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APPLICATION OF COMPUTER TO LITHOSTRATIGRAPHIC CORRELATION AND THREE-DIMENSIONAL CONFIGURATION

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

APPLICATION OF COMPUTER TO LITHOSTRATIGRAPHIC CORRELATION AND THREE-DIMENSIONAL CONFIGURATION

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

M. MUMMTAZ NAJJAR-BAWAB

Norman, Oklahoma

1980

APPLICATION OF COMPUTER TO LITHOSTRATIGRAPHIC CORRELATION AND THREE-DIMENSIONAL CONFIGURATION

DISSERTATION COMMITTEE

ABSTRACT

Prediction of subsurface detailed geological structures can be enhanced by implementing a quantitive digital lithostratigraphic correlation of well logs. In order to demonstrate the ability of a computer model to construct a three-dimensional configuration of a reservoir or a coal bed, it is essential to establish lateral stratigraphic unit continuity and variation in bed thickness in the investigation site.

The method of constructing the subsurface structure in two and three dimensions consists of four procedures. First, digitize the original logs and establish stratigraphic units by automatically or manually segmenting each individual well log. Secondly, cross-correlate four well logs at a time by spectral analysis to determine the lateral continuity, variation of bed thickness, and depth of stratigraphic unit at each well. Thirdly, initiate a structure map based on data from the previous procedure. Finally, project the structure map down between the computer correlated wells that produces the two-dimensional cross sections and the three-dimensional configuration of the stratigraphic unit.

The computer model BASEL developed in this research is tested by investigating the configuration of the Lower Earlsboro Sand unit in the St. Louis Oil Field, Oklahoma,

using resistivity logs. It is further tested by evaluating the configuration of coal beds in the Knife River Basin, North Dakota, using gamma logs.

The BASEL computer model demonstrates that the computer can provide an important tool to geologists and engineers in detecting the subsurface structure effectively with great details in a very short time.

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GLOSSARY

Correlation function: refer to page 53, Equation (34).

Cross-correlation: involves measuring the similarity of two spatial series, pages 50-57, 65, 66-70, Eqn. (32).

Digitization: is the transformation of the continuous curve (log) into discrete numerical data, page 27.

Fourier transform: refer to pages 35-42.

Frequency filter (digital filter): implies the passing of certain frequencies and blocking others, to filter out certain frequencies, pages 31-35.

Lag τ: is the amount of displacement or shift between the two correlated segments, pages 51-52, 65, Eqn. (46).

Lithostratigraphic correlation: reflects the similarity in geological properties and in stratigraphic location of geological strata, pages 15-26.

Nonstationary log data: involves the type of data whose statistical properties change with time, pages 32, 129, and refer to Bendat and Piersol, 1971, pages 344-376.

Normalized cross-correlation function: refer to pages 53, 57, Equations (34) and (36).

Nyquist frequency: refer to the frequency $F_n = 1/(2T)$. It is the highest frequency which can be detected with data sampled at intervals τ.

Segmentation (Zonation): dividing the digitized log into homogeneous units, pages 28-31, 134.

Spectral analysis: refer to pages 38, 45-47 and Eqs. 12, 30.

Stretching and stretching factor: refers to a mathematical approach to account for the relative variation of bed thickness between wells, page 58. Stretching factor $S = 10^{\tau \cdot \Delta}$, where τ is digitizing interval and Δ is the interpolation interval, pages 48-50, 54, 58-65, Eqn. (47).

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The author is sincerely grateful to his parents for giving him the motivation, guidance and sacrifices in order to enable him to receive the best education possible.

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CHAPTER I

INTRODUCTION

The principles of correlation techniques have been established in various fields of science to measure the degree of similarity between two or more sets of variables. In geology, however, the correlation techniques are widely used in correlation of subsurface strata either visually or by computer.

Automatic correlation of lithostratigraphic sequences usually is considered to be the matching by computer of two or more sequences of digital measurements that represent lithology. In subsurface geological correlation the measurements may be obtained from geological logs. Thus, computer correlation is the mathematical quantification of visual correlation where a geologist lines up the logs and visually locates the best alignment. Indeed, the human eye is a good correlator, and a trained geologist with a knowledge of probable lateral variations in lithology can outperform present automatic methods. Comparison of two curves is not difficult, however, if the geologic sequences in the wells are similar. Yet in most cases, facies changes and structural variations complicate the process of pattern recognition.

The ability of the computer to correlate well logs efficiently is demonstrated in Figure 1. If correlation of this kind could be done by computer, it would have the obvious advantages of objectivity and speed. Considerable differences in perception, however, occur among geologists. The recent trends in correlation are toward producing a standard, relatively accurate (with respect to conventional methods), consistent, and free-from-human errors correlation. In short, a correlation by the application of computer-assisted mathematical operations seems to coinside with these trends.

Jagelar and Matuszak (1972) and Matuszak (1972) discussed the common logs used for automatic lithostratigraphic correlation (spontaneous potential, SP; gamma ray, GR; Acoustic and others), factors affecting the measurement such as porosity and/or permeability, fluid saturations, formation resistivities and other parameters. It is recommended that one have a thorough understanding of these parameters in order to achieve a successful correlation using geophysical logs.

Previous Work

Computer correlation of time series--an orderly sequence of regularly spaced data--has been attempted in the past with limited success. Methods for analyzing time series in both time and frequency domains have been well discussed by Jenkins and Watts (1969). The mathematical principles of

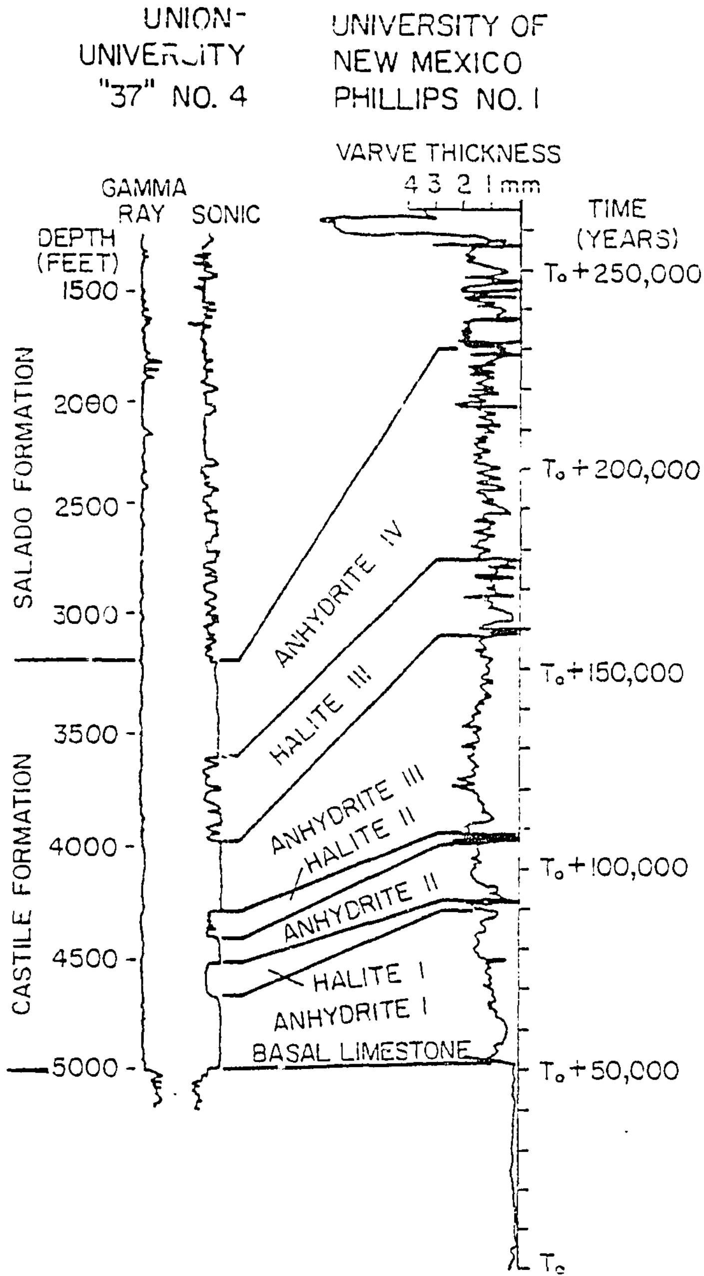


Figure 1. Correlation between gamma ray and sonic logs of Union-University well and smoothed calcite-anhydrite couplet thickness in Phillips core of Castile Formation. Couplet thickness is estimated for halite units (After Anderson and others, 1972).

correlation techniques were described earlier by Lee (1960). Weiner (1949) first used the cross-correlation function to determine the dependence of two time series on each other. Anstey (1964) discussed several applications of this technique. The first worker to implement the computer for correlation was Daskam (1964). He described a computer process based on existing computer programs. Working on parallel lines, Southwick and Adair (1964) employed electrical logs to correlate the porosity and resistivity indices of porous zones.

Along the same line in automatic correlation, Matuszak (1972) used the computer to correlate dipmeter logs. He concluded that automatic correlation of subsurface data by computer does not provide efficient results even in simple geologic situations. He recommended more research to refine existing methods or to develop new techniques. Schoonover and Holt (1971) enhanced Matuszak's approach by filtering the original data to get a higher correlation factor.

Two difficulties are encountered in all earth-science applications of cross-correlation techniques: first, the problem of determining unique points common to both records; second, the problem of shrinking or stretching of the two records due to relative variations in sedimentation rates. To overcome the second problem, stretching, Haites (1963) proposed a perspective correlation to consider this effect by giving different degrees of compression of the depth scale until the value of the correlation factor was a maximum.

The technique for solving the stretching and correlation problems was first discussed by Neidell (1969). He implemented an optimum Weiner interpolation function $\left(\frac{\sin \frac{\pi t}{\Delta t}}{\frac{\pi t}{\Delta t}}\right.$ where Δt is the sampling interval$\Big)$ to expand sections that compensate for the thinning of beds and proceeded with the correlation after he applied high frequency filters to eliminate any noise caused by the stretching process. Merriam (1971) played a distinguished role in similar work to Neidell's. He emphasized the value of segmentation of well logs prior to correlation.

Rudman and Lankston (1973) used the computer to iteratively stretch one of the logs and then used mathematical cross-correlation to measure the lag τ and the cross-correlation function. Henderson (197?) modified the Rudman and Lankston algorithm and added the correlation of four series of logs in the frequency domain. His approach was successfully applied to various logs from onshore and offshore wells (Rudman, Blakely, and Henderson, 1975). Henderson also introduced the concept of normalized cross-correlation functions instead of comparing the auto- and cross-correlation functions used earlier by Rudman and Lankston (1973). In these techniques, he applied the fast Fourier transform (FFT) computer algorithm to the stretching and correlation routines. It should be noticed that his method of iterative stretching and correlation requires considerable computer time, partly because the stretching procedure is repeated twice. Besides, the geologist is unsure as to which log is to be stretched.

The most recent technique of lithostratigraphic correlation was introduced by Rudman, Blakely, and Kwon (1978). Their algorithm predicted automatically not only the amount of stretch but also the direction of stretch. This procedure provided further insight into the spectral character of well logs and its application to the fast correlation. Although they succeeded in obtaining a high value of the correlation function in the model test data, the results of the real data tests were not encouraging due to the low value of the correlation function. In addition, the tie-lines did not represent the actual structure confined between the correlated logs. In this research, double precision is used to generate the plot of Figure 2. Finally, in the case of a large number of logs, the correlation of two logs at a time requires a considerable amount of computer time.

Statement of the Problem

Automatic computer correlation of digital lithostratigraphic measurements can be useful and fairly accurate. It eliminates perceptive differences in visual correlation by the geologist. Unfortunately, the information content in a well log usually is not sufficient to determine the true correlation and the subsurface structure. Results may be in error unless additional information is provided such as

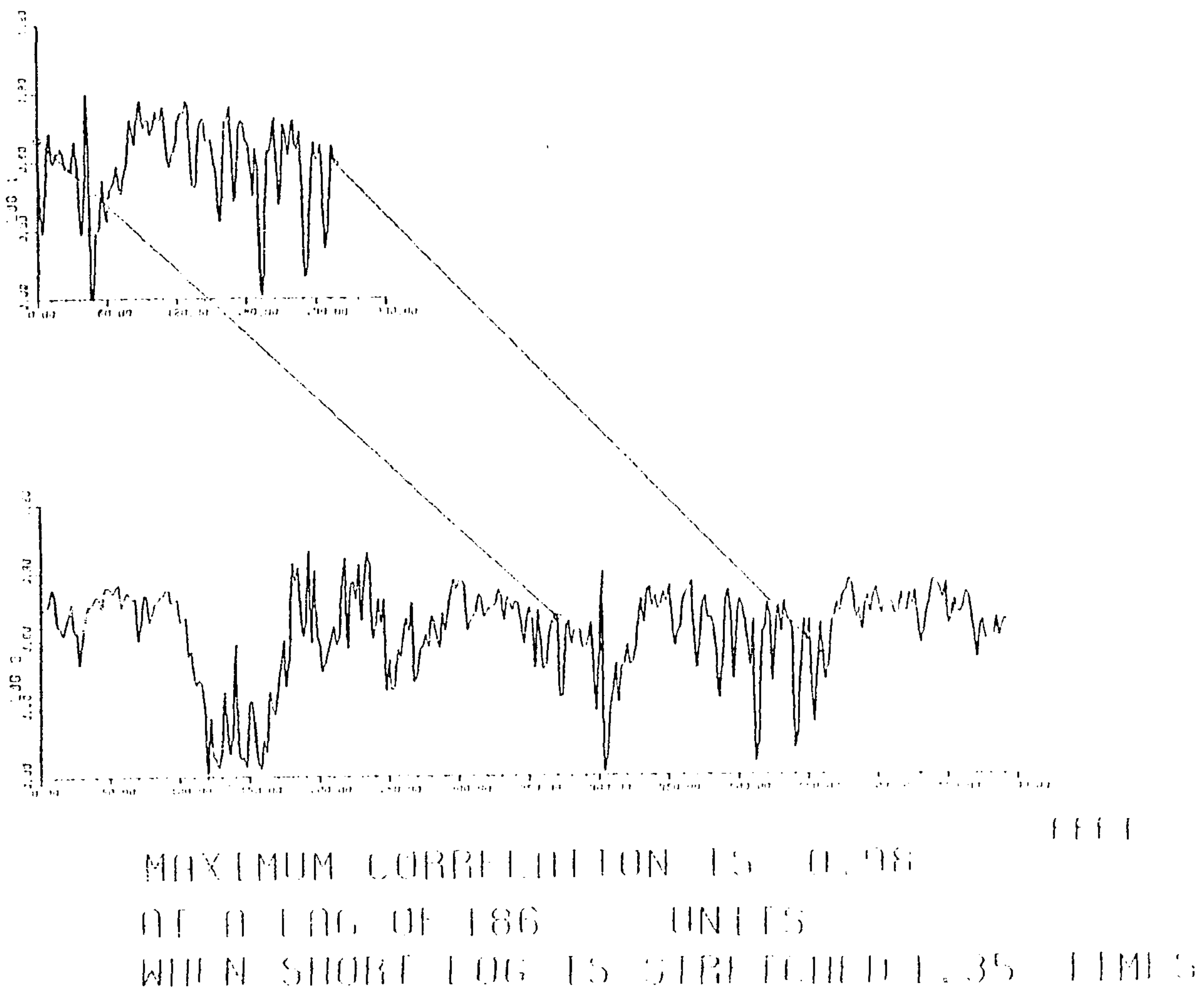


Figure 2. Automatic cross-correlation of two density logs by the computer program SPECOR

structure and isopach maps, paleontology and paleogeology studies, and the geologist's experiences with the study area.

The existing computer correlation of digital litho-stratigraphic measurements have provided the geologists with a practical tool for correlation. Kwon, Rudman, and Blakely (1978) illustrated this method beautifully. Yet their algorithm is insufficient to show the exact or accurate subsurface structure. The tie-lines connecting the aligned segments from the two correlated logs do not represent the actual subsurface structure, especially if the distance between the wells is more than a half mile (.85 km). Even at this short distance, structure might change. The other disadvantage is that the program consumes a considerable amount of computer time in those cases where there are more than two wells to be correlated.

In this study, the computer algorithm BASEL offers a rapid method of comparing four geophysical logs of one type from different wells. It further illustrates a fairly accurate picture of the subsurface in two- and three-dimensional display. The two-dimensional cross section substitutes the straight tie-lines in Rudman's and others algorithm (SPECOR, Figure 2). In order to further demonstrate the subsurface structure of the study area, the previous two-dimensional cross section will be converted to a three-dimensional representation.

Objectives

The ultimate purpose of this research is to develop the computer model BASEL that produces a three-dimensional configuration based mainly on the simultaneous computer correlation of four geophysical logs of the same type from four different well sites with a minimum amount of computer time (Figures 3 and 4). The accuracy of this computer model is tested by comparing the CALCOMP output of the BASEL model to the output of the conventional method. Furthermore, the accuracy of the BASEL model is examined by implementing field data from Oklahoma and North Dakota.

Approach

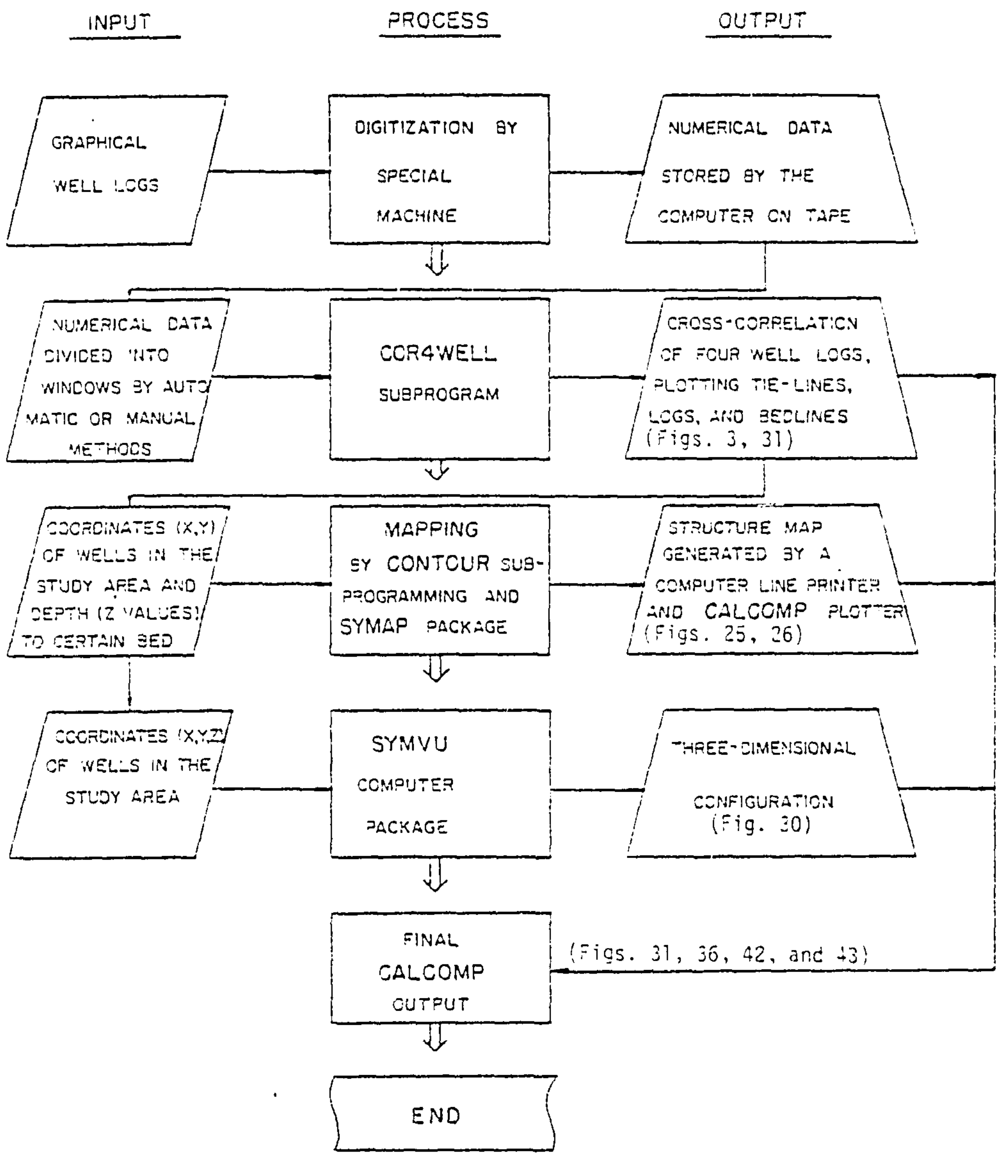
The general approach followed in this dissertation to develop this model is detailed in ten steps which define three procedures in an attempt to obtain the three-dimensional configuration. A conceptual diagram is provided to further illustrate the procedures of the program BASEL.

The first procedure, the simultaneous correlation of the four logs by the computer program COR4WELL, consists of seven steps:

1. Digitization of well logs at two-foot intervals. This interval is chosen because the segments correlated do not have significant beds that are less than two feet thick.

2. Establishing the stratigraphic unit visually or by using a movable window technique (Zonation method).

CONCEPTUAL DIAGRAM
OF
BASEL PROGRAM



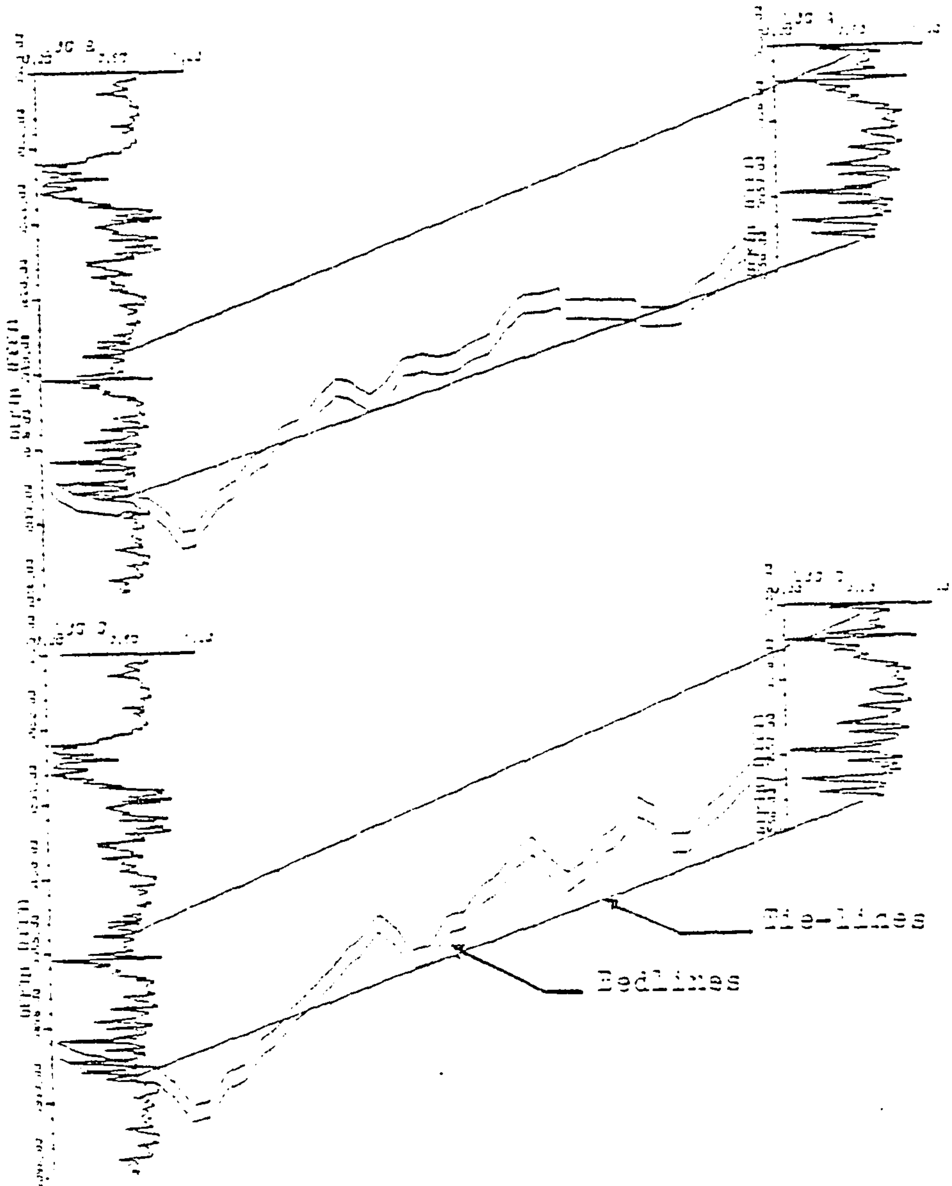


Figure 3. Cross-correlation of model density logs by the computer subprogram COR4WELL. Simultaneous correlation of four well logs showing the superimposed bedlines on the tie-lines of Figure 2.

