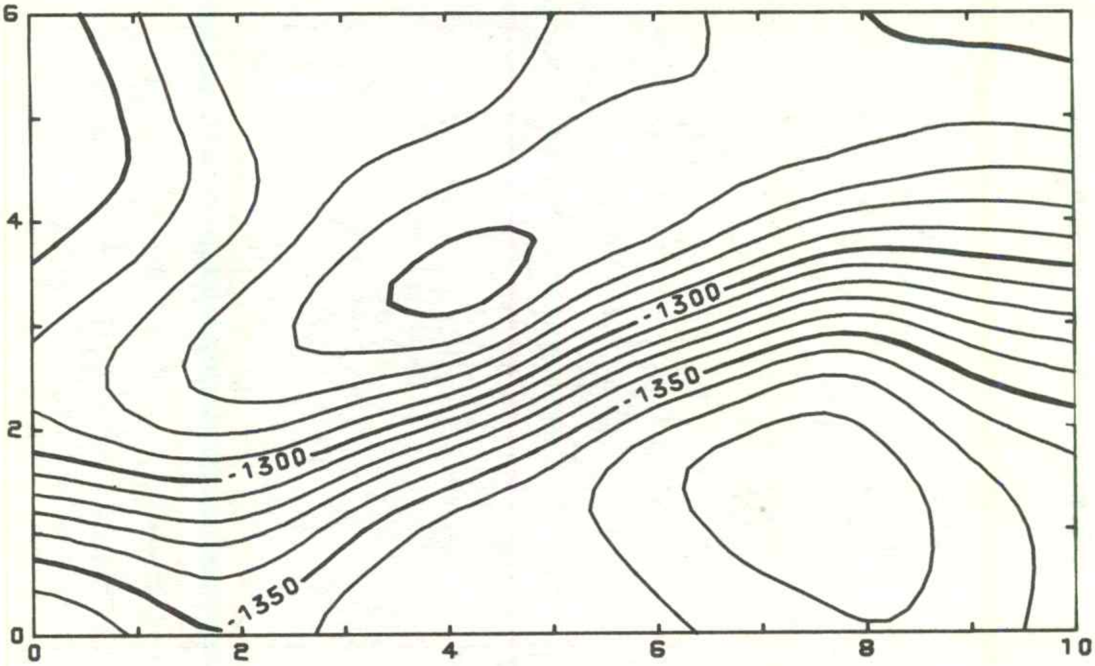


Figure 118.--Grid from Figure 110 smoothed by a weighted average of five rows and five columns on either side of each grid node. Weighting is inversely proportional to the distance between points. Parameters of 'MSMO'OTH are 1, 2, 1, 5, 5.

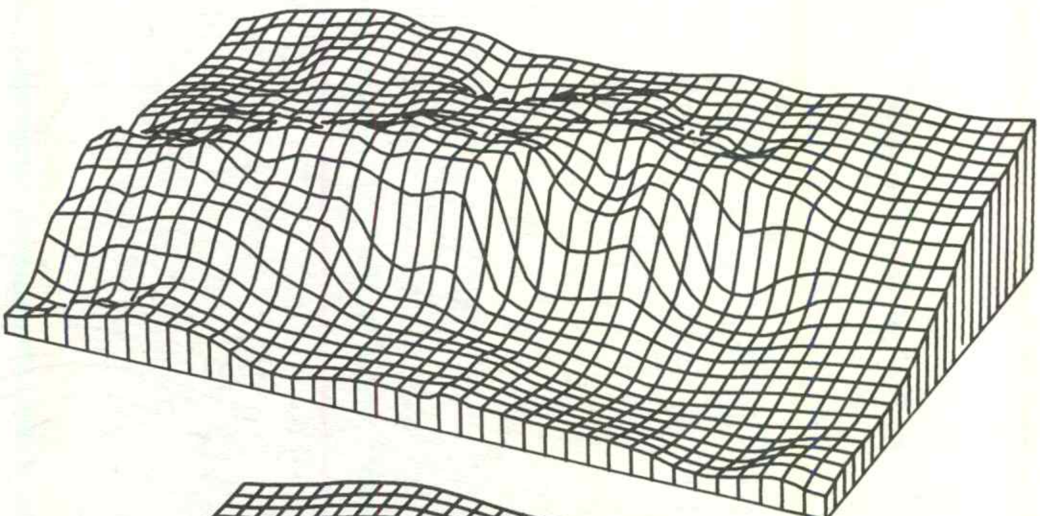


Figure 119.--Grid from Figure 110 displayed as a perspective block diagram.

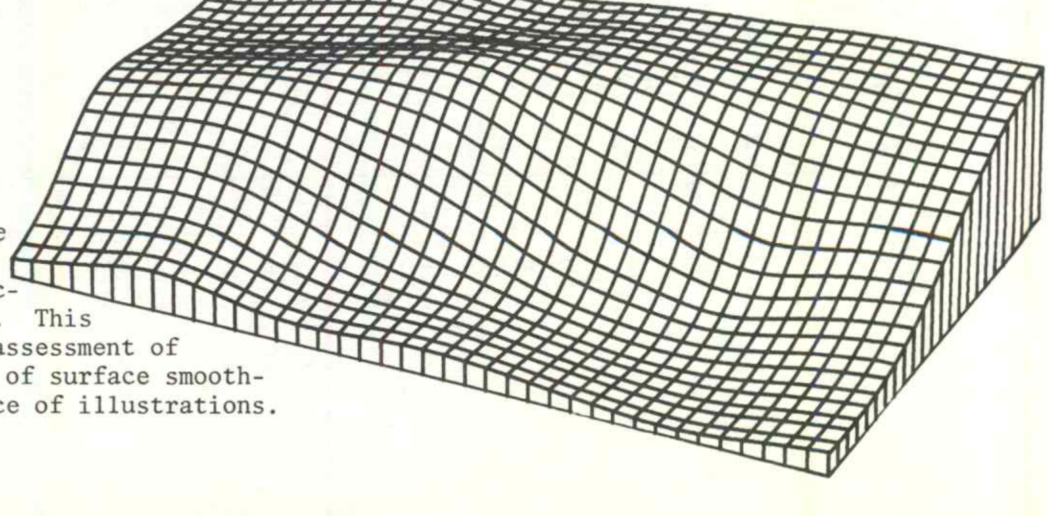


Figure 120.--Smoothed grid used to create Figure 118 displayed as a perspective block diagram. This provides a visual assessment of the maximum degree of surface smoothing in this sequence of illustrations.

'NEAR' - specifies that sample data points to be used to estimate an element in the grid matrix be found by a nearest neighbor search around that element. A nearest neighbor search finds the n nearest points regardless of their radial distribution around the element to be estimated.

Field Number	Parameter Description	Assumed Value
1	Use of the search procedure. If 1, use a nearest neighbor search in Phase 1 of 'GRID'. If 2, use a nearest neighbor search in Phase 2 of 'GRID'. If 3, use a nearest neighbor search in 'DMAP'.	1
2	Number of neighboring data points to be found.	8
3	Maximum allowable distance, in units of X and Y, of the nearest data point.	Variable[1]
4	Maximum search radius, in units of X and Y.	Variable[2]

This search procedure calculates the Euclidean (straight-line) distance from the location of a grid node to the surrounding data points. The closest n of these, as specified by parameter two, are used to estimate a value Z at the grid node. The nearest point must lie within the radial distance specified by parameter three. All of the specified number of points must lie within the maximum radial distance specified by parameter four. If either of these conditions is not met, the search "fails" and the grid node is set to the default or blank value. Figure 121 shows the 'NEAR' search pattern on a typical data point distribution.

The minimum number that may be specified for parameter two is 4, and the maximum allowable is 48. The assumed values of parameters three and four are calculated from the size of the map area, as defined by the 'EXTR'EMES command, and the number of points on the map. The assumed limits are sufficiently broad so all grid elements will be estimated if the data points are distributed in a reasonably uniform manner across the map.

Specification of a small number of control points in parameter two may result in an irregular estimated surface that contains abrupt changes in slope. Grid nodes near control points will be estimated with great accuracy, because the value of the nearby point is averaged with only a few more distant points. However, poor estimates may be made of grid nodes in areas of sparse control. On the other hand, specification of a large number of control points may cause

[1] Set to the radius necessary to include twice the required number of data points specified in parameter two, assuming a uniform density of points across the map.

[2] Set to the radius necessary to include five times the required number of data points specified in parameter two, assuming a uniform density of points across the map.

excessive smoothing of the surface. Figures 122, 123, and 124 show maps constructed using different numbers of nearest neighbors in the estimation procedure. Selection of an optimum number of points to be used in the estimating algorithm can be made only by considering the variability in the surface to be estimated and the nature of the data point distribution. Experimentation with different parameters may be necessary to determine the best selection.

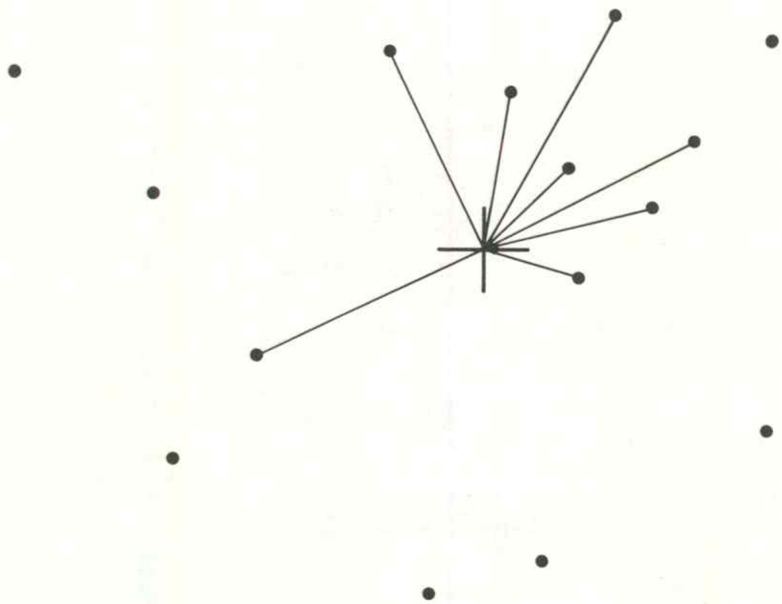


Figure 121.--Search pattern used by 'NEAR' to find the eight closest values to a grid node being estimated.

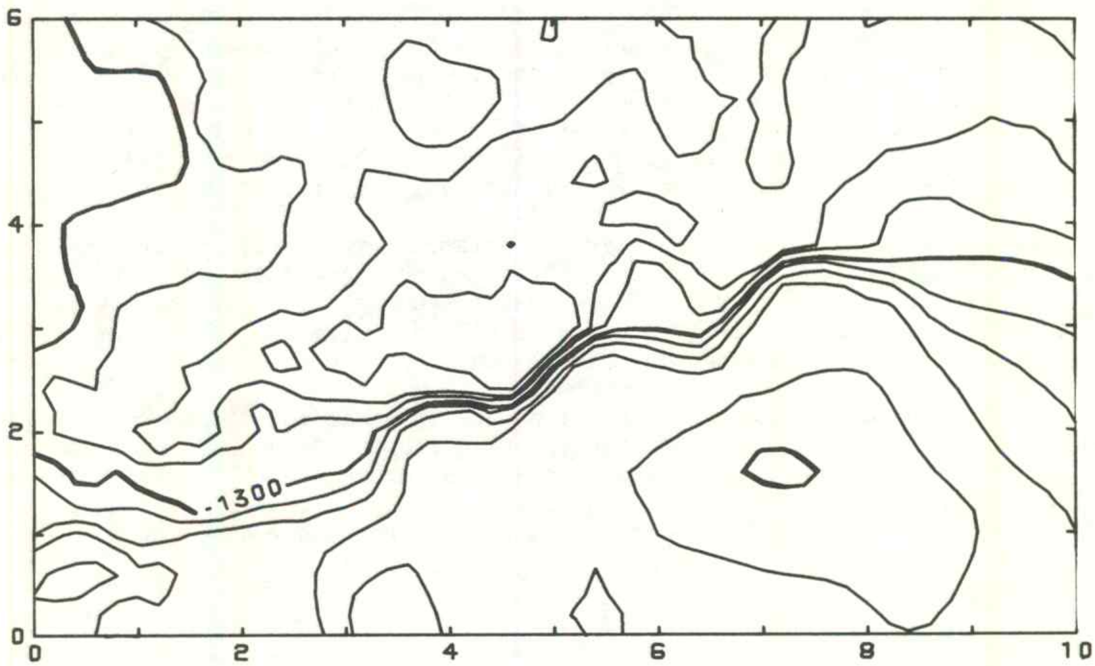


Figure 122.--Subsurface structural map of the top of Lansing Group (Pennsylvanian) in part of Graham County, Kansas. Grid nodes were estimated from points found by a nearest neighbor search for the five closest control points.

NEAR

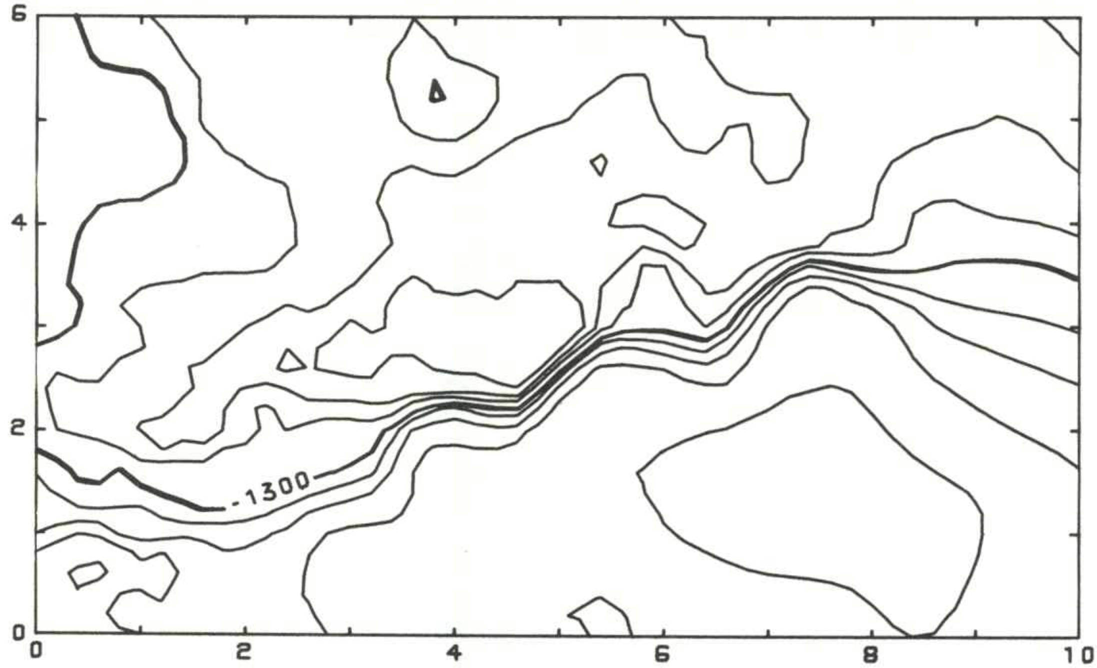


Figure 123.--Contour map of the data shown in Figure 122, but gridded using eight closest control points in a nearest neighbor search.

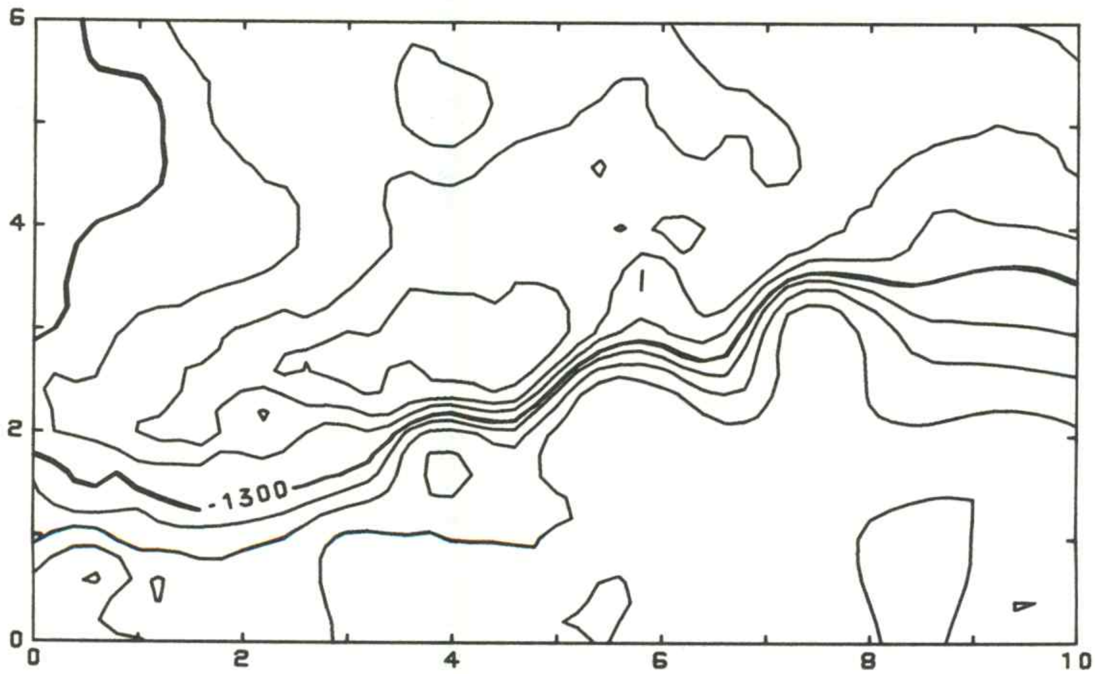


Figure 124.--Contour map of the data shown in Figure 122, but gridded using sixteen closest control points in a nearest neighbor search.

'NNA ' - performs a nearest neighbor analysis of control point locations.

Field Number	Parameter Description	Assumed Value
1	Class interval width for histogram.	Variable[1]

The distance between each control point and the closest other control point (nearest neighbor) is calculated. Nearest neighbor distances are presented in the form of a histogram and summary statistics of the distribution are calculated. These include the first four moments of the distribution and the nearest neighbor statistic, R, calculated as

$$R = \frac{\overline{D}}{\overline{\Delta}}$$

$\overline{D}$ is the mean nearest neighbor distance and $\overline{\Delta}$ is the expected nearest neighbor distance for a random distribution of points ($\overline{\Delta} = \frac{1}{2}\sqrt{p}$, where p is the density of points, defined as the number of control points divided by the map area).

R ranges from 0 for a distribution where all points coincide, to 1.0 for a random distribution of points, to a maximum of 2.15 which characterizes a point distribution in which the mean distance to the nearest neighbor is maximized. Values of R less than 1.0 indicate a tendency for clustering of points, whereas values greater than 1.0 indicate a tendency for uniform spacing of points.

---

[1] The range of nearest neighbor distances is divided into 25 categories whose boundaries are adjusted to rational limits.

'OCTA'NT - specifies that sample data point to be used to estimate an element in the grid matrix be found by an octant search around that element. An octant search finds the n nearest point in each octant around the element to be estimated.

Field Number	Parameter Description	Assumed Value
1	Use of the search procedure. If 1, use an octant search in Phase 1 of 'GRID'. If 2, use an octant search in Phase 2 of 'GRID'. If 3, use an octant search in 'DMAP'. If 4, use an octant search in the standard neighborhood for Kriging. If 5, use an octant search in the wide neighborhood for Kriging.	1
2	Maximum number of points to be retained in each octant.	2
3	Maximum allowable distance, in units of X and Y, of the nearest data points. For Kriging, this is the minimum number of data points that must be found in a search. The assumed number of points is eight.	Variable[1]
4	Maximum search radius, in units of X and Y.	Variable[2]
5	Minimum number of sectors that must have at least one data point.	6
6	Orientation of octants to the X-Y axis (-22.5 to 22.5 degrees).	0°

An octant search procedure divides the area around a grid node into eight equal segments. The nearest n points, where n is specified by parameter two, are found in each octant. The grid node is not estimated and is set to the default or blank value. The search for additional points in an octant will not extend beyond the maximum search radius specified by parameter four. The search pattern is shown in Figure 125.

Unless the minimum number of octants specified by parameter five contain at least one control point each, the search "fails" and the grid node around which the search is being conducted is set to the default or blank value. A total of at least four data points must be found for a successful search.

---

[1]Set to the radius necessary to include twice the required number of data points specified in parameter two, times eight, assuming a uniform density of points across the map. For Kriging, the assumed value is eight points.

[2]Set to the radius necessary to include five times the required number of data points specified in parameter one, times eight, assuming a uniform density of points across the map. For Kriging, the maximum search radius must be specified.

The maximum allowable number of points per octant that may be specified in parameter two is 6. The assumed values of parameters three and four are calculated from the size of the map area, as defined by the 'EXTR'EMES command, and the number of points on the map. The assumed limits are sufficiently broad so all grid elements will be estimated if the data points are distributed in a reasonably uniform manner across the map. However, if the minimum acceptable number of filled octants is large (over 6), searches around grid nodes near the margins of the map may fail because most of two or more octants may lie outside the map area.

An octant search may introduce more smoothing into an estimated surface than will a nearest neighbor search using the same number of points. This is because points will be ignored in an octant in which the maximum number of points have already been located, even if these points are closer to the grid node than points in other octants. The effect is to spread the search over a greater area, using more distant points than would otherwise be the case.

Octant searches are especially useful with certain types of control point distributions. If data such as aeromagnetic or seismic measurements are collected at closely spaced intervals along widely separated traverses, a nearest neighbor search may attempt to estimate grid nodes using control values from only a single line of points. Such estimates are essentially unconstrained except in one dimension, and unrealistic slopes may be generated between the lines of control points. An octant search forces the estimating procedure to use control points radially distributed around the grid node being estimated. This introduces control from neighboring traverses and insures a two-dimensional constraint on the surface between the traverses. Figures 126 and 127 show a surface generated from simulated seismic traverses using the nearest neighbor and octant searches.

It is possible that traverses of control points, such as aircraft flight lines, might parallel the orientation of rows or columns in the grid matrix. This can lead to an undesirable interaction with the octant search pattern. Parameter six allows the octant pattern to be rotated to minimize this interaction effect.