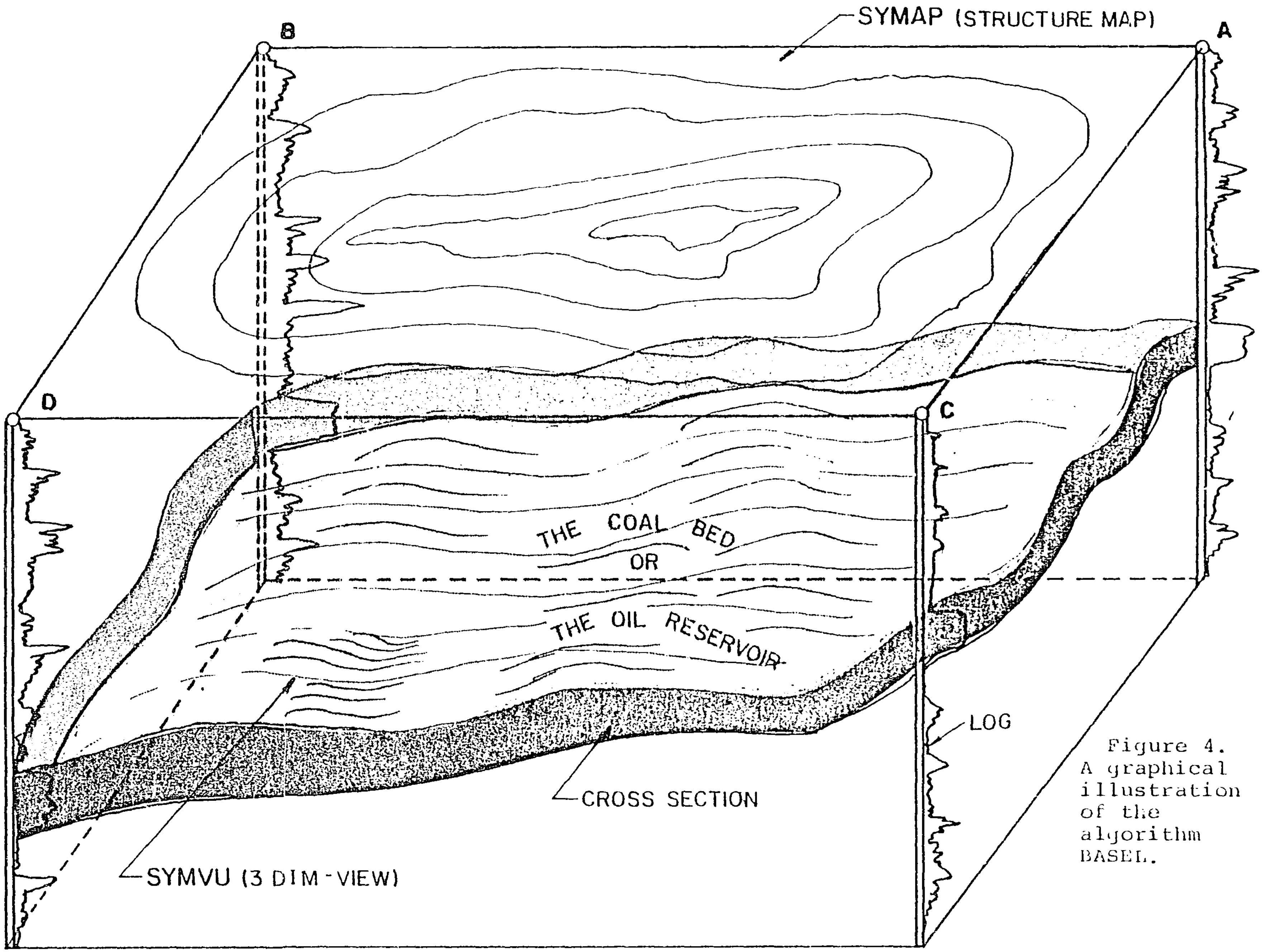


Figure 4.
A graphical illustration of the algorithm BASEL.

3. Filtering of the original data by implementing either the high pass filter or the low pass filter depending on the segment correlated (nonstationary frequency data require high pass filters).

4. Using discrete Fourier transforms (DFT) and fast Fourier transforms (FFT) to calculate the spectra of the logs (the power spectra imply the square of the spectrum amplitude; refer to Equation 30).

5. Perform the stretching process in the frequency domain. This process accounts for changes in thickness between wells.

6. Cross-correlating of the stretched power spectra to estimate the best value of the stretching factors. The best value is defined as the highest value in the plot of lag (for stretch) versus the cross-correlation coefficient.

7. Cross-correlating the stretched logs to evaluate the maximum value of the correlation coefficient and consequently the corresponding value of the lag. This value of the correlation coefficient is defined as the highest amplitude point in the plot of the correlation coefficient versus the lag factor.

The second procedure, the projection of the structure, consists of three steps:

1. A structure map of the study area is to be drawn by a computer. The control points of this map are obtained from the correlated logs in the previous procedure and other logs correlated visually.

2. Connecting the correlated wells by an imaginary straight path on the structure map.

3. The points initiated by the intersection of the contour lines and the imaginary path are projected down between the correlated wells. The interconnection of the projected points results in a smooth curve that represents a two-dimensional cross section of the structure confined between the computer-correlated logs.

The third procedure is the three-dimensional modification. The two-dimensional cross section from the previous procedure is converted to a three-dimensional configuration by implementing the SYMVU computer package. The outcome of this modification illustrates the configuration of the correlated segments.

CHAPTER II

PRINCIPLES OF LITHOSTRATIGRAPHIC CORRELATION

The concept of lithostratigraphy was first introduced by Steno (1669) who defined it as a geological unit of consistent lithology. Schenk and Muller (1941) modified Steno's definition to include the description of consistent lighology strata without regard to the time framework of deposition. The American Commission on Stratigraphic Nomenclature (1972) and Hedberg (1976) described lithostratigraphy in a broader sense as organizing strata into units based on lithological character.

One of the major stratigraphic principles involves the distinction between rock-stratigraphic correlation and time stratigraphic correlation. Rocks of different lithologies that formed at the same time may be assigned different ages and vice versa. Thus, time correlations do not prove lithological continuity (Shaw, 1964) (Figure 5).

The need for lithostratigraphic correlation in all types of geology fields arises from the necessity of establishing lithologic continuity and structure pattern of the area of concern, ultimately defining the oil and/or gas bearing strata, coal beds, geothermal zones and other applications.

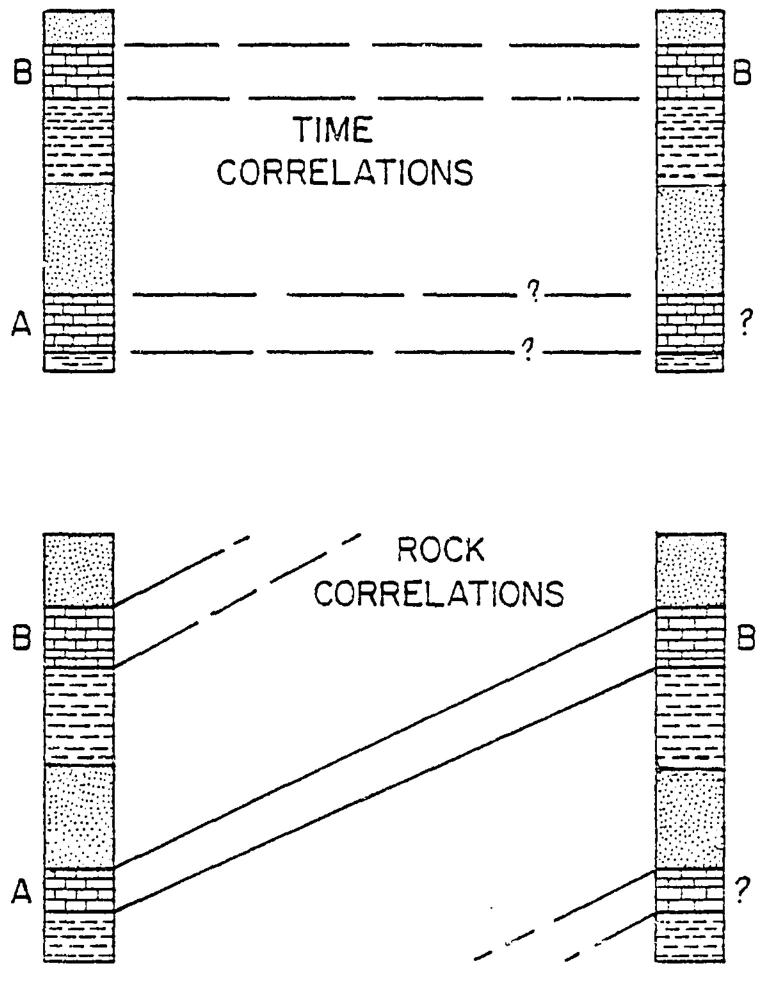


Figure 5. Two sections with similar rock and fossil subdivisions. Fossil zones A and B are only present in limestones. Upper figure indicates time correlations, lower figure indicates rock correlations (Modified after Shaw, 1964).

Krumbein and Sloss (1963) introduced two types of lithostratigraphic units: (1) rock stratigraphic units which are defined by outcrop or subsurface lateral continuity; (2) lithostratigraphic units that are established by lithologic criteria lacking lateral continuity. Typical examples of the second type are insoluble residues, heavy-mineral distributions and others.

Due to the indirect nature of the lithostratigraphic units defined by well logs, it is important that they should be identified in a consistent and objective manner to insure a close approximation to formal stratigraphic concepts (first type of stratigraphic unit).

Dunbar and Rogers (1957) defined correlation as the attempt to determine a common time relationship, while Weller (1960) interpreted the correlation process in terms of common relationships only. Krumbein and Sloss (1963) modified the concept of correlation to involve the matching between equivalent stratigraphic units. A comprehensive and efficient definition was presented by Hedberg (1976). He concluded that a correlation procedure should reflect the similarity in geological properties (lithology, fossil contents, etc.) and in a certain stratigraphic location of geological strata.

Several types of correlations exist for different features of study. The International Subcommission of Stratigraphic Classification stronly emphasizes the independence of correlation on time implications. The major types of correlation are: formal correlation, indirect correlation, and matching correlation.

(a) Formal correlation: demonstrates the actual physical continuity of the unit in question. Schwarzacher (1975) and other workers emphasized the concept of formal correlation as the physical tracing of a stratigraphic unit on the surface of the earth.

(b) Indirect correlation: refers to the process of comparing attributes of stratigraphic units such as lithology, fossil content, porosity and other characteristics. Some methods of indirect correlation are highly accurate, whereas others are not. This type of correlation can be classified as either a systematic correlation such as core correlation, or an arbitrary correlation like visual comparison of well log curves.

(c) Matching correlation: consists of comparison of sequences that do not adapt to a stratigraphic unit. An example of mathcing is the statistical comparison of arbitrary segments of well logs (Rudman and Blakely, 1976).

CHAPTER III

PRINCIPLES OF DIGITAL LITHOSTRATIGRAPHIC CORRELATION BY COMPUTER

Correlation of subsurface data is one of the major approaches established by geologists to construct an exploration framework. In this framework, continuous well logs contribute significant subsurface data for the reconstruction of genetic history of the prospecting area. This history involves the projection of subsurface structure and stratigraphic features such as lithology, porosity, permeability, and other parameters.

There are two types of computer correlations. The first is semiautomatic correlation. This implies the use of computers to process digital logs to provide valuable aids for use in sharpening subsurface correlations in a given study area. Digitizers can be used to reduce the log data to digital form, computers to process the data, and plotters to provide the geologists with graphical depth plots emphasizing characteristics not always directly observable in the original logs. Holgate (1960) developed an approach which was significantly valuable during the correlation of core and log data within a given stratigraphic interval. It implies that the information deduced from core and logs are first stored into arrays and the arrays are then cross-correlated by computer. Figure 6 shows a scatter diagram of core porosity versus log response, while Figure 7 refers to a scatter diagram based on Holgate's reduction of the same set of data. The Holgate method theoretically could be extended to establish a relationship between areally distributed parameters; for example, average porosity log response and average core data through a given stratigraphic interval penetrated by many wells could be related by using this method. Several other advantages of semiautomatic correlation are thoroughly discussed by other workers such as Davis (1973), Robinson (1975), Beck (1976), and Jupp (1976).

The second type of computer correlation is the automatic correlation. In fact, no completely successful automatic correlation technique involving the use of the digital computer and digitized logs from many wells has been reported yet. Automatic correlation of the time series represented by digital well logs consists of calculating a degree of fit or likeness of a curve with another curve (matching).

In general, comparing automatic correlation with semiautomatic correlation, the former technique has several advantages such as accuracy, capability of processing a tremendous amount of data in a short time; and it results in a standard and systematic output.

Automatic correlation is accomplished either in the time domain or in the frequency domain. Automatic correlation

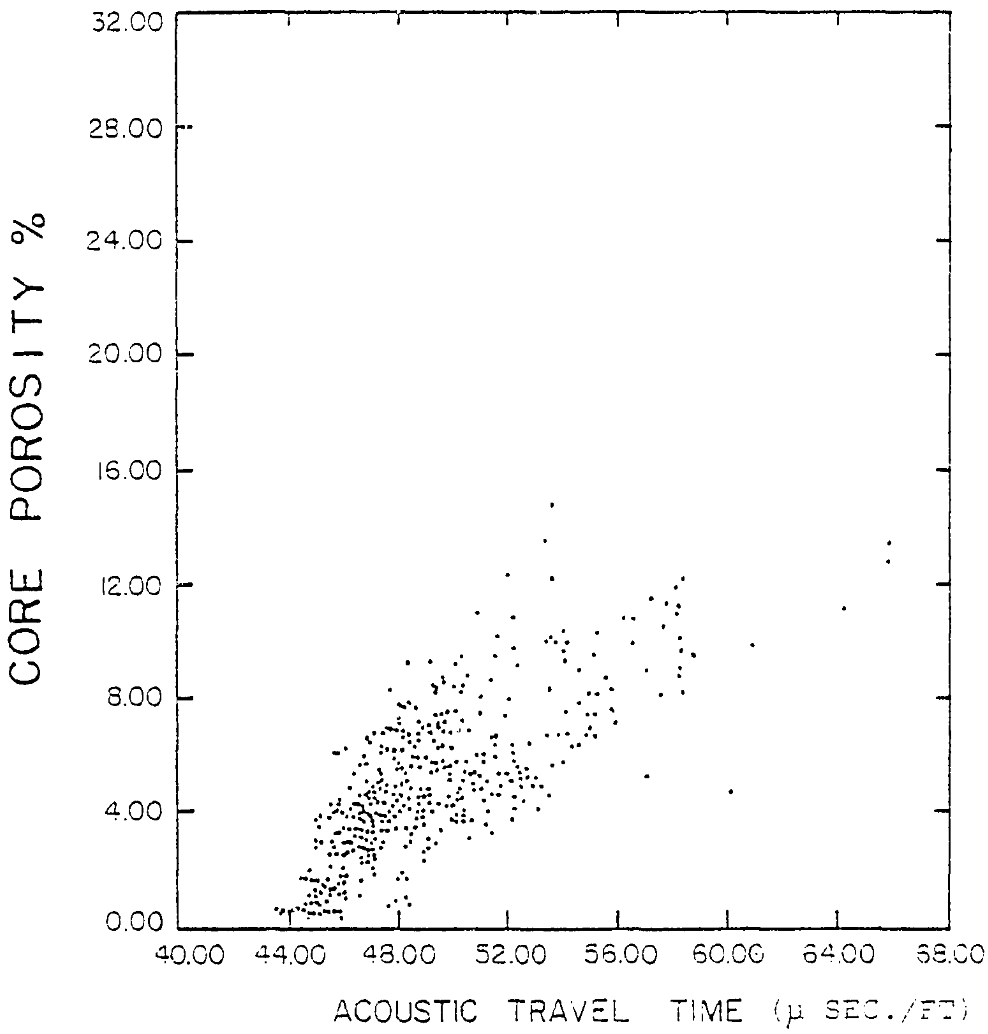


Figure 6. Cross plot of core porosity and sonic log data (After Hawkins, 1972).

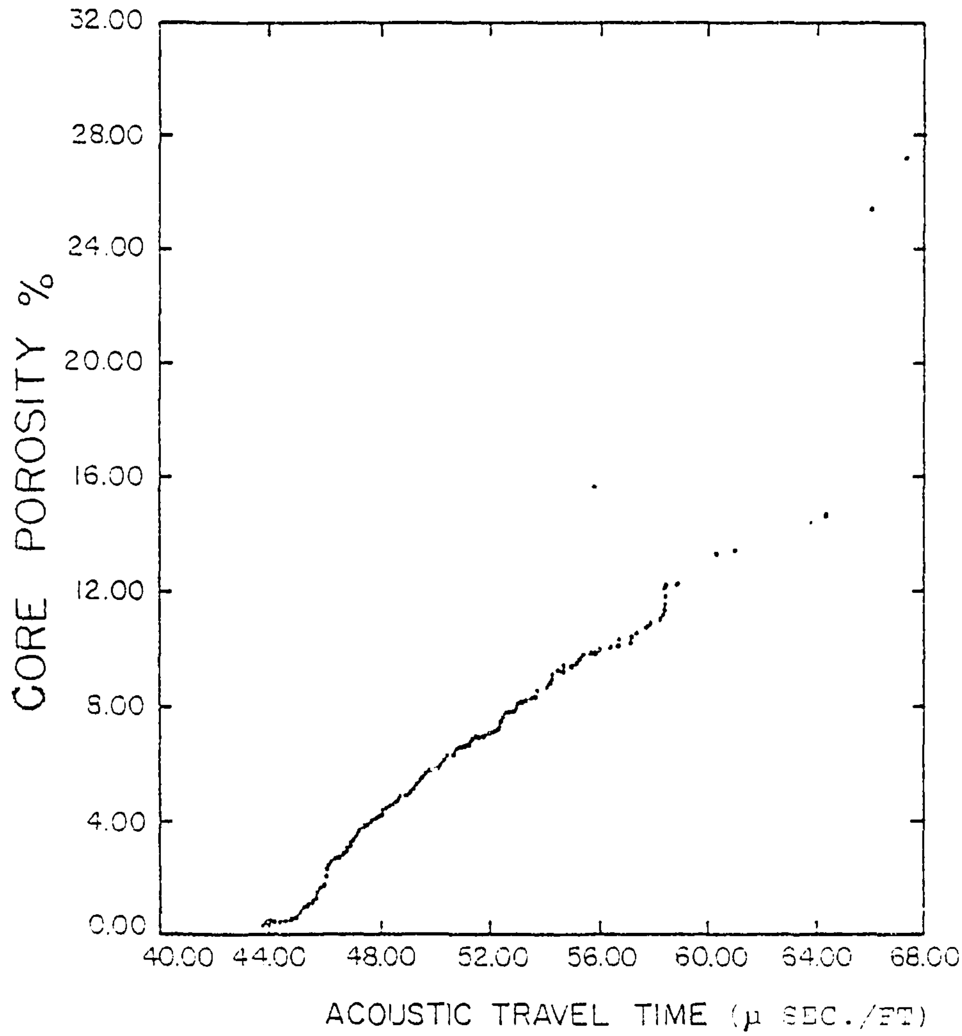


Figure 7. Cross plot of Holgate reduced core porosity and sonic log data (After Hawkins, 1972).

in the time domain implies the correlation of selected segments by graphical evaluation of a regression correlation coefficient. Dean and Anderson (1974) employed this method to make a detailed stratigraphic correlation over the entire Delaware Basin. Extensive research has been done by Anderson (1967), Anderson and Kirkland (1966) on the automatic correlation in the time domain. Vincent, Gortner, and Altali (1977) used pattern recognition to correlate features from one well to another. This approach is capable of correlating four resistivity logs that form a dipmeter log. Dienes (1974) correlated two logs using the time domain as well.

The frequency domain analysis of a spatial series is a faster procedure for correlation. It employs fast Fourier techniques. Many researchers investigated the efficiency of correlation in the frequency domain such as Rudman and Langston (1973), Rudman, Blakely and Henderson (1975); and Rudman, Blakely, and Kwon (1978). The analysis of these investigators display the significance and efficiency of the frequency domain in obtaining a higher value of the correlation function utilizing less computer time.

The effectiveness of the frequency domain in producing higher correlation functions using the FFT algorithm made it an attractive tool to be implemented in this research.

The automatic correlation is divided into two processes: auto-correlation and cross-correlation.

1. Auto-correlation consists of comparing a sequence with itself at successive positions to locate the maximum correspondence and measure the degree of similarity between corresponding segments (Figures 8 and 9).

2. Cross-correlation implies the comparison of two different time series. This is accomplished by sliding one series past the other until a maximum correlation function is obtained (Figure 10).

Since the matching of lithostratigraphic units is a principal step in this study, the cross-correlation technique is the method to be employed in order to accomplish this goal. The principles of cross-correlation in the frequency domain are introduced in the following chapter.

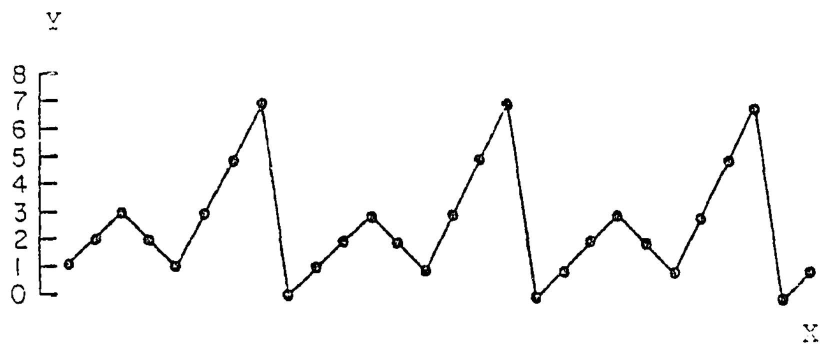


Figure 8. Sequence of repeating values of Y along a traverse X through time or space (After Davis, 1973).

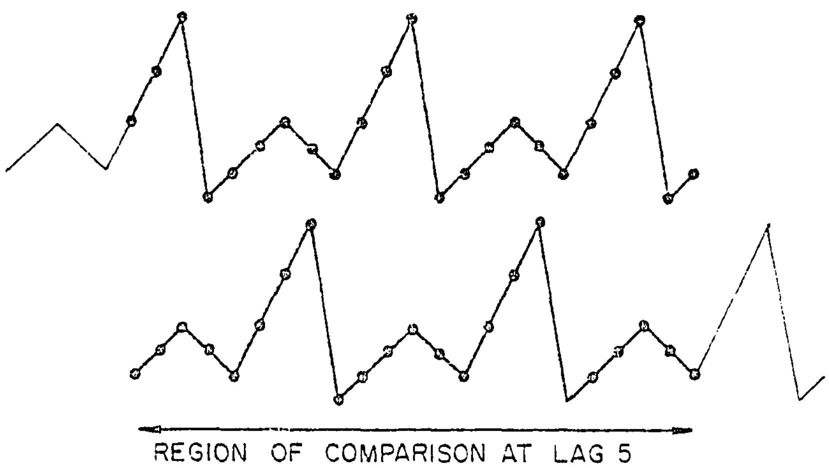


Figure 9. Sequence from Figure 8 compared to itself, for example, at lag 5 (After Davis, 1973).

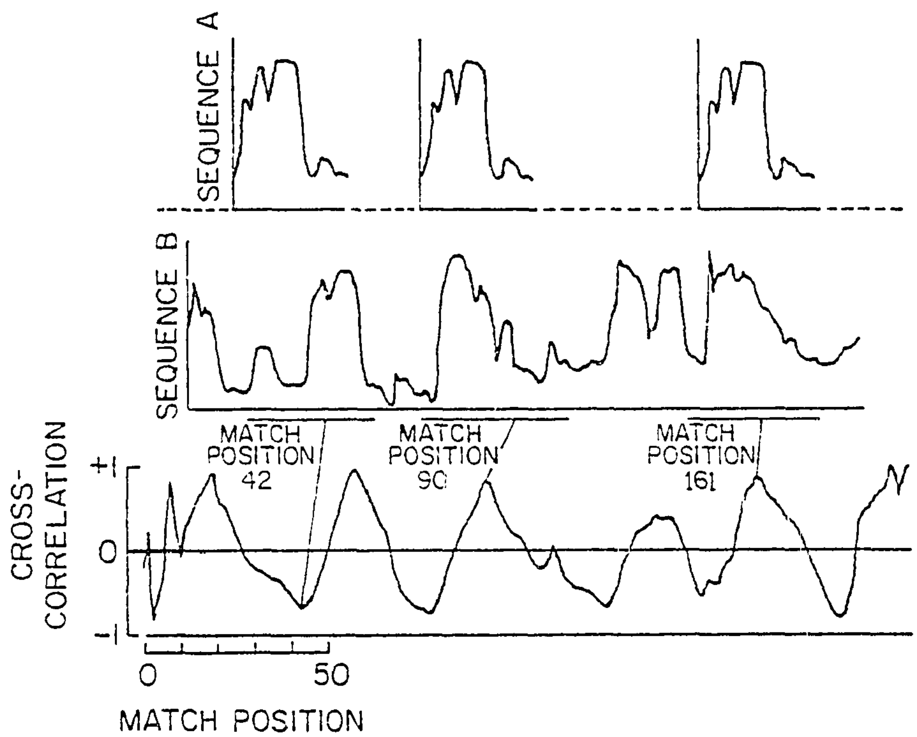


Figure 10. Cross-correlation of two data sequences A and B. Sequence A is shown at several positions of comparison. The bottom graph shows the similarity of the two sequences at all match positions (After Davis, 1973).

CHAPTER IV

DISCUSSION OF THE PROCEDURES AND MATHEMATICS OF THE COMPUTER SUBPROGRAM COR4WELL

As stated earlier, the ultimate purpose of this research is to produce a computer model or a computer software system capable of constructing a three-dimensional representation. This system is founded on the digital lithostratigraphic correlation of digital well logs. In order to obtain this accomplishment, the following steps need to be evaluated to guarantee successful results.

Digitization of Well Logs

Digitizing is the transformation of the continuous curve (log) into discrete numerical data. This data is stored on magnetic tape, disc or punched cards in a special format. A FORTRAN IV program (written by the author) is provided in Appendix IV to convert the data from the form supplied by the digitizing companies to the numerical data that can be used by the computer. The digitizing interval is either at one or two foot sampling depending on the thickness of the beds correlated. The cost of digital computation is low, about $25 per length of log plus 0.04¢ per sample point as of December 1979.

Segmentation Techniques

The second step in utilizing automatic lithostratigraphic correlation techniques is to segment the digitized logs into homogeneous units, then to determine which units are equivalent.

Two types of segmentation techniques exist: automatic segmentation and visual segmentation.

1. Automatic segmentation. This technique is divided into two branches: (a) automatic zonation techniques which imply the segmentation of a spatial series into homogeneous segments (Figure 11); and (b) automatic windowing techniques which involve the passing of two windows of fixed width over two spatial series and determining the optimum matching position (Figure 12). The first method of automatic segmentation involves complicated mathematical equations, and it is less efficient in terms of applications and results than the second method.