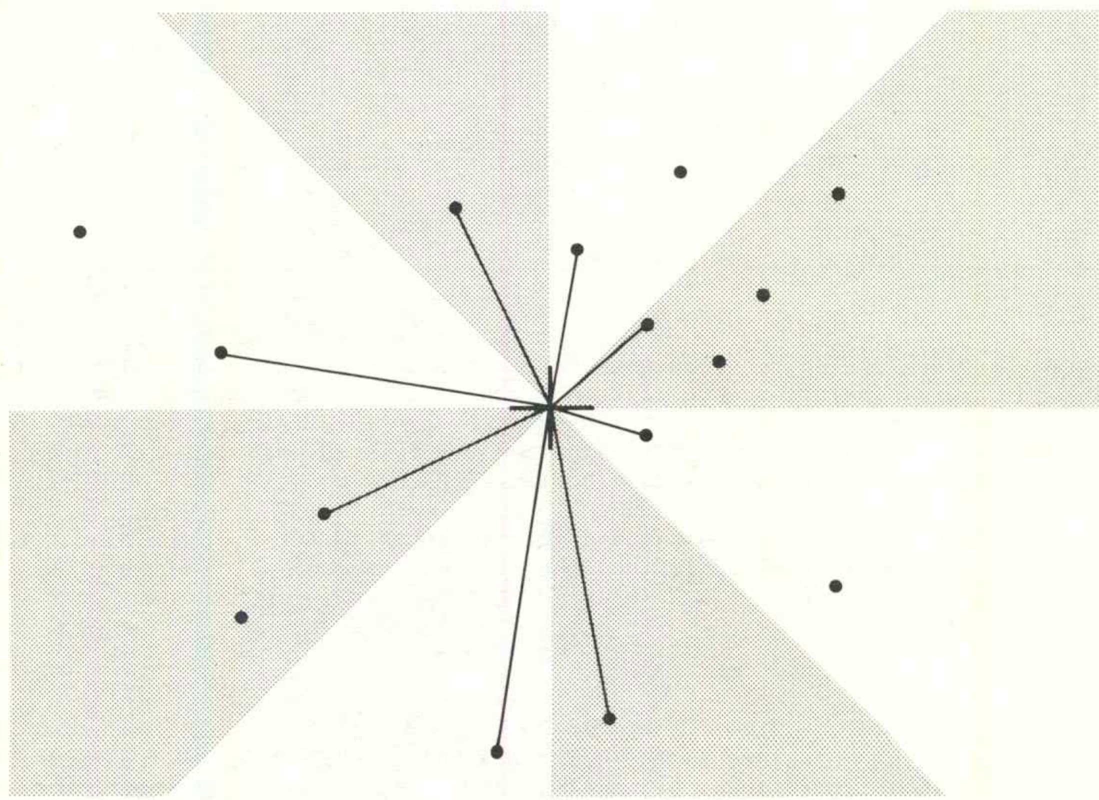


Figure 125.--Search pattern used by 'OCTA'NT to find the closest control point in each octant around a grid node.

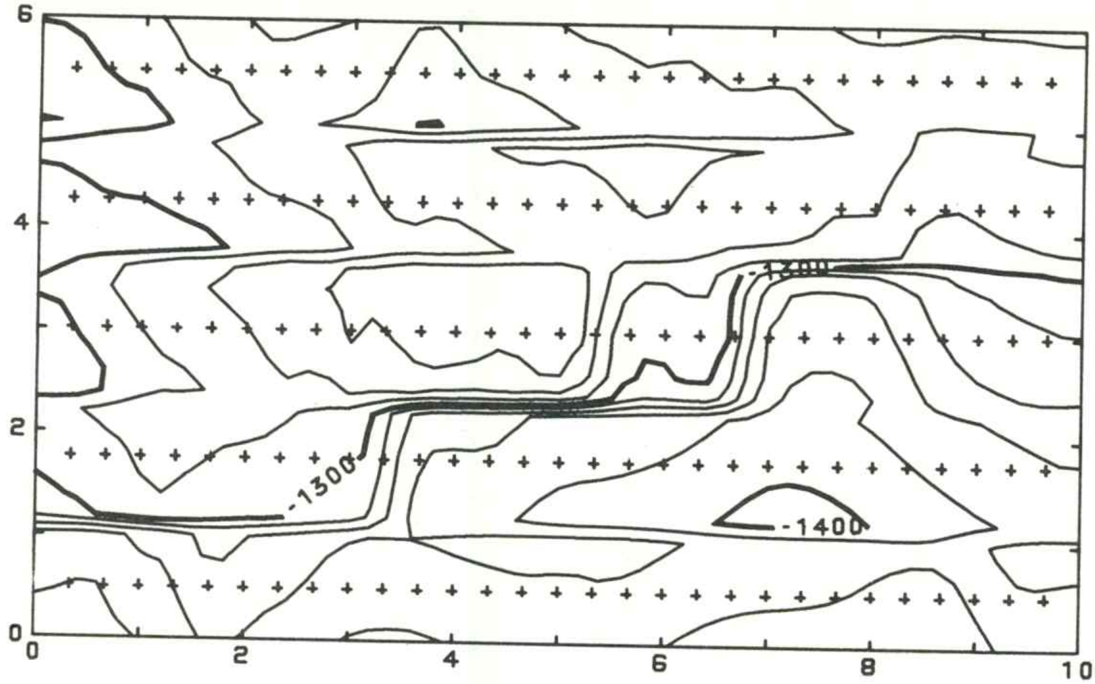


Figure 126.--Simulated seismic structure map of the top of the Lansing Group in part of Graham Co., Kansas, created by a nearest neighbor search for eight points. The simulated seismic data is spaced along widely separated traverses.

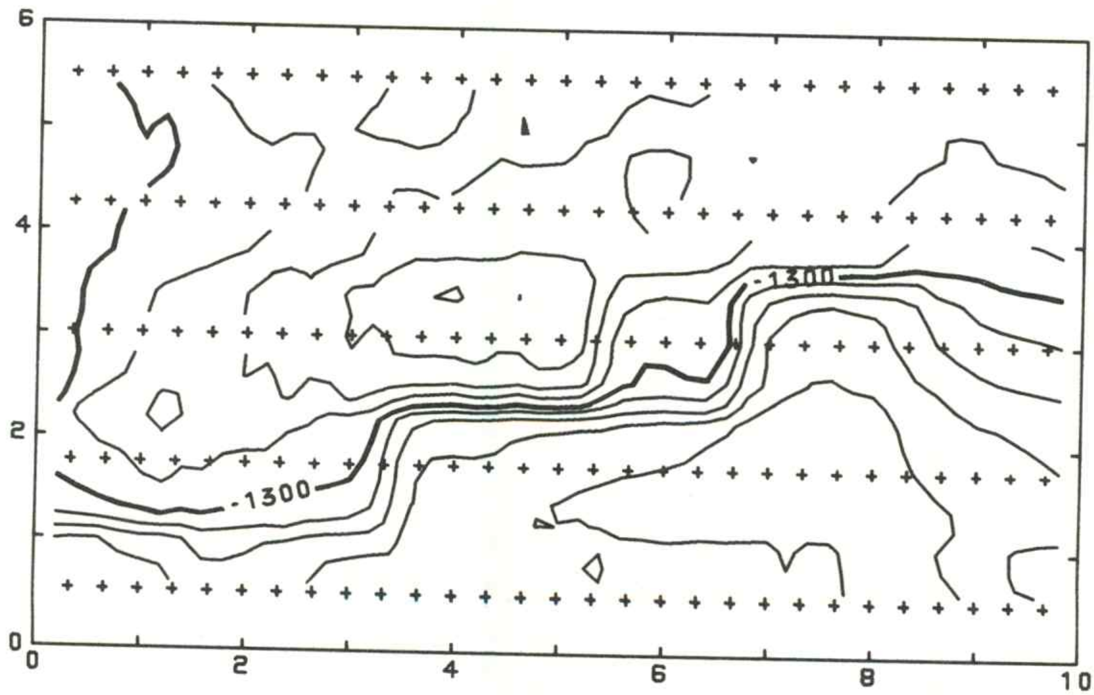


Figure 127.--The same data shown in Figure 126, contoured using an octant search procedure. The search specified one point per octant, or eight points for each estimated grid node.

'ODXY' - prints or punches the sample data set.

Field Number	Parameter Description	Assumed Value
1	Type of output desired. If 0, a listing of the data points will be printed. If 1, a card deck of the data points will be punched.	0
2	Format of output deck.[1]	Required only for punched output

This command prints a listing or punches a deck of cards containing the array of sample data points after all alterations to the data set have been executed. One use of 'ODXY' is to list residuals from original sample data points, which have been calculated by 'MLEV'EL or 'TREN'D.

Five fields are punched or printed on each logical record, in the following order: (1) ID-variable, (2) X-value, (3) Y-value, (4) Z-value, and (5) posting symbol character. The second parameter of this command is required to specify the location and size of the five fields in the output record.

---

[1]See Appendix B.

'OFF ' - resets the parameters of a SURFACE II command to their assumed values.

Field Number	Parameter Description	Assumed Value
1	The SURFACE II command to be reset to its assumed value.	Required

The parameter field should contain the first four letters of the SURFACE II command which is to be reset to its assumed parameter values. Only one SURFACE II command may be specified in an 'OFF ' command.

The following series of SURFACE II commands illustrate the use of the 'OFF ' command. The first 13 commands grid a data set and produce the transect diagram shown in Figure 26. The OFF AZIM command will cause the 'AZIM'UTH command to revert to its assumed value of 45°.

	Command	Parameters
Grid original data	TITLE	OFF COMMAND TEST FOR SURFACE MANUAL
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	GRID	1,0.2,0.2
	EXTREMES	0,10,0,6
	DEVICE	1,'SAMPSON',60,40,3,3
	PERFORM	
Establish dimensions and draw first diagram (Fig. 26)	TRANSECT	0,20,0
	SIZTRANSECT	6
	LINES	1,40,24
	DISTANCE	100
	ELEVATION	30
	AZIMUTH	25
	PERFORM	
Reset 'AZIM'UTH to assumed value (45°) & draw another diagram	OFF	AZIM
	TRANSECT	0,20,0
	PERFORM	
	STOP	

'OVER'LAY - allows superposition of two or more maps.

No parameters

The 'OVER'LAY command causes a map or posting to be drawn on top of a previously drawn map. The command must appear within the command sequence of the second map. The map border will not be redrawn. As the overlain map is always drawn on the immediately preceding map, a series of overlays may be placed on a common base by repeated use of the 'OVER'LAY command. An 'OVER'LAY map must not exceed the dimensions of the map on which it is to be placed, as defined by the 'BXEX'TREMES command.

Examples of the use of 'OVER'LAY are shown in Figures 132 and 133.

'PCON'TOUR - prints a contour map on the line printer.

Field Number	Parameter Description	Assumed Value
1	Method of printing contour intervals. If 0, contour intervals are shown as successive bands of print, each band consisting of identical characters. If 1, contour intervals are shown as bands of print alternating with blank bands. If 2, contour intervals are shown as bands of overprinted characters, producing different shadings.	0
2	Elevation of lowest contour level.	0
3	Size of contour interval.	10
4	Maximum number of contour levels.	Variable[1]

A contour map may be displayed using the line printer with the command 'PCON'TOUR. Instead of attempting to print lines (which would be discontinuous in a line printer presentation), SURFACE II produces solid bands of print to denote intervals between successive contour lines. Figures 128-130 show maps of subsurface structure in Graham County, Kansas, printed using the three options of parameter one. These maps were originally 10 x 6 1/4 inches.

The physical size of the printed map is controlled by 'SIZP'CONTOUR. The size of a map is not restricted to the 120-character width of the line printer; it may be printed in successive strips which can be spliced together to create a map of any desired physical size. SURFACE II will automatically print a map in strips if the specified size exceeds the width of the printer carriage. In general, a line printer map should be larger than an equivalent plotted contour map. This will avoid loss of surface features which otherwise would be smaller than a single print position.

The value of the lowest surface elevation to be displayed on a printed contour map is given by parameter two. The contour interval, or distance between contour levels, is given in parameter three and the maximum number of contour levels is set by parameter four. The actual number of contour levels generated depends on the range of $\dot{Z}$ values in the grid matrix. For example, suppose SURFACE II executed the command

PCONTOUR 0,1000,50,15

and $\dot{Z}$ values in the grid matrix range from 935 to 1284. Since the lowest elevation that will appear on the printed contour map is 1000, all $\dot{Z}$ values below 1000 are ignored. Only seven contour levels will be generated, and thus there will be six distinct bands of print, each representing one contour interval on the final map. The contour levels will be:

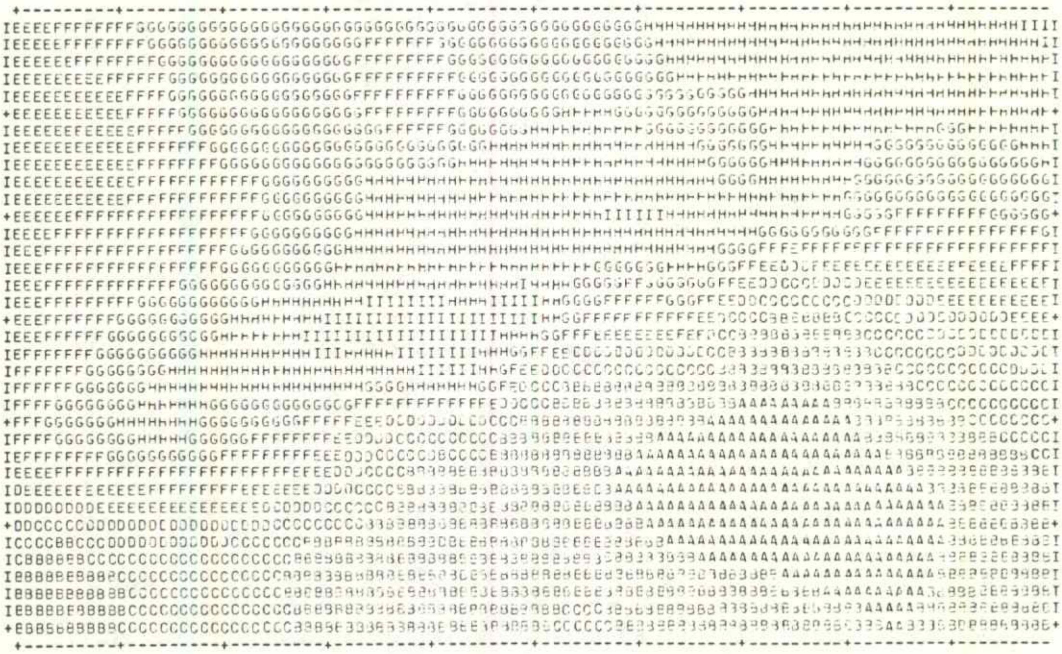
---

[1] If parameter four is not specified or is 0, sufficient contour intervals will be created to cover the range of the data.

1000
1050
1100
1150
1200
1250.

Contour intervals displayed on the map represent the following intervals:

1000 to 1050
1050 to 1100
1100 to 1150
1150 to 1200
1200 to 1250
1250 to 1300.



****** CONTOUR LEVELS TABLE ******

-1400.0000	TO	-1380.0000	=	AAAA
-1380.0000	TO	-1360.0000	=	BBBB
-1360.0000	TO	-1340.0000	=	CCCC
-1340.0000	TO	-1320.0000	=	DDDD
-1320.0000	TO	-1300.0000	=	EEEE
-1300.0000	TO	-1280.0000	=	FFFF
-1280.0000	TO	-1260.0000	=	GGGG
-1260.0000	TO	-1240.0000	=	HHHH
-1240.0000	TO	-1220.0000	=	IIII
-1220.0000	TO	-1200.0000	=	JJJJ

Figure 128.--Line printer contour map of subsurface structure in Graham Co., Kansas, printed under option 0 of parameter one.

Figure 129.--Line printer contour map printed using option 1 of parameter one.

****** CONTOUR LEVELS TABLE ******

-1400.0000	TO	-1380.0000	=	AAAA
-1380.0000	TO	-1360.0000	=	
-1360.0000	TO	-1340.0000	=	BBBB
-1340.0000	TO	-1320.0000	=	
-1320.0000	TO	-1300.0000	=	CCCC
-1300.0000	TO	-1280.0000	=	
-1280.0000	TO	-1260.0000	=	DDDD
-1260.0000	TO	-1240.0000	=	
-1240.0000	TO	-1220.0000	=	EEEE
-1220.0000	TO	-1200.0000	=	

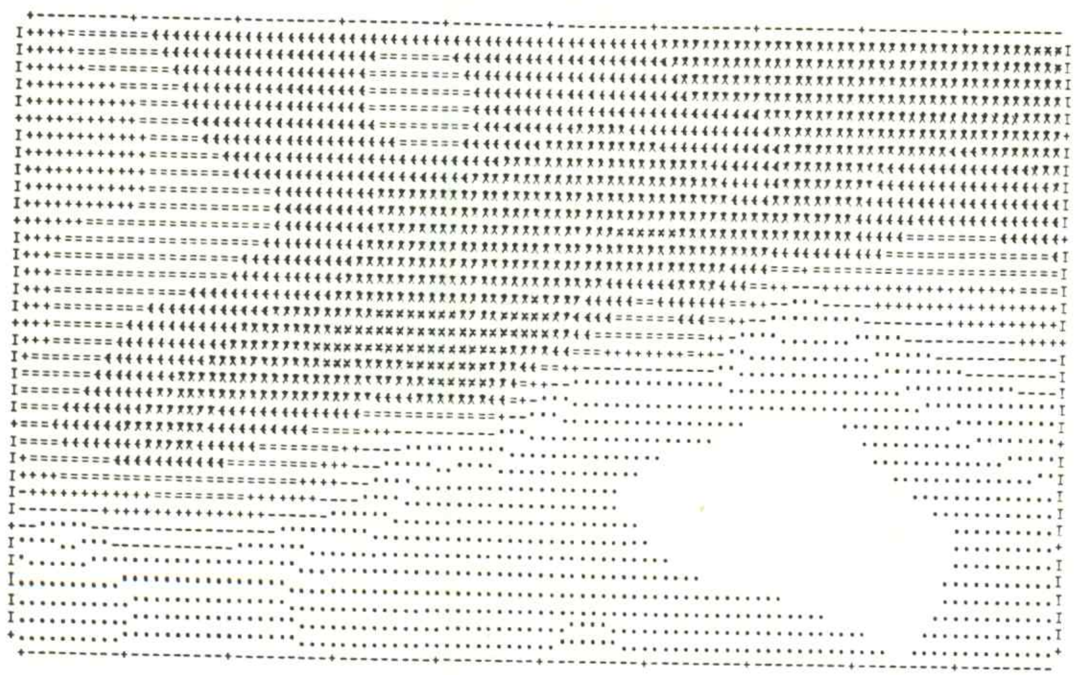


Figure 130.--Line printer contour map printed using option 2 of parameter one.

****** CONTOUR LEVELS TABLE ******

-1400.0000	TO	-1380.0000	=	
-1380.0000	TO	-1360.0000	=	....
-1360.0000	TO	-1340.0000	=	''''
-1340.0000	TO	-1320.0000	=	----
-1320.0000	TO	-1300.0000	=	++++
-1300.0000	TO	-1280.0000	=	====
-1280.0000	TO	-1260.0000	=	((((
-1260.0000	TO	-1240.0000	=	XXXX
-1240.0000	TO	-1220.0000	=	XXXX
-1220.0000	TO	-1200.0000	=	MMMM

'PERF'ORM - initiates processing of SURFACE II commands. No processing is done until this command is encountered.

NO PARAMETERS

SURFACE II commands (with the exceptions of 'CLEA'R, 'OFF ', and 'STOP') are not executed until a 'PERF'ORM command is encountered in the command sequence. All unexecuted commands prior to the 'PERF'ORM are then executed. The order in which SURFACE II commands will be executed is predetermined and not influenced by the physical arrangement of the commands in the command sequence (this predetermined order is listed in the Introduction). However, 'PERF'ORM statements may be used to alter this sequence and give the user complete flexibility in controlling the sequence of operations. For example, a typical command segment might be

```
GRID
SAVE     12
MSMOOTH  1,0,1,1,1
PERFORM
```

Because of the predetermined order of execution, the gridded matrix will be smoothed prior to being saved on external file 12. The command segment

```
GRID
SAVE     12
PERFORM
MSMOOTH  1,0,1,1,1
PERFORM
```

is identical except for the second 'PERF'ORM statement after the 'SAVE' command. This will cause the original matrix to be saved on the external file before smoothing.

IMPORTANT NOTE: Although the 'PERF'ORM command is used to alter the predetermined order of execution, it does not change the values of certain previously set parameters. New parameters may be specified by repeating the commands with the desired new values, or may be reset to their assumed values by an 'OFF ' command.

'POST' - generates a posting of the sample data points.

Field Number	Parameter Description	Assumed Value
1	Determines how points are to be labeled. If 0, points are labeled with the value of the Z-variable. If 1, points are labeled with the ID-variable. If 2, symbols are posted without labels	0
2	Number of characters to the right of the decimal point in the label.	1
3	Height of symbol, in inches.	0.1
4	Height of label, in inches	0.1
5	Code for symbol to be posted.	1

A posting is a map which shows the locations of sample data points. The points may be indicated by a variety of different symbols, and may be labeled with either an identification number or with their Z-value. Choice of labels is made by parameters one and two of 'POST'. A posting may be a separate, independent plot or may be superimposed on a contour map. Examples of these two applications are shown in Figure 131 and 132, which show the well control in an area of Graham Co., Kansas. A post can be placed on a previously drawn contour map (or on a previously drawn posting) by use of the 'OVER'LAY command.

Symbol and label size can be controlled independently using parameters three and four. The symbols which can be used and their code are given in the following table. Parameter size allows selection of a desired symbol if the input data file does not contain symbol codes. If parameter five of 'POST' is set to 0, symbol codes for individual points may be entered using the 'IDXY' command.

Figure 133 shows wells in part of Graham Co., Kansas, plotted with different symbols for dry and producing wells.

Codes and posting symbols specified by parameter five of 'POST'

0 = read symbol code from input data file

1 = +	4 = ⌖
2 = ×	5 = △
3 = ○	6 = □

AUXILIARY COMMANDS used with 'POST':

'BOX '
'BXEX'TREMES
'OVER'LAY
'POUT'LINE
'SIZC'ONTOUR

The 'BOX ' command controls the annotation of the border of the plot. The size of this border is controlled by 'BXEX'TREMES. A posting can be superimposed on a contour map using 'OVER'LAY. Outlines and similar information can be placed on a posting using 'POUT'LINE. The physical dimensions of the posting are given by 'SIZC'ONTOUR.

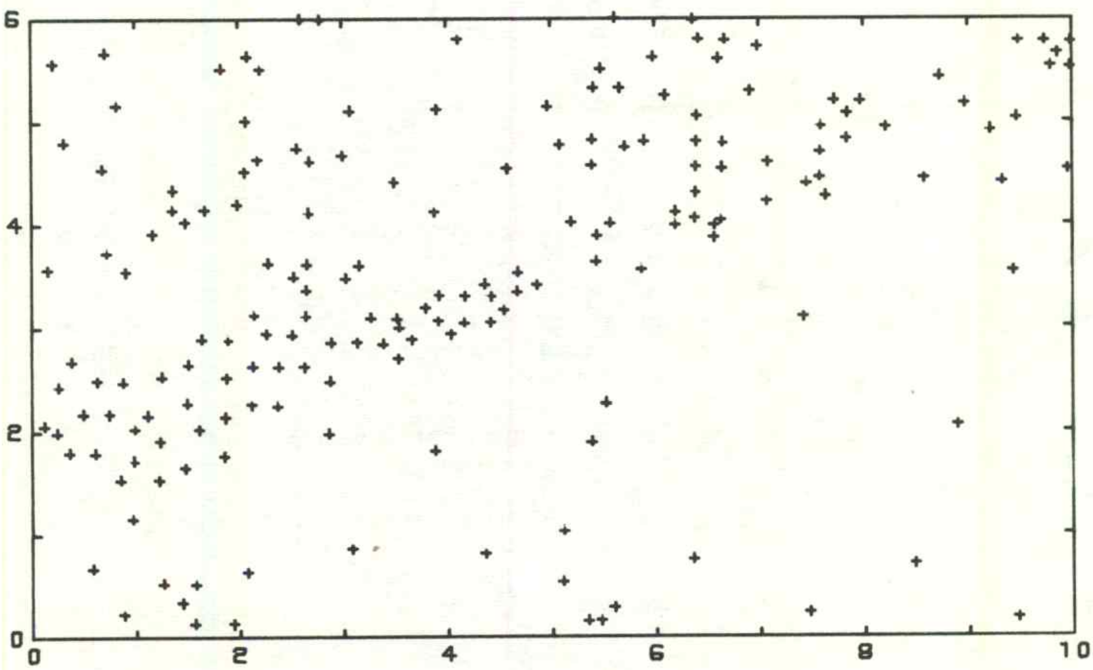


Figure 131.--Posting of control wells in a portion of Graham Co., Kansas.

POST

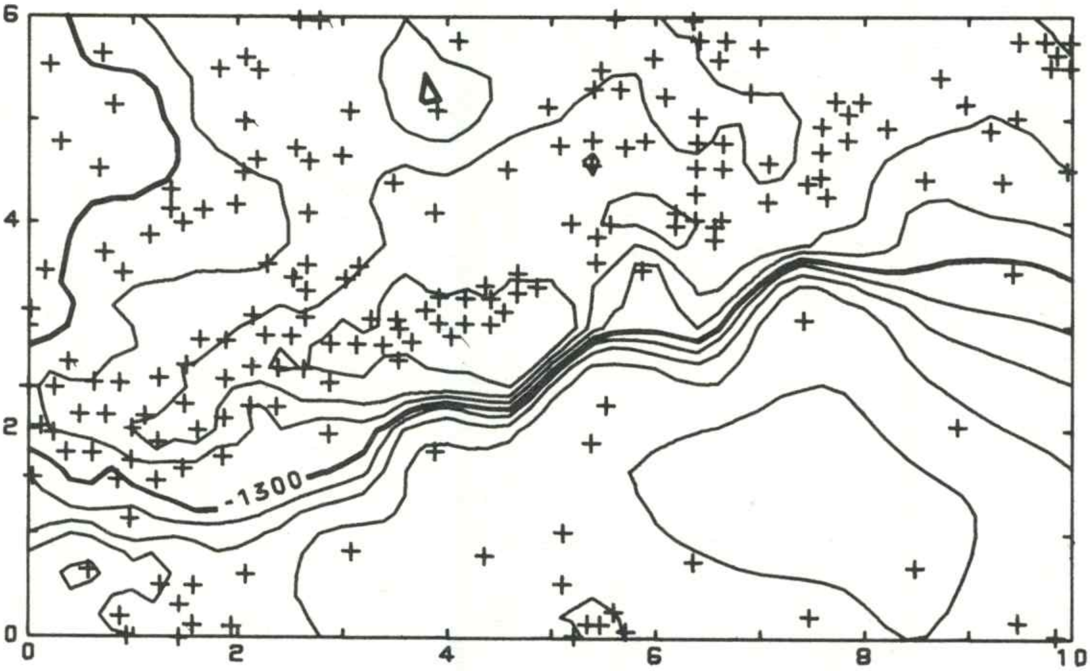


Figure 132.--Combined posting of control wells and subsurface structure contour map of the top of the Lansing Group in Graham Co., Kansas.

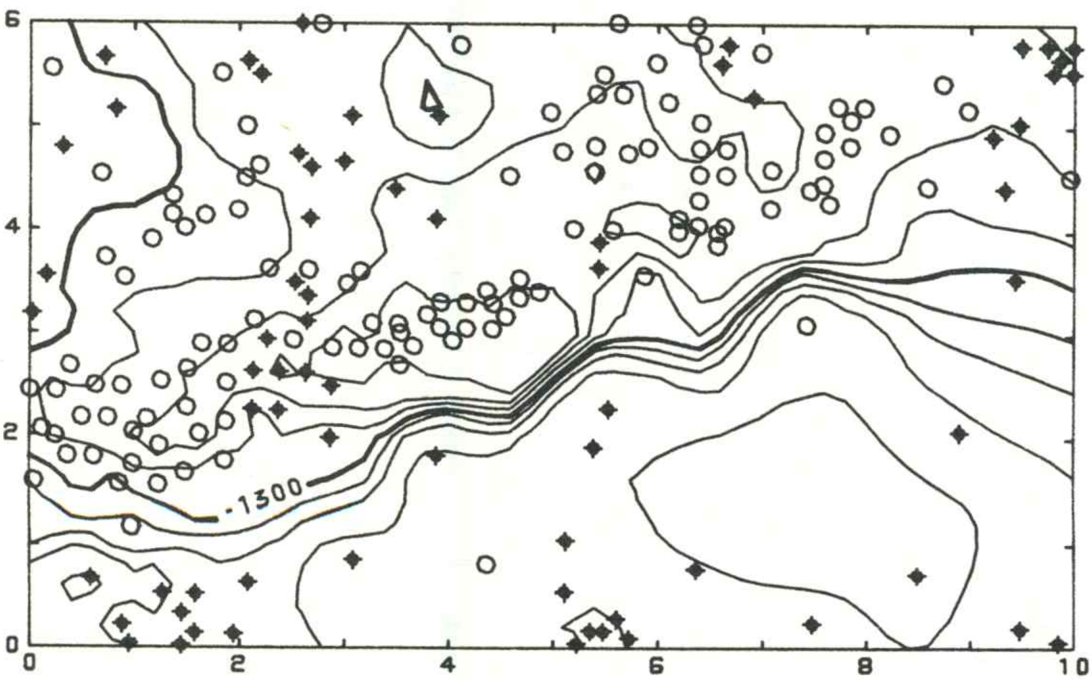


Figure 133.--Same map as Figure 132, but plotted to distinguish between producing (○) and dry (⊕) wells.

'POUT'LINE - draws outlines on a contour map or posting. The lines are drawn inside the map area only.

NO PARAMETERS

Any outline to be drawn on a map or posting must have been read in by 'ROUT'LINE. All outlines which have been previously read in and not removed by 'CLEA'R will be drawn on the contour map or posting when command 'POUT'LINE is given in the same sequence with 'CONT'OUR or 'POST'.

Figure 134 shows a posting of well locations on which lease boundaries have been plotted using 'POUT'LINE. Note that the boundaries can be drawn at arbitrary positions through the field of figures. Figure 135 is a contour map of annual rainfall in the state of Illinois. 'POUT'LINE has been used in conjunction with 'BLAN'K to create a map in which the outline forms the boundary of the map.

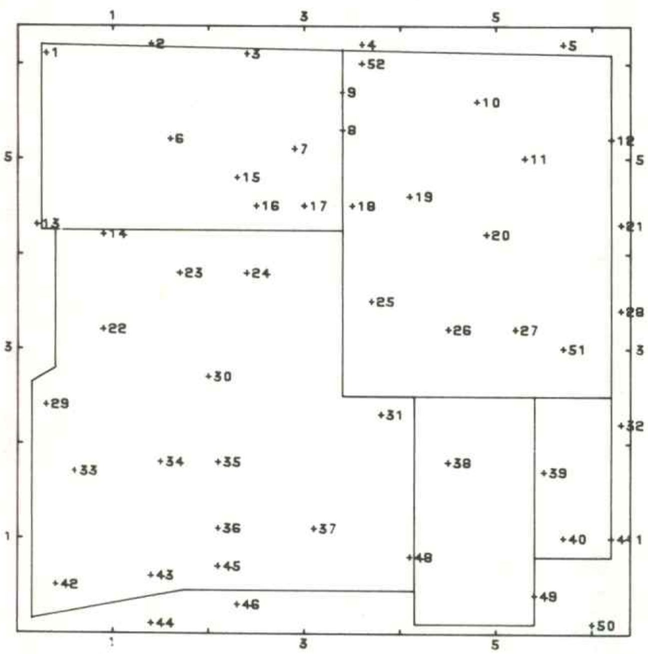


Figure 134.--Well posting in a drilling tract in western Kansas, showing locations of lease boundaries. Horizontal scale in quarter-mile increments. Posted numbers are well identification numbers.

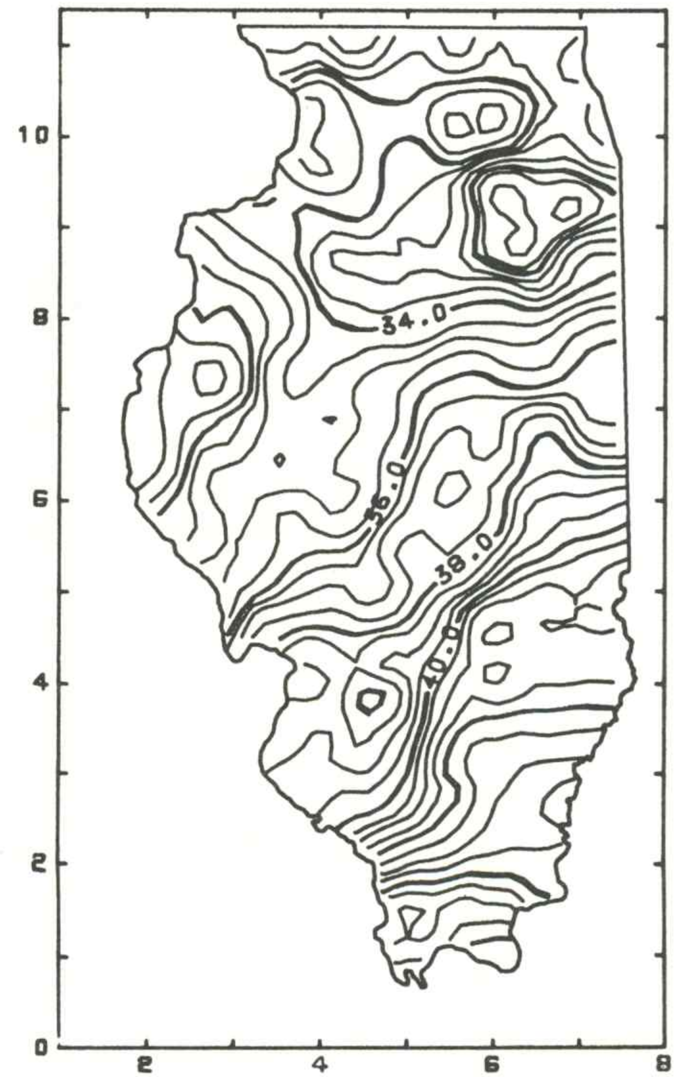


Figure 135.--Inches of annual rainfall in Illinois, drawn with a digitized outline of the state as a border. This illustration is taken from Figure 19 of the Introduction.

'PPOS'T - prints a posting of sample data points on the line printer.

Field Number	Parameter Description	Assumed Value
1	If 0, use map symbols read in with X, Y, Z data. If 1, use + for all data points. If 2, use X for all data points. If 3, use O for all data points.	1

Points on a printer posting are not labeled. Boundaries of the map area are specified by the 'EXTR'EMES command. Size of the posting is determined by 'SIZP'CONTOUR.

The dimensions of the map should be large enough so each symbol represents only one data point. If the data points are too closely spaced, one symbol on the printed posting may represent more than one data point. If this occurs, the physical size of the map should be increased by using 'SIZP'CONTOUR. Figure 136 shows a posting of well control data from a part of Graham County, Kansas. The character 2 on the map represents a point where two wells have been posted as a single character.

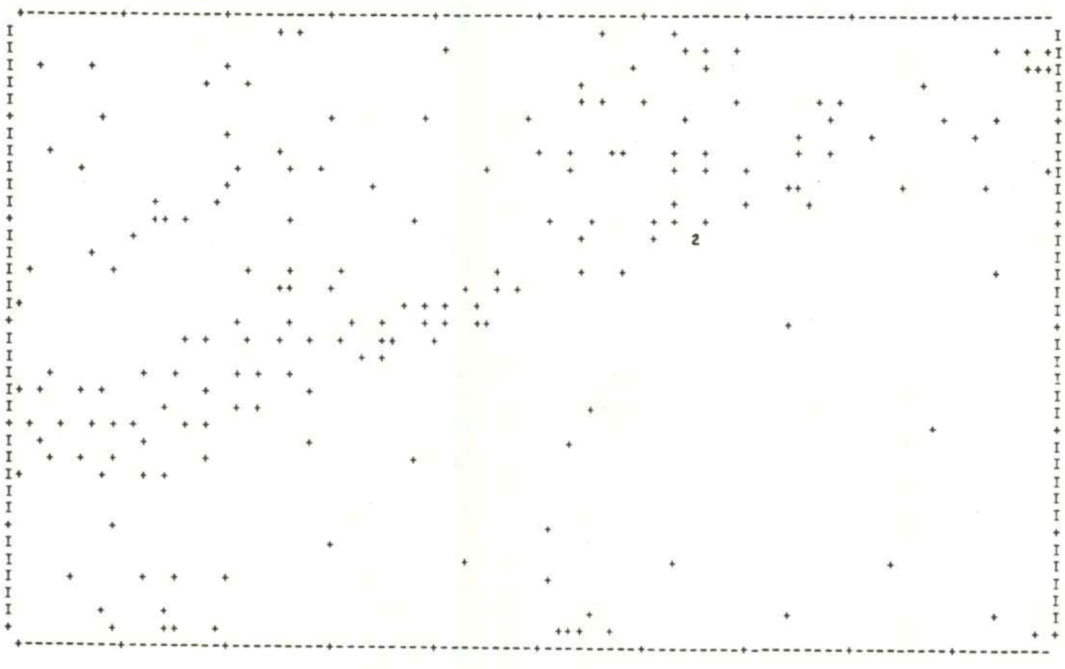


Figure 136.--Line printer posting of Graham County subsurface well data. Map reduced from an original size of 10 x 6 1/4 inches.

'QUAD'RANT - specifies that sample data points to be used to estimate an element in the grid matrix be found by a quadrant search around that element. A quadrant search finds the n nearest points in each quadrant around the element to be estimated.

Field Number	Parameter Description	Assumed Value
1	Use of the search procedure. If 1, use a quadrant search in Phase 1 of 'GRID'. If 2, use a quadrant search in Phase 2 of 'GRID'. If 3, use a quadrant search in 'DMAP'.	1
2	Maximum number of points to be retained in each quadrant.	4
3	Maximum allowable distance, in units of X and Y, of the nearest data point.	Variable[1]
4	Maximum search radius, in units of X and Y.	Variable[2]
5	Minimum number of sections that must have at least one data point.	3
6	Orientation of quadrants to the X-Y axis (-45 to 45 degrees).	0°

A quadrant search procedure divides the area around a grid node into four equal segments. The nearest n data points, where n is specified by parameter two, are found in each quadrant. If the distance to the nearest data point exceeds the distance specified by parameter three, the grid node is not estimated and is set to the default or blank value. The search for additional points in a quadrant will not extend beyond the maximum search radius specified by parameter four. The search pattern is shown in Figure 137.

Unless the minimum number of quadrants specified by parameter five contain at least one control point each, the search "fails" and the grid node around which the search is being conducted is set to the default or blank value. A total of at least four data points must be found for a successful search.

The maximum allowable number of points per quadrant that may be specified in parameter two is 12. The assumed values of parameters three and four are calculated from the size of the map area, as defined by the 'EXTR'EMES command, and the number of points on the map. The assumed limits are sufficiently broad so all grid elements will be estimated if the data points are

---

[1]Set to the radius necessary to include twice the required number of data points specified in parameter two, times four, assuming a uniform density of points across the map.

[2]Set to the radius necessary to include five times the required number of data points specified in parameter one, times four, assuming a uniform density of points across the map.

distributed in a reasonably uniform manner across the map. However, if parameter five specifies that three or four quadrants must be filled, searches around grid nodes near the margins of the map may fail because most of one or more quadrants may lie outside the map area.

A quadrant search introduces more smoothing than a nearest neighbor search, but less than an octant search. Points in a quadrant will be ignored if the maximum number of points have already been located in that quadrant, even though these points may be closer to the grid node than points in other quadrants. The effect is to increase the radius of search, using more distant points than would be the case with a simple nearest neighbor search.

Quadrant searches are useful under the same conditions as octant searches, especially where data points are collected along lines or traverses. A nearest neighbor search may find the specified number of points for an estimation entirely on a single line. An estimate made from such a collection of control points will be unconstrained except in one direction. A quadrant search pattern insures that some degree of radial control is used in the estimating procedure, and will avoid the creation of unrealistic slopes parallel to traverses of control points. Because the radial constraint on a quadrant search is not as stringent as an octant search, it produces effects intermediate between octant and nearest neighbor search patterns. Figures 138 and 139 show examples of quadrant searches using different numbers of points per quadrant.

It is possible that traverses of control points, such as aircraft flight lines, might parallel the orientation of rows or columns in the grid matrix. This can lead to an undesirable interaction with the quadrant search pattern. Parameter six allows the quadrant pattern to be rotated to minimize this interaction effect.

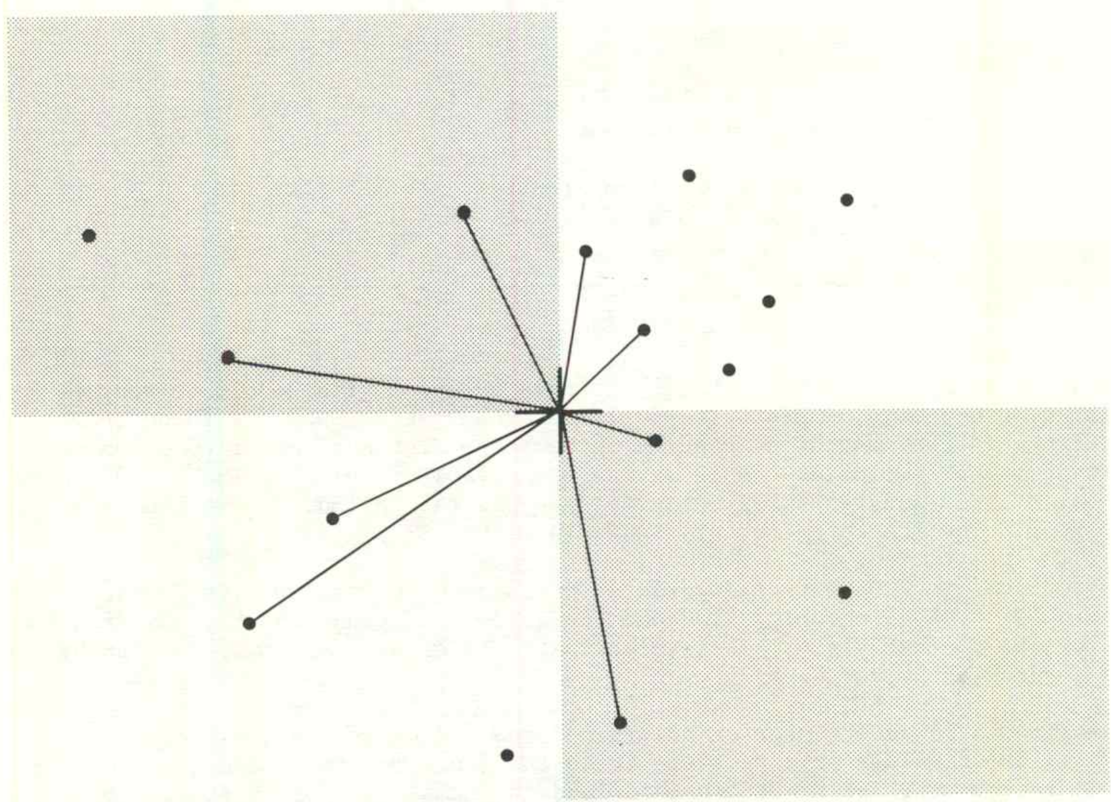


Figure 137.--Search pattern used by 'QUAD'RANT to find the closest control point in each quadrant around a grid node.

QUAD

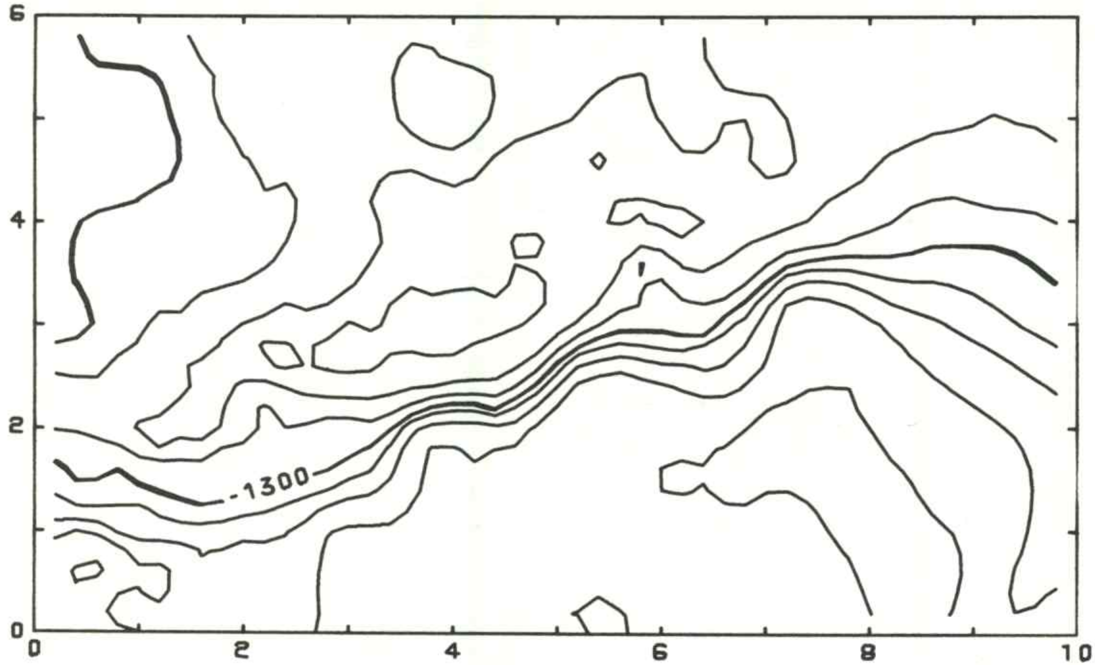


Figure 138.--Subsurface structural contour map of the top of the Lansing Group in Graham Co., Kansas, mapped using a quadrant search with two points per quadrant.