2. Visual or manual segmentation. The conventional method of visually selecting a window consists of determining the boundary lines between homogeneous units. These lines are selected according to certain geological aspects such as regression-transgression cycles, coal sequence, formation confined between two distinguished marker beds, and other

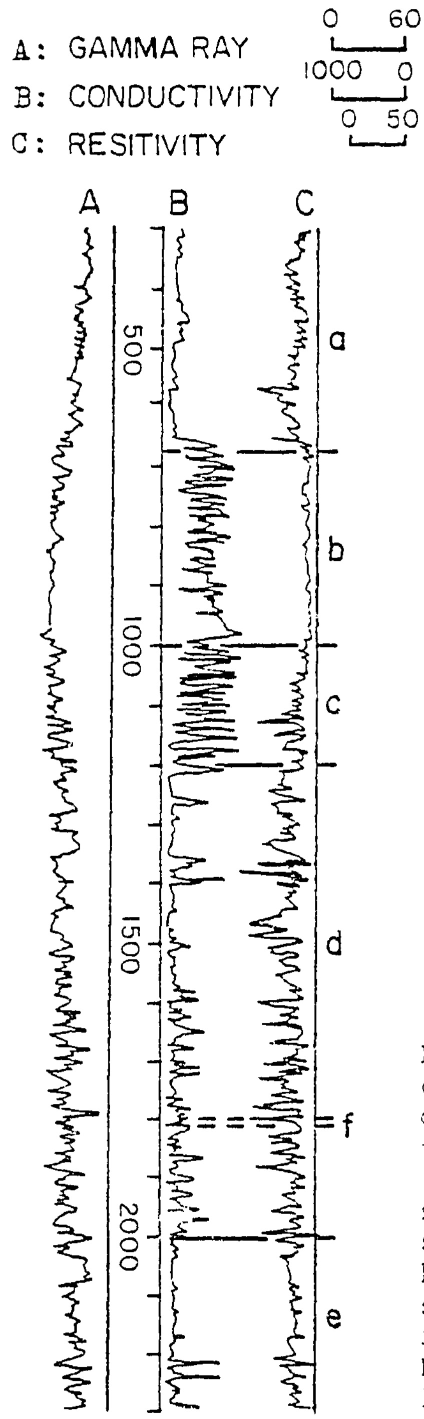


Figure 11. Standard curves include: A, gamma ray; B, resistivity; and C, laterolog—scales shown. Breaks for 5-segment fit labeled a, b, c, d, and e; text segment f also indicated (After Hawkins, and others, 1972).

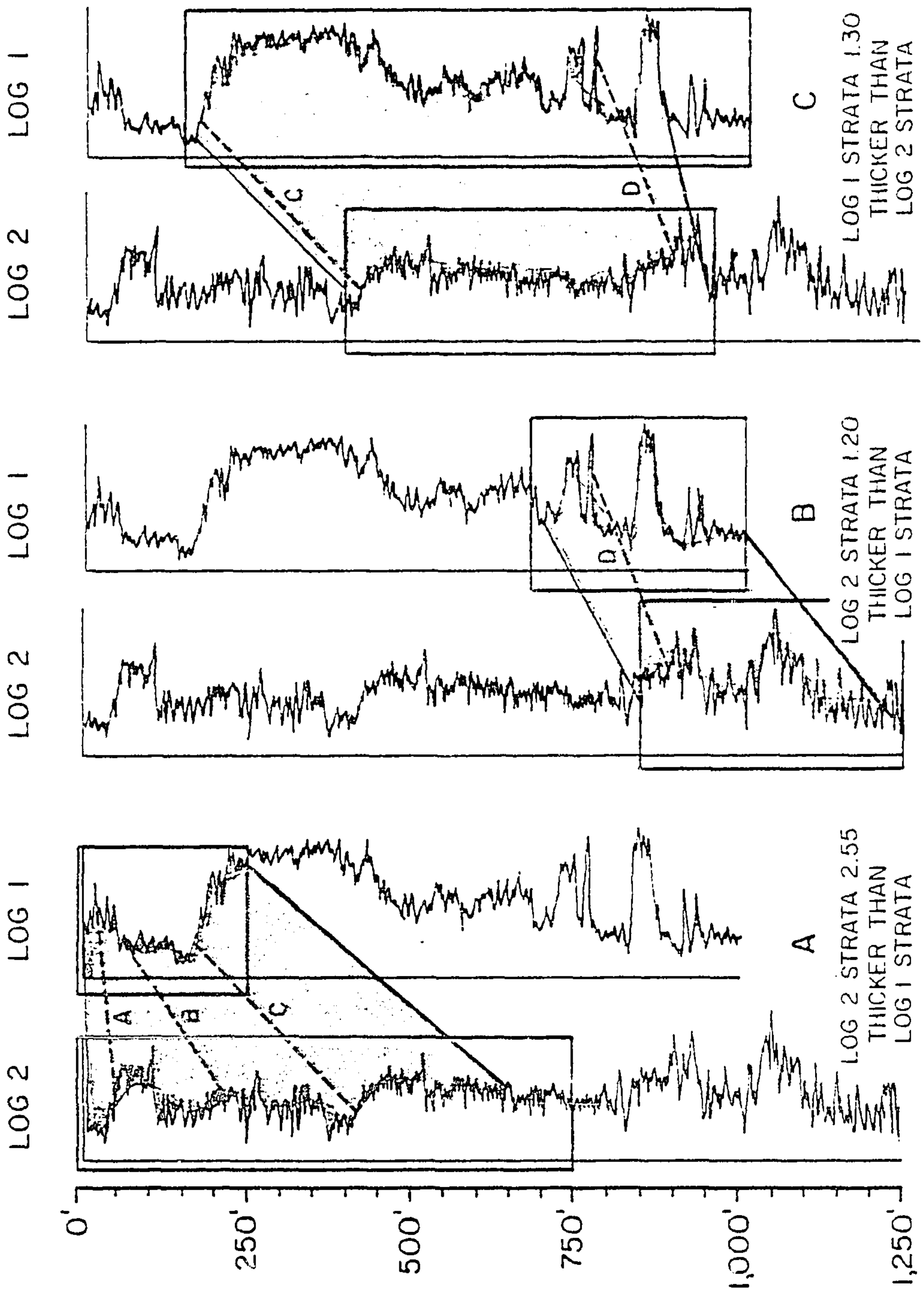


Figure 12. Computer correlation of two gamma-ray logs with variable thickening and thinning of strata. Stippled areas identify computer-selected units of correlation. Rectangles mark "windows of data" submitted for computer analysis. Dashed lines and letters A through D identify known stratigraphic correlations (After Rudman and Lankston, 1972).

geological features. This manual technique of choosing the window usually depends upon the geologist's experiences in the investigated area. It is an accurate and a simple method to perform. However, automatic window techniques are more efficient in terms of handling tremendous amounts of data in a short time.

Once the segmentation of two distinct well logs is established, it may be easier to identify equivalent zones on the basis of statistical parameters or geologic information within the zones. The boundaries of equivalent zones, however, may not be picked in the same order for two logs or on the expected position because of geological variations involved between logs. Therefore, it may be necessary to screen out the less meaningful boundaries for correlation based on the visual examination.

Since a limited number of logs are involved in this research, there is no need to employ automatic segmentation techniques. All logs are visually segmented.

Digital Filtering of the Original Data

The concept of digital filtering in general implies the passing of certain frequencies and blocking others, to filter out certain frequencies. This process has several applications in the various branches of science.

In applying the filtering process to digital log data, the geologist should pay extra attention in choosing the type of filtering. Removing any frequencies may radically affect the result obtained. Heavy filtering (on the order of a few terms or higher) of well logs is not appropriate without solid geologic justification. For example, low frequency spatial series represented by nonstationary log data requires filtering in order to obtain a higher correlation function.

The filtering techniques are briefly reviewed here to analyze the effect of filtering on the process that determines the stretch factor and displacement by the spectral method.

a. Digital smoothing filter (low-pass filter or moving average filter): The function of this filter is to pass the low frequencies and to block out the high frequencies. There are several types of smoothing filters depending on the number of points (interval) involved in the process, i.e., 3-term, 4-term, or 5-term filters. The formula for a moving average filter is computed by (Davis, 1973):

$$\bar{Y}_i = \frac{\sum_{j=i-k}^{j+K} y_j}{m} \quad (1)$$

where $K = \frac{m-1}{2}$

m = length of the smoothing interval

$i = 1, 2, \cdots, n$

$j = 1, 2, \cdots, i + K;\ i \neq j$

$\bar{Y}_i$ = value of a new point in the moving average sequence

This equation calculates an interval of length m centered around the point to be evaluated. Thus, m has to be an odd number for the computed value of $\bar{Y}_i$ to correspond to the central point. On the other hand, if m is even, a group of values will be estimated that are halfway between adjacent observations. In the case of m = 3, the filter passing down the data sequence incorporates one new observation at each step and drops one from the previous interval. The following diagram illustrates this concept:

Original Sequence	5	7	4	3	2	3	4	5	7	2	6	4
Moving Average (results of filtering--$\bar{Y}_i$)		5.3	4.7	3.0	2.7	3.0	4.0	5.3	4.7	5.0	4.0	

These points are plotted on a diagram as shown in Figures 13 and 14. The change in the value of m is based on the degree of filtering required. A high value of m (heavy filtering) could easily result in missing the original data. In some cases, however, a high value of m is preferable to correlate a major section of a log.

b. Differentiating filter (high-pass filter or derivative filter): This type of filter is designed to pass the high frequencies and to block the low frequencies. The high-pass filter is calculated by differentiating the inverse Fourier transform equation:

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(\omega)\, e^{i\omega t}\, d\omega \qquad (2)$$

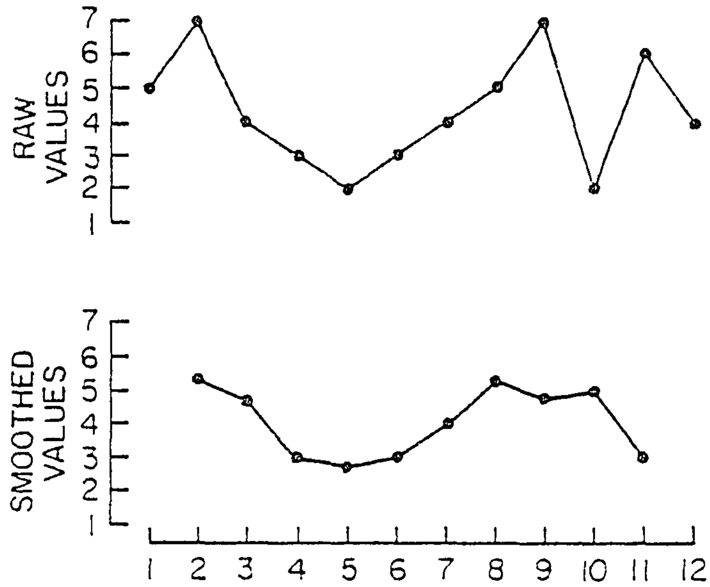


Figure 13. Original data sequence and sequence smoothed by three-term moving average. Note shift in peak positions in the smoothed sequence (After Davis, 1973).

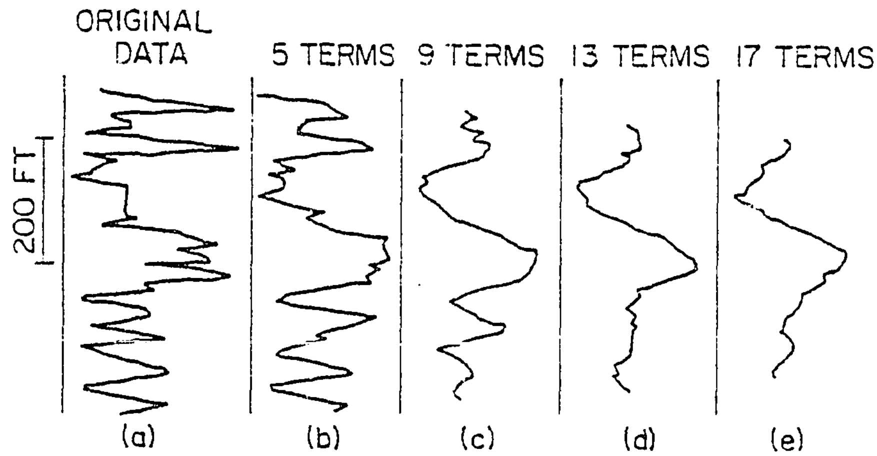


Figure 14. Digitized drilling-time log smoothed by various equations (After Harbaugh and Merriam, 1968).

where $X(\omega)$ = Fourier transform of a continuous time signal $x(t)$

$x(t)$ = original time signal

$i = \sqrt{-1}$

ω = frequency increment, equal to $\frac{2\pi}{NT}$

N = number of sample

T = sampling interval in the time or space domain

The derivative of Equation (2) is given as:

$$x'(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} i\omega \, X(\omega) \, e^{i\omega t} \, d\omega$$

Thus,

$$FT[x'(t)] = i\omega \, FT[x(t)] \qquad (3)$$

This concludes that taking the time derivative of the inverse Fourier transform of a continuous time series correlates to high-pass filtering in the frequency domain.

c. Band-pass filter: This is the result of combining the smoothing and derivative filter techniques. It retains intermediate frequencies.

Fourier Analysis

Automatic lithostratigraphic correlation of digital spatial data is based primarily on the correlation of the spectra of well logs. Spectral analysis brings together two very important theoretical approaches, the statistical analysis of time series and the methods of Fourier analysis.

In this section, Fourier analysis is discussed briefly. The applications of Fourier transforms are introduced in later sections of this chapter.

The general formula for calculating a Fourier series is given by (Preston and Henderson, 1964):

$$Y(Z) = \frac{a_o}{2} + \sum_{n=1}^{\infty} \left(a_n \cos \frac{\pi n Z}{L} + b_n \sin \frac{\pi n Z}{L} \right) \quad (4)$$

where L = half of the basic or fundamental period. It equals half the length over which a signal is sampled.

Z = the independent variable of length along the well bore, wherein $-L \leqslant Z \leqslant L$.

a_o = the zeroth coefficient of a.

a_n = the maximum value (or amplitude) of the cosine term, $\cos \frac{\pi n Z}{L}$.

b_n = the maximum value (or amplitude) of the sine term, $\sin \frac{\pi n Z}{L}$.

n = number of data points.

Y = the dependent variable, such as resistivity, taken to be a function of length or distance Z along the well bore.

The Fourier coefficients a_o, a_n, b_n are determined from the following equations:

$$a_o = \frac{1}{K} \sum_{j=-K}^{K-1} y_j \quad (5)$$

$$a_n = \frac{1}{K} \sum_{j=-K}^{K-1} y_j \cos \frac{\pi n Z_j}{L} \quad (6)$$

$$b_n = \frac{1}{K} \sum_{j=-K}^{K-1} y_j \sin \frac{\pi n Z_j}{L} \qquad (7)$$

where y_j = the measured resistivity or other logged property at the point j in the interval from -L to +L.

j = an index denoting the j'th value of y.

K = the number of equal width panels in the interval 0 to L.

There are two types of Fourier transforms needed in this research: discrete Fourier transforms and fast Fourier transforms.

1. Discrete Fourier Transform (DFT).

The Fourier expression mentioned previously implies the continuous expansion of the Fourier formula. The analog Fourier transform, or integral, of a continuous time series x(t) is given by:

$$X(\omega) = \int_{-\infty}^{\infty} x(t)\, e^{-i\omega t}\, dt \qquad (8)$$

In order to recover the original time signal x(t), one employs the inverse Fourier transform which is given as:

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(\omega)\, e^{+i\omega t}\, d\omega \qquad (9)$$

In the case of a sequence of N samples x(nT) where $0 \leqslant n \leqslant N-1$, the DFT is calculated by:

$$X(K\omega) = \sum_{n=0}^{N-1} x(nT)\, e^{-i\omega TnK} \qquad (10)$$

defining:

N = number of sample points in the spatial series

n = number of intervals in the spatial series

T = sampling intervals in the time or frequency domain

$X(K\omega)$ = Fourier coefficient

$K = 0, 1, \cdots, N-1$

The quantities $X(\omega)$ and $x(t)$ in Equation (8) are called the Fourier transform pair. The Fourier transform $X(\omega)$ is a complex function and can be represented by its real and imaginary parts by:

$$X(\omega) = X_R(\omega) + iX_I(\omega) \qquad (11)$$

and can be represented by its amplitude and phase as well by:

$$X(\omega) = |X(\omega)|\ e^{i\theta(\omega)} \qquad (12)$$

where: $|X(\omega)|$ = amplitude spectrum of $X(\omega)$, and equals

$$\sqrt{X_R^2(\omega) + X_I^2(\omega)} \qquad (12')$$

$\theta(\omega)$ = the phase spectrum of the Fourier transform, and equals $\tan^{-1}[X_I(\omega)/X_R(\omega)]$

The subroutine FOURT in the subprogram COR4WELL utilizes spatial series considering the depth as a function.

2. Properties of Discrete Fourier Transforms (Jenkins and Watts, 1968):

a. In the case of two series, $x(nT)$ (in this research, implies short log) and $y(nT)$ (implies long log), with periods nT, then DFT of x(nT) + y(nT) is:

$$\mathrm{DFT}\{x(nT) + y(nT)\} = \mathrm{DFT}\{x(nT)\} + \mathrm{DFT}\{y(nT)\} \quad (13)$$

$$= X(K\omega) + Y(K\omega) \quad (14)$$

where: T = the sampling interval in the time or spatial domain.

ω = frequency increment = $\frac{2\pi}{NT}$

K = 0, 1, $\cdots$, N-1

The other linearity property is:

$$\mathrm{DFT}\{c[x(nT)]\} = cX(K\omega) \quad (15)$$

b. Shift of time series: The DFT of the shifted series $x[(n+m)T]$ is expressed by:

$$\mathrm{DFT}\{x[(n+m)T]\} = \sum_{n=0}^{N-1} x(nT)\, e^{-i\omega T(n+m)K} \quad (16)$$

$$= \sum_{n=0}^{N-1} [x(nT)\, e^{-i\omega TnK}]\, e^{i\omega TmK}$$

$$= X(K\omega)\, e^{-i\omega TmK} \quad (17)$$

c. Lengthening of series: Assume there is a spatial series x(nT), $0 \leq n \leq N-1$, and a longer series y(nT) is generated, $0 \leq n \leq rN-1$, and where

$$y(nT) = \begin{cases} x(nT) & 0 \leq n \leq N-1 \\ 0 & \text{otherwise} \end{cases}$$

The increased length of y(nT) changes the frequency increment ω to $\frac{\omega}{r}$, where r is any integer, and the form of Equation (10) is transformed to:

$$Y\left[K\left(\frac{\omega}{r}\right)\right] = \sum_{n=0}^{rN-1} y(nT)\ e^{-i\omega TnK/r}$$

$$= \sum_{n=0}^{N-1} x(nT)\ e^{-i\omega TnK/r} \qquad (18)$$

So, if K is divisible by r, then:

$$Y\left[K\left(\frac{\omega}{r}\right)\right] = X\left[\left(\frac{K}{r}\right)\omega\right] \qquad (19)$$

d. Relationship between Fourier transform and correlation function as described by Papoulis (1962), Champeney (1972), and Brancewell (1978). Suppose that f(t) is real and its Fourier integral exists and is given by:

$$F(\omega) = A(\omega)\ e^{j[\theta(\omega)]} \qquad (20)$$

The inverse transform of their energy spectrum is:

$$E(\omega) = A^2(\omega)$$

known as autocorrelation, will be denoted by $\phi(\tau)$:

$$\phi_x(\tau) = \frac{1}{2\pi}\int_{-\infty}^{\infty} A^2(\omega)\ e^{j\omega t}\ d\omega \qquad (21)$$

$$= \frac{1}{2\pi}\int_{-\infty}^{\infty} A^2(\omega)\ \cos\ \omega t\ d\omega$$

$$= \int_{-\infty}^{\infty} f(t+\tau)\ f^*(t)\ d\tau \qquad (22)$$

Now consider the real functions $f_1(t)$ and $f_2(t)$, their Fourier integrals $F_1(\omega)$ and $F_2(\omega)$, and their cross-energy is given by:

$$E_{12}(\omega) = F_1^*(\omega)\ F_2(\omega)$$

where * indicates complex conjugate. The inverse transform of $E_{12}(\omega)$, denoted by ϕ_{12}, is called the cross-correlation function between $f_1(t)$ and $f_2(t)$. We thus have:

$$\phi_{12}(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F_1^*(\omega)\ F_2(\omega)\ e^{j\omega t}\ d\omega \qquad (23)$$

After a simple substitution of Equation (22), Equation (23) is given by:

$$\phi_{12}(t) = \int_{-\infty}^{\infty} f_1^*(\tau)\ f_2(t+\tau)\ d\tau \qquad (24)$$

In general:

$$\mathrm{DFT}\left[\sum_{n=0}^{N-1} x(nT)\ y(n+\tau)\right] = X^*(K\omega)\ Y(K\omega) \qquad (25)$$

In the following section, we will see that the cross-correlation of two spatial series x(nT) and y(nT) consists of iterative multiplications and summations. These operations can be accomplished in the frequency domain by simply multiplying their Fourier transforms. This method is considered more efficient in the computer correlation process.

3. Fast Fourier Transform (FFT)

The fast Fourier transform was discovered and adequately publicized by Cooley and Tukey (1965). It is based on a method of factoring the transform into the product of two transforms. The form of the FFT is similar to that of the DFT. It is given by (Bendat and Piersol, 1971):

$$X(k) = \sum_{n=0}^{N-1} x(n)\ e^{-2\pi ikn/N} \qquad (26)$$

and the inverse Fourier transform is:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k)\ e^{+2\pi ikn/N} \qquad (27)$$

where $k = 0, 1, \cdots, N-1$

$n = 0, 1, \cdots, N-1$

N = number of points in the spatial series

$x(n)$ and $X(k)$ = Fourier transform pair

Suppose a spatial series contains N data points and if N can be factored into N = GH, where G and H are integers, then in place of N^2 multiplications and additions, we get approximately N(G + H) operations of each type. Repeated application of the factoring leads to the following results. If:

$$N = r_1 r_2 \cdots r_m \qquad (28)$$

then we will have approximately

$$N(r_1 + r_2 + \cdots + r_m) \qquad (29)$$

operations. In most favorable cases, when N is a power of 2, say 2^K, we have $N(2^K)$ operations, where $K = \log_2 N$. Thus, we have approximately $N \log_2 N$ operations in place of N^2 operations. In other cases, where N has many small factors, somewhat the same effect of greatly decreasing the number of operations happens. Cooley and Tukey (1965), and Hamming (1973) investigated the properties and applications of FFT and DFT. Their contributions are of great help to geologists interested in this field.

Concepts of Time and Frequency Domains

Fourier analysis transforms the data from one domain to another. Consider the observations in the form of values Y_i at points in space X_i. The succession of points develops a wave form, defined by X and Y. The data, defined in this manner, are said to be in the time or spatial domain, depending upon whether X implies points in time or distance, respectively. By determining the component frequencies in a signal, we have transformed the data to the frequency domain.

The concepts of time and frequency domains are best illustrated by a physical analogy drawn with the effect of a glass prism on sunlight (Figure 15). As described by Davis (1973), the prism acts as a frequency analyzer which separates the beam into its components. In a similar fashion, examining the power spectrum of a data sequence may tell us a great deal about its nature and origin, information which may not be apparent in any other way. The role of the prism in this illustration is similar to that of the Fourier transform which is considered a powerful tool in signal processing due to its ability to identify or distinguish the different frequency sinusoids. These sinusoids and their respective amplitudes combine to form an arbitrary waveform.

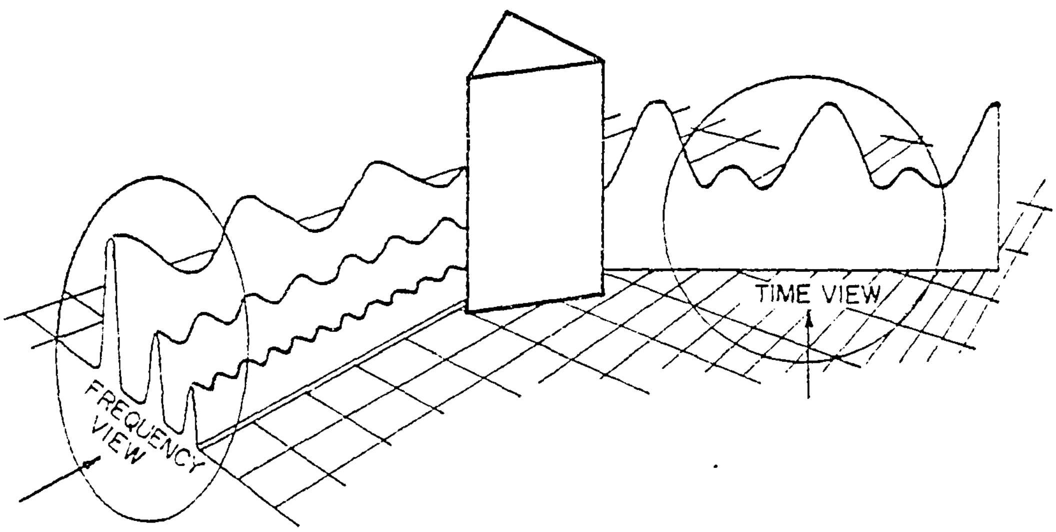


Figure 15. A prism acts as a frequency analyzer, transforming white light (time or spatial domain) into its constituent spectrum of colors (frequency domain) (After Davis, 1973).

Power Spectrum Analysis

The implementation of power spectrum and Fourier analysis in the correlation of digital stratigraphic units was developed by Kwon (1977). In fact, this concept was first introduced by Preston and Henderson (1964) who correlated resistivity logs by utilizing their power spectra. The resistivity (short normal) log profiles in this area are shown in Figure 16 and the corresponding power spectra are given in Figure 17. These line spectra can be considered a type of transformed resistivity log. Therefore, adjacent wells can be compared for similarity by comparing their power spectra. Preston and Henderson's method was very long and impractical on a commercial scale.

The power spectrum of a series x(nT) is defined as the square of its amplitude spectrum (Equation 12).

$$P_x(K\omega) = |X(K\omega)|^2 = X^*(K\omega)\cdot X(K\omega) \qquad (30)$$

The power spectrum can be defined in another form using Equations (6) and (7). The plot of

$$c_n^2 = a_n^2 + b_n^2$$

is called the power spectrum of the function given by Equation (4). Comparing Equation (25) with Equation (30), one concludes that the power spectrum of series x(nT) is also defined as the Fourier transform of its autocorrelation function.