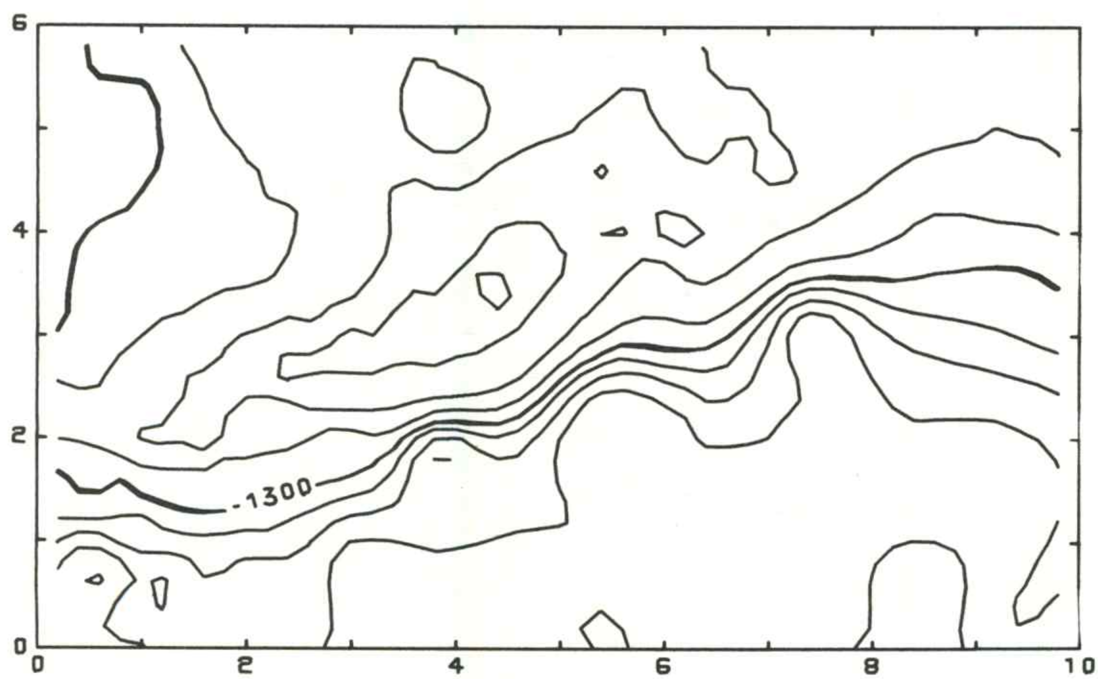


Figure 139.--Same surface as in Figure 138, but mapped using four points per quadrant.

'RANG'E - checks for values in the grid matrix that may be above or below specified limits.

Field Number	Parameter Description	Assumed Value
1	Minimum acceptable value of $\dot{Z}$ in the grid matrix.	0.0
2	Maximum acceptable value of $\dot{Z}$ in the grid matrix.	100.0
3	Code specifying how values outside the allowable range are to be modified (see text).	0

The 'RANG'E command allows the user to change or eliminate $\dot{Z}_{c,r}$ values in the grid matrix which are smaller than some minimum value or larger than some maximum value.

If parameter three is 0, each value of $\dot{Z}_{c,r}$ in the grid matrix is compared to the range of values given. A matrix element below the acceptable range is assigned the minimum value specified by parameter one. An element having a value greater than the maximum allowable value specified by parameter two is set equal to the allowable maximum.

If parameter three is set to 1, the value of any grid element outside the allowable range is assigned the code value used to indicate missing data. Contours are not created for grid elements outside the allowable range, and hence are not plotted. Figure 140 shows the Graham County test surface as a contour map with all elevations confined to the range -1100 to -1300 feet. Commands used to create this illustration are given below.

```
TITLE        RANGE TEST FOR SURFACE MANUAL
DEVICE       1,'DAVIS'
IDXY         200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
GRID         1,0.2,0.2
EXTREMES     0,10,0,6
PERFORM
RANGE        -1300,-1150,0
CONTOUR
CINTERVAL    0,0,20,0,5,0.1,0,2.0,5
SIZCONTOUR   1,6,3.6
BOX          1,2,1,2,0,0,0,1,0.1
PERFORM
STOP
```

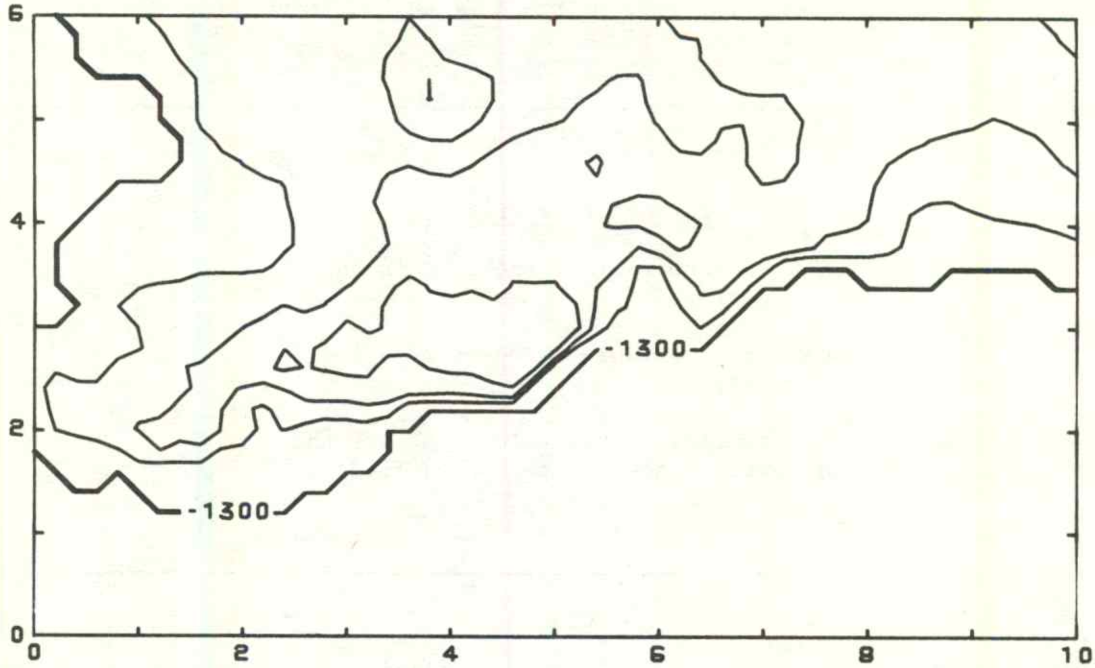


Figure 140.--Contour map of subsurface geologic structure in part of Graham Co., Kansas. All elevations below -1300 feet were set to -1300, and all elevations above -1100 were set to -1100.

'REGR'ID - changes the number of columns and rows in an existing grid matrix.

Field Number	Parameter Description	Assumed Value
1	If 0, the number of columns and rows in the new grid matrix will be specified. If 1, the number of columns and rows in the new grid matrix will be calculated; the distances between columns and rows must be given.	0
2	Either the number of columns in the new grid <u>or</u> the distance in units of X between columns; interpretation depends on parameter one.	25/1
3	Either the number of rows in the new grid <u>or</u> the distance in units of Y between rows; interpretation depends on parameter one.	25/1

The parameters of 'REGR'ID specify the size of the modified grid matrix and are completely independent of the original grid. Elements in the new matrix are estimated by double linear interpolation from elements in the original matrix.

The user may define the size (i.e., the number of columns and rows) of the matrix in two different ways. By setting parameter one to 0, the number of columns and rows in the matrix may be given explicitly. Then, the distance between columns is

$$\frac{X_{max} - X_{min}}{NC - 1}$$

and the distance between rows is

$$\frac{Y_{max} - Y_{min}}{NR - 1}$$

where X_{min}, X_{max}, Y_{min}, and Y_{max} are determined by 'EXTR'EMES, and NC and NR are given by parameters two and three.

When parameter one is set to 1, the user defines the distance between columns and rows, and NC and NR are calculated by dividing these distances into the ranges of X and Y, as specified by 'EXTR'EMES. If there is any remainder, the ranges of X and Y are expanded so the distances between all rows and columns are uniform. For example, if

$X_{min} = 1 \quad Y_{min} = 1 \quad$ parameter two = 3

$X_{max} = 25 \quad X_{max} = 20 \quad$ parameter three = 3

the number of columns in the matrix will be

$$\frac{25 - 1}{3} + 1 = 9$$

and the number of rows in the matrix will be

$$\frac{20 - 1}{3} + 1 = 7\ 1/3\ .$$

To avoid fractions, the number of rows will be increased to 8, and the value of Y_{max} automatically expanded to 22.

AUXILIARY COMMAND used with 'REGR'ID:

'EXTR'EMES

'EXTR'EMES defines the X, Y limits of the regridded matrix. This command can be used to expand or contract the limits of the original grid matrix. Elements in the regridded matrix which are outside the limits of the original matrix are set to the default or blank value.

'REST'ORE - reads a matrix stored in binary format into memory. The matrix must have been previously stored in the same format as a file created by the 'SAVE' command.

Field Number	Parameter Description	Assumed Value
1	File code from which the matrix is to be read.[1]	Required
2	Determines the order of columns in the grid matrix. If 0, columns are stored starting with the left edge and proceeding to the right edge of the grid matrix. If 1, columns are stored from right to left.	0
3	Determines the placement of rows in the grid matrix. If 0, rows are stored beginning at the bottom of the matrix and proceeding to the top. If 1, rows are stored from top to bottom.	0

The 'REST'ORE command is used to read a grid matrix into memory. The grid matrix must have been previously stored on an external file using the 'SAVE' command. A matrix computed by another program also may be read into memory using the 'REST'ORE command if the matrix is stored on a file in binary format.

The first record of the file must contain the number of columns (field one) and rows (field two) to be read. The matrix must be stored by rows with one row per record. A third field is included on the first record which is a code indicating the contents of the second record on the file. If this code value is 1, the second record will contain information about the matrix (including the range of X and Y values) which is used by SURFACE II. If this code value is 0, the second record of the file will be the first row of the matrix. Under this option, no information about the minimum and maximum values for X and Y can be obtained from the file. This option should be used to read in all binary files not created by the 'SAVE' command.

AUXILIARY COMMAND used with 'REST'ORE:

'INCR'EMENT

If only part of a saved matrix is to be restored, the 'INCR'EMENT command may be used to specify which rows and columns of the saved matrix are to be read into memory.

'ROUT'LINE - reads in X and Y coordinates of points to be connected by straight lines, forming an outline within the map area.

Field Number	Parameter Description	Assumed Value
1	Code of file containing coordinates of outline.[1]	Required
2	Number of outlines to be read.	1
3	Format of input file.[2]	Required

An outline read by this command may be used to define blanked areas, or may be drawn on a contour map to denote special areas or features. The area defined by coordinates read by 'ROUT'-LINE must be contained within the map area.

The first record read from the input file must contain a description of the boundary coordinates that follow. There are two fields in the first record, which must be read in 2I4 format. The first field contains the number of points in the outline. The second field contains a code which specifies how the outline should be interpreted. If the second field is 0, the outline to be read does not define blanked areas, but may be drawn on the contour map using 'POUT'LINE, as in Figure 134. This outline does not necessarily define a closed area. If the code in the second field is 1, the map area outside the space enclosed by the outline will be blanked (see 'BLAN'K), as in Figure 135. If the code value in the second field is 2, the area inside the outline is blanked. If code 1 or 2 is used, the outline must define a closed area; that is, the first coordinate pair must be identical to the last pair.

Following the first record are the X-Y coordinate pairs, one pair to a record, which define the end points of the line segments of the outlined area. If more than one outline is to be read, the first record and the coordinate pairs for each succeeding outline immediately follow.

AUXILIARY COMMANDS used with 'ROUT'LINE:

'ECHO'
'RTXY'

The coordinates of the digitized outline can be listed using 'ECHO'. The set of coordinates of the outline may be rotated, translated, and scaled to some other coordinate configuration using 'RTXY'.

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[1]See Appendix C.
[2]See Appendix B.

'RTXY' - rotates, translates, and changes scale of X and Y axes.

Field Number	Parameter Description	Assumed Value
1	Rotation angle θ, measured clockwise in degrees from the X axis.	0
2	Scale factor for X axis.	1
3	Scale factor for Y axis.	1
4	Amount of translation of origin, in X direction.	0
5	Amount of translation of origin, in Y direction.	0

This command is used to alter the coordinate axes of a data set, to bring them into coincidence with the axes of other data sets. It is used only in conjunction with 'IDXY' or 'ROUT', and can be applied either to the coordinates of data points or boundaries.

First, the data set is rotated, then the X and Y scales are adjusted, and finally the origin is moved. Therefore, the amount of translation should be given in units of the new scale.

'SAVE' - stores the contents of a grid matrix on a file.

Field Number	Parameter Description	Assumed Value
1	Code for the file on which the matrix will be saved.[1]	Required

Once a SURFACE II matrix has been created, it may be written onto a disc or tape file and saved, either permanently or temporarily, for future use. The matrix is saved after all alterations (such as 'RANG'E, 'SCAL'E, 'MLEV'EL, 'FILT'ER, 'DERI'VATIVE, 'ISOP'ACH) have been performed. If a matrix is to be saved before modifications, a 'PERF'ORM statement should be included between the 'SAVE' command and the matrix modification commands. Refer to the 'PERF'ORM command for further explanation.

The first record written on the file by the 'SAVE' command is a header containing three fields. The first two fields specify the number of columns and the number of rows in the grid matrix. The third field contains a code value which tells SURFACE II how to interpret the second record on the file. If the value in this field is 1, the second record written on the file contains additional information about the grid matrix, including the number of columns, number of rows, distance between columns, distance between rows, X-value at left edge of matrix, X-value at right edge of matrix, Y-value at bottom of matrix, Y-value at top of matrix, $\dot{Z}$ minimum value, $\dot{Z}$ maximum value, number of missing $\dot{Z}$ values in grid matrix, and nine words reserved for future use. The grid itself will be stored in the third and succeeding records, one row to a logical record. If the stored value in the third field is 0, the second and succeeding records will contain the grid matrix.

If a matrix is stored by SURFACE II under the instruction of a 'SAVE' command, the third field contains a 1 and the appropriate information is placed in the second record. If a matrix is to be written by some other program with the intention of reading the matrix into SURFACE II by a 'REST'ORE command, the third field should contain a 0. The file should be written using FORTRAN unformatted I/O routines. An example of a FORTRAN program that writes a file in the 'SAVE' format is:

```
      REWIND IFILE
      IZERO = 0
      WRITE (IFILE) NCOLS, NROWS, IZERO
      DO 100 I = 1, NROWS
      WRITE (IFILE) (A(I,J), J = 1, NCOLS)
  100 CONTINUE
```

[1]See Appendix C.

'SCAL'E - Performs various arithmetic operations on elements of the grid matrix, including scaling $\dot{Z}_{c,r}$ values from their original range into a range specified by the parameters.

Field Number	Parameter Description	Assumed Value
1	Type of operation to be performed. See table below for codes.	1
2	A constant to be added to each element in the grid matrix before the operation requested by parameter one is performed.	0
3	A constant to be used in the arithmetic operation. If the operation to be performed is scaling, this parameter defines the new minimum value of $\dot{Z}$.	1
4	A constant to be used in the arithmatic operation. If the operation to be performed is scaling, this parameter defines the new maximum value of $\dot{Z}$.	Varies, see text.

The operations which may be performed using 'SCAL'E are outlined in the table below, and are selected by the first parameter. In all options, the value specified in parameter two is added to every element in the grid matrix. One purpose for this addition is to insure that all elements are non-negative if a square root operation is to be performed, or that all elements are greater than 0 if the log of each element is to be calculated. If parameter one is 1, 2, or 3, the assumed value of parameter four is the minimum range of X and Y. If parameter one is 4, 5, or 6, then the assumed value of parameter four becomes 0.

Operations which can be performed on elements of the grid matrix using the 'SCAL'E command.

Code value of parameter one	Operation	Action performed on each $\dot{Z}_{c,r}$ element
1	linear scaling	($\dot{Z}_{c,r}$ + parameter two) is scaled to the range of parameter three to parameter four (see Fig. 141)
2	square root scaling	($\sqrt{\dot{Z}_{c,r}}$ + parameter two) is scaled to the range of parameter three to parameter four (see Fig. 142)

(cont.)

Code value of parameter one	Operation	Action performed on each $\dot{Z}_{c,r}$ element
3	logarithmic scaling	Log_{10} ($\dot{Z}_{c,r}$ + parameter two) is scaled to the range of parameter three to parameter four (see Fig. 143)
4	addition and/or multiplication of elements, without scaling	$\dot{Z}_{c,r}$ is replaced by the value of [($\dot{Z}_{c,r}$ + parameter two) * parameter three + parameter four] (see Fig. 144)
5	square root transformation without scaling	$\dot{Z}_{c,r}$ is replaced by the value of [$\sqrt{(\dot{Z}_{c,r} + \text{parameter two})}$ * parameter three + parameter four] (see Fig. 145)
6	logarithmic transformation without scaling	$\dot{Z}_{c,r}$ is replaced by the value of $\log_{10}$ [($\dot{Z}_{c,r}$ + parameter two) * parameter three] + parameter four (see Fig. 146)

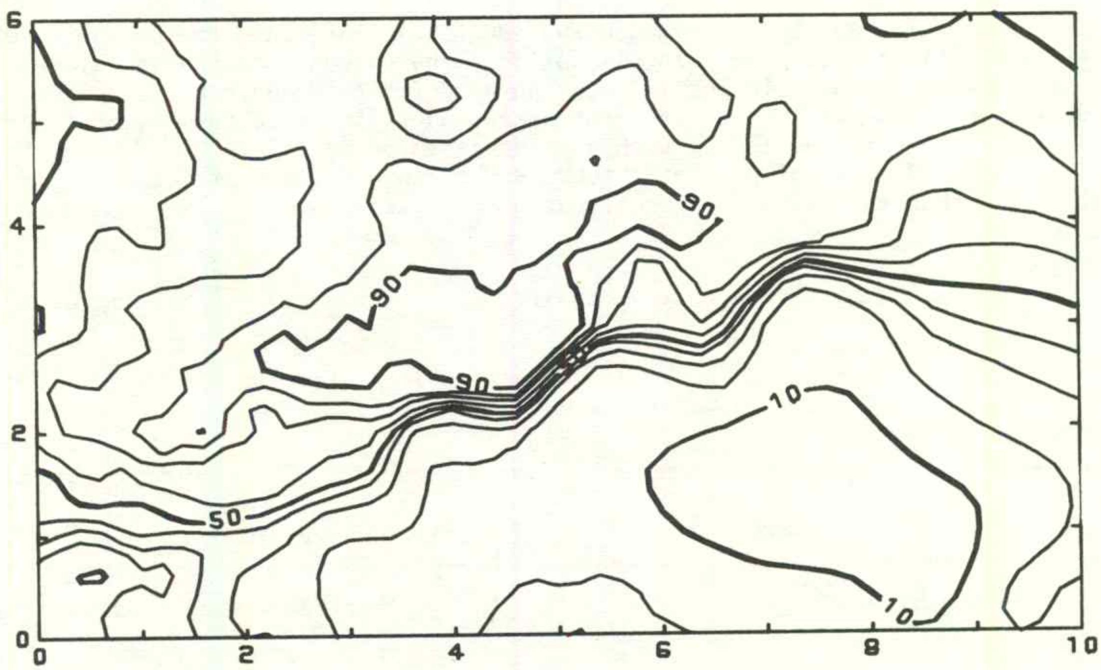

Figure 141.--Contour map of subsurface structure in part of Graham Co., Kansas, scaled linearly to the range 0-100. Original surface is shown in Figure 101. Parameters of 'SCAL'E are 1, 1400, 0, 100.

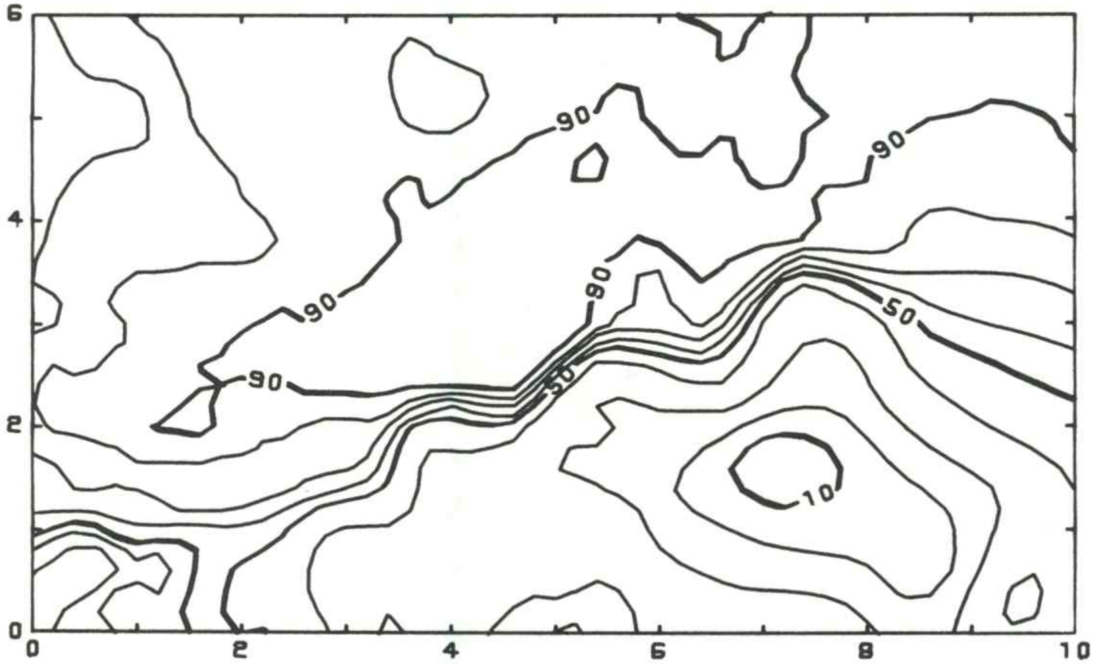

Figure 142.--Contour map transformed and scaled so the square roots of $\dot{Z}_{c,r}$ values are within the range 0-100. This is equivalent to a linear rescaling of the square root transformation shown in Figure 145. Parameters of 'SCAL'E are 2, 1400, 0, 100.