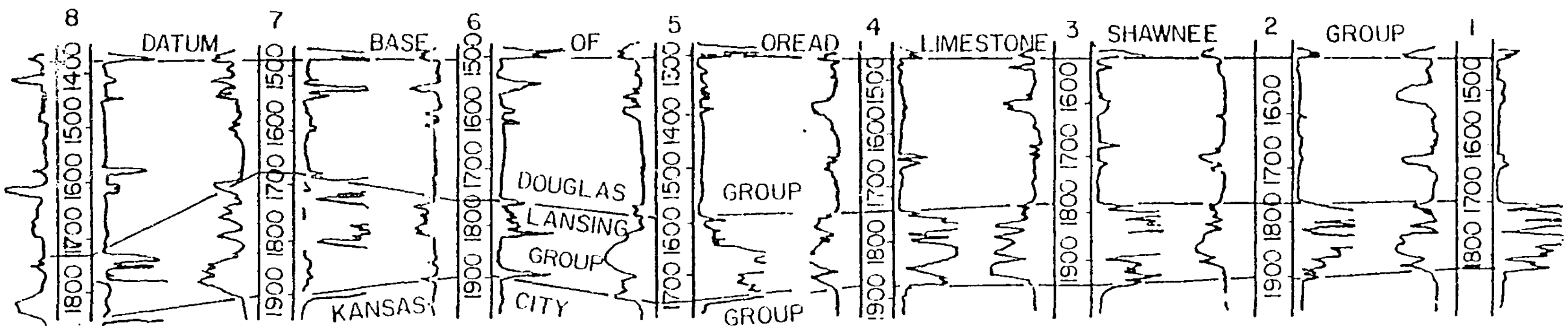


Figure 16. Cross section of logs correlated by spectral analysis (After Preston and Henderson, 1964).

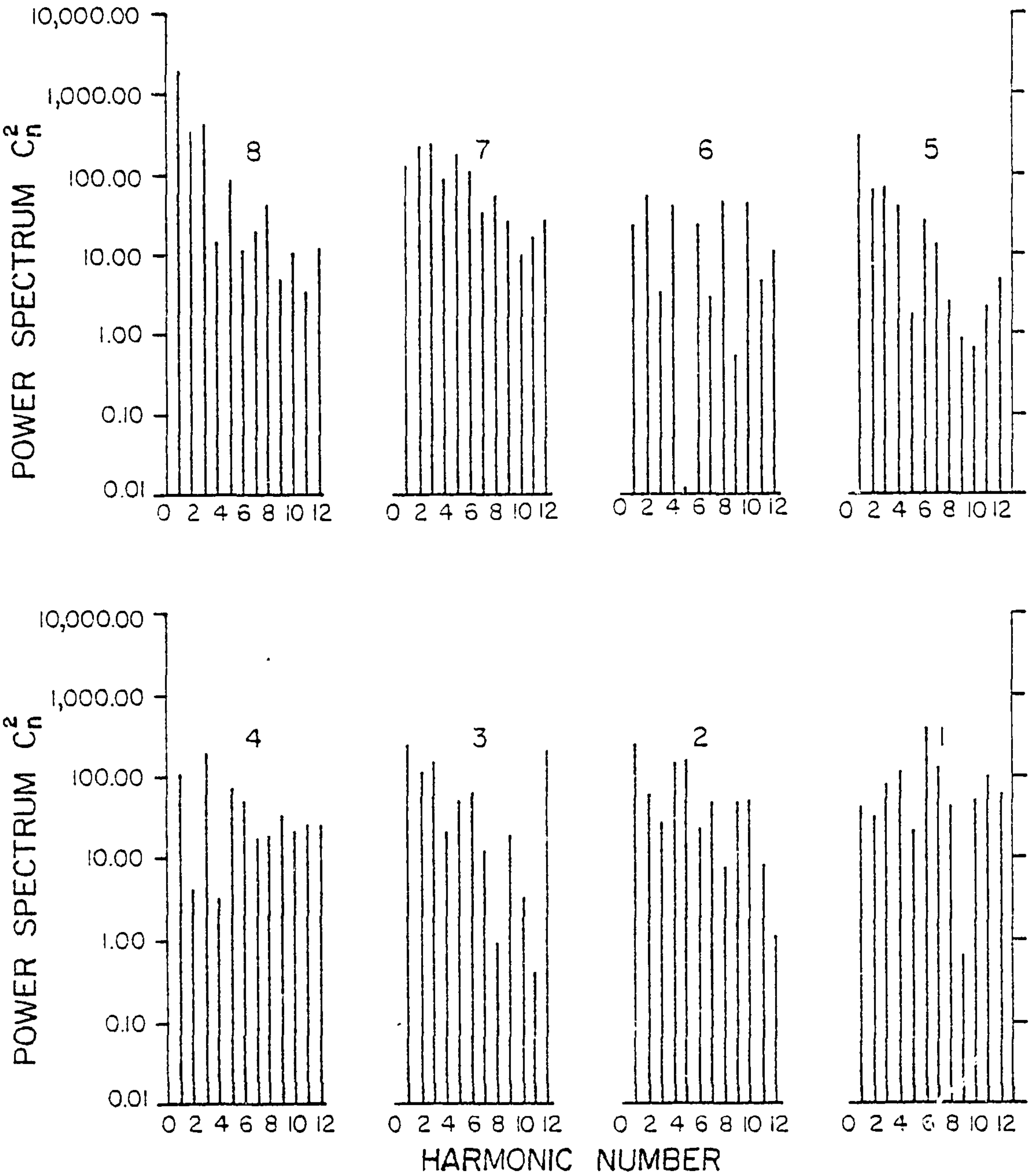


Figure 17. Power spectra for Lansing Group wells shown in Figure 16: (1) Saturn No. 1 Stone; (2) Sutton No. 1 Gish; (3) Kewanee No. 1 Ferry; (4) Gross No. 7 Seward; (5) Holley No. 27 Ferrell; (6) Gralapp & Everly No. 1 Ellis; (7) Marts No. 1 "A" Smith; (8) Royal No. 1 Fox (After Preston and Henderson, 1964).

Techniques of Data Interpolation

In correlation of digital well log data, there are two well-established methods of data interpolation:

1. The interpolation of data in the time domain. DeBoor (1972), Jupp (1976) and Shaw (1977) discussed this concept. They concluded that interpolation in the time domain can be performed by transforming the series of points in homogeneous space and resampling the curve by manipulating the parameters of a B-spline curve approximation.

2. Rudman and others (1976, 1978) performed interpolation in the frequency domain by using the Lagrange interpolation method, which is calculated by the use of FFT.

In order to understand the interpolation technique in the frequency domain, we suppose only N equispaced sample points of a time signal are known, and assume the known N points represent one period of a periodic band limited function (no frequency components above the Nyquist frequency). To estimate the original time signal by M, (M > N), we simply insert (M - N) zeros in the middle of the DFT values (Figure 18-a). Because no new frequencies were added above the Nyquist, the inverse transform gives the same time series of M data points. The normalizing factor of the inverse FFT should be 1/N to obtain the amplitude of a stretching signal.

Lagrange's method of interpolation (in the frequency domain) is used in this investigation because of its ability to interpolate arbitrarily spaced data (Hamming, 1973).

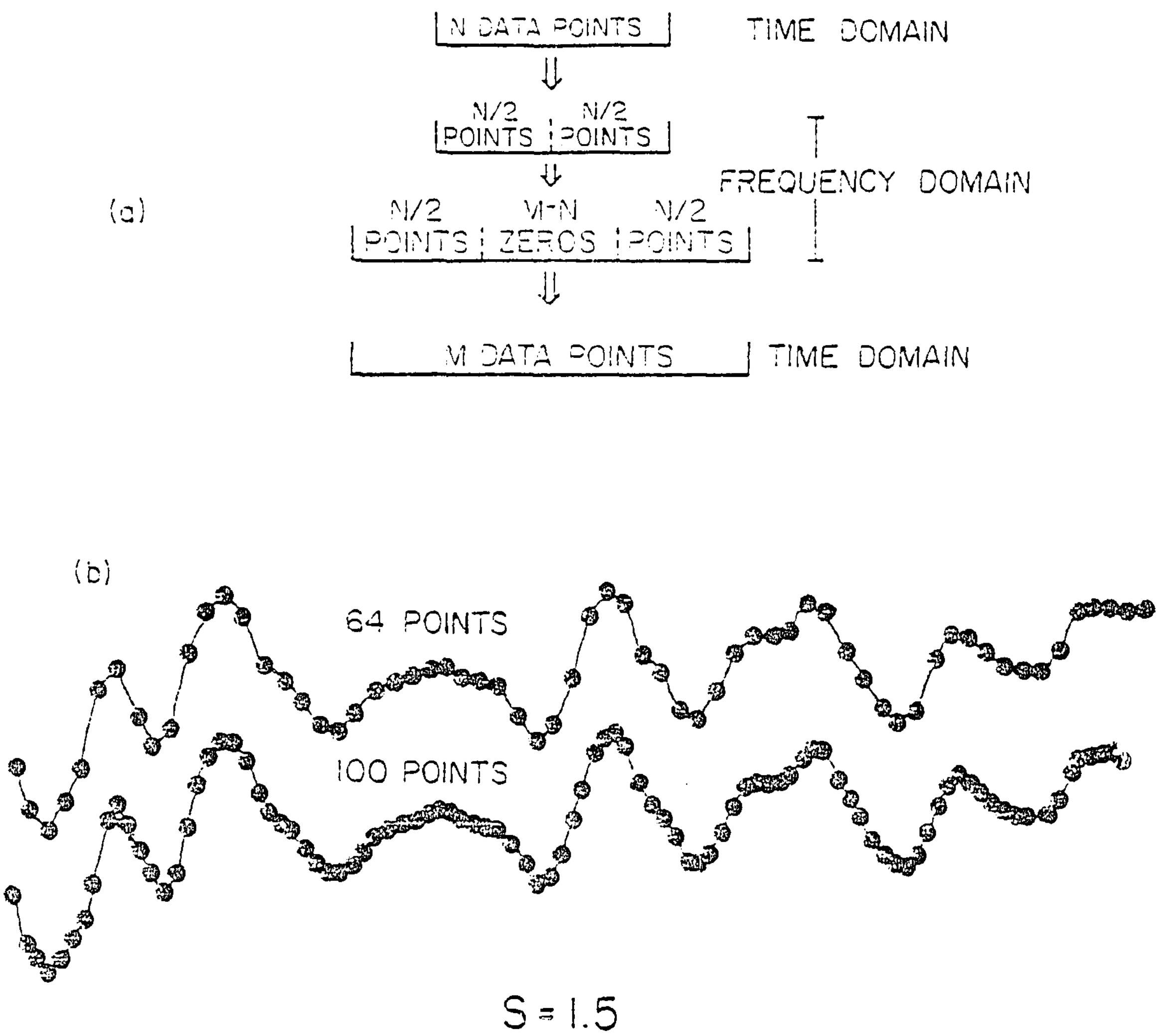


Figure 18. Interpolation (stretching) in the frequency domain. a. N data points are stretched to M values by inserting M-N zeroes into the array. b. stretching of 64 points to 100 point (S = 1.5) using frequency interpolation (modified after Rudman and others, 1975).

Lagrange's interpolation polynomial of degree n - 1 requires n known sample points through which the polynomial is passing. Let $f_1, f_2, \cdots, f_n$ by distinct points, and p(f) is given at these points. The unique polynomial g(f) of degreen n - 1 on these points is given by:

$$g(f) = \frac{(f - f_1)(f - f_2)\cdots(f - f_n)}{(f_1 - f_2)(f_1 - f_3)\cdots(f_1 - f_n)} p(f_1) + \frac{(f - f_1)(f - f_3)\cdots(f - f_n)}{(f_2 - f_1)(f_2 - f_3)\cdots(f_2 - f_n)} p(f_2) + \cdots + \frac{(f - f_1)(f - f_2)\cdots(f - f_{n-1})}{(f_n - f_1)(f_n - f_2)\cdots(f_n - f_{n-1})} p(f_n) \qquad (31)$$

In general, Lagrange's equation is given by:

$$g(f) = \sum_{i=1}^{n} p(f_i) \prod_{\substack{j=1 \\ j \neq i}}^{n} \left\{ \frac{(f - f_j)}{(f_i - f_j)} \right\}$$

Mathematics of Correlation

Rudman and others (1972) described the correlation processes as follows: Suppose there are two spatial series; x(nT) represents the short log while y(nT) represents the long log. Recall that correlation of two spatial series may be established in the time domain or in the frequency domain.

1. Correlation in the time domain:

Cross-correlation in the time domain involves measuring the similarity of two spatial series, x(nT) with length

L_2 and y(nT) with length L_1, $L_2 > L_1$ (x = A and y = B in the author's discussion of Chapter 5), in two distinct steps:

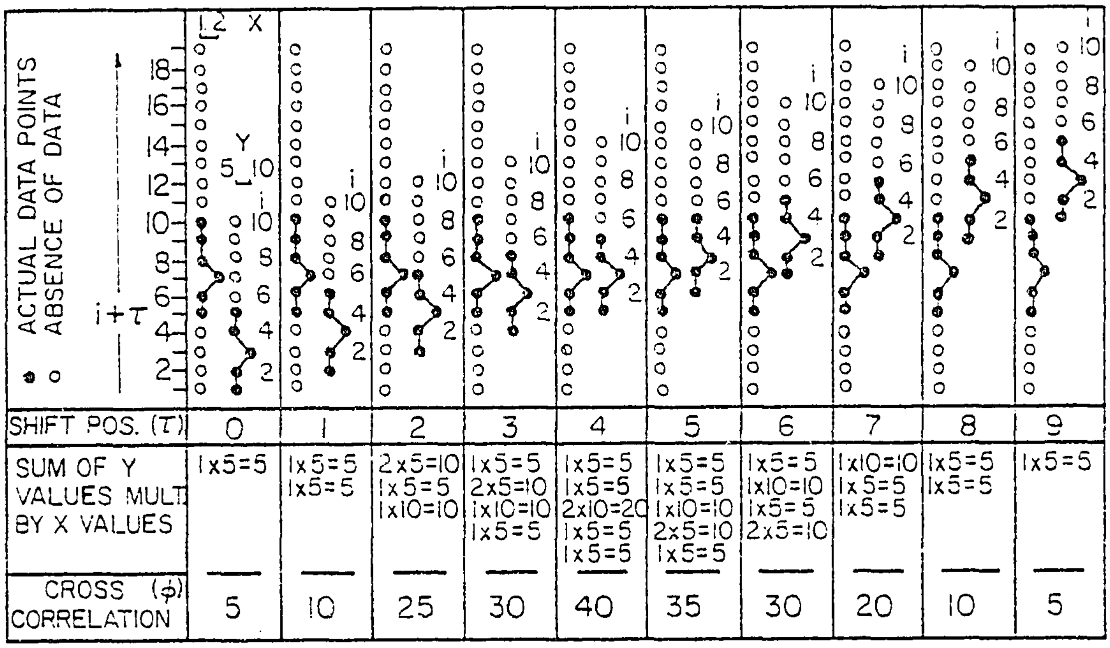
a. The first step involves the multiplication of all the values y(nT) of the long log by the corresponding values x(nT) of the short log and summed to one value ϕ_{xy} (Figure 19-A). As illustrated in this figure, there is only one point from log X (value of X on scale of 1 to 2) that matches one point from well log Y at the shift position 0. Thus, the cross-correlation coefficient ϕ_{xy} is 1 x 5 = 5.

b. The second step represents the vertical shift τ of one log past the other, one point at a time. So at shift position 1, the correlation coefficient is: 1 x 5 + 1 x 5 = 10.

Step (b) is repeated for ten times in this case, which is equal to the range of shifting τ, from 1 to $L_1 + L_2 - 1$. The cross-correlation coefficient $\phi_{xy}(S,\tau)$ is computed by:

$$\phi_{xy}(S,\tau) = \sum_{i=1}^{L_1} X_i Y_{i+\tau}, \qquad i = 1, 2, \cdots, L_1 \quad (32)$$

The value of the cross-correlation coefficient at position 4, $\phi(4)$, represents the maximum value of this coefficient, or the peak of the plot of τ versus $\phi_{xy}(\tau)$ (Figure 19-B). In fact, this value of $\tau = 4$ corresponds to the position of the optimum alignment between well log X and well log Y. In general, as τ is increased, the correlation between the values of x(nT) and y(nT) increases to a maximum value, then it decreases to zero as $\tau \to \infty$.



(A)

(B)

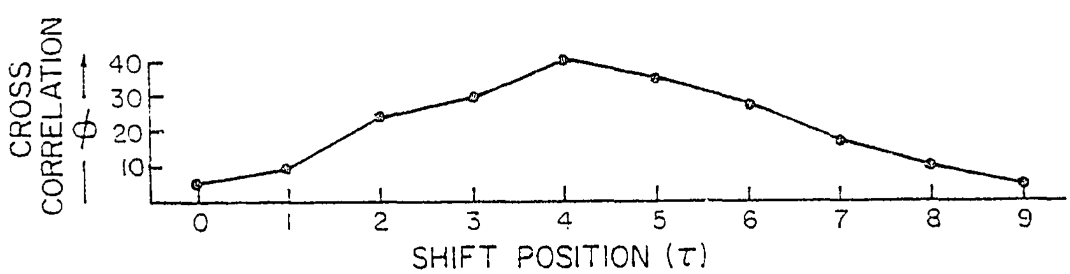


Figure 19. Cross correlation of two model logs. A: Procedural calculation for Equation 32 of cross-correlation coefficient. B: Optimum correlation is at maximum value of cross-correlation coefficient ϕ_{xy} (at shift position $\tau = 4$) (After Rudman and others, 1972).

Bendat and Piersol defined the autocorrelation as a special case of cross-correlation. It implies the case where $L_1 = L_2$, as opposed to the case where $L_2 > L_1$; the series is cross-correlated with itself. The autocorrelation coefficient of a sequence of data $x(nT)$, $n = 1, 2, \cdots, N$, is defined for discrete (digital) data at lags $\tau = 0, 1, \cdots, N-1$ as follows:

$$\phi_{xx}(\tau) = \frac{1}{N - \tau} \sum_{n=1}^{N-\tau} [x(nT) - \bar{x}_o][x(n(nT) + \tau) - \bar{x}_\tau] \quad (33)$$

where $\bar{x}_o$ and $\bar{x}_\tau$ represent the mean value of the points at lag 0 and lag τ, respectively.

In order to characterize the cross-correlation coefficient completely, the idea of normalized cross-correlation is introduced. The normalized cross-correlation coefficient is the ratio of the cross-correlation function $\phi_{xy}(\tau)$ to the square root values of the cross-correlation at lag zero. This definition is represented by the following equation:

$$R_{xy}(\tau) = \frac{\phi_{xy}(\tau)}{[\phi_x(0)\phi_y(0)]^{\frac{1}{2}}} \quad (34)$$

The value of the coefficient $R_{xy}(\tau)$ is confined between -1 and +1. The +1 indicates direct maximum correlation, while -1 implies inverse maximum correlation. The main objective of normalizing the cross-correlation coefficient is to avoid biased results that may be formed during the comparison of cross-correlation coefficients computed for different interval lengths and various values of the stretch factor (S).

Having discussed the concept of cross-correlation, autocorrelation and normalized cross-correlation coefficients, now we lead our attention to the process of cross-correlation in the time domain. This process is established by two steps:

a. The cross-correlation function is obtained by calculating the normalized cross-correlation function between two spatial series of unequal lengths, $L_2 > L_1$ (Rudman and others, 1975).

$$R_{xy}(S,\tau) = \frac{\sum_{i=1}^{L_1} x_i y_{i+\tau} - L_1 \bar{X}\bar{Y}_\tau}{\left[\left(\sum_{i=1}^{L_1} x_i^2 - L_1\bar{X}^2\right)\left(\sum_{i=1}^{L_1} y_{i+\tau}^2 - L_1\bar{Y}_\tau^2\right)\right]^{\frac{1}{2}}} \qquad (35)$$

defining

$$\bar{X} = \frac{1}{L_1}\sum_{i=1}^{L_1} x_i, \qquad \bar{Y}_\tau = \frac{1}{L_1}\sum_{i=1}^{L_1} y_{i+\tau}$$

S = stretch factor ($S = 1$ implies no stretch)

L_1 = length of the short log

$i = 1, 2, \cdots, L_1$

In this method the edge of the short log is aligned with the edge of the long log (Figures 20, 21-B), then the short log is vertically shifted past the stationary long log. The normalized cross-correlation coefficient $R_{xy}(S,\tau)$ is calculated point by point multiplication and summation just as in Figure 19. The operations of multiplication and summation continue up to a maximum of $L_2 - L_1$. Then the spatial series $x(n)$ is stretched by ΔS (i.g. + 0.05) to $L_1 + \Delta L$, where $\Delta L = L_1(\Delta S)$. This process is repeated until the maximum value of $R_{xy}(S,\tau)$ is reached. This maximum value

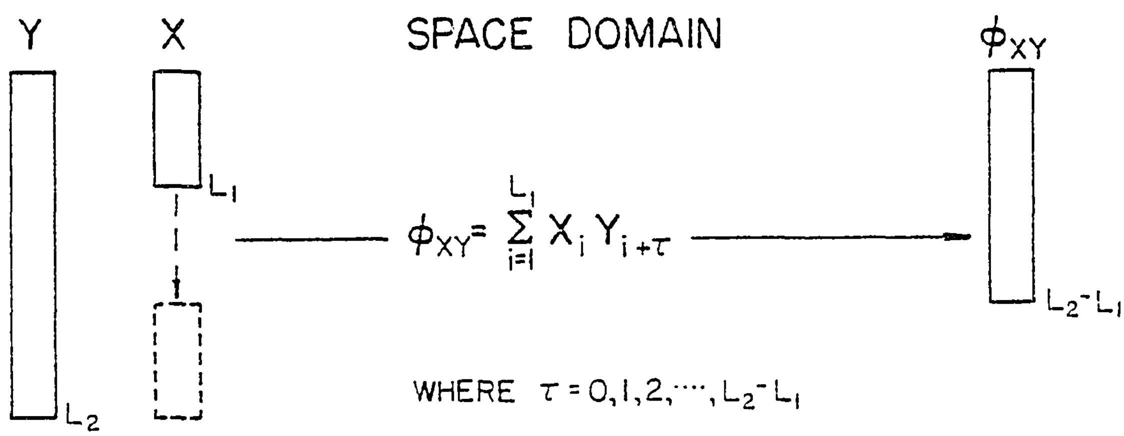


Figure 20. Cross correlation in the space domain. Series X slides past Y with each new value of I (After Rudman, 1975).

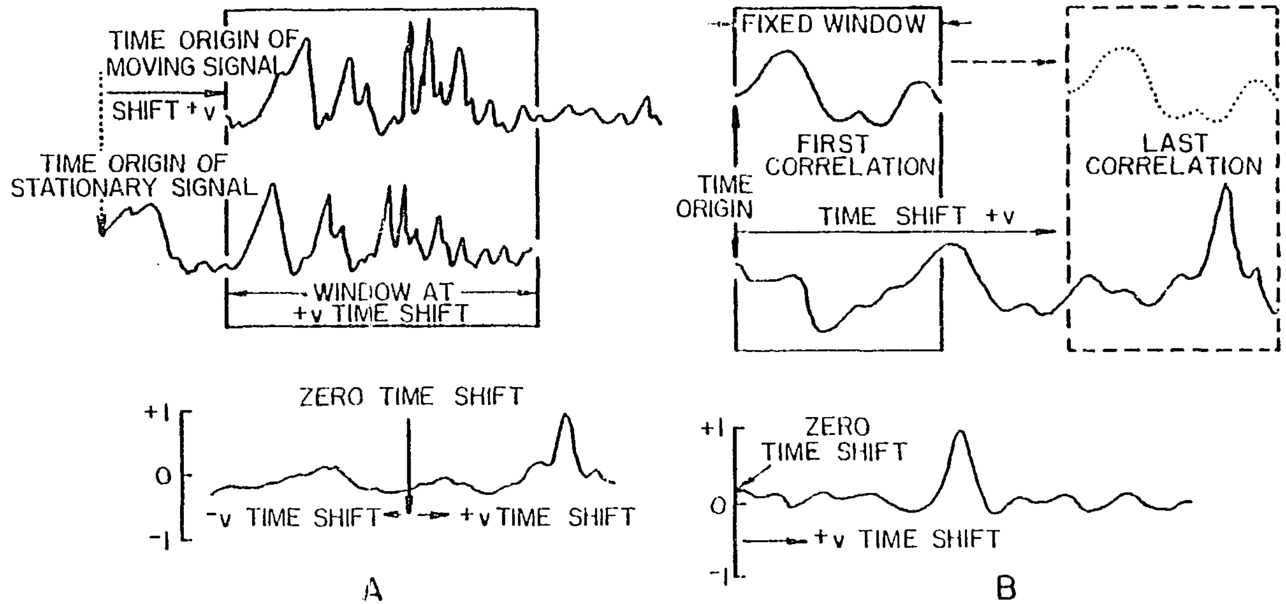


Figure 21. Sketches showing the crosscorrelation process. A, With variable window size and normalized crosscorrelation function. B, With fixed window size and normalized crosscorrelation function (After Kwon and others, 1978).

corresponds to the optimum values of S and τ required to draw the tie-lines shown in Figure 2.

b. The other method of cross-correlation in the time domain is performed with two series of equal lengths, $L_1 = L_2$. In this method, the length of the correlation window is maximum when the edges of the two series are aligned (Figure 21-A), then the width of the window decreases with each time shift τ.

The normalized cross-correlation function for two series x(n) and y(n+τ) of equal lengths is given by:

$$R_{xy}(S,\tau) = \frac{\sum_{n=1}^{N-\tau} [x(n) - \bar{x}_o][y(n+\tau) - \bar{y}_\tau]}{\left[\sum_{n=1}^{N-\tau} [x(n) - \bar{x}_o]^2 \sum_{n=1}^{N-\tau} [y(n+\tau) - \bar{y}_\tau]^2\right]^{\frac{1}{2}}} \quad (36)$$

where

$$\bar{x} = \frac{1}{N-\tau} \sum_{n=1}^{N-\tau} x(n), \qquad \bar{y}_\tau = \frac{1}{N-\tau} \sum_{n=\tau+1}^{N} y(n)$$

and

$$R_{xy}(S,\tau) = \begin{cases} +1 & \text{maximum correlation} \\ 0 & \text{no correlation} \\ -1 & \text{reverse correlation} \end{cases}$$

2. Cross-correlation in the frequency domain:

The advantage of this concept lies in the reduction of the computer time consumed by the operation of multiplication and summation. This time reduction is established by the introduction of the fast Fourier transform into the correlation process.

Stretching Process

Correlation of digital lithostratigraphic units, as in visual correlation, is complicated by the lateral changes in thickness and vertical shifting. Stretching is a mathematical approach to account for the relative variation of bed thickness between wells. The computer algorithm COR4WELL established in this study identifies the direction and degree of thickening of stratigraphic sequences between wells. It also determines the amount of vertical shifintg of beds between wells.

In order to understand the procedure of stretching, we should discuss first the power spectra. Kwon, et al. (1978) discussed the stretching process as follows. Let us assume that there are two spatial series: The first one, series x(nT) of N samples, represents the short well log of one well and the other, series y(nT) of L samples, represents the long log of the second well. Furthermore, Kwon et al. (1978) explained that a segment of the long well log y(nT) is called Z(n) and is equivalent to the short well log stretched to a length M with a stretch factor S (= M/N) and displacement D. As illustrated in Figure 22, the long well log y(nT) is actually the sum of two segments: Segment s(n), which is equivalent to the segment Z(n), and the other segment is the noise series h(n). Since FFT does not recognize the actual time or frequency increment, sequential numbers are only needed to be identified in the following argument. In

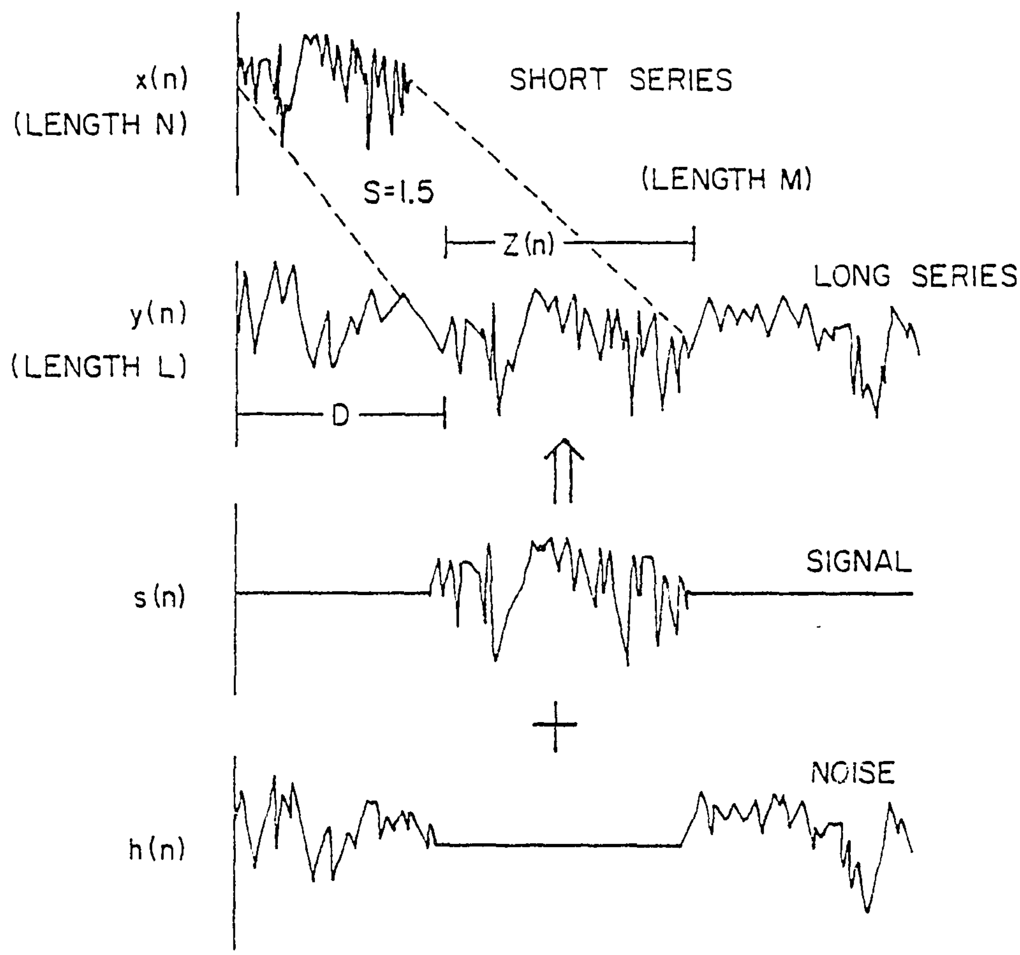


Figure 22. Model data used to demonstrate crosscorrelation of a series x(n) with a series y(n) comprised of a signal s(n) and (noncorrelative) noise h(n). Z(n) is equivalent to the short series x(n) with a stretch factor S ($=\frac{M}{N}$) and displacement D (Modified after Kwon et al, 1978).

Equation (19) the differences of the two frequency increments $\frac{\omega}{r}$ and ω are ignored and only the K values are considered. The DFT form of z(n) is the ordered sequence Z(K). This form Z(K) can be obtained from the Fourier transform X(K) as follows:

$$Z(K) = \begin{cases} X(K) & 0 \leqslant K \leqslant \frac{N}{2} \\ 0 & \frac{N}{2} \leqslant K \leqslant \frac{M}{2} \end{cases} \qquad (37)$$

Let us assume that the segment s(n) is first stretched from z(n) by an additional (M - N) zeros and then time shifted by an amount D. The relationship between the two DFT's Z(K) and S(K) can be deduced from Equations (17) and (19). By adding zeros in the segment s(n), the phase and the frequency scaling of Z(K) may change. Thus, to overcome this problem, we compute the power spectra $P_z(K)$ and $P_s(K)$ from the DFT's Z(K) and S(K), respectively. These two power spectra are related by:

$$P_s(K) = P_z(K/S') \qquad (38)$$

where S' represents the scaling factor (S' = M/N). So if S' is computed, the length of segment z(n) is known. Thus, the stretching factor S between the two series, x(n) and z(n), is calculated by comparing their lengths.

After we have developed the understanding of the relationship between power spectra and stretching, let us discuss the steps involved in the stretching procedure.

The following steps are performed in the frequency domain to calculate the value of the lag (τ) that is used to obtain the value of the stretch factor S, in the time domain, according to Equation (47). The first step is logarithmic scaling of frequencies. The problem facing us here is the scaling in the frequency domain of P_z and P_s (Figure 23). If we take the logarithm of Equation (38), we get:

$$\mathrm{Log}\{P_s(K) = P_z(K/S')\}$$

or

$$P_s(\mathrm{Log}\ K) = P_z(\mathrm{Log}\ K - \mathrm{Log}\ S') \qquad (39)$$

We notice that the multiplication factor S' in Equation (38) is changed to an additive factor. Thus, logarithmic scaling of frequencies modifies power spectra by a frequency delay of Log S'. The factor S' can be obtained by the cross-correlation of $P_x(\mathrm{Log}\ K)$ and $P_s(\mathrm{Log}\ K)$ (refer to Figure 23). In this figure we have the long log or series y(n) which is the sum of two series s(n) and h(n). The Fourier transform of the series y(n) is Y(K). It is calculated based on Equation (14) as:

$$Y(K) = S(K) + H(K) \qquad (40)$$

Equation (40) can be rewritten in terms of its real and imaginary parts as:

$$Y_R(K) + iY_I(K) = [S_R(K) + H_R(K)] + i[S_I(K) + H_I(K)] \qquad (41)$$

or

$$Y_R(K) = S_R(K) + H_R(K)$$

$$Y_I(K) = S_I(K) + H_I(K)$$

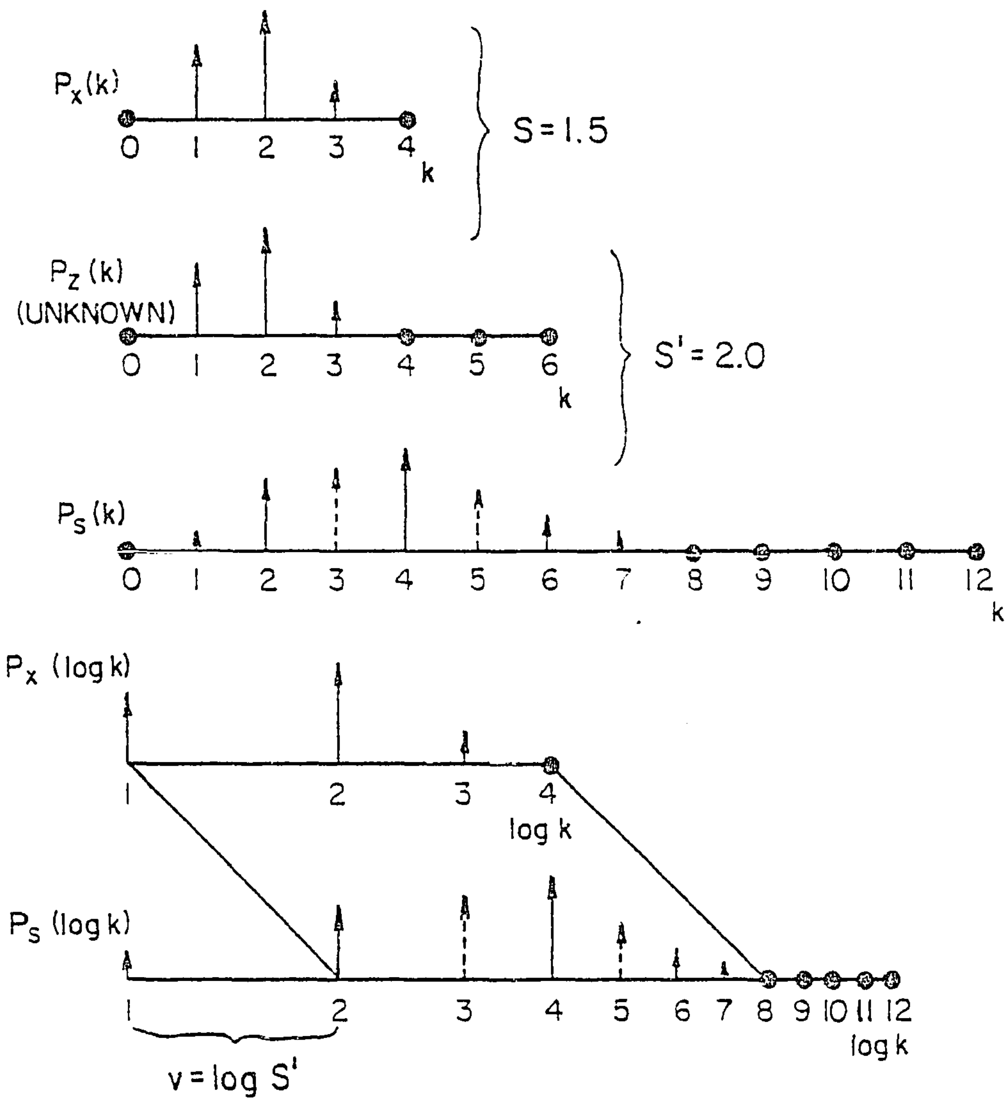


Figure 23. Graphical illustration of cross-correlation of power spectra to determine the stretch factor (S) between two series x and z (unknown) shown in Figure 22. The long series y is assumed to involve only a signal s. Additional spectra (dashed lines) appear in P_s as the consequence of lengthening the series. The lag v between two equivalent spectra on the logarithmically scaled frequency axis is related to the ratio of lengths (M/N = 2) between s and z. The stretch factor between x and z is equal to M/N (After Kwon, 1977).

where subscripts R and I denote the real and imaginary parts, respectively.

The power spectrum of series y(n) is computed from Equation (30) as:

$$
\begin{aligned}
P_y(K) &= Y_R^2(K) + Y_I^2(K) \\
&= [S_R(K) + H_R(K)]^2 + [S_I(K) + H_I(K)]^2 \\
&= [S_R^2(K) + S_I^2(K)] + [H_R^2(K) + H_I^2(K) \\
&\quad + 2S_R(K)H_R(K) + 2S_I(K)H_I(K)] \qquad (42)
\end{aligned}
$$

The first bracket of Equation (42) represents the power spectra, $P_s(K)$, of segment s(n). The second bracket is defined as an additive (background) noise spectrum N(K). Thus:

$$P_y(K) = P_s(K) + N(K) \qquad (43)$$

However, since we are concerned with the actual signals, we have to filter the noise signals N(K). The differentiating filtering technique was applied in this operation.

One may notice from Figure 22 that the signals s(n) and x(n) are quite similar except for the frequency scaling. Therefore, one may conclude that there is a definite relationship between the power spectra of these signals, $P_s(K)$ and $P_x(K)$. Keeping this in mind, it is easy to extract $P_s(K)$ and $P_y(K)$ by cross-correlation of the power spectra $P_x(K)$ and $P_y(K)$ after some change.

The second step in calculating the stretch factor S is the interpolation of power spectra in the frequency domain. After transforming frequencies to a logarithmic scale, the values of a power spectrum are at unevenly spaced intervals. Since automatic correlation requires values at equal intervals, we need an interpolation to obtain an evenly spaced spectrum. Following the calculation of the power spectra of four spatial series (four well logs) and replacing them in two complex arrays, (P_a, P_c) and (P_b, P_d), then we employ Lagrange's interpolation method and cross-correlate the interpolated spectra in the complex domain (next step) to get the optimum stretch value based on four logs.

The third step involves the cross-correlation of the interpolated spectra. Suppose there are two series of interpolated spectra $P'_x(i)$ and $P'_y(i)$, the cross-correlation function $R_{P'_x P'_y}(\tau)$ of these two spectra is given by the following equation:

$$R_{P'_x P'_y}(\tau) = \sum_{i=1}^{N-\tau} P'_x(i)\ P'_y(i+\tau) \qquad (44)$$

where i is a dummy variable for the interpolated spectrum. In order to avoid complexity in the following calculation, the denominator of $R_{P'_x P'_y}(\tau)$ is omitted.

Let us propose that there is no similarity between spectra P_x and the noise spectra $N'(K)$. Equation (44) is rewritten in the following form using Equations (38), (39), and (43):

$$\begin{aligned} R_{P'_x P'_y}(\tau) &= \sum_{i=1}^{N-\tau} P'_x(i)\{P_s(i+\tau) + N'(i+\tau)\} \\ &= \sum P'_x(i)\ P'_s(i+\tau) \\ &= \sum P'_z(i)\ P'_z(i - \tfrac{1}{\Delta}\log S' + \tau) \qquad (45) \end{aligned}$$

where Δ is the interpolation interval. The optimum value of the coefficient $R_{p'_x p'_y}(\tau)$ is obtained if

$$\tau = \frac{1}{\Delta} \log S' = \frac{1}{\Delta} \log \frac{M}{N} \qquad (46)$$

Determining the shift τ, for the optimum value of the correlation ratio (M/N) will be given by

$$S' = S = \frac{M}{N} = 10^{T \cdot \Delta} \qquad (47)$$

The immediate result deduced from the previous discussion implies that the stretch factor S is gained from the comparison of the length (N) of the short spatial series x(nT) and the length (M) of the long spatial series y(nT) given by Equation (47). Similarly, the negative value of the shift τ is inferred from Equation (47) as well.

Cross-Correlation of the Stretched Logs

So far we have calculated the stretch factor S. The proceeding step consists of stretching the log using the frequency interpolation method. Then cross-correlating the stretched logs utilizing Equation (35) finally computes the relative displacement D, between the short log and the similar part of the long log.

The value D is determined in two ways:

1. In the case of stretching the long log, the value of the optimum correlation represents D (i.e., $D = \tau$).
2. In the case of stretching the short log, $D = \tau/S$.

CHAPTER V

CROSS-CORRELATION OF FOUR WELL LOGS

One of the advantages of the computer algorithm BASEL is its ability to simultaneously correlate four well logs of one type. This correlation is established by the subprogram COR4WELL.

In the subprogram COR4WELL, the spatial series A, B, C, and D symbolize four similar logs obtained from four wells (Figure 24). The cross-correlation Equation (32) will be modified to account for the correlation of four well logs assuming the series x(n) and y(n) to be a complex number. These two complex numbers consist of real and imaginary parts:

$$X(n) = A(n) + jC(n)$$

$$Y(n) = B(n) + jD(n)$$

where $j = \sqrt{-1}$

Logs A and C are stored in complex array X, and logs B and D are stored in array Y. Using a fast Fourier transform (FFT), the spatial series X(t) and Y(t) are first transformed to the frequency domain. After this transform, complex series X(K) and Y(K) are multiplied to obtain the cross-correlation function $\phi_{xy}(K)$, given by (Papoulis, 1962):

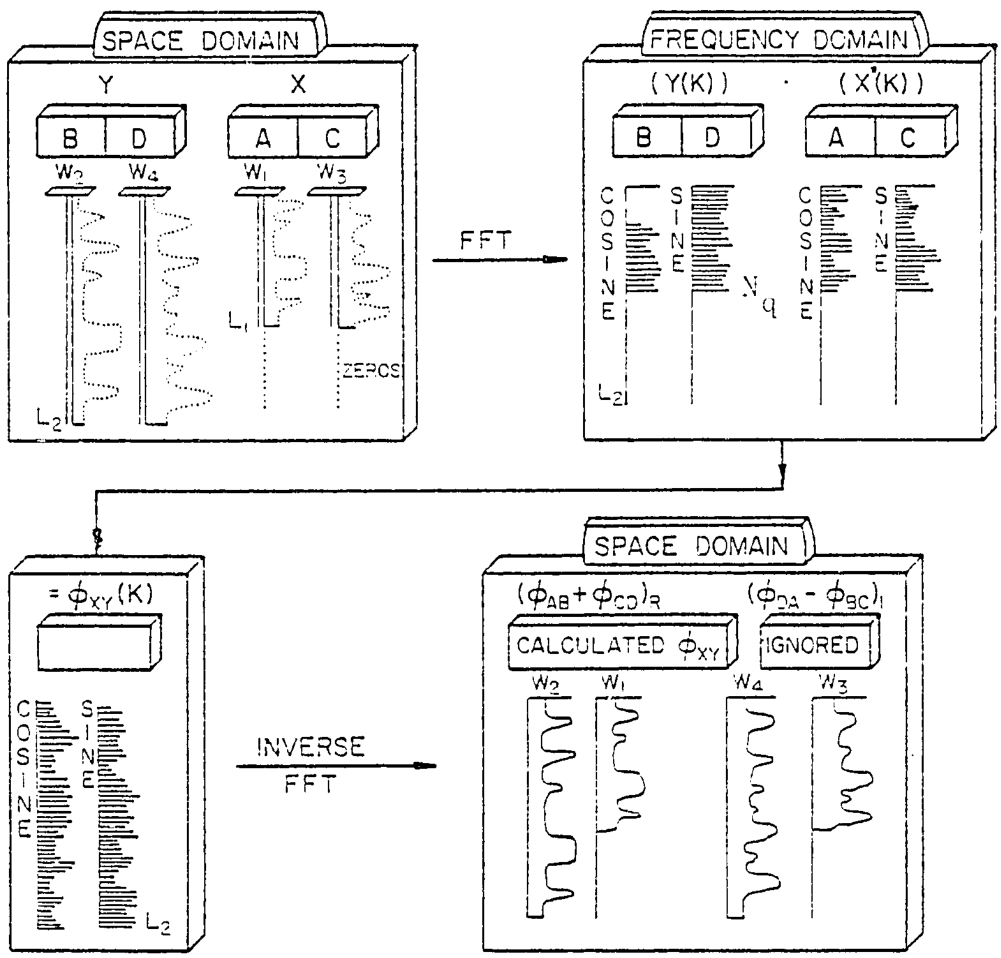


Figure 24. Graphical illustration of cross-correlating four logs in the frequency domain. In this graph, X and Y imply complex series A + jC and B + jD, respectively. * indicates complex conjugate and N_q implies Nyquist frequency.

$$\phi_{xy}(K) = \sum_{i=1}^{L_1} X_i^*(K)\ Y_i(K)$$

where X_i = the i'th point of well log x

Y_i = the i'th point of well log y

$$= \sum_{i=1}^{L_1} [(A_i C_{i+\tau} + B_i D_{i+\tau}) + j(B_i C_{i+\tau} - A_i D_{i+\tau})] \quad (48)$$

where A, B, C, and D = spatial series representing the short and long well logs of Figure 24

$i = 1, 2, \cdots, L_1$

* = complex conjugate

Recall from previous sections that cross-correlation is performed with stationary series; therefore, for stationary Y spatial series (Bendat and Piersol, 1971), $\phi(s,\tau)$ is maximum for those L_1 values of the Y series that are the best linear approximation of the X series. The Y series is stationary if all intervals of L_1 length have nearly the same average. If this is true, then the maximum of $\phi(s,\tau)$ occurs at the value of τ where the L_1 values of the Y series best approximate the L_1 values of the X series.

The process of cross-correlation is established by repeatedly stretching the spatial series A(n) by the frequency domain interpolation method, then comparing to the spatial series B(n). In a similar manner, C is compared to D.

The normalized cross-correlation coefficient of Equation (48) is defined as (using Equation 35):

$$R_{xy}(S,\tau) = \frac{\sum_{i=1}^{L_1} X_i Y_{i+\tau}^* - L_1 \bar{x}\bar{y}_\tau^*}{\left[\left(\sum_{i=1}^{L_1} X_i X_i^* - L_1 \bar{X}\bar{X}^*\right)\left(\sum_{i=1}^{L_1} Y_{i+\tau} Y_{i+\tau}^* - L_1 \bar{Y}_\tau \bar{Y}_\tau^*\right)\right]^{\frac{1}{2}}} \tag{49}$$

or

$$R_{xy}(S,\tau) = \phi_R(S,\tau) + j\phi_I(S,\tau) \tag{50}$$

The symbols R and I imply real and imaginary, respectively. The real part of Equation (49) is given by:

$$\phi_R(S,\tau)$$

$$= \frac{\sum_{i=1}^{L_1} (B_i A_{i+\tau} + D_i C_{i+\tau}) - L_1(\bar{B}\bar{A}_\tau + \bar{D}\bar{C}_\tau)}{\left\{\left[\sum_{i=1}^{L_1}(B_i^2 + D_i^2) - L_1(\bar{B}^2 + \bar{D}^2)\right]\left[\sum_{i=1}^{L_1}(A_{i+\tau}^2 + C_{i+\tau}^2) - L_1(\bar{A}_\tau^2 + \bar{C}_\tau^2)\right]\right\}^{\frac{1}{2}}} \tag{51}$$

while the imaginary part is given by:

$$\phi_I(S,\tau)$$

$$= \frac{\sum_{i=1}^{L_1} (D_i A_{i+\tau} - B_i C_{i+\tau}) - L_1(\bar{D}\bar{A}_\tau - \bar{B}\bar{C}_\tau)}{\left\{\left[\sum_{i=1}^{L_1}(B_i^2 + D_i^2) - L_1(\bar{B}^2 + \bar{D}^2)\right]\left[\sum_{i=1}^{L_1}(D_{i+\tau}^2 + C_{i+\tau}^2) - L_1(\bar{A}_\tau^2 + \bar{C}_\tau^2)\right]\right\}^{\frac{1}{2}}} \tag{52}$$

defining

$$\bar{B} = \frac{1}{L_1}\sum_{i=1}^{L_1} B_i, \qquad \bar{A}_\tau = \frac{1}{L_1}\sum_{i=1}^{L_1} A_{i+\tau}$$

$$\bar{D} = \frac{1}{L_1}\sum_{i=1}^{L_1} D_i, \qquad \bar{C}_\tau = \frac{1}{L_1}\sum_{i=1}^{L_1} C_{i+\tau}$$

The real part $\phi_R(S,\tau)$ is the sum of two normalized cross-correlation functions:

$B_i A_{i+\tau}$ is the cross-correlation of series A and B

and $D_i C_{i+\tau}$ is the cross-correlation of series C and D.

On the other hand, the imaginary part $\phi_I(S,\tau)$ acts as the difference of two normalized cross-correlation coefficients:

$\sum_{i=1}^{L_1} D_i A_{i+\tau}$ is the cross-correlation of A with D

and $\sum_{i=1}^{L_1} B_i C_{i+\tau}$ is the cross-correlation of B and C.

Consequently, the real $\phi_R(S,\tau)$ symbolizes the cross-correlation function while $\phi_I(S,\tau)$ does not.

After the values of S and τ are determined for the maximum value of $R_{xy}(S,\tau)$, the inverse FFT returns the complex function $\phi_{XY}(S',\tau)$ to the space domain.

CHAPTER VI

COMPUTER-ASSISTED PREDICTION OF SUBSURFACE STRUCTURE

The concept of evaluating the structure confined between the correlated wells is established by this research in three distinct procedures: (1) initiation of the structure map of the formation or the bed correlated by the four well logs using the SYMAP computer package (Dougenik and Sheehan, 1976); (2) projecting the structure, derived from the contour map, down between the correlated wells and ultimately drawing the bed-lines. These lines illustrate the structure and thickness variations of the correlated bed or formation; (3) converting the two-dimensional cross section thus obtained to a three-dimensional configuration using the SYMVU computer package (Dougenik and Sheehan, 1976).

Initiation of the Structure Map

A. Mapping: With the advent of the digital computer, automatic contouring has become common in geologic exploration, and oil companies are among the largest markets for the manufacture of automatic plotters. The reliability of contour maps is directly dependent upon the density and uniformity of control points. Even though the desirability of a uniform distribution of control points (X and Y points on the map) is often cited, the degree of uniformity is seldom measured.

The point distribution coefficient R is given by the following formula (Dougenik and Sheehan, 1976):

$$R = \frac{\bar{D}(o)}{\bar{D}(e)} \qquad (53)$$

defining: $\bar{D}(o)$ = mean point distances of the observed (actual) distribution

$$\bar{D}(o) = \frac{\sum d_i}{N}$$

$\bar{D}(e)$ = mean point distances of the expected (random) distribution

$$\bar{D}(e) = \frac{\sqrt{A/N}}{2}$$

where d_i = distance from any point to its nearest neighbor

A = area within map

N = number of data points

The value of R ranges between 0 when all points are very close to each other (clustered) in a small location, to 2.15, when data points are positioned at their maximum well spacing. The point distribution coefficient is introduced as an elective no. 28 in the SYMAP package of Dougenik and Sheehan (1976). In this study, the data points of the model test are positioned in a grid pattern (equally spaced points and equal number of points per subarea). Therefore, there is no need to perform a uniformity test or calculate the coefficient R. However, the real data requires a point distribution coefficient test to examine the uniformity of distribution.