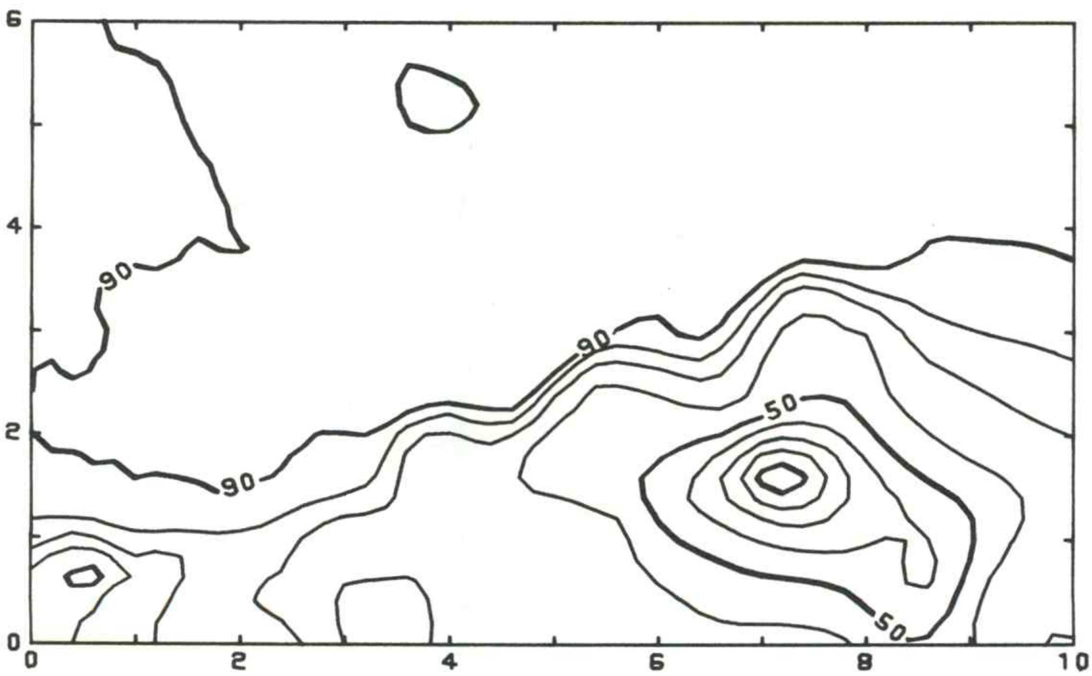

Figure 143.--Contour map transformed and scaled so the logarithms to the base ten of $\dot{Z}_{c,r}$ values are within the range 0-100. This is equivalent to a linear rescaling of the log transformation shown in Figure 146. Parameters of 'SCAL'E are 3, 1400, 0, 100.

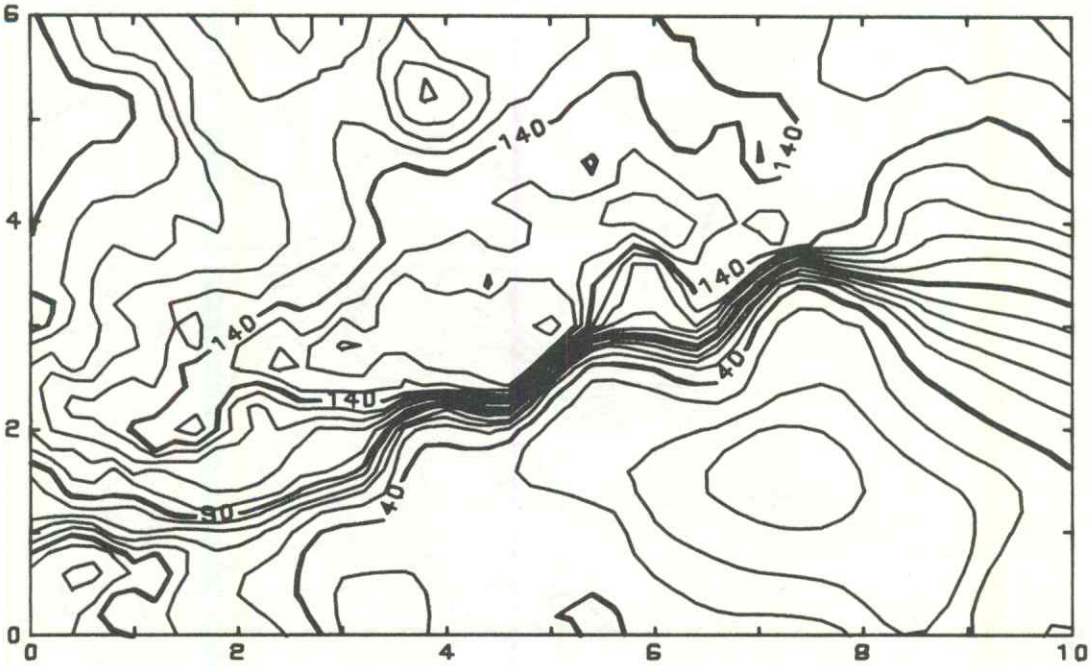

Figure 144.--Contour map adjusted upward by the constant 1400 which has been added to all grid values to raise them to values greater than zero. Parameters of 'SCAL'E are 4, 1400, 1, 0.

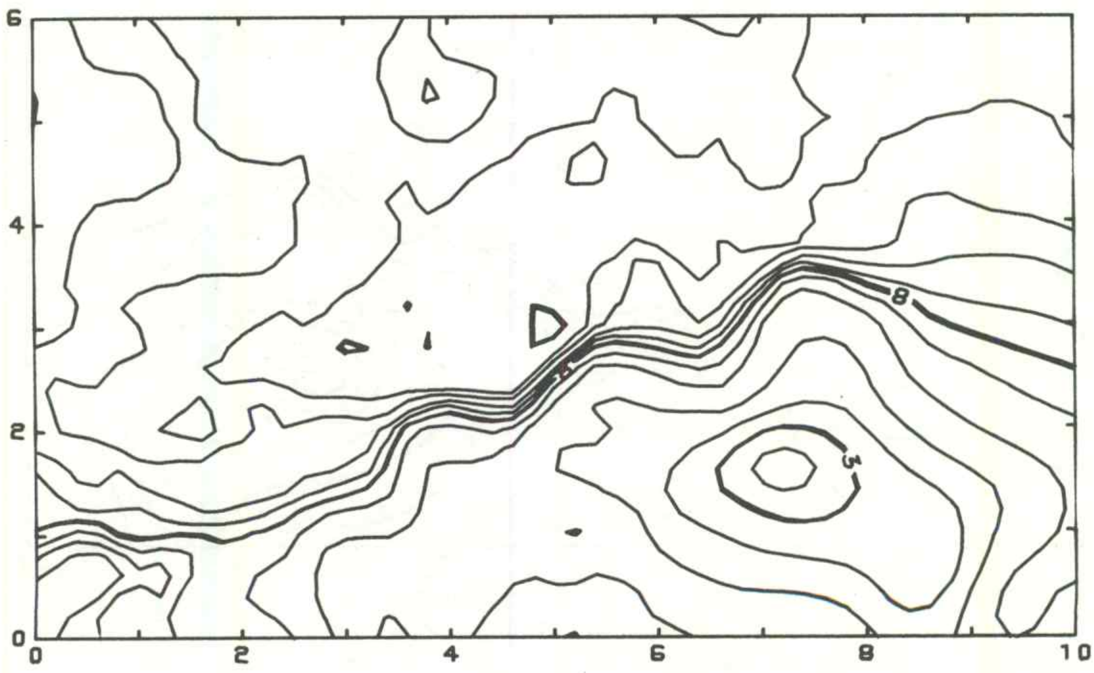

Figure 145.--Square root transformation of map shown in Figure 144. Parameters of 'SCAL'E are 5, 1400, 1, 0.

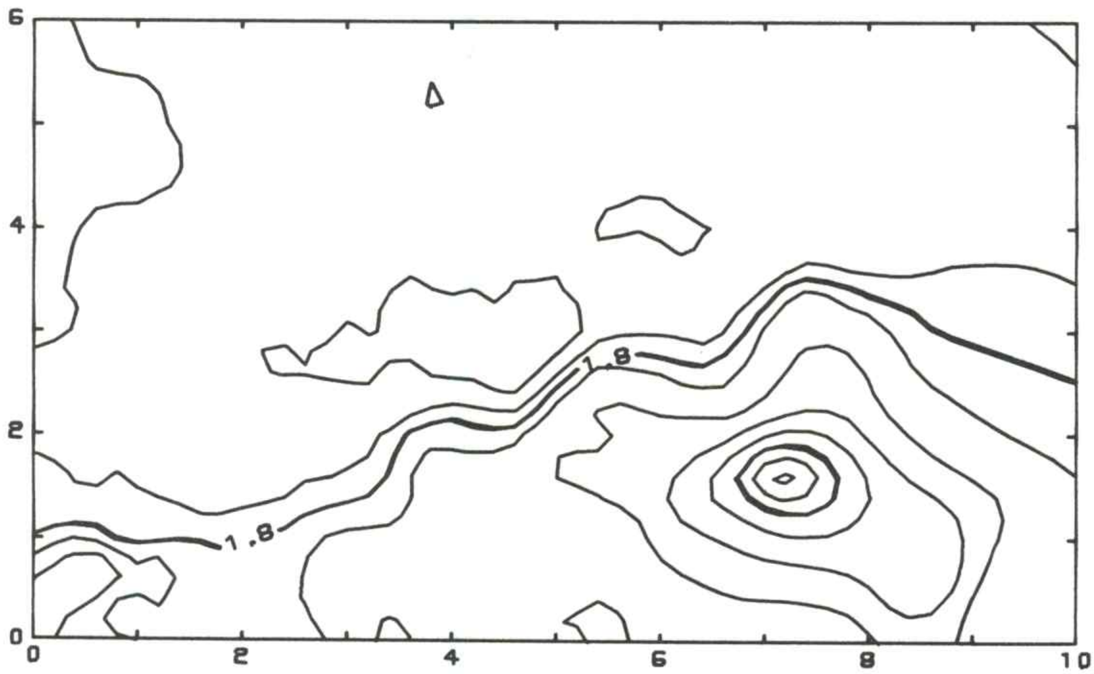

Figure 146.--Base-ten logarithmic transformation of map shown in Figure 144. Parameters of 'SCAL'E are 6, 1400, 1, 0.

'SIZC'ONTOUR - specifies the physical size of a contour map or posting created on a plotter.

Field Number	Parameter Description	Assumed Value
1	If 0, the map size will be specified as the number of units per inch. If 1, the map size will be specified in inches.	0
2	Length of plot in X-direction.	1 unit per inch or 12 inches
3	Length of plot in Y-direction.	Variable, at the same scale as the X-direction

When parameter one is set to 1, the physical size of the plot in inches is given by parameters two and three. The scale factor (number of units per inch) is automatically calculated by SURFACE II. When parameter one is 0, the value of parameter two is the scale factor (number of units per inch) in the X-direction and parameter three is the scale factor in the Y-direction. The physical size of the map in inches is calculated by SURFACE II. The finished map will be $(X_{max} - X_{min})$/(parameter two) inches long in the X-direction by $(Y_{max} - Y_{min})$/(parameter three) inches long in the Y-direction.

If the third parameter is omitted, the scale factor in the Y-direction is assumed to be the same as the scale factor in the X-direction. The physical size of the plot in the Y-direction will be calculated as $(Y_{max} - Y_{min})$/(number of units per inch in X-direction). Minimum and maximum values of X and Y are defined by 'BXEX'TREMES, and are in map units such as "miles," "kilometers," or whatever units are used in the X-Y coordinate system.

'SIZE'LEVATED - determines the physical size of a perspective block diagram with elevated contour lines.

Field Number	Parameter Description	Assumed Value
1	Maximum size of plot, in inches	12

The size specified in the parameter is the length of the block diagram in its longest direction. SURFACE II scales the other dimensions to agree with the size given. This command is identical in operation to 'SIZT'RANSECT; refer to Figures 147 and 148 under that command.

'SIZP'CONTOUR - specifies the physical size of a contour map or posting created on the line printer.

Field Number	Parameter Description	Assumed Value
1	If 0, the map size will be specified as the number of units per inch. If 1, the map size will be specified in inches.	0
2	Length of plot in X-direction.	1 unit per inch or 12 inches
3	Length of plot in Y-direction.	Variable, at the same scale as the X-direction
4	Number of characters per inch across page.	10
5	Number of lines per inch down page.	6

When parameter one is set to 1, the physical size of the plot in inches is given by parameters two and three. The scale factor (number of units per inch) is automatically calculated by SURFACE II. When parameter one is 0, the value of parameter two is the scale factor (number of units per inch) in the X-direction and parameter three is the scale factor in the Y-direction. The physical size of the map in inches is calculated by SURFACE II. The finished map will be $(X_{max} - X_{min})$/(parameter two) inches long in the X-direction by $(Y_{max} - Y_{min})$/(parameter three) inches long in the Y-direction.

If the third parameter is omitted, the scale factor in the Y-direction is assumed to be the same as the scale factor in the X-direction. The physical size of the plot in the Y-direction will be calculated as $(Y_{max} - Y_{min})$/(number of units per inch in X-direction). Minimum and maximum values of X and Y are defined by 'EXTR'EMES at the time the grid matrix is generated, and are in map units such as "miles," "kilometers," or whatever units are used in the X-Y coordinate system.

If the specified size of a printed contour map is wider than the output form, the map will be printed in strips which may be spliced together to form the complete map. Generally, the size of a printed map must be much larger than that of an equivalent plotted map to display the same degree of detail. This is necessary because any surface features smaller than the size of a print position will be omitted from a printed map.

'SIZT'RANSECT - determines the physical size of a perspective block diagram.

Field Number	Parameter Description	Assumed Value
1	Maximum size of plot, in inches.	12

The size specified in the parameter is the length of the block diagram in its longest direction. SURFACE II scales the other dimensions to agree with the size given.

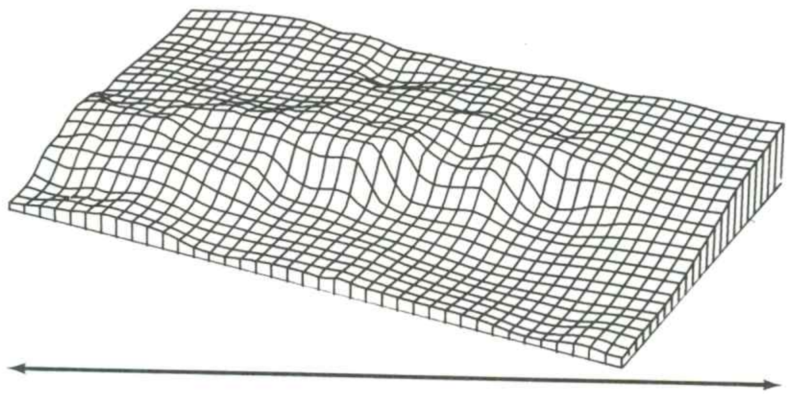

Figure 147.--The horizontal dimension is specified by 'SIZT'RANSECT for a block which is wider than it is tall.

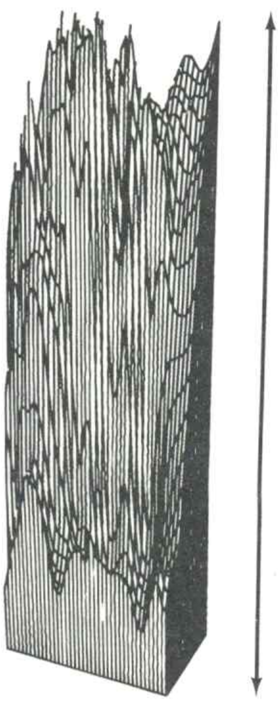

Figure 148.--The vertical dimension is specified by 'SIZT'RANSECT for a block which is taller than it is wide.

'STER'EO - plots a block diagram in the form of stereoscopic pairs. The viewing position for the block diagram, as determined by the 'AZIM'UTH command, is offset to produce a pair of plots corresponding to views of the surface as seen by each of the observer's eyes.

Field Number	Parameter Description	Assumed Value
1	Viewing angle, in degrees, between the block diagrams.	2°
2	Determines the placement of the two block diagrams. If 0, two separate blocks are drawn. If 1, the blocks are drawn on top of each other. By changing the color of ink, a three-dimensional anaglyph may be created for viewing with two-color glasses.	0
3	The number of inches from the center of one block diagram to the center of the second block diagram. This option is used only when parameter two is 0.	Maximum size of plot (set by 'SIZT'RAN-SECT)

The 'STER'EO command is used in conjunction with the 'TRAN'SECT or 'ECON'TOUR command to produce a stereoscopic pair of block diagrams. All the commands that are used with 'TRAN'SECT or 'ECON'TOUR to control viewing position ('AZIM'UTH, 'ELEV'ATION, 'DIST'ANCE), size ('SIZT'-RANSECT, 'SIZE'LEVATED), and number of lines ('LINE'S) are also used to plot a stereoscopic pair.

Parameter one controls stereoscopic exaggeration, or the degree of the three-dimensional effect. Parameter two controls the type of stereoscopic diagram to be produced. When parameter two is 0, the plot consists of two offset blackline images to be viewed through a lens or mirror stereoscope. Plots shown in Figures 149 and 150 are examples of stereoscopic pairs to be viewed with a standard pocket stereoscope. (A pocket stereoscope has lenses 2.4 inches apart and can accept images up to 2 inches in size. Note that these illustrations were drawn two times final size and photographically reduced. If the plots had been made at final size, the lines would have been excessively heavy.)

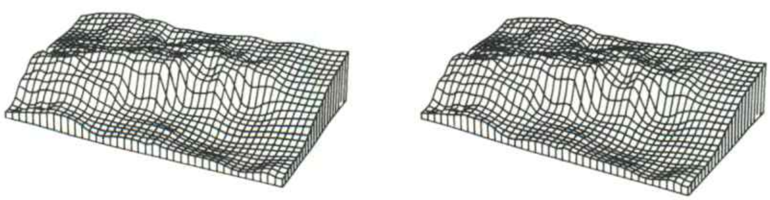

Figure 149.--Perspective block diagram of subsurface geologic structure in part of Graham Co., Kansas, plotted as a stereo pair for viewing with a pocket stereoscope. Viewing distance is 100 matrix units.

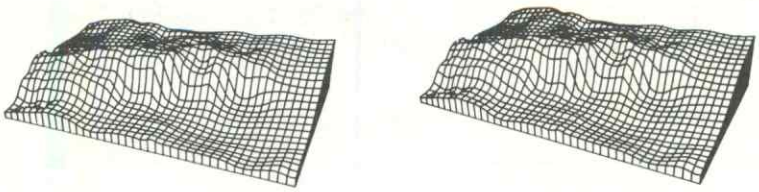

Figure 150.--Perspective block diagram plotted as seen from a viewing distance of only 20 matrix units. Exaggerated convergence heightens the three-dimensional effect.

Figure 151 is an anaglyph, or stereo pair, plotted in two colors for viewing through two-color glasses. Anaglyphic glasses have a green right lens and a red left lens. The plotting sequence involves changing colors if a single-pen plotter is used. First, the left block is drawn with green ink. Then, the right block is drawn with red ink. On the finished plot, the title (including the check +) should be lettered in green and the check X should be drawn in red.

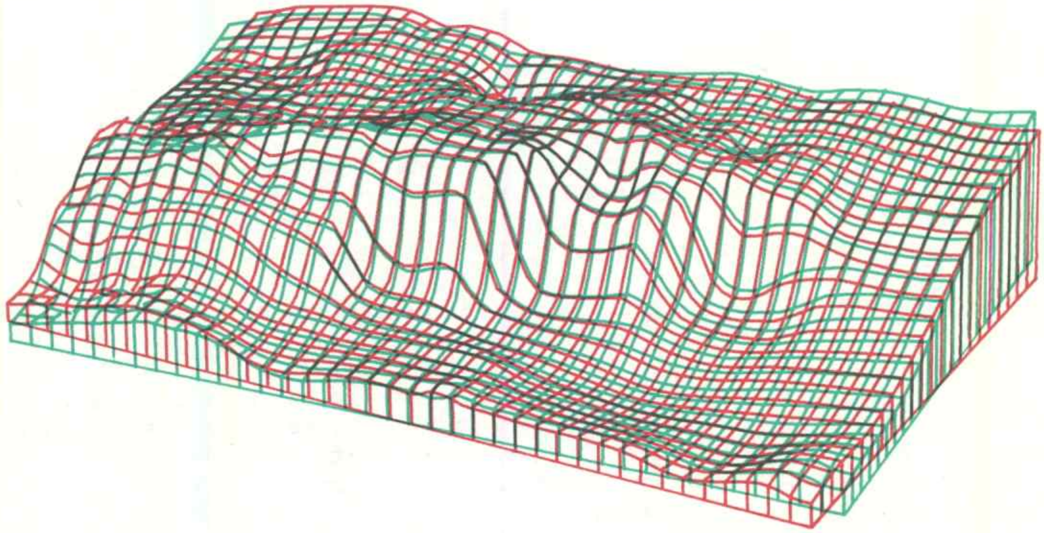

Figure 151.--Perspective block diagram plotted as an anaglyph for viewing through red and green glasses. View corresponds to Figure 149, but there is no restriction on the physical size of the plot.

Parameter three is used to specify the separation between the viewing lenses of the stereoscope to be used. The maximum size of the plots as specified by 'SIZT'RANSECT should be no larger than the separation distance. Mirror stereoscopes may have lens separations of 10 inches or more; pocket stereoscopes are limited to a maximum separation of 2.4 inches. Because anaglyphic images are "separated" by color filtering and are not physically separated, they may be plotted at any size.

The commands used to produce Figures 149-151 are:

Read in data, grid, and plot anaglyph (Fig. 151)	TITLE	STEREO TEST FOR SURFACE MANUAL
	DEVICE	1,'DAVIS'
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	GRID	1,0.2,0.2
	EXTREMES	0,10,0,6
	TRANSECT	0,20,0
	STEREO	4,1
	LINES	1,40,24
	SIZTRANSECT	6
	DISTANCE	100
	ELEVATION	30
	AZIMUTH	25
	PERFORM	
Plot Figure 149	TRANSECT	0,20,0
	STEREO	4,0,4.8
	SIZTRANSECT	4
	PERFORM	
Plot Figure 150	TRANSECT	0,20,0
	STEREO	4,0,4.8
	DISTANCE	20
	PERFORM	
	STOP	

'STOP' - halts execution of SURFACE II. This command must be used to terminate a SURFACE II run and should be the last card in the SURFACE II control deck.