B. Contouring: Geologists demonstrate their artistic talents as well as their geologic skills when they create contour maps. The case of contouring practice is similar, to some extent, to that of log interpretation in the sense that geologic judgment becomes biased, and the subtle effects of personal opinion detract rather than add to the utility of a map. However, there may be situations where a high degree of bias is desirable and machine contouring is less appreciated. Computer contouring methods are totally consistent, and provide a counterbalance to overly interpretive mapping. In any case, comparison between machine-contoured and manually-contoured maps serves as a safeguard against excessive imaginative interpretation. To accomplish this purpose, manual and computer contoured maps are compared in this research. The reader is advised to exercise a subjective judgment in choosing an algorithm that ultimately provides efficient mapping. The other motive behind the development of automatic contouring is economic. Of course, this is an attempt to utilize the vast investment the petroleum industry has in stratigraphic data banks.

The procedure of contouring established in this research consists of a combination of a computer line printer and an automatic plotter.

Line printer method: In this routine, the line printer can be used to print bands of characters (Figure 25) in which edges of the bands represent the contour lines. The line printer output is established by the computer package SYMAP (Dougenik and Sheehan, 1976). This package consists of a computer mapping program using a standard line printer as its output device. The process involved in obtaining the contour lines is based on a theory similar to that of fitting a grid to data points, calculating the meshpoint values, and finally drawing the contour lines by interpolation of the grid values.

Automatic contouring plotter method: The contours in this approach are plotted in two ways: plotting a single, complete contour at one time (the case of the contouring program in this research, Figure 26); or plotting segments of several contours and progressively working across the map (Figure 27). The choice depends on the size of the map, speed of the computer used, and other factors.

Prediction of the Subsurface Structure

The concept of this prediction is determined by several interrelated procedures which are described below.

First, the coordinates (X, horizontal distance; Z, depth) of each point of the bedline along the straight

Figure 25. Output print of a structure map drawn by the computer package SYMAP.

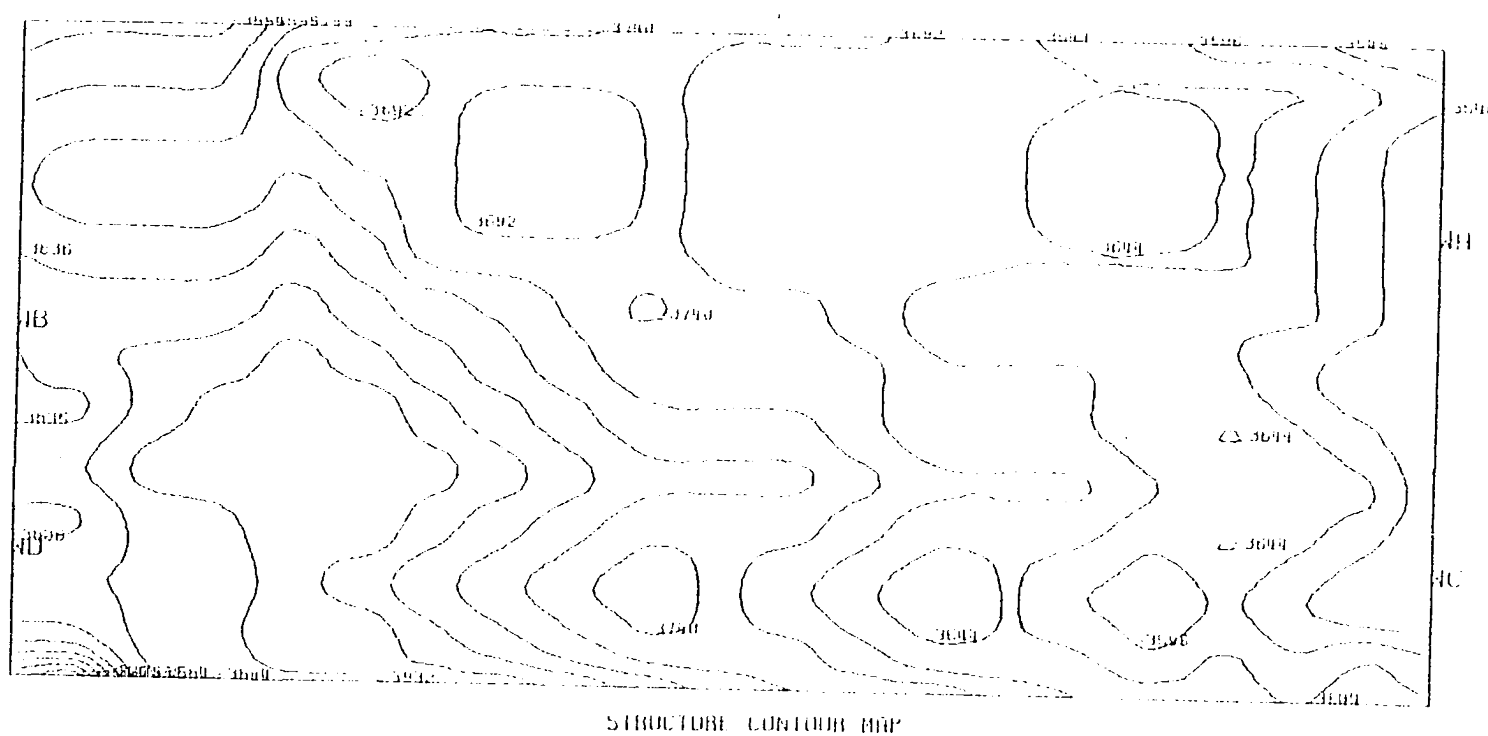


Figure 26. Calcomp plot of the structure map in Figure 25.

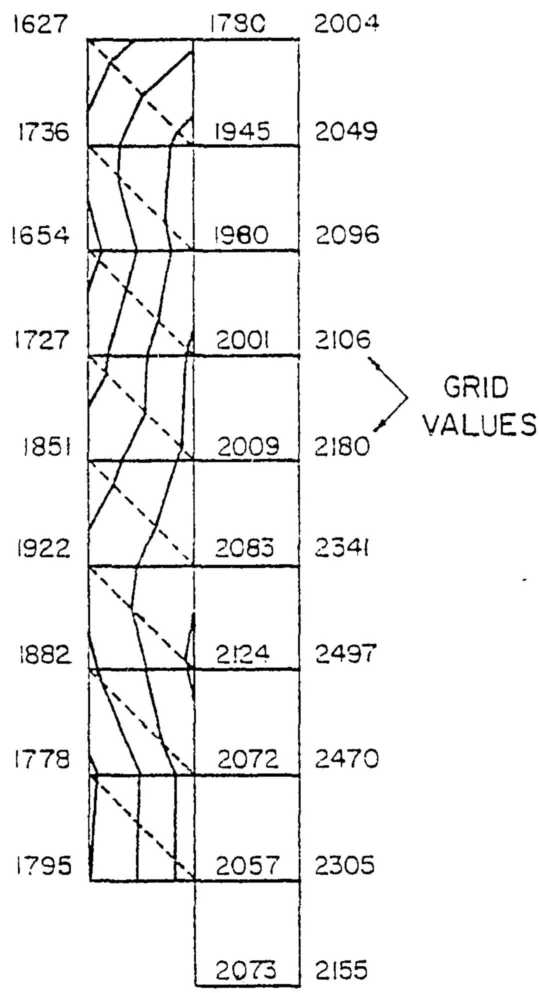


Figure 27. Column-by-column plotting of contours (After Harbough and Merriam, 1968).

path connecting each two wells (refer to Figure 29) is evaluated. At this point, two possibilities exist in this calculation:

a. Each two wells are on a horizontal line parallel to the grid lines. The X and Z values of each point along this path are the X and Z values of the corresponding point of the grid (Figure 28-A).

b. In case the two wells are on a path that makes an angle (positive or negative) with the grid lines (line A-B) (Figure 28-B, C), the X and Z values of each point on the path do not represent the X and Z values of the corresponding points of the grid. The correction of these values is required before the final projection takes place. By way of example, suppose the angle is negative (Figure 28-C); the Z value of each point is the value of the previous point plus a variable increment determined by the following equation:

$$\frac{\overline{DE}}{\overline{BC}} = \frac{\overline{AD}}{\overline{AB}} \qquad (54)$$

In simplified form,

$$Z \text{ increment} = DE = \frac{\overline{BC}}{\overline{AB}}$$

which is implemented in the computer program, bearing in mind that

$$AD = 1 = \text{grid interval}$$

The X increment in the triangle AED (Figure 28-C) is given by:

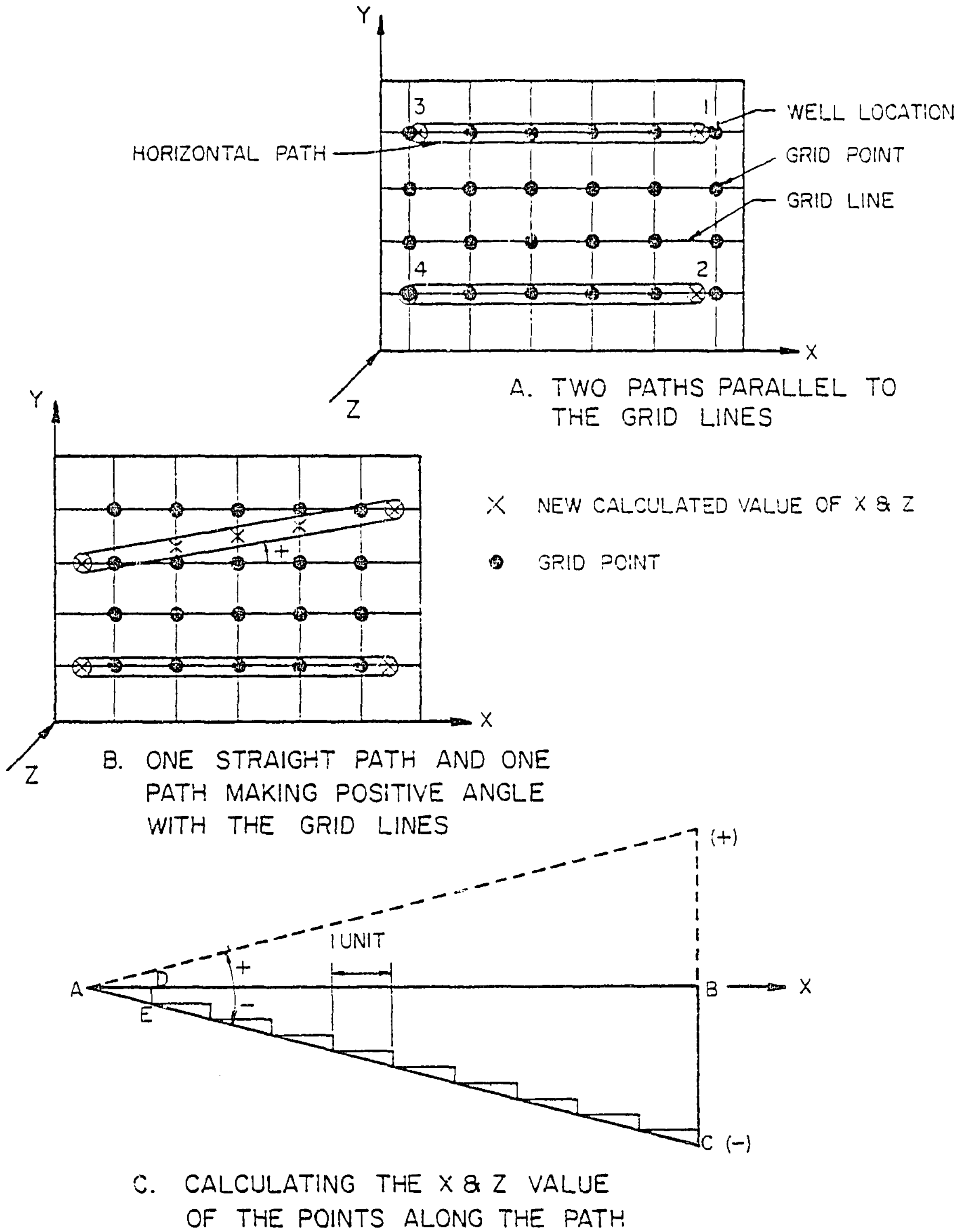


Figure 28. Calculating the X and Z values of the projected bed lines.

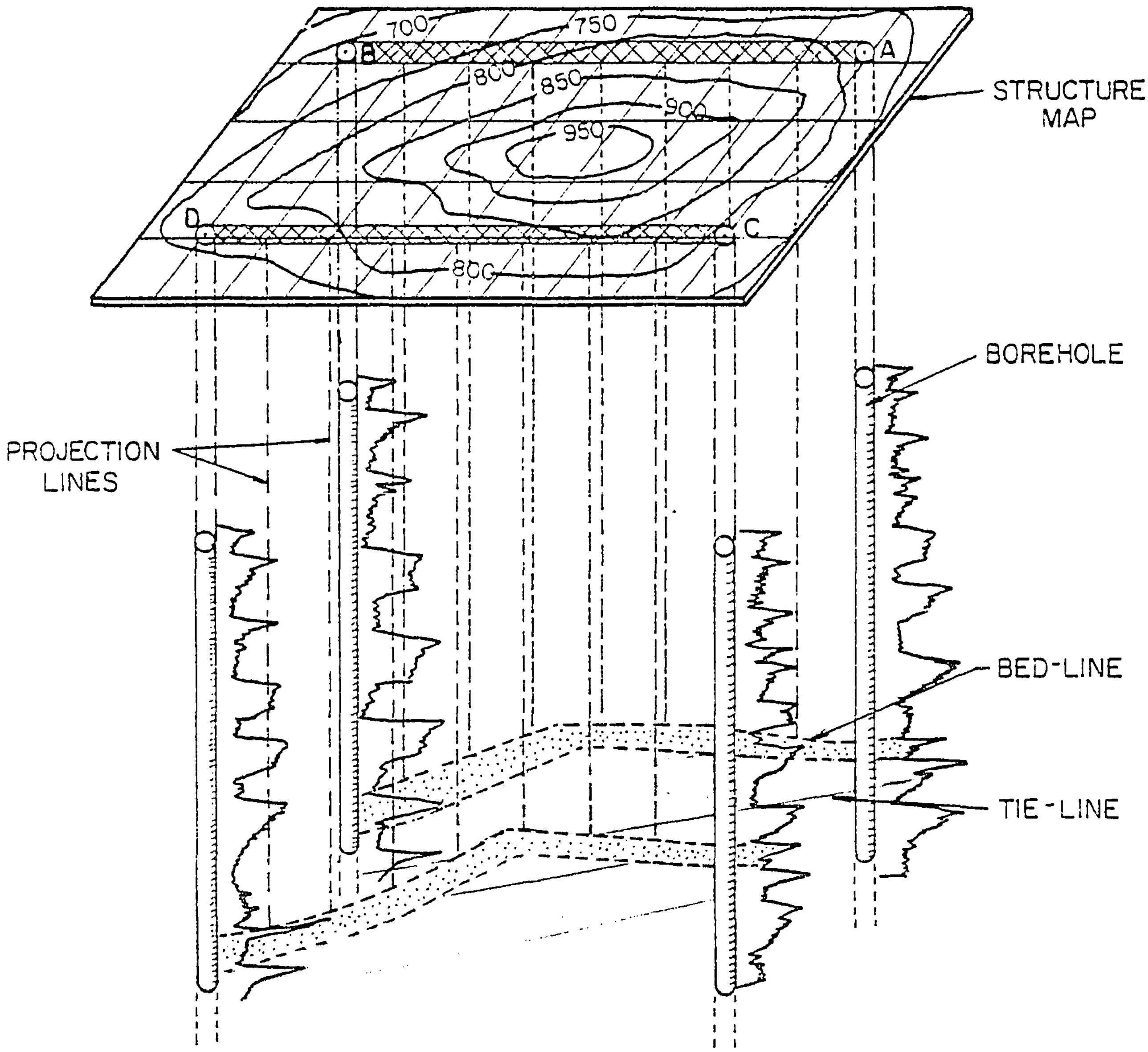


Figure 29. Illustration of the correlated four logs, tie-lines, bed-lines, well logs and the structure map.

$$X \text{ increment} = AE^2 = (AD)^2 + (DE)^2$$
$$= (1)^2 + (DE)^2 \quad (55)$$

In the case of a horizontal path (or zero angle), the X increment equals one and the Z increment equals zero. The evaluation of X and Z increments starts from one well and continues along the path to the other well. After establishing these values, the projection step is followed to plot the bedline.

Second, the variation in the thickness of the correlated bed is accounted for in the suggested algorithm. The algorithm stretches the bed vertically with the same value of the stretch factor utilized in the main program.

The procedures of correlation and prediction of the subsurface structure are illustrated in Figure 29.

Transform to Three-Dimensional Configuration

This procedure is accomplished by the implementation of the SYMVU computer package (Dougenik and Sheehan, 1976). This computer program is written to generate three-dimensional line-drawing displays of data. Only three control cards are necessary for the generation of the graphic displays. As in the case of the SYMAP package, SYMVU also has a number of electives or options which are built into the program allowing for considerable flexibility in generating the displays of data. However, in the author's work only a much smaller number of options are used in the program. The advantage of this program is its capabilities of conformant and proximal mapping using data generated by the SYMAP program. SYMVU is written in FORTRAN-IV as a SYMAP program and is operated on the IBM-370. The output is produced by a CALCOMP plotter of either 10 or 29 inches (Figure 30).

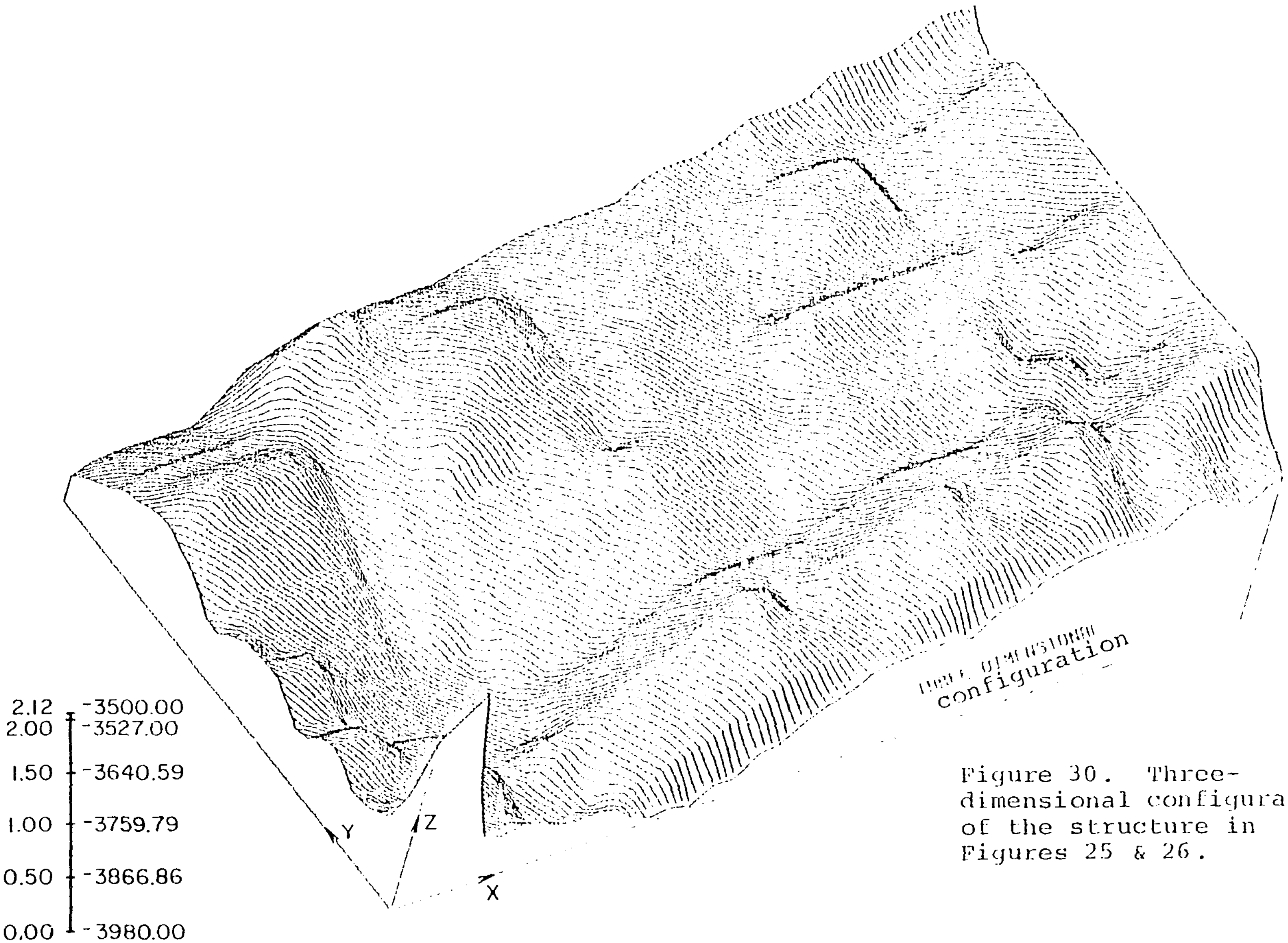


Figure 30. Three-dimensional configuration of the structure in Figures 25 & 26.

CHAPTER VII

ANALYSIS OF MODEL DATA

The computer model BASEL developed in the previous chapters (Appendix I) enhances the geologist's efforts to visualize the subsurface configuration of an oil field or to explore the lateral or vertical extension of an ore body or a coal seam, in a standardized automatic method. The applications of this computer model are introduced in Chapter IX.

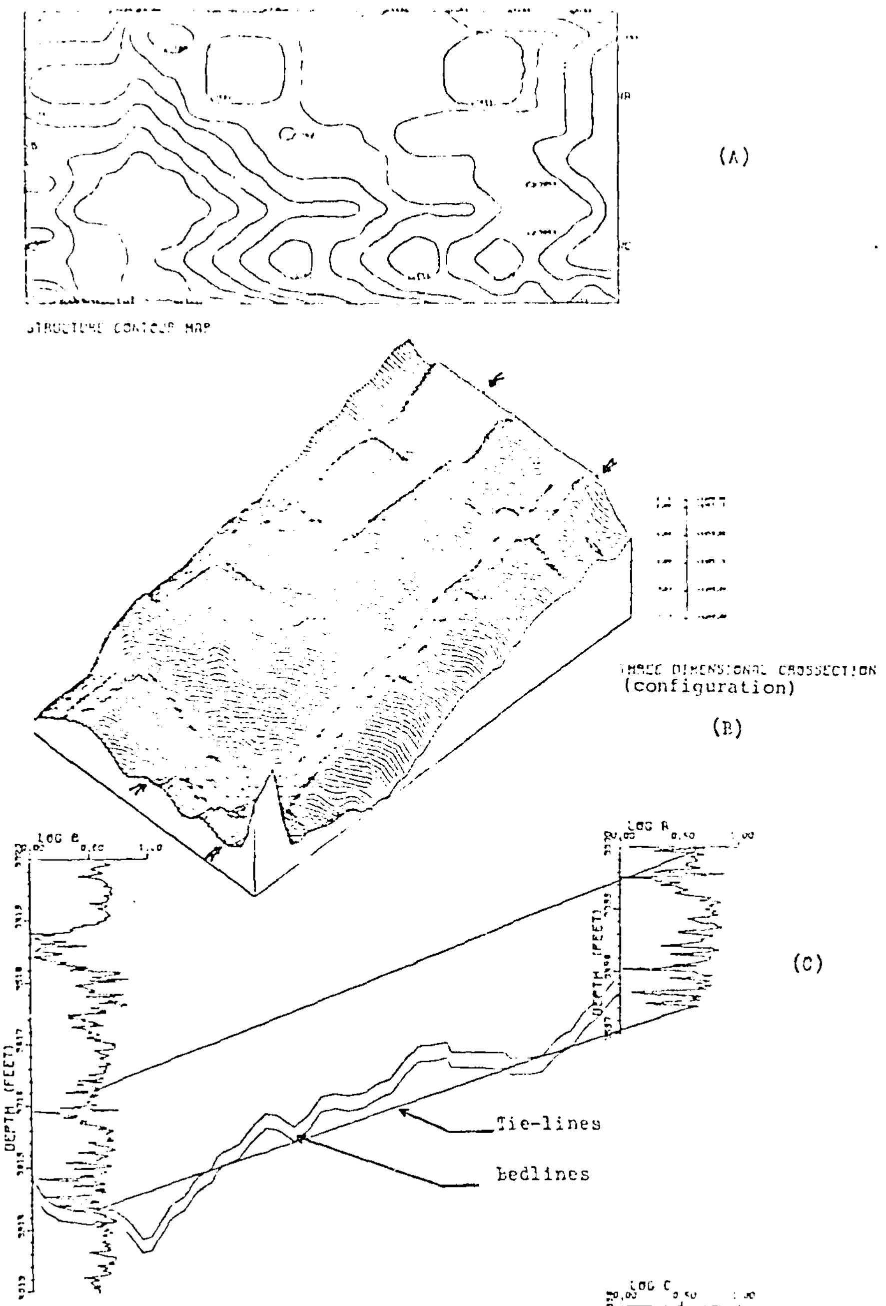
The BASEL program has the capacity of correlating all of the digitized logs in the study area, four logs at a time. Since limited numbers of digitized logs are available in this investigation, only four logs are tested.

The procedure of inputing the model data to the BASEL program consists of four steps: (1) The subprogram COR4WELL correlates four logs of the same kind, stores the boundaries of the correlated formation or bed on a magnetic tape or disc, correlates another adjacent four logs, stores the data, and so on until all the prospective area is scanned. (2) The main program recalls the data from the tape and generates the structure map, first by the SYMAP program, then by the CONTOUR subprogram. (3) It locates the position of the logs that form the edges of the two dimensional cross section (logs A, B, C, and D in Figures 4 and 29) and draws the bedlines. And (4) the computer package SYMVU converts the two dimensional cross section to the three-dimensional configuration.

The efficiency of the BASEL computer model is first inspected by utilizing model test data in this chapter; then real data are employed in the next chapter.

The test data consist of four density logs (Kennedy et al., 1968) assumed to represent four well sites. The control points of the structure map are measured from sea level and read in the program as positive values. In this study, the four points of the data are determined from the automatic correlation of the four density logs by the COR4WELL subprogram; the rest of the points symbolize visual correlation of the imaginary logs located in the exploration site. The structure map initiated from this data is shown in Figure 31-A.

The length of the long window used is 350 sampling points while the length of the short window is 130 sampling points. In fact, various window lengths are tested and the highest correlation factor obtained is at 350 and 130 sampling points for the long window and short window, respectively. The top depth reading on each window represents the first reading on the Z axis (the Y axis represents the Z axis in Figure 31-C).