NO PARAMETERS

'SUBS'ET - allows selection of specified data points from an input file.

Field Number	Parameter Description	Assumed Value
1	Number of variable to be checked.	Required
2	Code of the condition to be checked.	1
3	First or lower boundary condition.	Required
4	Second or upper boundary condition.	Required if code is 1 or 2

Each sample read by 'IDXY' is examined to see if the specified condition has been satisfied. If not, the data point is ignored and will not be used in the gridding procedure nor will it appear in a posting. If more than one condition is to be checked, a separate 'SUBS'ET command must be included to define each condition. If a sample read by 'IDXY' fails <u>any</u> of the conditions, it will be rejected. Conditions which can be specified are listed in the table below.

As an example, suppose all data points on the input file whose Z-values are less than 0 or greater than 1000 are to be deleted. Data points whose X-coordinates are less than -100 are to be deleted as well. The following SURFACE II commands would accept up to 100 data points satisfying the above conditions:

```
IDXY     100,11,4,2,3,4,1,,,,(F10.0,3F15.4)
SUBSET   4,1,0,1000
SUBSET   2,6,-100
PERFORM
```

The 'IDXY' command specifies that X is in the second field of each record and Z is in the fourth field. The first 'SUBS'ET command checks the condition that the fourth field (Z) of the record has a value ranging from 0 to 1000; the second 'SUBS'ET command checks that the second field (X) is not less than -100. If either check fails, that record is excluded from the set of sample data points stored in memory.

Conditions which can be specified for selection of data points using the 'SUBS'ET command.

Code value of parameter two	Condition
1	The variable must lie between the values of parameter three and parameter four. Note that parameter three must be less than parameter four.
2	The variable must not lie between the values of parameter three and parameter four.
3	The variable must be less than parameter three.
4	The variable must be less than or equal to parameter three.

(cont.)

Code value of parameter two	Condition
5	The variable must be greater than parameter three.
6	The variable must be greater than or equal to parameter three.
7	The variable must be equal to parameter three.
8	The variable must not be equal to parameter three.

'TITL'E - accepts a 60-character alphanumeric phrase which is used to label the printed output and any plots that are produced by SURFACE II.

Field Number	Parameter Description	Assumed Value
1	Phrase to be used as a heading.	"SURFACE II Graphics System"

The phrase appearing with the 'TITL'E command is printed on the top line of each page of printed output and at the left of each plot generated by SURFACE II. The heading may be changed between each 'PERF'ORM command.

The title drawn on a plot also includes a check of the accuracy of the plotted illustration. The check consists of a cross which is drawn at the origin of the plotting area. After completion of a plot, the pen will return to the origin and draw an X. The + and X intersect at the same point, as in (a), below. If they are offset, as in (b), an error has been made in plotting, perhaps by failure of the plotter to correctly read the plot tape.

(a)

(b)

'TRAN'SECT - creates a perspective block diagram (sometimes called a transect or fishnet plot) of the grid matrix.

Field Number	Parameter Description	Assumed Value
1	If 0, the block diagram will have a base. If 1, only the surface will be displayed as in Figure 152. If 2, vertical grid lines will not be drawn on base.	0
2	Percent of range in X- or Y-direction (whichever is greater) into which the range of Z will be scaled. If 0, no scaling is done.	50%
3	Determines the directions of lines across the surface. If 0, lines are drawn across the surface parallel to both X and Y axes. If 1, lines are drawn parallel to the X-axis only. If 2, lines are drawn parallel to the Y-axis only. If 3, lines are drawn perpendicular to the line of sight between the observer and the block diagram.	0
4	Scales X and Y axes with respect to each other. If 0, one unit in X equals one unit in Y. If 1, Y is scaled to a percentage of the range of X. If 2, X is scaled to a percentage of the range of Y.	0
5	Percent scaling to be used if parameter four is 1 or 2.	100
6	Check to determine if specified size of plot is reasonable. If 0, check will be made. If 1, no check will be made.	0

Figure 152 shows a surface drawn as a perspective block diagram without a base, by setting parameter one to 1. Other illustrations were prepared with this parameter set to 0.

The shape of a block diagram is determined by the relative length, width, and range of heights of the surface. The range of the surface in the $\dot{Z}$-direction is the difference between the smallest and largest values in the grid matrix. If the numerical range of $\dot{Z}$ is much larger than the range of X and Y, the block diagram may appear as a spike, and the plot may be useless. The 'SCAL'E command allows the user to scale the values of $\dot{Z}$ in the grid matrix to within a specified range; this operation permanently destroys the original $\dot{Z}$ values. In contrast, 'TRAN'-SECT allows scaling without altering the original values in the grid matrix. Parameter two of

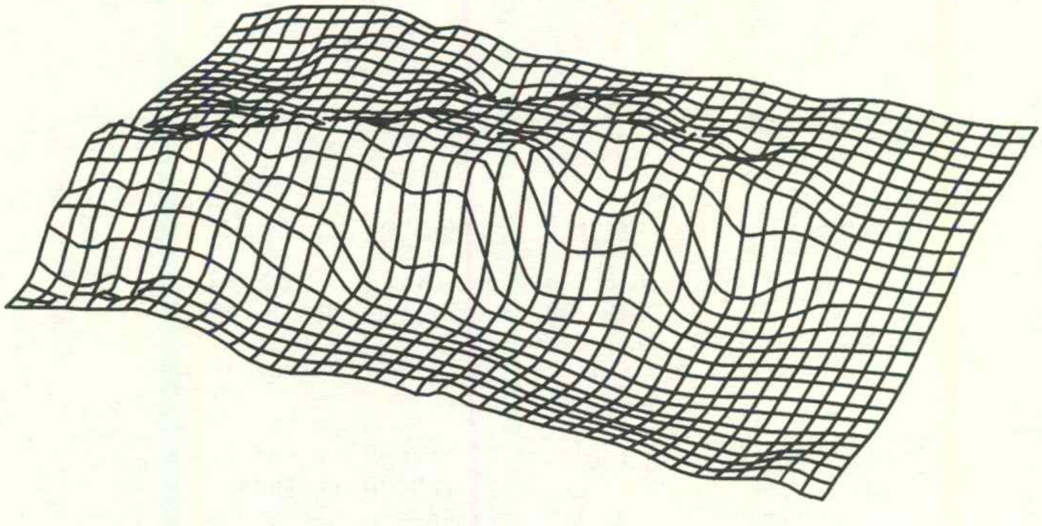

Figure 152.--Diagram showing subsurface geologic structure in part of Graham Co., Kansas, drawn in perspective without a base.

'TRAN'SECT specifies degrees of scaling as a percent of the X- or Y-range; a value of 40 to 60% usually produces a block diagram which has acceptable proportions. If too much scaling is specified, low features on the surface may be lost. If the vertical range is specified as a large percentage of the horizontal scale, surface features may appear exaggerated. Figures 153-156 show a block diagram drawn with varying degrees of scaling of Ż.

Parameter three controls how lines will be drawn across the surface of the block. Figures 157-160 illustrate the four options.

Parameters four and five can severely affect the appearance of a transect plot. In Figure 161, parameter four was set to 1 and parameter five to 20. This scales the Y-axis to 20% of the X-axis. In Figure 162, parameter four has been set to 2 and parameter five to 50, scaling the X-axis to 50% of the Y-axis.

AUXILIARY COMMANDS used with 'TRAN'SECT:

'AZIM'UTH
'DIST'ANCE
'ELEV'ATION
'LINE'S
'SIZT'RANSECT
'STER'EO

The 'SIZT'RANSECT command determines the physical size of the finished plot in inches. The length, width, and height of the surface are scaled to the dimensions defined by 'SIZT'-RANSECT when the plotting instructions are generated. The matrix is not affected by this command.

'LINE'S defines the number of lines that will appear on the block to represent the surface. It has no effect on the size or shape of the plot.

The 'SIZT'RANSECT and 'LINE'S commands control the appearance of a perspective block diagram. If the assumed values of their parameters are not appropriate for displaying a specific matrix, they should appear with the 'TRAN'SECT command. Other commands used in conjunction with 'TRAN'SECT are 'DIST'ANCE, 'AZIM'UTH, and 'ELEV'ATION. These determine the observer's point of view with respect to the block diagram and control the perspective effect. 'STER'EO specifies that the block diagram will be drawn as a stereo pair.

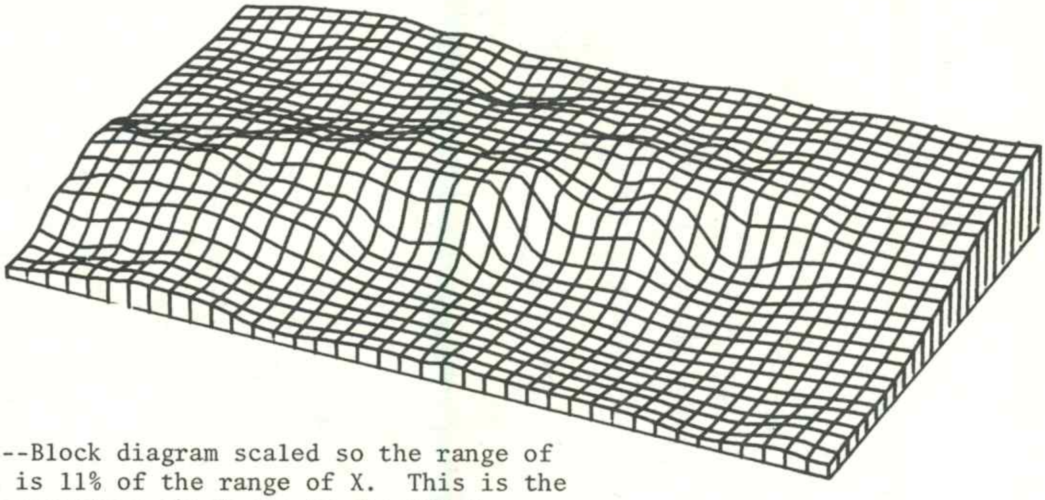

Figure 153.--Block diagram scaled so the range of $\dot{Z}$ values is 11% of the range of X. This is the minimum percentage which can be specified.

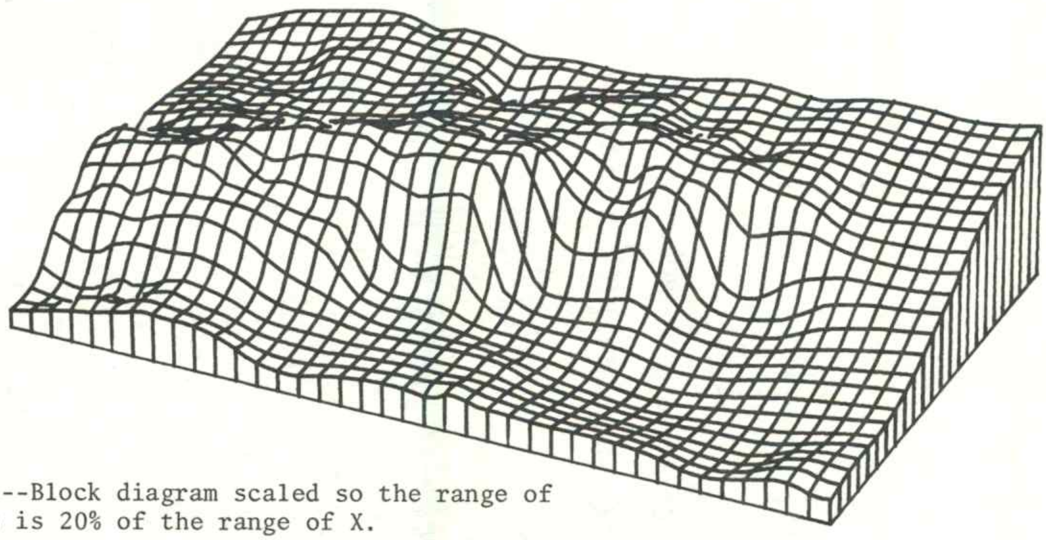

Figure 154.--Block diagram scaled so the range of $\dot{Z}$ values is 20% of the range of X.

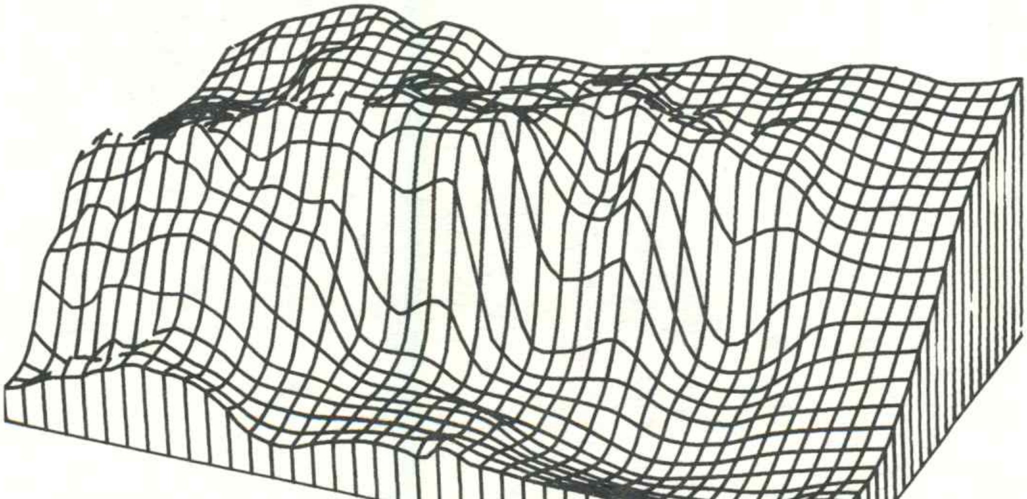

Figure 155.--Block diagram scaled so the range of $\dot{Z}$ values is 35% of the range of X. Vertical exaggeration appears slightly excessive.

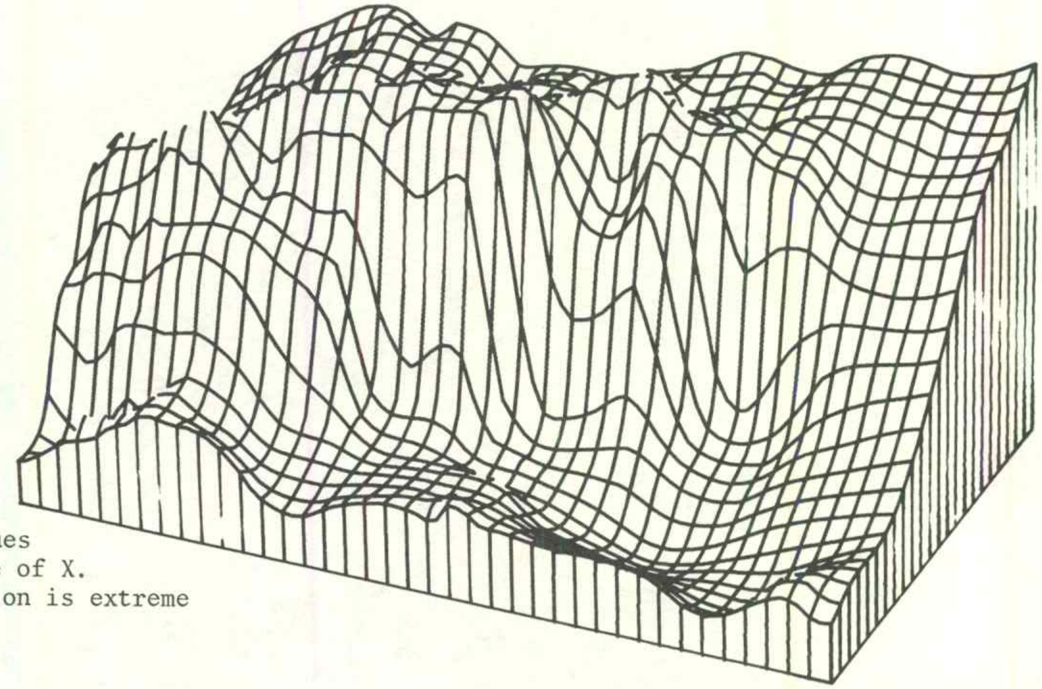

Figure 156.--Block diagram scaled so the range of Ż values is 50% of the range of X. Vertical exaggeration is extreme in this example.

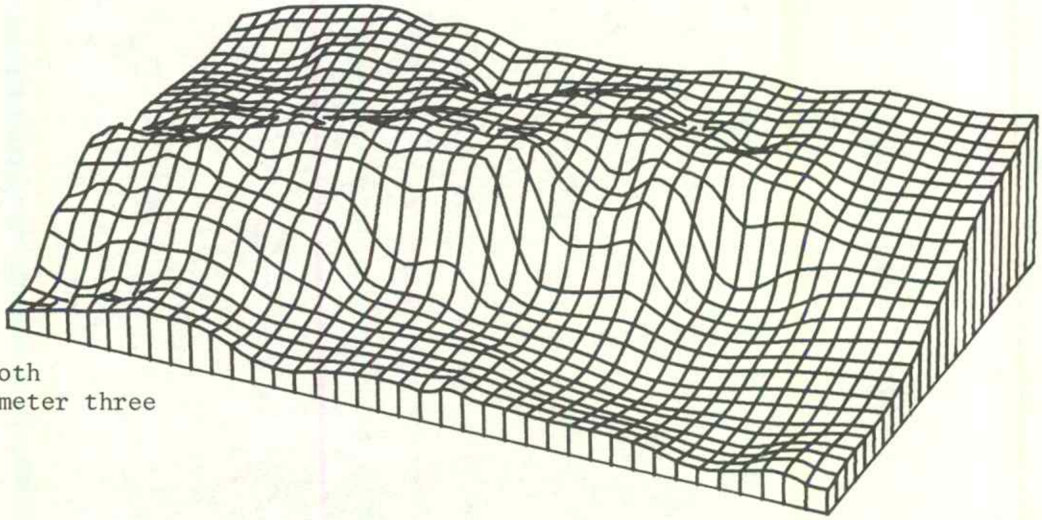

Figure 157.--Block diagram drawn with lines parallel to both X and Y axes. Parameter three is set to 0.

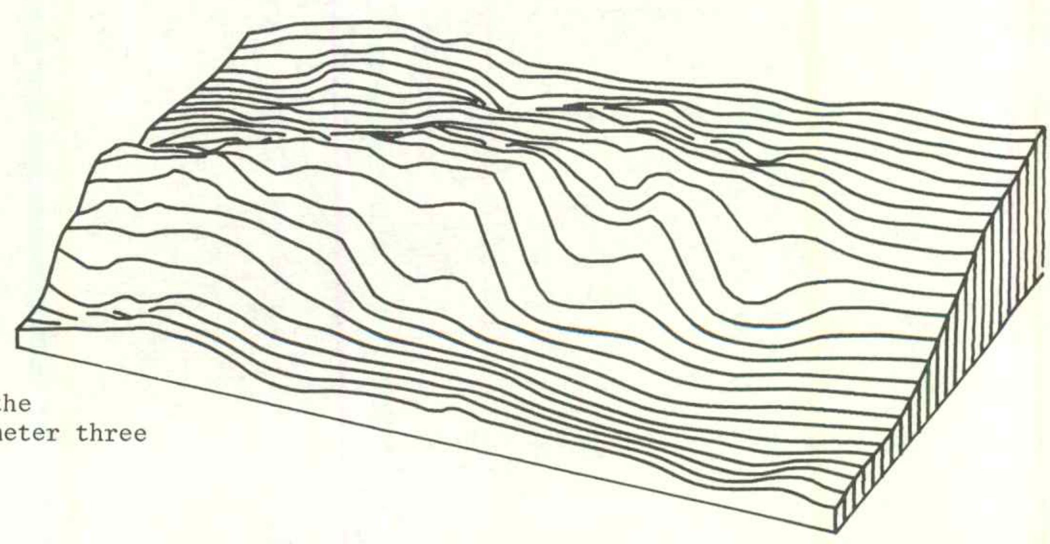

Figure 158.--Block diagram drawn with lines parallel to the X-axis only. Parameter three is set to 1.

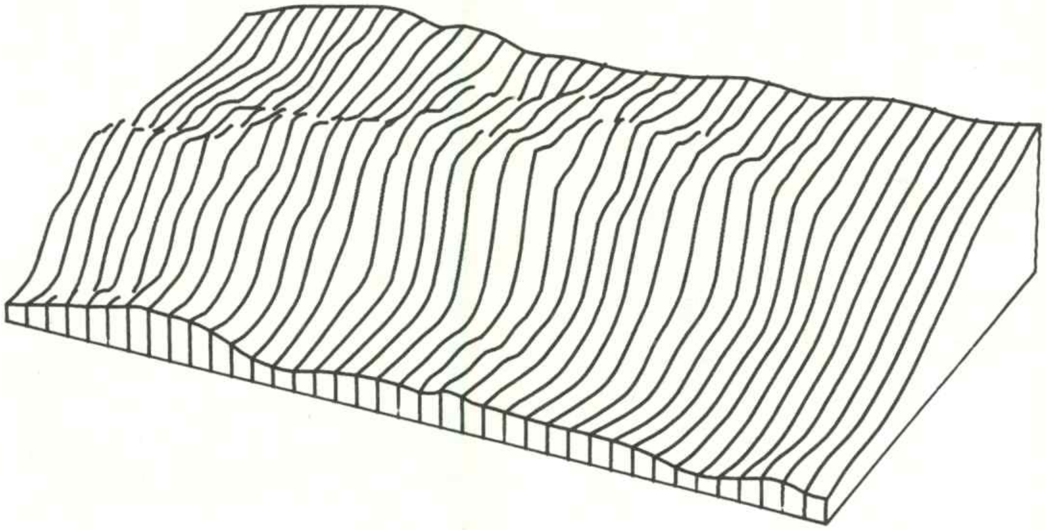

Figure 159.--Block diagram drawn with lines parallel to the Y-axis only. Parameter three is set to 2.

This option of 'TRAN'SECT is not implemented in the initial release of SURFACE II.

Figure 160.--Block diagram drawn with lines perpendicular to the line of sight from the observer to the block. Parameter three is set to 3.

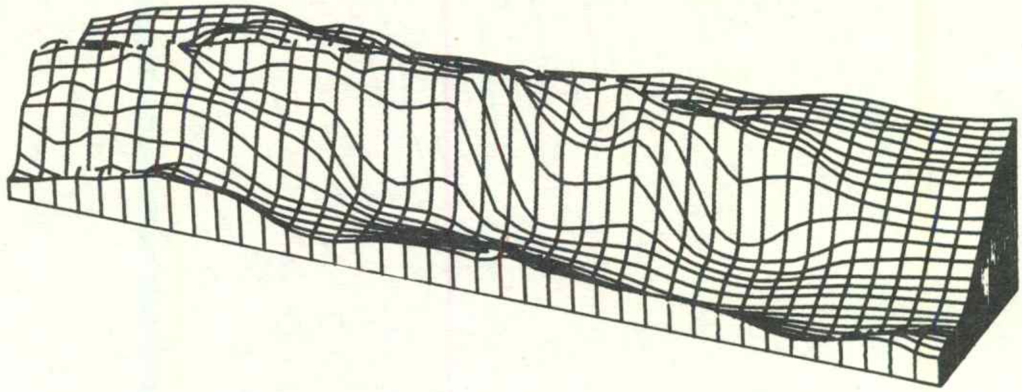

Figure 161.--Block diagram drawn with values of the Y-axis scaled to 20% of the scale of the X-axis.

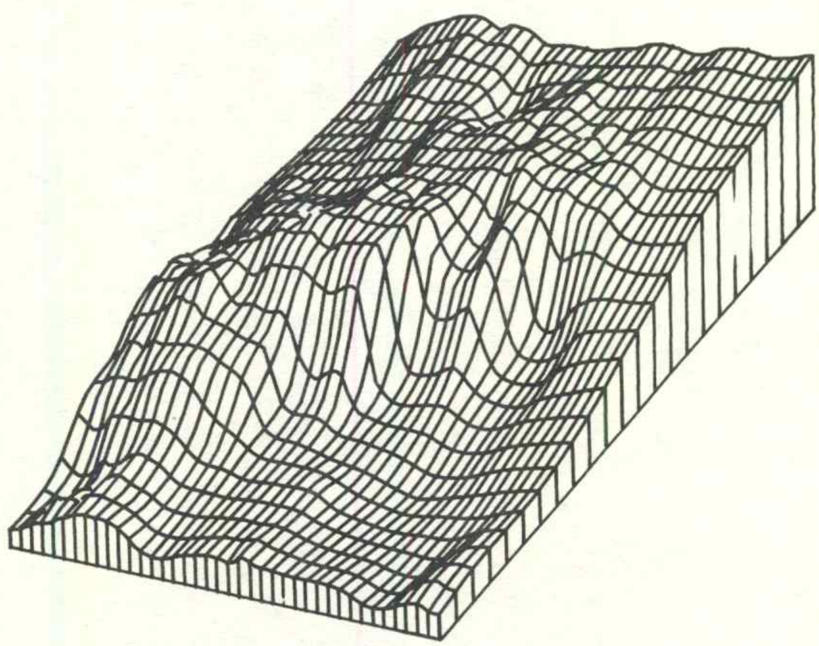

Figure 162.--Block diagram drawn with values of the X-axis scaled to 50% of the scale of the Y-axis.

'TREN'D - generates a matrix of estimated surface values by evaluating a trend surface or two-dimensional polynomial regression fitted to coordinates of the sample data points.

Field Number	Parameter Description	Assumed Value
1	Method of determining the grid size. If 0, the number of columns and rows in the grid matrix will be specified. If 1, the number of columns and rows in the grid matrix will be calculated. The distance desired between columns and rows must be given.	0
2	Either the number of columns in the grid matrix, <u>or</u> the distance between columns; the interpretation depends on parameter two.	25/1
3	Either the number of rows in the grid matrix, <u>or</u> the distance between rows; the interpretation depends on parameter two.	25/1
4	Degree of the regression equation.	3
5	Determines which values will be stored in the grid matrix. If 0, the estimated $\hat{Z}$-value of the regression equation will be evaluated at each grid intersection and stored in the grid matrix. If 1, the estimated $\hat{Z}$-value of the regression equation at each grid intersection will be subtracted from the original value of the grid matrix at each grid intersection. The difference or residual will be stored in the grid matrix as a new value of Z.	0
6	If 0, retain sample data in memory. If 1, replace the Z values with the residuals. If 2, delete the sample data from memory.	0
7	Determines allowable range of trend surface. Limits to trend surface are range of original Z-values ± specified percentage of original range.	Original range ± 50%
8	If 0, trend surface residuals are not listed. If 1, trend surface residuals are listed.	0
9	Class interval width of histogram of residuals.	Variable[1]

[1]The range of values is divided into 25 categories whose boundaries are adjusted to rational limits.

A polynomial regression of Z on the powers and cross-products of X and Y is fitted by least squares. The regression or trend surface equation is evaluated for values of X and Y that correspond to grid intersections in the Z matrix.

The user may define the size (i.e., the number of columns and rows) of the matrix in two different ways. By setting parameter one to 0, he may specify the exact number of columns and rows in the matrix. The distance between columns is $\frac{X_{max} - X_{min}}{NC - 1}$ and the distance between rows is $\frac{Y_{max} - Y_{min}}{NR - 1}$, where X_{min}, X_{max}, Y_{min}, and Y_{max} are determined by 'EXTR'EMES, and NC and NR are specified by parameters two and three.

When parameter one is set to 1, the user specifies the distance between columns and rows, and NC and NR are calculated by dividing these distances into the ranges of X and Y as specified by 'EXTR'EMES. If there is any remainder, the ranges of the X and Y variables are expanded so the distances between all rows and columns are uniform. For example, if

$$X_{min} = 1 \quad Y_{min} = 1 \quad \text{parameter one} = 3$$

$$X_{max} = 25 \quad Y_{max} = 20 \quad \text{parameter two} = 3$$

the number of columns in the matrix is

$$\frac{25 - 1}{3} + 1 = 9$$

and the number of rows in the matrix is

$$\frac{20 - 1}{3} + 1 = 7\ 1/3\ .$$

To eliminate fractions, the number of rows is set to 8, and the value of Y_{max} is automatically changed to 22.

The user may store the trend surface values at each grid intersection in the grid matrix, or he may subtract the trend value from a previously defined grid matrix to form a difference or residual matrix. This option is controlled by parameter five. If parameter five is set to 1, the size (number of columns and rows) of the matrix specified in the 'TREN'D command must be identical to the previously defined grid matrix. Parameter six subtracts trend surface values from sample data points. The Z values which were read in by 'IDXY' are replaced with the differences or trend residuals. Postings of the residual values may then be made.

Figure 163 is a linear (first degree) trend surface fitted to subsea elevations of the top of the Lansing Group in part of Graham County, Kansas. The surface has the form of a gently dipping plane (Fig. 164). A third degree surface fitted to the same data has the form shown in Figures 165 and 166. Residuals from the third degree surface are shown in Figures 167 and 168.

The printed output produced by 'TREN'D includes a statistical analysis of the regression, including goodness-of-fit measures, information essential for analyses of variance, and the solution to the specified degree of regression. The B_i coefficients of the regression equation are listed by rows. The arrangement of coefficients in the listing, through the sixth order, is:

$$\underbrace{B_0 + B_1X + B_2Y}_{\text{1st}} +$$

$$\underbrace{B_3X^2 + B_4XY + B_5Y^2}_{\text{2nd}} +$$

$$\underbrace{B_6X^3 + B_7X^2Y + B_8XY^2 + B_9Y^3}_{\text{3rd}} +$$

$$\underbrace{B_{10}X^4 + B_{11}X^3Y + B_{12}X^2Y^2 + B_{13}XY^3 + B_{14}Y^4}_{\text{4th}} +$$

$$\underbrace{B_{15}X^5 + B_{16}X^4Y + B_{17}X^3Y^2 + B_{18}X^2Y^3 + B_{19}XY^4 + B_{20}Y^5}_{\text{5th}} +$$

$$\underbrace{B_{21}X^6 + B_{22}X^5Y + B_{23}X^4Y^2 + B_{24}X^3Y^3 + B_{25}X^2Y^4 + B_{26}XY^5 + B_{27}Y^6}_{\text{6th}}$$

The SURFACE II commands which produced the maps in Figures 165 and 167 are listed below:

Read XYZ data, calculate and plot trend surface (Fig. 165)	TITLE	TREND TEST FOR SURFACE MANUAL
	DEVICE	1,'DAVIS'
	IDXY	200,11,4,2,3,4,1,0,1,9999,'(F6.0,2F12.5,F7.0)'
	EXTREMES	0,10,0,6
	TREND	3,1,0.2,0.2,0,0
	CONTOUR	
	CINTERVAL	0,0,10,0,5,0.1,0,2.0,5
	SIZCONTOUR	1,6,3.6
	BOX	1,2,1,2,0,0,0,1,0.1
	PERFORM	
Plot trend residual (Fig. 167)	GRID	1,0.2,0.2
	TREND	3,1,0.2,0.2,1,0
	CONTOUR	
	PERFORM	
	STOP	

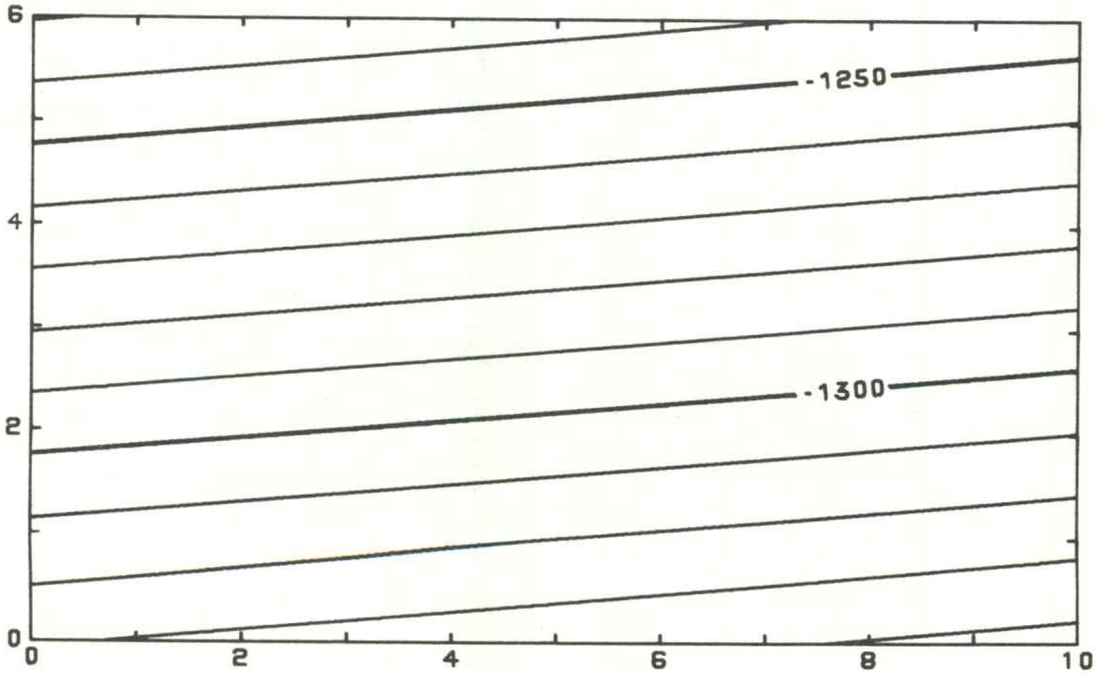

Figure 163.--Linear trend surface of the top of the Pennsylvanian Lansing Group in part of Graham Co., Kansas. Contours are in feet below sea level.

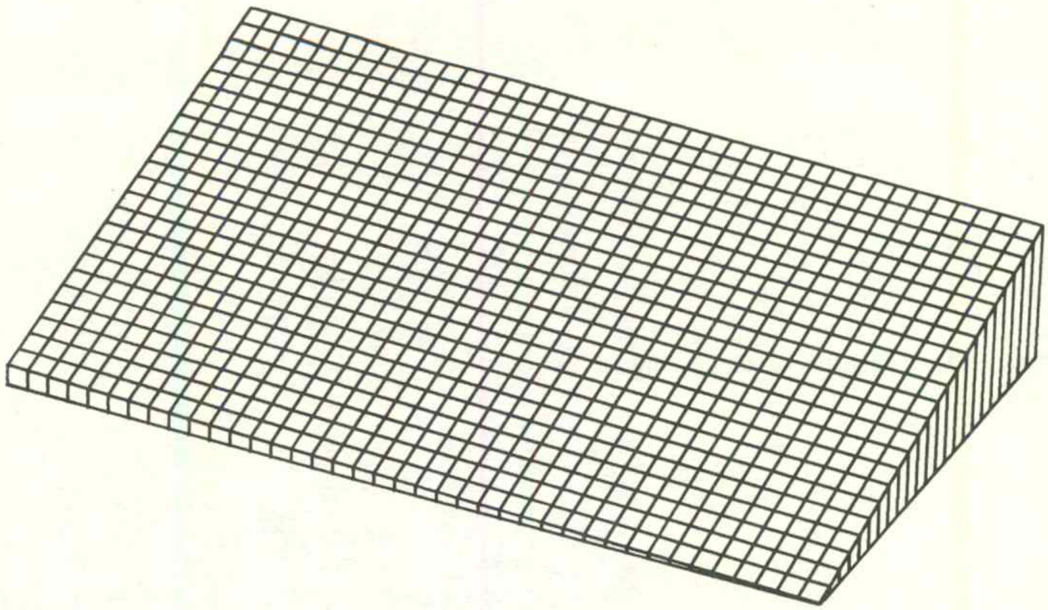

Figure 164.--Block diagram of the trend surface shown in Figure 163, showing the gentle dip of this surface.

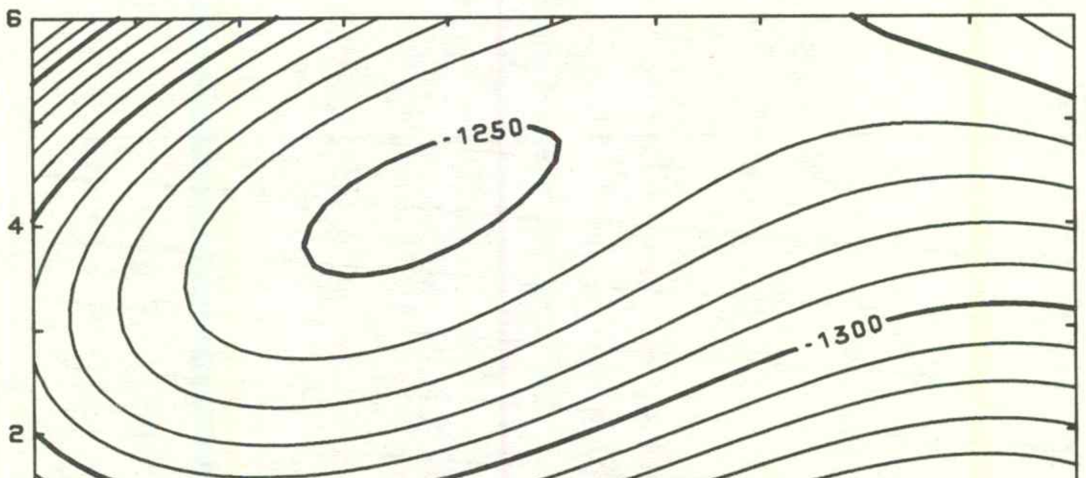

Figure 165.--Third degree trend surface of the same area as Figure 163.

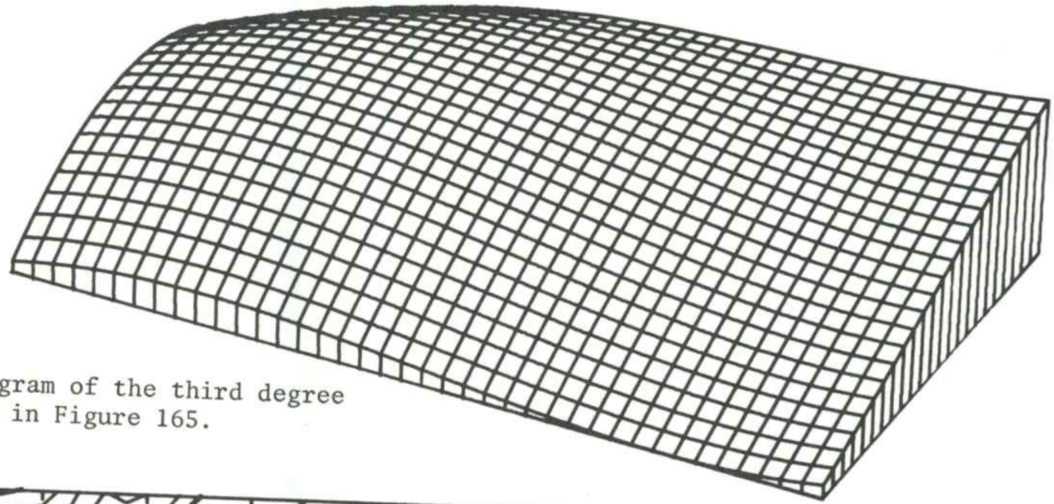

Figure 166.--Block diagram of the third degree trend surface shown in Figure 165.

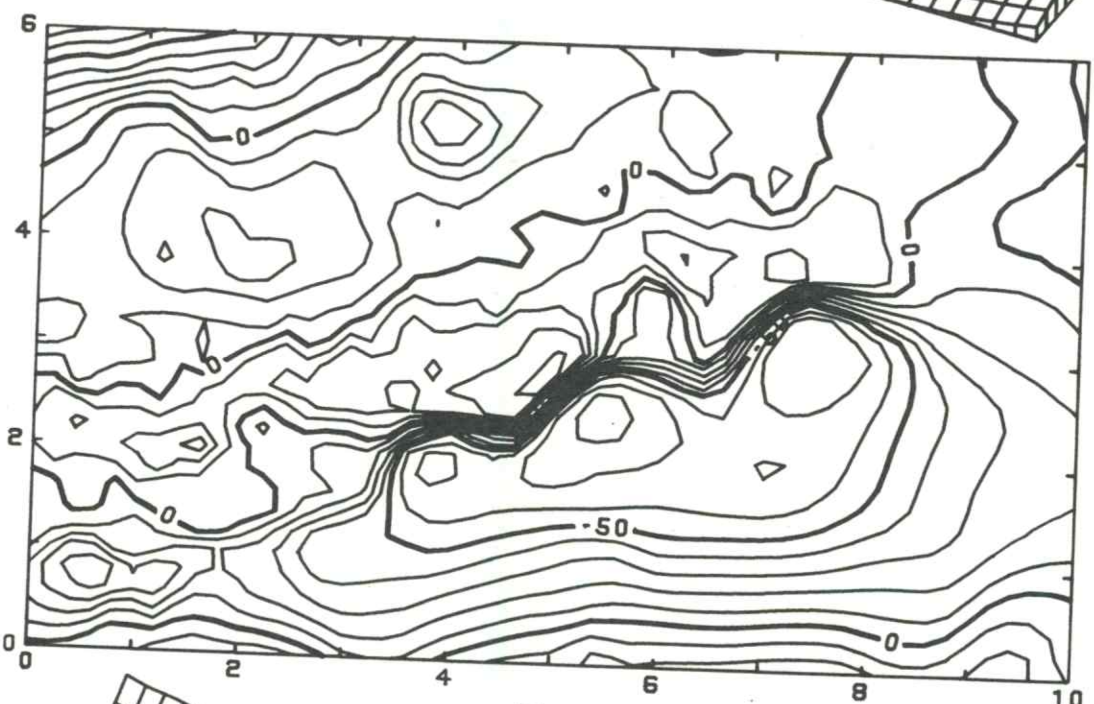

Figure 167.--Map of the residuals from the third degree trend surface shown in Figure 165. This is equivalent to an isopach between the original surface (see, for example, Fig. 77) and the trend surface of Figure 167, but created directly by parameter five of 'TREN'D.

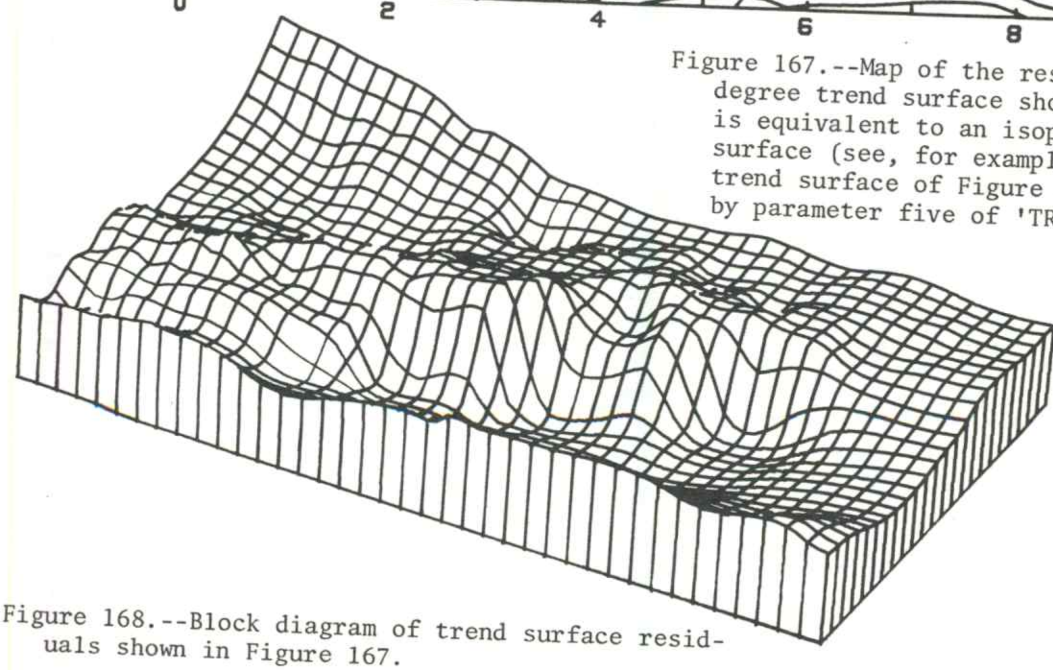

Figure 168.--Block diagram of trend surface residuals shown in Figure 167.

'VRAD'IUS - specifies that sample data points to be used to estimate an element in the grid matrix be found by a search of a circular area of specified size around that element. A radius search finds all points within a specified distance of the element to be estimated.

Field Number	Parameter Description	Assumed Value
1	Use of the search procedure. If 1, use a variable radius search in Phase 1 of 'GRID'. If 2, use a variable radius search in Phase 2 of 'GRID'. If 3, use a variable radius search in 'DMAP'.	1
2	Minimum number of points which must be found for a successful search.	8
3	Maximum number of points to be retained in the search procedure.	1 1/2 x (parameter 2)
4	Initial radius of search, in units of X and Y.	variable[1]
5	Maximum radius of search, in units of X and Y.	variable[2]
6	Number of increments in expansion from minimum to maximum search radius.	4

---

[1] Set to the radius necessary to enclose an area that will contain, on the average, the number of points specified by parameter two.

$$\text{radius} = \sqrt{\frac{A}{\pi}}$$

$$\text{where } A = \frac{\text{total map area}}{\text{total number of data points}} \times \text{parameter two}$$

[2] Set to the radius necessary to enclose an area that will contain, on the average, five times the number of points specified by parameter three.

$$\text{radius} = \sqrt{\frac{A}{\pi}}$$

$$\text{where } A = \frac{\text{total map area}}{\text{total number of data points}} \times (\text{parameter three} \times 5)$$

The search performed by 'VRAD'IUS is an iterative process (Fig. 169). First, all data points are found whose distance from the grid intersection is less than or equal to the initial search radius. If the total number of data points found is greater than or equal to parameter two and less than or equal to parameter three, the data points are retained and the search procedure is successful.