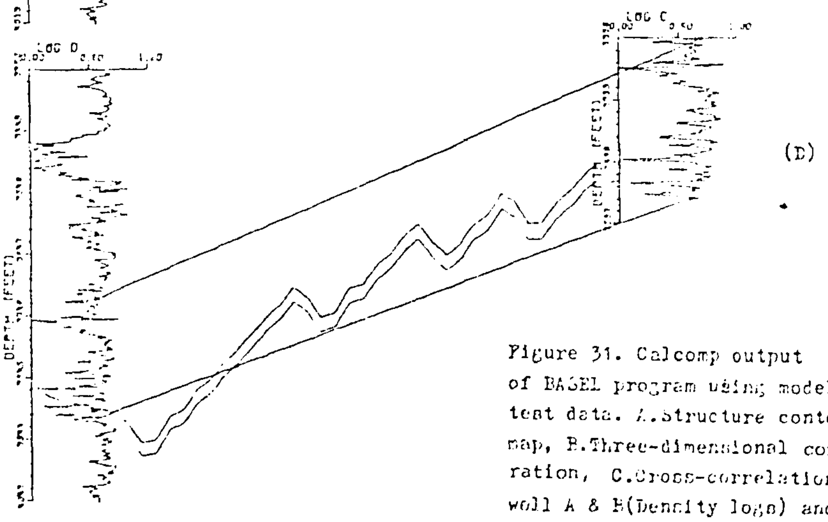
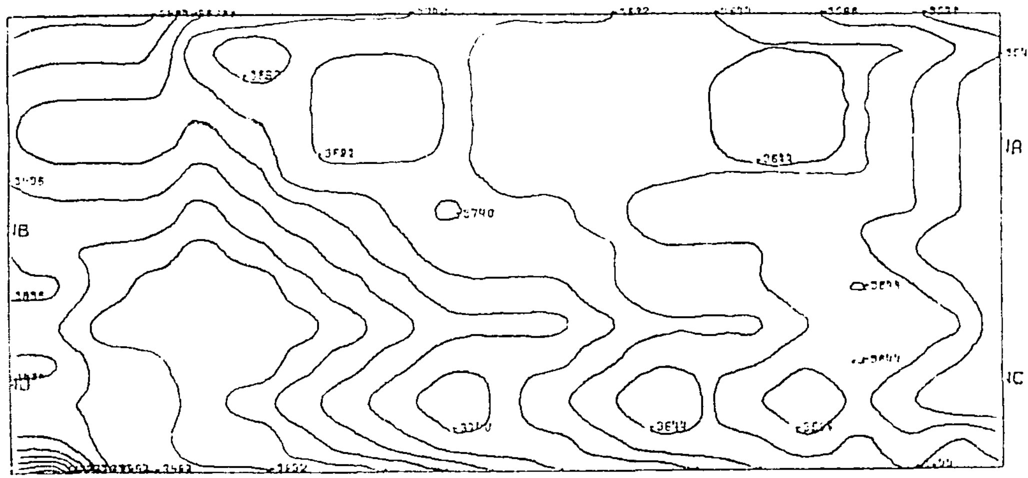
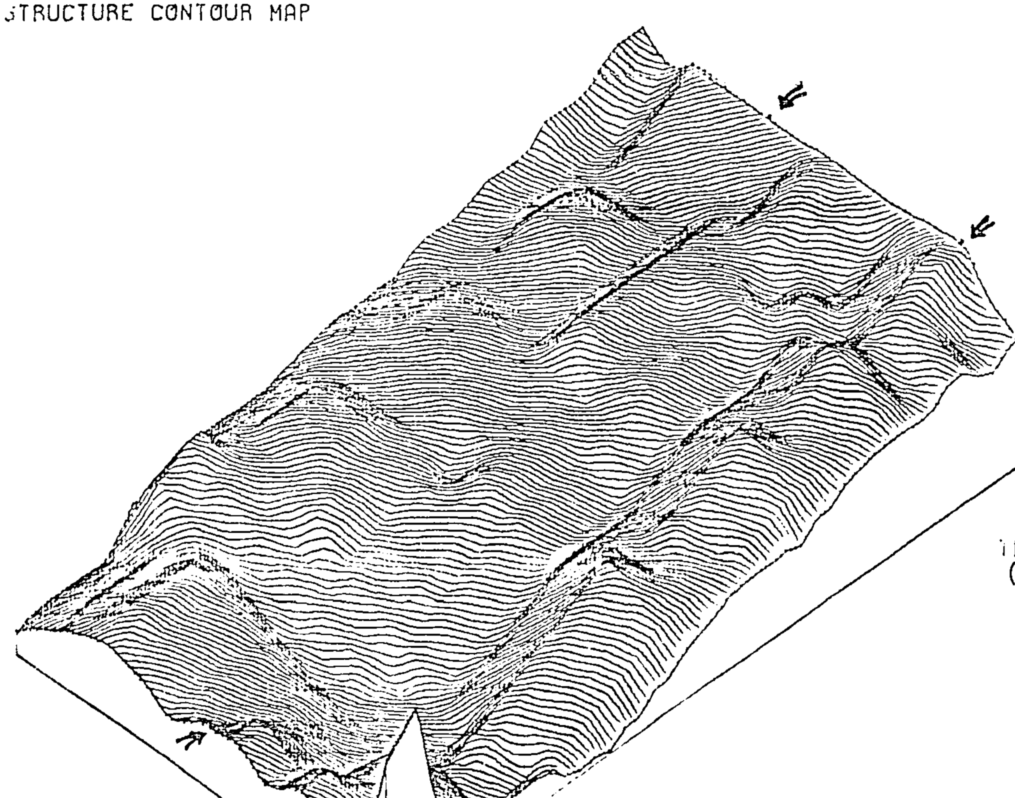


Figure 31. Calcomp output of BASEL program using model test data. A.Structure contour map, B.Three-dimensional configuration, C.Cross-correlation of well A & B(Density logs) and the cross section between wells A & B, D.Cross-correlation of wells C & D.Arrows in(B) indicate the location of the wells A,B,C,and D.



STRUCTURE CONTOUR MAP

(A)

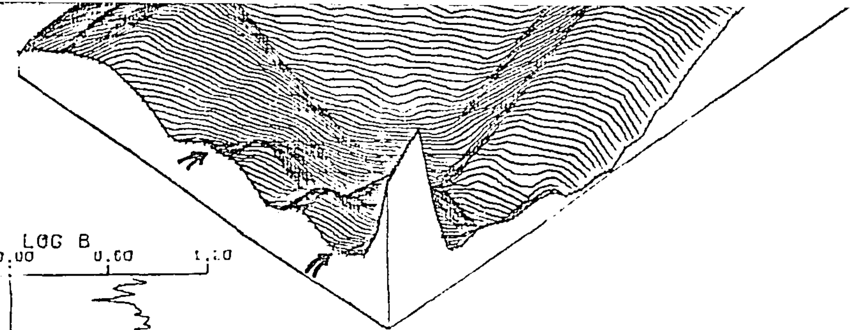


THREE DIMENSIONAL CROSSECTION
(configuration)

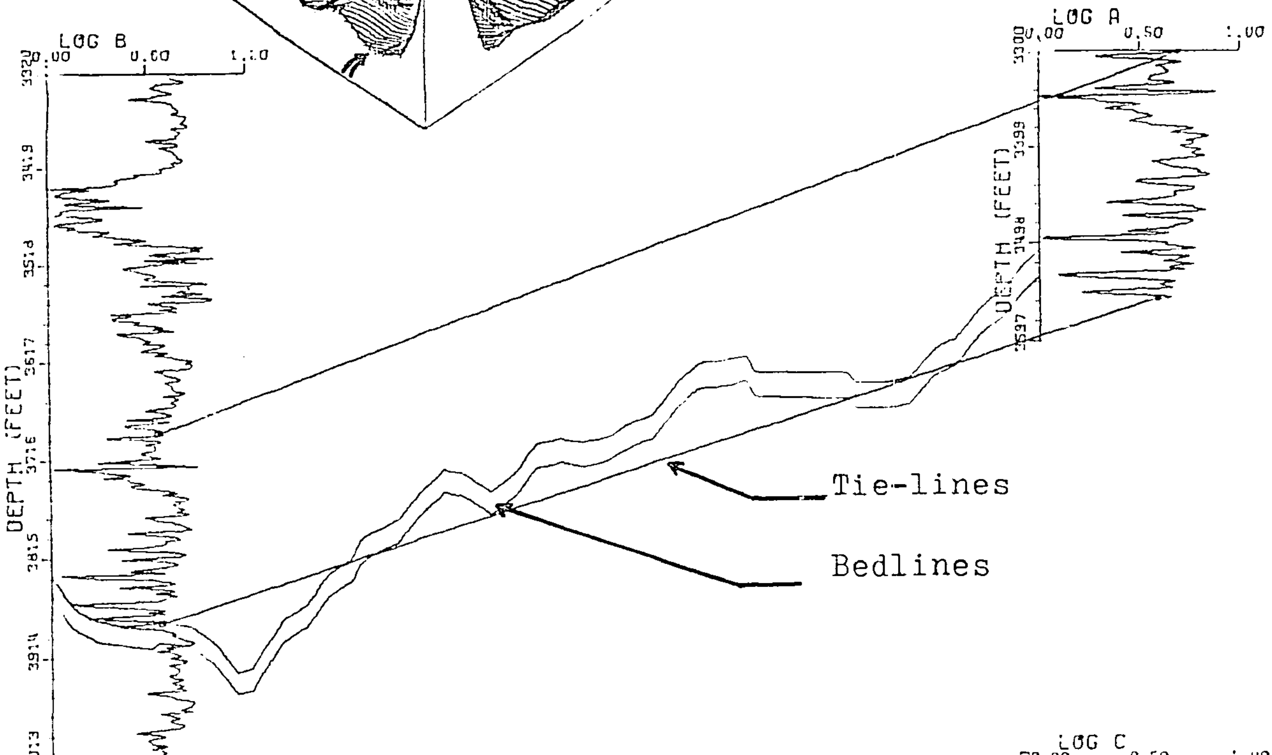
(B)

LOG A

(B,



(C)



(D)

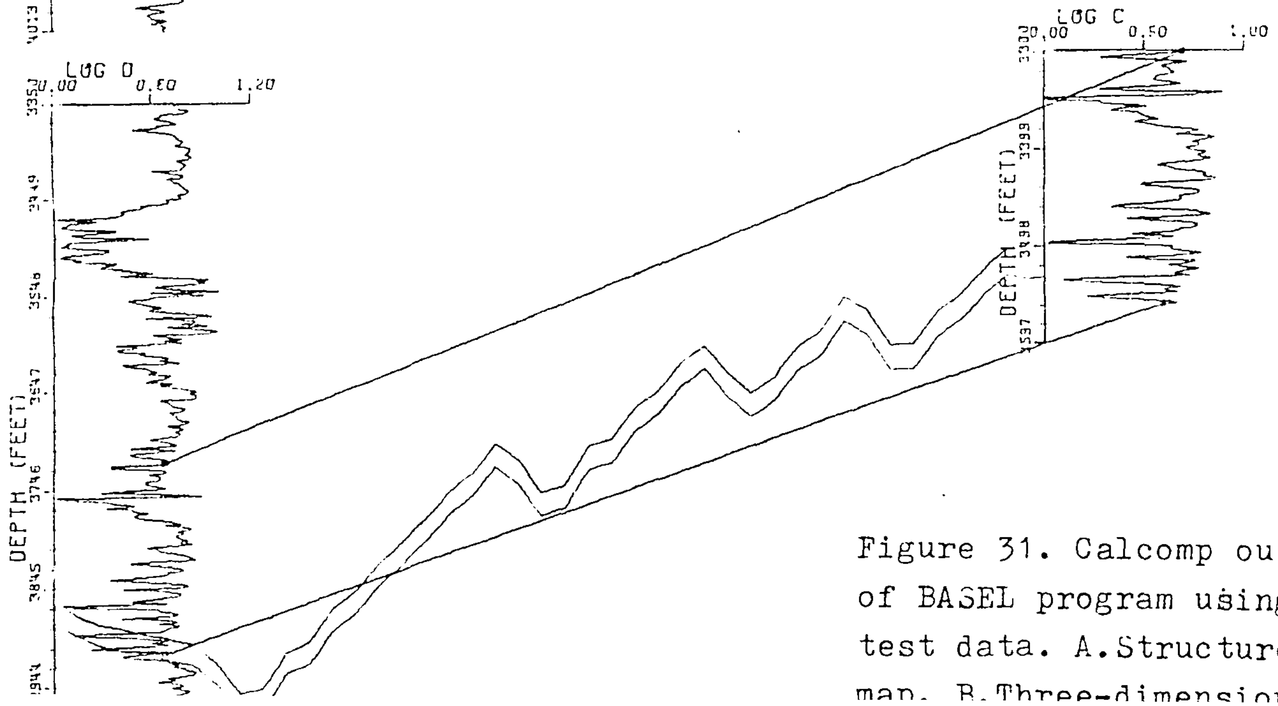
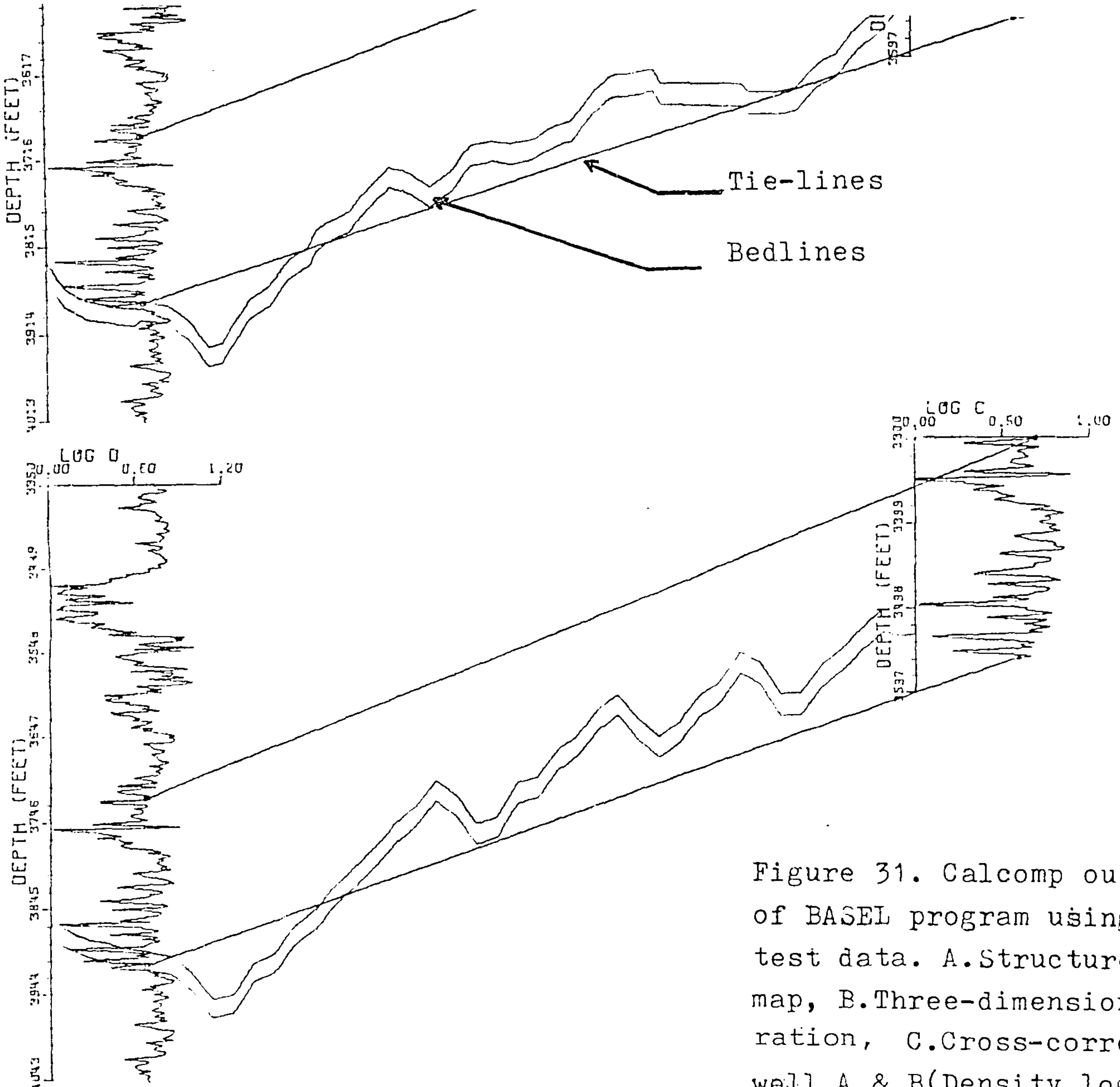


Figure 31. Calcomp output of BASEL program using model test data. A.Structure contour map. B.Three-dimensional configu-



(D)

Figure 31. Calcomp output of BASEL program using model test data. A.Structure contour map, B.Three-dimensional configuration, C.Cross-correlation of well A & B(Density logs) and the cross section bet ‿en wells A & B, D.Cross-correlation of wells C & D.Arrows in(B) indicate the location of the wells A,B,C,and D.

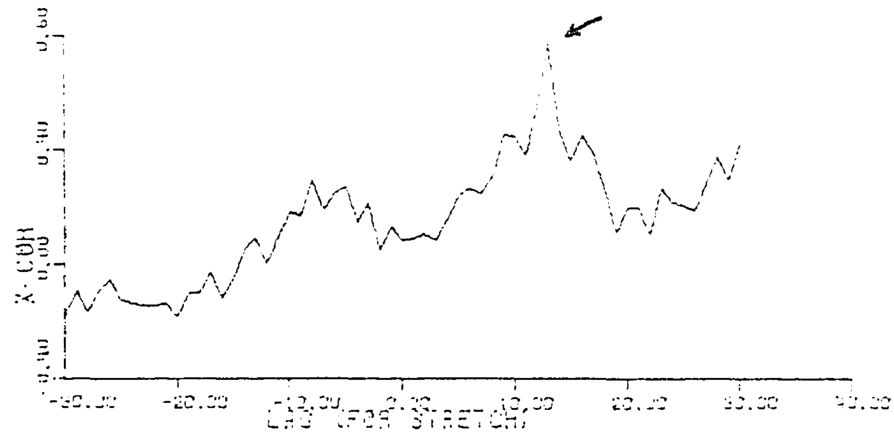
DEEP SEA DENSITY LOG

MAXIMUM CORRELATION IS 0.65

AT A LAG OF 165

WHEN SHORT LOG IS STRETCHED 1.65 TIMES

(E)



(F)

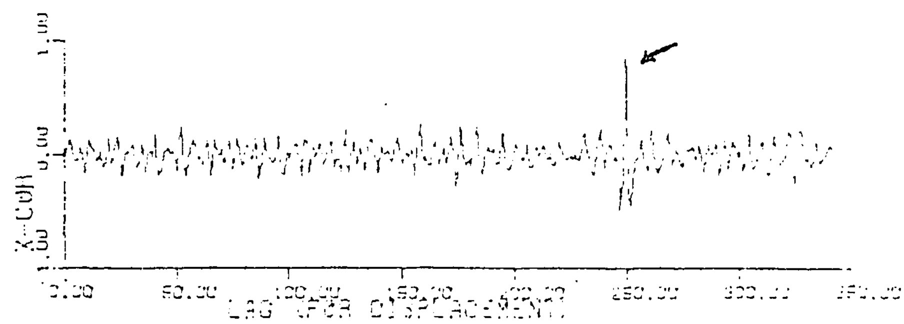


Figure 31, Cont.: E. Plot of lag (for stretch) versus cross-correlation. F. Plot of lag (for displacement) versus cross-correlation. Arrows indicate the locations of maximum correlation.

The vertical exaggeration of the three-dimensional configuration is set up at 3 (Figure 31-B). This variable is used as a control card in the program to allow the user a freedom in choosing the value of the vertical exaggeration.

The final step in the BASEL program output consists of two plots illustrated in Figure 31-E and F. These figures represent the cross-correlation vs. the lag displacement for the stretched spectra and the stretched logs, respectively.

The values of the displacement, correlation factor, and stretch are indicated in Figure 31-G.

In order to compare the results of the BASEL program (Figure 31) with those obtained from the conventional method (hand drawing method) a structure map and two cross sections are drawn between the correlated logs. Figures 32, 33, and 34 show the results of comparing the BASEL output with the conventional results. They are quite identical. However, the efficiency and capability of SYMAP in showing a more detailed interpolation than the conventional method can be appreciated.

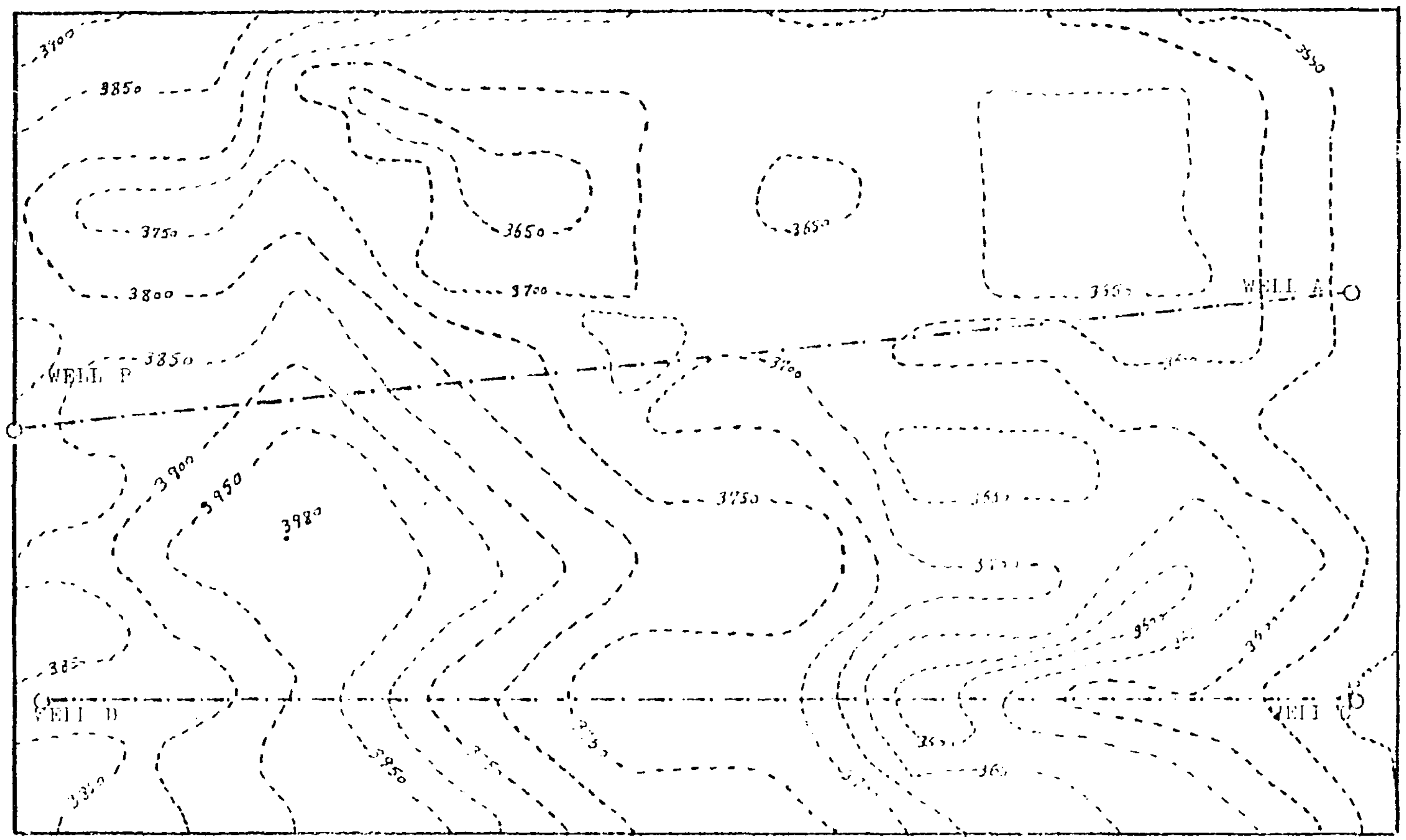


Figure 32. Structure map of the model test data drawn by conventional method.

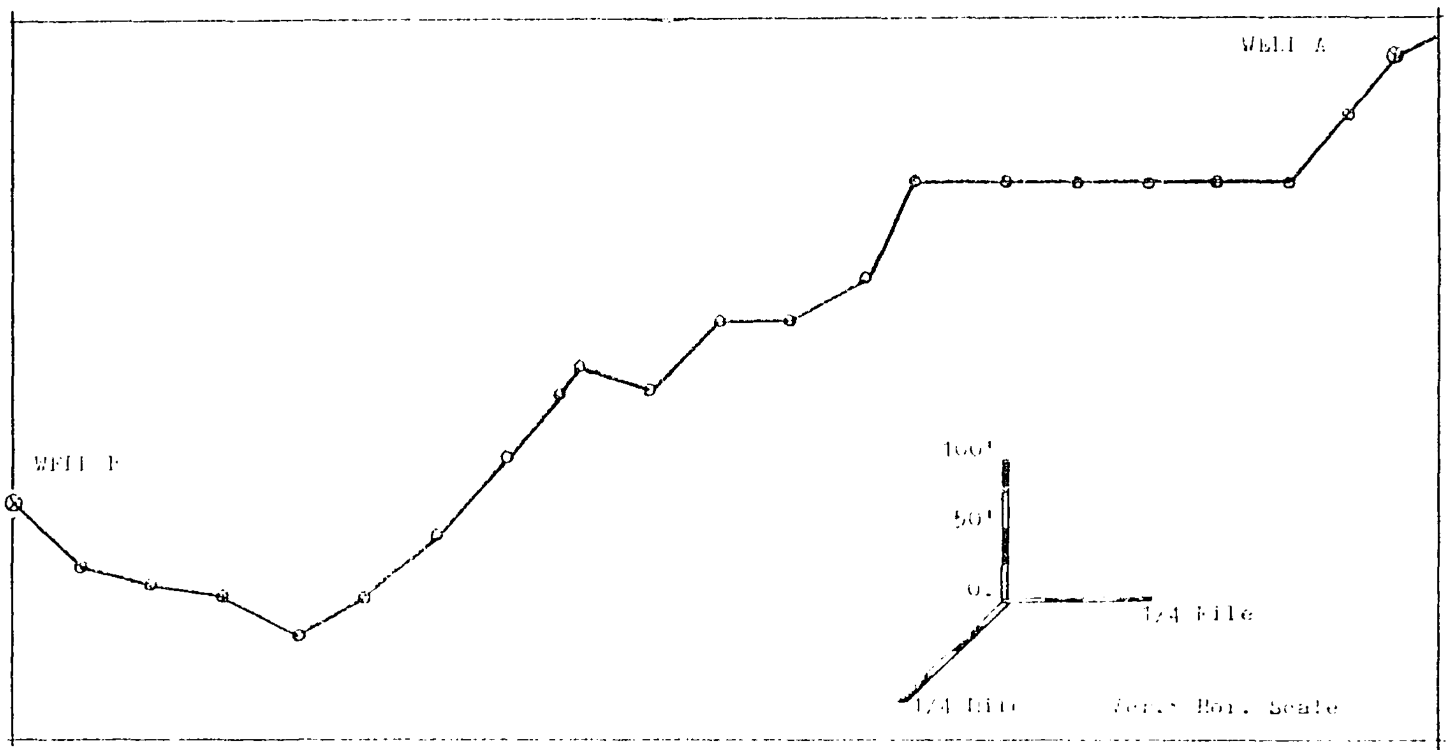


Figure 33. Cross section between well A and B.