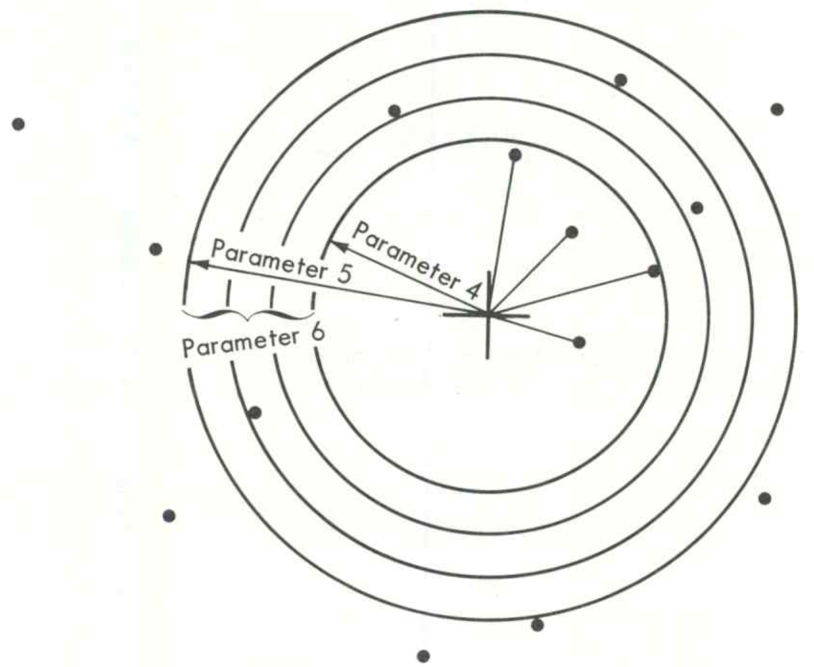

Figure 169.--Search pattern used by 'VRAD'IUS to find the control points within an area around a grid node.

If more than the maximum number of data points specified in parameter three are found, the points used are selected from within the area by a nearest-neighbor procedure. If too few points are found, the search radius is expanded to a radius equal to parameter five + (parameter five - parameter four) / parameter six, and another search is begun. This continues until (1) the specified minimum number of points is found, in which case the search is successful, or (2) the maximum search area has been examined without finding a sufficient number of points, in which case the search fails and the grid node being evaluated is set to the default or blank value.

The minimum allowable value for parameter two is 4. The maximum allowable value for parameter three is 48. The assumed values of parameters four and five are calculated from the size of the map area, as determined by the 'EXTR'EMES command. Figures 170 and 171 show examples of contour maps made using different values for the 'VRAD'IUS command.

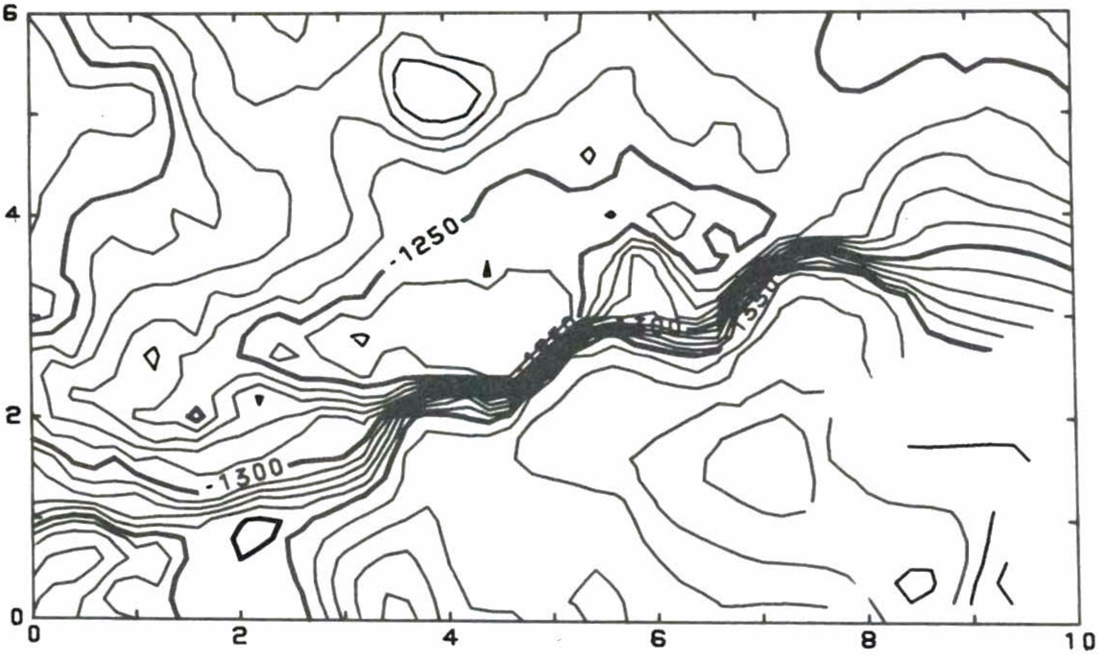

Figure 170.--Subsurface structural contour map of the top of the Lansing Group in Graham Co., Kansas, mapped using a variable radius search extending a maximum of two miles.

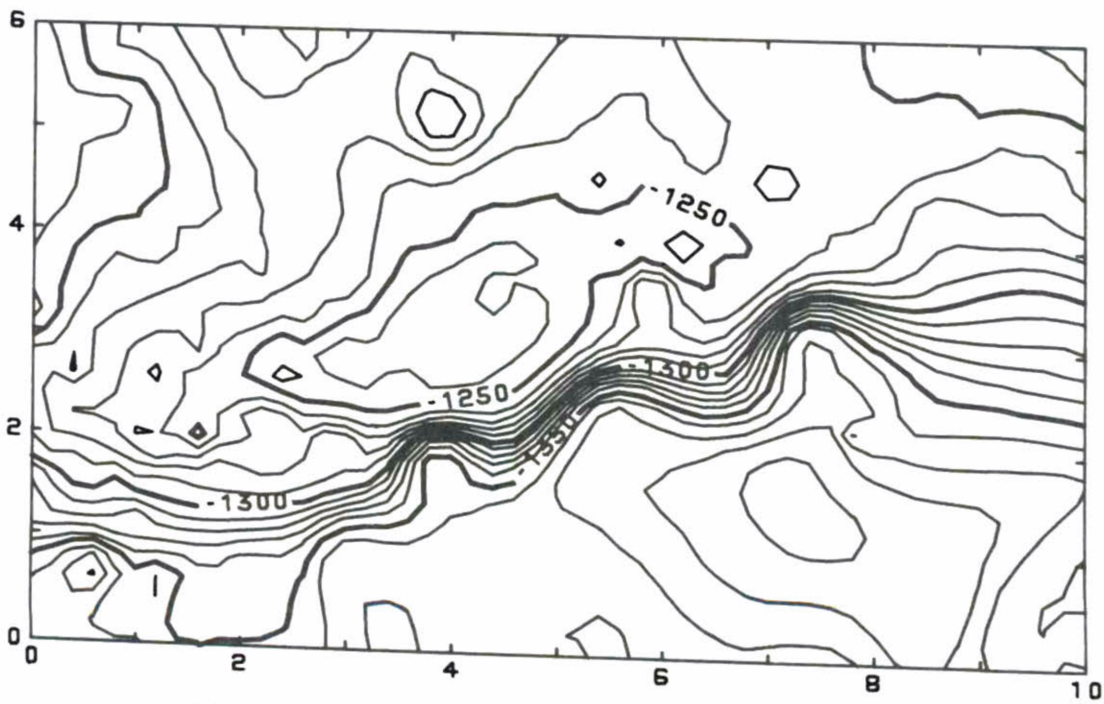

Figure 171.--Same surface as in Figure 170, but mapped using a search extending to a maximum of six miles.

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APPENDIX A

Listing of Test Data for SURFACE II

This listing includes 190 well locations and elevations of formation tops in a part of Graham County, Kansas. The first variable is a well identification number. The second variable is the X or east-west coordinate given in miles from an arbitrary origin in the southwest (lower left) corner. The third variable is the Y or north-south coordinate, also in miles from the origin. The fourth variable is elevation of the top of the Lansing Group (Pennsylvanian), measured in feet below sea level. The fifth variable is top of the Stone Corral formation (Permian), measured in feet above sea level. The final variable is elevation of the ground surface at the well location, also measured in feet above sea level. The value 9999 is a code indicating missing data.

747.	0.20730	5.53875	-1312.	459.	2375.
749.	0.31324	4.78629	-1312.	457.	2392.
753.	0.15635	3.54070	-1304.	457.	2382.
754.	0.02175	3.16929	-1314.	437.	2397.
759.	0.00239	2.42004	-1289.	470.	2383.
760.	0.25231	2.41357	-1269.	474.	2357.
761.	0.38373	2.66010	-1296.	453.	2383.
762.	0.49575	2.15732	-1265.	479.	2382.
763.	0.36105	1.78592	-1291.	447.	2406.
764.	0.24097	1.97649	-1277.	461.	2385.
765.	0.11763	2.04218	-1290.	460.	2367.
768.	0.04215	1.54430	-1321.	414.	2387.
772.	0.58160	0.65542	-1382.	358.	2427.
773.	0.88250	0.21010	-1352.	378.	2424.
774.	1.26558	0.51249	-1368.	364.	2422.
775.	1.44809	0.32020	-1345.	390.	2428.
776.	0.96955	1.14517	-1326.	424.	2403.
777.	0.85438	1.52312	-1307.	442.	2408.
778.	1.22925	1.51335	-1295.	454.	2390.
779.	1.48242	1.63174	-1288.	439.	2392.
780.	1.23901	1.88806	-1255.	454.	2422.
781.	0.98421	1.70721	-1277.	455.	2415.
782.	0.99234	2.01945	-1258.	460.	2402.
783.	0.61097	1.77942	-1286.	447.	2401.
784.	0.62880	2.46630	-1280.	459.	2333.
785.	0.74566	2.15084	-1270.	472.	2373.
786.	0.87872	2.45983	-1269.	462.	2376.
787.	1.12054	2.14111	-1265.	467.	2397.
788.	1.25521	2.51257	-1274.	9999.	2366.
789.	1.49865	2.25629	-1258.	488.	2393.
790.	1.50836	2.63101	-1256.	479.	2379.
791.	0.72347	3.71359	-1289.	456.	2361.
792.	0.90610	3.52143	-1286.	9999.	2378.
793.	1.16563	3.88972	-1299.	464.	2332.
794.	1.48123	4.00662	-1288.	469.	2322.
795.	1.35946	4.13473	-1289.	464.	2344.
796.	1.36425	4.32208	-1299.	469.	2354.
797.	0.68176	4.52697	-1305.	453.	2357.
798.	0.82261	5.14825	-1314.	459.	2391.
799.	0.71030	5.65098	-1291.	9999.	2339.
801.	1.83179	5.49762	-1278.	478.	2348.
802.	2.08487	5.61622	-1263.	497.	2347.
803.	2.20667	5.48813	-1266.	506.	2329.
804.	2.59417	5.97838	-1275.	503.	2305.
805.	2.06903	4.99161	-1272.	490.	2347.
806.	2.56252	4.72904	-1279.	476.	2296.
807.	2.18445	4.61366	-1279.	483.	2318.
808.	2.05631	4.49192	-1280.	481.	2321.
809.	1.98586	4.18121	-1284.	489.	2306.

410.	4.17340	3.28831	-1236.	525.	2300.
411.	4.42333	3.28222	-1232.	535.	2291.
412.	4.36388	3.40799	-1253.	526.	2294.
413.	4.16734	3.03983	-1232.	532.	2292.
414.	4.41727	3.03373	-1238.	515.	2280.
415.	4.03934	2.91865	-1239.	521.	2309.
416.	3.53341	2.68243	-1250.	514.	2330.
417.	3.88692	1.80361	-1362.	425.	2302.
418.	4.36214	0.79733	-1366.	411.	2296.
419.	5.11808	1.02720	-1364.	421.	2263.
420.	5.38952	1.89088	-1374.	423.	2284.
421.	4.54526	3.15492	-1237.	527.	2284.
422.	4.67477	3.33825	-1231.	523.	2279.
423.	4.67931	3.52463	-1244.	525.	2274.
424.	4.86373	3.39581	-1240.	527.	2268.
425.	5.43211	3.63066	-1253.	529.	2250.
426.	5.19123	4.00953	-1248.	530.	2264.
427.	5.39219	4.56420	-1263.	526.	2241.
428.	5.43814	3.87920	-1241.	542.	2236.
429.	4.57843	4.52166	-1254.	529.	2250.
430.	5.39818	4.81273	-1255.	536.	2252.
431.	5.41012	5.30981	-1260.	530.	2215.
432.	5.47707	5.49472	-1268.	518.	2243.
433.	4.96828	5.13391	-1267.	516.	2226.
434.	5.08428	4.75812	-1250.	535.	2224.
436.	5.61390	5.98883	-1267.	530.	2226.
439.	6.36369	5.97096	-1254.	545.	2253.
440.	6.42173	5.78303	-1260.	539.	2295.
441.	6.39789	4.78867	-1269.	540.	2237.
442.	5.66005	5.30382	-1254.	9999.	2211.
443.	5.70910	4.74308	-1248.	538.	2256.
444.	6.09593	5.23120	-1269.	540.	2237.
445.	5.97990	5.60704	-1263.	9999.	2211.
446.	6.40387	5.03726	-1264.	538.	2253.
447.	5.89804	4.80070	-1254.	541.	2289.
448.	6.39190	4.54008	-1252.	539.	2258.
449.	5.56612	4.00044	-1239.	543.	2247.
450.	6.19094	3.98530	-1232.	548.	2254.
451.	6.38590	4.29150	-1253.	538.	2258.
452.	6.37989	4.04291	-1240.	537.	2274.
453.	6.19394	4.10959	-1243.	534.	2251.
454.	5.86797	3.55789	-1284.	494.	2294.
455.	5.52366	2.26062	-1376.	434.	2274.
456.	6.36152	0.74759	-1378.	410.	2356.
457.	7.41941	3.08479	-1372.	448.	2299.
458.	7.45109	4.39015	-1252.	534.	2376.
459.	7.08070	4.58566	-1270.	527.	2392.
460.	6.64183	4.53406	-1253.	9999.	2272.
461.	7.07170	4.21273	-1251.	539.	2287.
462.	6.62981	4.03686	-1249.	9999.	2264.
463.	6.56281	3.85192	-1257.	525.	2273.
464.	6.56582	3.97622	-1240.	528.	2263.
465.	6.64782	4.78266	-1255.	526.	2296.
466.	6.90969	5.27387	-1260.	536.	2331.
467.	6.60472	5.59211	-1256.	532.	2302.
471.	6.67166	5.77706	-1256.	541.	2255.
475.	6.98258	5.70745	-1260.	540.	2287.
478.	7.83647	4.81625	-1255.	540.	2392.
479.	8.21435	4.93157	-1254.	548.	2358.
480.	7.84245	5.06491	-1255.	547.	2355.
481.	7.72047	5.19223	-1250.	529.	2360.
482.	7.58953	4.94658	-1257.	9999.	2397.
483.	7.58355	4.69794	-1250.	541.	2405.

810.	1.67186	4.12674	-1296.	475.	2319.
811.	2.28385	3.61105	-1281.	465.	2298.
812.	2.53056	3.47970	-1268.	480.	2309.
813.	2.14604	3.11456	-1271.	480.	2365.
814.	1.63977	2.87761	-1275.	490.	2377.
815.	1.88968	2.87116	-1255.	484.	2377.
816.	2.26617	2.92394	-1241.	496.	2372.
817.	2.51609	2.91750	-1244.	496.	2348.
818.	2.38306	2.60839	-1236.	496.	2376.
819.	2.13315	2.61486	-1245.	489.	2372.
820.	1.88000	2.49640	-1254.	487.	2384.
821.	1.87029	2.12165	-1264.	470.	2393.
822.	2.12344	2.24009	-1285.	474.	2382.
823.	2.37336	2.23360	-1273.	481.	2378.
824.	1.61713	2.00322	-1243.	463.	2406.
825.	1.86055	1.74689	-1284.	451.	2390.
826.	2.08108	0.61608	-1350.	405.	2395.
827.	1.57797	0.50428	-1344.	403.	2420.
828.	1.56812	0.12955	-1344.	401.	2419.
829.	1.94299	0.11968	-1348.	399.	2419.
830.	3.08729	0.83974	-1366.	400.	2338.
831.	2.86670	1.97076	-1293.	458.	2352.
832.	2.63298	2.60193	-1240.	493.	2368.
833.	2.88935	2.84535	-1233.	505.	2350.
834.	2.87966	2.47053	-1245.	493.	2346.
835.	3.13927	2.83890	-1228.	520.	2353.
836.	3.38918	2.83245	-1235.	520.	2342.
837.	3.52059	3.07914	-1230.	518.	2337.
838.	3.27067	3.08558	-1250.	506.	2343.
839.	2.64588	3.10168	-1266.	490.	2360.
840.	2.65231	3.35155	-1263.	499.	2333.
841.	2.65873	3.60142	-1271.	495.	2295.
842.	3.03040	3.46685	-1263.	494.	2326.
843.	3.15857	3.58859	-1261.	494.	2323.
844.	2.67154	4.10117	-1277.	491.	2304.
845.	2.68429	4.60092	-1279.	480.	2283.
846.	2.99828	4.65543	-1266.	492.	2267.
847.	3.49175	4.39279	-1257.	521.	2274.
848.	3.07188	5.09115	-1271.	499.	2297.
849.	2.78161	5.97366	-1266.	505.	2284.
1633.	0.94004	0.02111	-1362.	379.	2419.
1634.	1.43987	0.00793	-1350.	392.	2405.
556.	9.85676	5.63881	-1242.	586.	2432.
557.	9.73477	5.76617	-1243.	589.	2429.
558.	9.98470	5.76020	-1235.	585.	2429.
569.	9.97875	5.51144	-1243.	588.	2424.
570.	9.79131	5.51592	-1248.	581.	2426.
573.	9.95487	4.51638	-1260.	560.	2446.
345.	5.34634	0.15112	-1355.	403.	2313.
346.	5.21827	0.02998	-1366.	398.	2303.
347.	5.10572	0.53015	-1365.	406.	2268.
349.	5.47130	0.14799	-1350.	407.	2309.
350.	5.71966	0.07961	-1364.	402.	2338.
352.	5.59936	0.26915	-1361.	414.	2361.
380.	7.47378	0.22234	-1371.	416.	2405.
401.	4.10840	5.77610	-1274.	502.	2268.
403.	3.90459	5.09729	-1297.	500.	2273.
404.	3.88062	4.10344	-1256.	506.	2296.
405.	3.91742	3.04594	-1232.	526.	2306.
406.	3.79549	3.17322	-1236.	525.	2317.
407.	3.92348	3.29440	-1241.	528.	2304.
408.	3.66293	2.86571	-1230.	530.	2339.
409.	3.54101	2.99299	-1234.	519.	2328.

484.	7.97039	5.18624	-1250.	557.	2368.
485.	7.57756	4.44929	-1255.	540.	2409.
486.	7.63553	4.26130	-1260.	539.	2349.
487.	8.48586	0.69476	-1388.	423.	2443.
488.	8.89458	2.05334	-1365.	458.	2421.
489.	9.43093	3.53347	-1305.	527.	2412.
490.	9.32705	4.40707	-1269.	539.	2442.
491.	8.57726	4.42517	-1274.	538.	2402.
492.	9.21406	4.90754	-1264.	556.	2439.
493.	8.97011	5.16227	-1252.	568.	2435.
494.	8.72614	5.41696	-1252.	573.	2393.
495.	9.46698	5.02591	-1258.	568.	2436.
496.	9.48484	5.77213	-1245.	584.	2430.
548.	9.84493	0.03867	-1372.	444.	2446.
549.	9.47315	0.17241	-1360.	455.	2438.

APPENDIX B

Data Formats

Formats must be provided for many of the data files that are read into or written by SURFACE II. When a format is required by a command, the format specification must be included as a parameter. Commands requiring a format parameter include:

IDXY
LEVELS
MATRIX
MOUTPUT
ODXY
ROUTLINE

All of these commands must use a FORTRAN format statement to describe records in the data file. The format statement, including parentheses, must be enclosed in single quotes. An example is:

'(2F10.3,I5,10X,F15.6)'

'IDXY', 'LEVE'LS, 'MATR'IX, and 'ROUT'LINE require a format parameter to specify the form of input data. If the data are on cards, a free format may be specified by the format parameter. A free format parameter consists of four parts separated by commas, and enclosed in single quotes. The first part contains the word FREE. The second part specifies what character will be used to separate fields of the input record.

If 0, fields will be separated by a comma.
If 1, fields will be separated by one or more spaces.

The assumed value of the second part of the free format parameter is 0, specifying separation by commas.

The third part of the free format parameter specifies the number of columns to be read from each card.

If 0, read 72 columns.
If 1, read 80 columns.

The assumed value of the third part of the free format parameter is 0, specifying that 72 columns will be read from each card.

The fourth part of the free format parameter specifies the number of cards in each logical record; one card per record is assumed. An example of a free format parameter is

'FREE,0,0,1'

This statement specifies that data will be read in under the free format option, with data fields separated by commas, that 72 columns will be read from each card, and that one card will constitute a logical record. This statement explicitly gives the assumed values of each part of the parameter; an equivalent statement is simply

'FREE'

In this statement, the unspecified three parts of the parameter will be set automatically to their assumed values.

The command 'IDXY' may specify a binary format by the parameter statement

'BINARY'

This parameter will read a file that was written by a FORTRAN unformatted I/O routine. An example of an unformatted I/O routine is included with the 'SAVE' command.

APPENDIX C

System Control Cards for SURFACE II

In addition to SURFACE II command cards, system control cards are necessary to run a job on a specific computer. These system control cards are unique for each computer center. Their function is to specify run time and core requirements for SURFACE II and to reserve the necessary tape drives and file space. They also identify the permanent file where the SURFACE II system resides.

System instructions are subject to change with updates in the computer's operational software. The current system control card sequence appropriate for this specific installation are given on the following inserted sheets.

NUMBER ONE
SERIES ON SPATIAL ANALYSIS

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