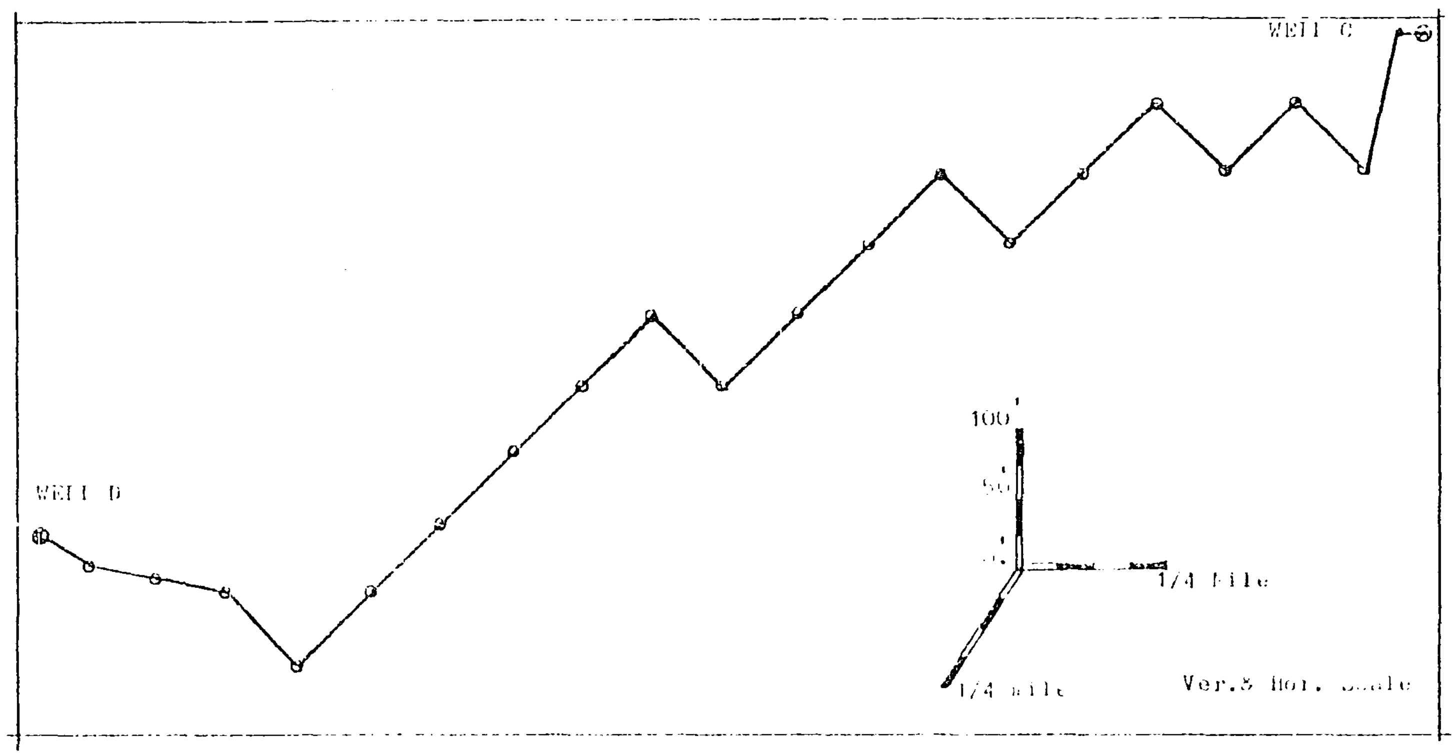


Figure 34. Cross section between well C and D.

CHAPTER VIII

ANALYSIS OF REAL DATA

The efficiency of the computer model BASEL is further tested by the application of the real data obtained from an oil field in Oklahoma and a coal deposit in North Dakota.

Analysis of Resistivity Logs from St. Louis Oil Field, Oklahoma

Objectives of the Analysis

The purposes of this analysis are: (1) to examine the lithostratigraphic relationship between various well sites in the St. Louis oil field. The relationship can be constructued by establishing a lithostratigraphic unit at each location and comparing these units to determine whether the Lower Earlsboro Sand unit is laterally continuous. (2) to determine the subsurface structure of this unit in the research area.

Description of the Study Area

1. Location: The investigation site is located in the north-central part of southern Pottowatomie County. The

area comprises three sections in R 3 E, T 7 N and twelve sections in R 4 E, T 7 N (Figure 35).

2. Geologic setting: Eighty percent of the wells in the area are producing from the Earlsboro Sand zone. The rest are from lower formations (Hunton, Viola and Wilcox). The analysis of the resistivity logs is confined to the correlation of the Earlsboror Sand zone because it persists in the study area, and it is easy to detect on all the available logs. Earlsboro Sand is Late Upper Pennsylvanian in age. It consists of two to four units, the upper most and lower units are persistent in the study area. However, most of the oil production is produced from the Lower Earlsboro Sand unit which will be considered in this analysis.

Analysis Methodology

The computer model BASEL developed in the previous chapters requires three procedures in order to produce the output illustrated in Figure 31.

1. Automatic drawing of the structure map: Data employed in this analysis consist of logs of 108 wells drilled in Pottawatomie County, Oklahoma (Figure 35 and Table 1).

The boundaries of the Lower Earlsboror Sand unit were chosen with the assistance of the correlation subprogram COR4WELL and visual correlation. Two subroutines are employed to draw the structure map, SYMAP and CONTOUR (Figure 36).

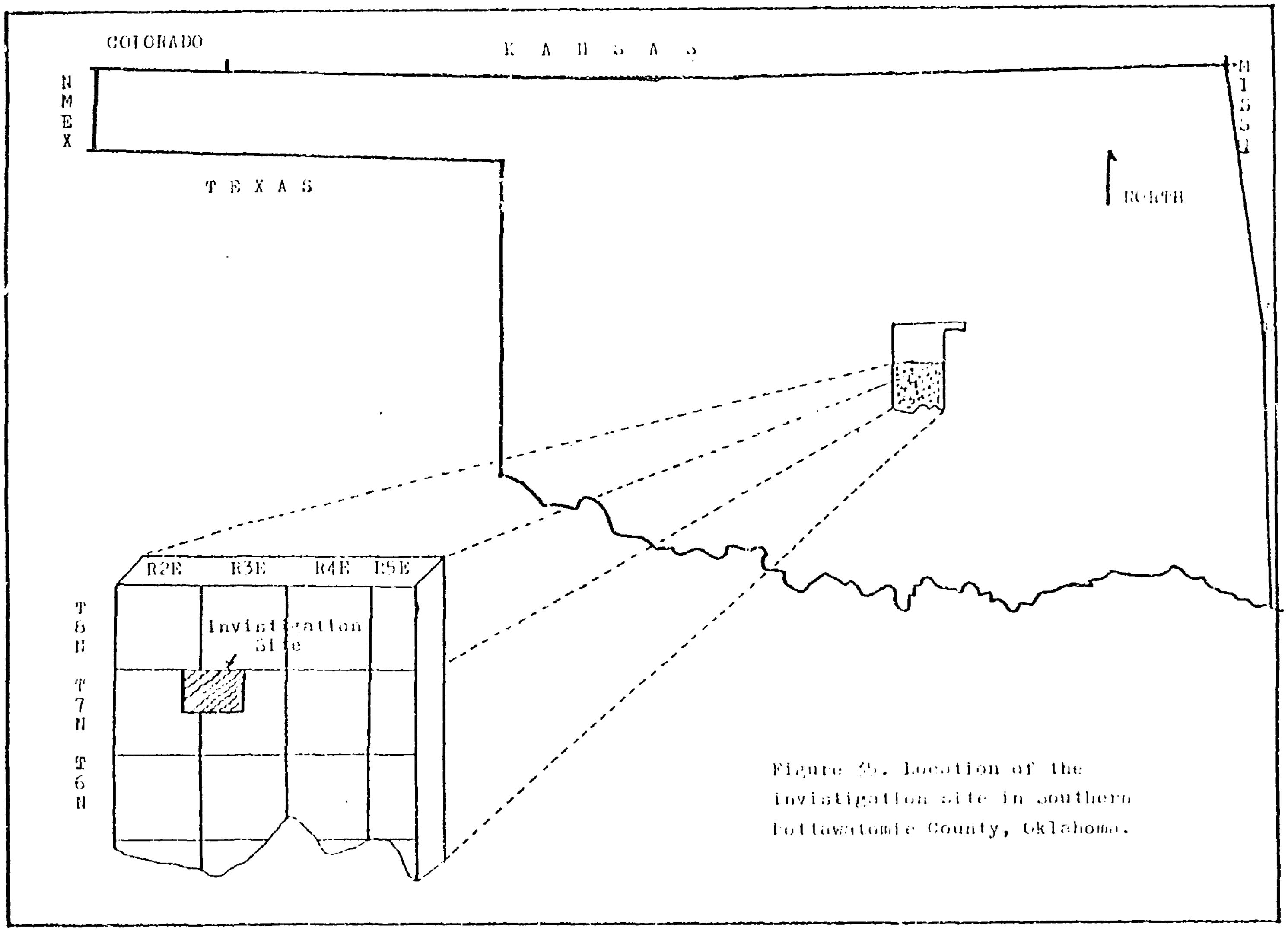


Figure 35. Location of the invistigation site in southern Pottawatomie County, Oklahoma.

Table 1. List of some of the oil and gas wells used in analyzing the St. Louis oil field.

Well No.	Operator	Well name	result	location
1	Dyco Pet.	Romuless Town	D&A	Sec 1-7N-3E
2	Barrett & Musg.	White #3	oil	Sec 13-7N-3E SW SE SW
3	Beach Oper. Co.	Draper #1	oil	Sec 13-7N-3E C NW SE SW
4	Newt Barrett, et al	White #1	oil	Sec 13-7N-3E NW NE SW
5	Newt Barrett et al	White #2	oil	Sec 13-7N-3E SW NE SW
6	Dearing Inc.	White #3	Oil	Sec 13-7N-3E SW NW SE
7	Melco Drilling Company	Wilson #1	D&A	Sec 13-7N-3E SE SW NW
8	T.H. Berry	Romulus Eals	?	Sec 13-7N-3E SW NW SE
9	J.F. Smith	F.L.B.#1	Oil	Sec 13-7N-3E SW SE NW
10	J.F. Smith	F.L.B.#2	D&A	Sec 13-7N-3E NW SE NW
11	R. Pet. Co.	Draper #1	D&A	Sec 13-7N-3E NW SE SE
12	Sun Oil Co.	Branden #2	D&A	Sec 13-7N-3E SE NW SW
13	J.F. Smith	Sanders #1	D&A	Sec 13-7N-3E SW SW NE
14	Sun Oil Co.	Branden #1	D&A	Sec 13-7N-3E NE NW SW
15	H.F. Sears	Thomas #1	D&A	Sec 4-7N-4E SW SE SE
16	E.F. McDonald	W. Ever. #1	D&A	Sec 5-7N-4E NW NE NE
17	H.F. Sears	McGee #1	D&A	Sec 4-7N-4E SE SW SE
18	H.F. Sears	McGee #1-A	Oil	Sec 4-7N-4E SE SW SE
19	Lobar Oil	Light foot #1-A	Oil	Sec 6-7N-4E SW NW NW
20	J.F. Smith	Bray #1	Oil	Sec 5-7N-4E SW NW NW
21	J.F. Smith	Krouch #1	D&A	Sec 5-7N-4E NW NW NE
22	S. Brths. Drlg. Company	Brundege #3-B	Oil	Sec 6-7N-4E SE NE SE
23	C. Comm. Co.	Thomas #1	Oil	Sec 9-7N-4E NW SE SW
24	Baron Kidd	Standridge #1	oil	Sec 7-7N-4E SE NE SE
25	Elise P. Chapman	J.W. Atwater #3	D&A	Sec 9-7N-4E S/2 SE SE
26	An-Son Pet. Co.	Thomas #1	D&A	Sec 9-7N-4E SE NW NW
27	Elise P. Chapman	Sally Boozes	Oil	Sec 9-7N-4E N/2 S/2 NE SE
28	F.H. Harber	Hines #1	Oil	Sec 9-7N-4E SE SW NE
29	Chapman & Poland	Bewley #1	Oil	Sec 9-7N-4E E½ NW SE
30	H.F. Sears	Nelson #3	Oil	Sec 9-7N-4E NE SW SE SW
31	H. Waggoner	Thomas #1	Oil	Sec 9-7N-4E NE NE NW
32	H.F. Sears	P. Nelson #1	Oil	Sec 9-7N-4E N½ SE SE SW
33	H.F. Sears	Nelson #2	D&A	Sec 9-7N-4E E½ SE SE SW
34	Marathon Oil	B.S. Unit #12	Oil	Sec 16-7N-4E NE SW SE NE
35	Reda Pump Co.	Rhodd #1	Oil	Sec 16-7N-4E NW NW NW
36	C. Pet. Res. Inc	Burke #7	Oil	Sec 16-7N-4E SE NE NE
37	Marathon Oil	Burke #10	Oil	Sec 16-7N-4E SW NW NE
38	Reda Pump Co	Rhodd #2	D&A	Sec 16-7N-4E SW NW NW
39	J.E. Rougeot	Youngblood #7	Oil	Sec 16-7N-4E NE NE NW
40	Reda Pump Co	Youngblood #5	Oil	Sec 16-7N-4E SW NE NW
41	H.F. Sears	Pappan #4	Oil	Sec 16-7N-4E NW SW SE
42	H.F. Sears	Pappan #5	Oil	Sec 16-7N-4E E/2 SW SE
43	J.E. Rougeot	Youngblood #8	Oil	Sec 16-7N-4E 850FSL-1990FWL

Table I. (cont.)

Well No.	Operator	Well name	result	location
44	H.E. Sears	Pappan #2A	Oil	Sec 16-7N-4E SW SW SE
45	H.E. Sears	Richard #5	Oil	Sec 16-7N-4E NW NE SW
46	H.E. Sears	Richard #6	Oil	Sec 16-7N-4E SE NE SW
47	H.E. Sears	Richard #1	Oil	Sec 16-7N-4E NW NW SE
48	H.E. Sears	Richard #2	Oil	Sec 16-7N-4E NE NE SE
49	H.E. Sears	Richard #1B	Oil	Sec 16-7N-4E NW SW NW
50	H.E. Sears	Richard #2B	Oil	Sec 16-7N-4E W/2 E/s SW NW
51	H.E. Sears	Richard #6	Oil	Sec 16-7N-4E SW NW SE
52	H.E. Sears	Richard #2A	Oil	Sec 16-7N-4E NE SW NW NW
53	S. Weems Oil	Burk #2A	D&A	Sec 16-7N-4E W/2 NW NW NE
54	H. Waggoner Co	B.S. Schoolland	D&A	Sec 16-7N-4E C E/2 NW NE
55	Cleary Pet.	W. St. L. Eals-Hun P-11	Oil	Sec 17-7N-4E SW NE SE
56	Cleary Pet.	W. St. L. Eals-Hun P-6	Oil	Sec 17-7N-4E NE NW NE SE
57	Magnolia Pet. Co.	T.J. Hugn. #5	Oil	Sec 17-7N-4E SE NE NW
58	Gulf Oil Co.	Mattie #2	Oil	Sec 17-7N-4E SW NW SE
59	Gulf Oil Co.	Mattie #4	Oil	Sec 17-7N-4E NE NW SE
60	Pico V. Oil Co.	Vassler 1-Twin	Oil	Sec 17-7N-4E SE NE SW
61	Sherrod & etal	Richard 1-B	Oil	Sec 17-7N-4E SE SE SW
62	Sherrod & etal	Richard #2	Oil	Sec 17-7N-4E SE SW SE
63	Sherrod & etal	Richard #3	Oil	Sec 17-7N-4E SW SE SE
64	Sherrod & etal	Richard #1-B	Oil	Sec 17-7N-4E SE SE SW
65	Sherrod & etal	Richard #1J	Oil	Sec 17-7N-4E SW SW SE
66	Sinclain Oil Co.	Rice-B #2	Oil	Sec 17-7N-4E SE NW NE
67	Sinclain Oil Co.	Reagan #4	Oil	Sec 17-7N-4E SW SE NE
68	Sinclain Oil Co.	Reagan #5	Oil	Sec 17-7N-4E NW SE NE
69	Sinclain Oil Co.	Rice-A-3	Oil	Sec 17-7N-4E NE SW NE
70	J.F. Smith	Conatser-B-1	D&A	Sec 18-7N-4E SW SW SW
71	J.F. Smith	Conatser-B-2	Oil	Sec 18-7N-4E NW SE SW
17'	Sinclair Oil Co.	E. Hargon #1	D&A	Sec 4-T7N-R4E N½ SW¼
33'	Central Com. Co.	Nixon #1	D&A	Sec 9-T7N-R4E SW SW SW
43'	Reda Pump Co.	Youngblood #1	D&A	Sec 16-T7N-R4E SE SE NW
38'	Phillips Pet.	H. Rhodd #4	Oil	Sec 16-T7N-R4E SE NW NW
F	Phillips Pet.	Light #2	?	Sec 18-T7N-R4E NW SW SE

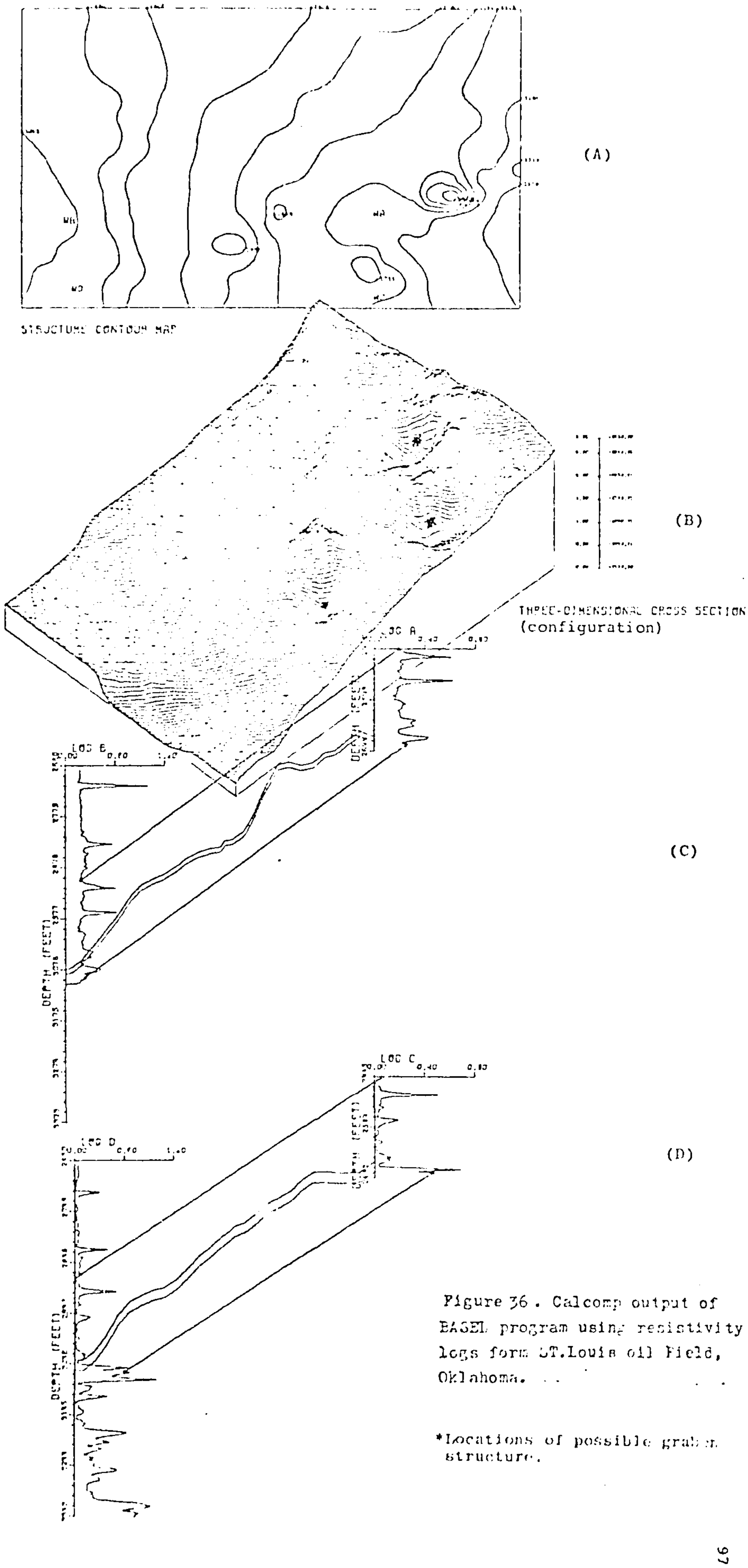
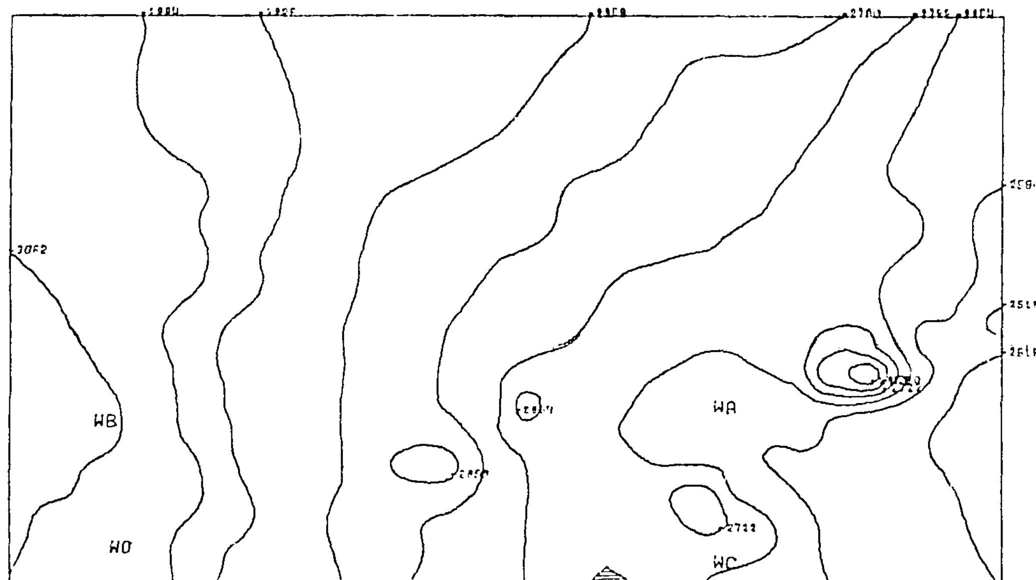


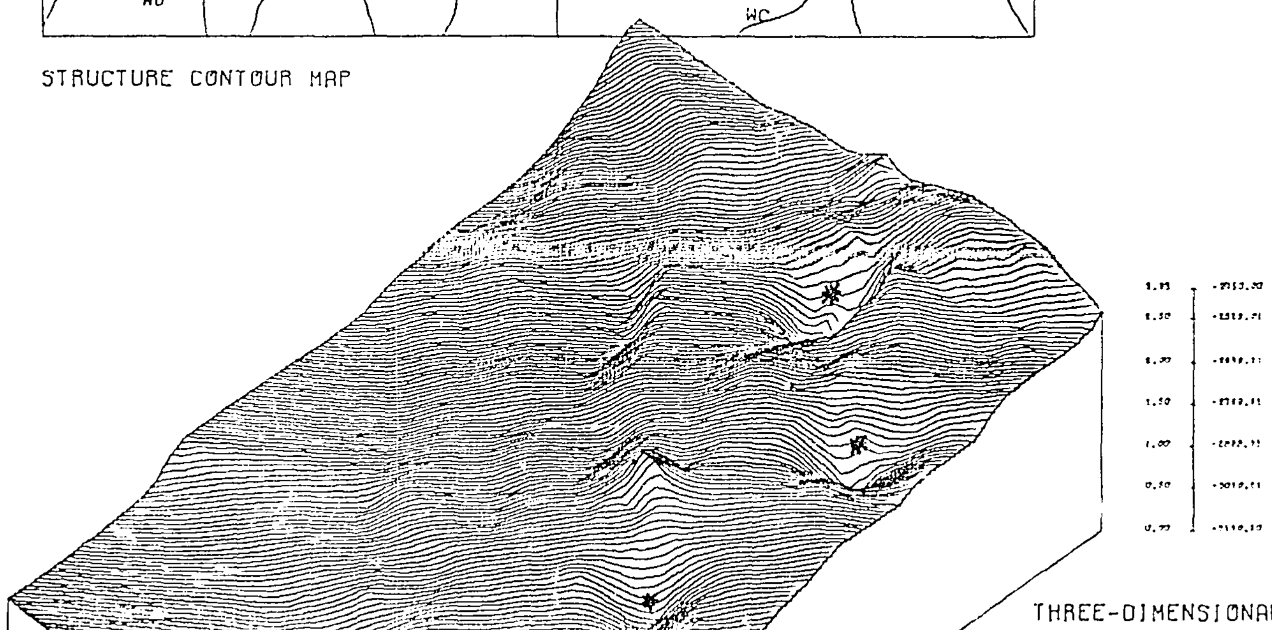
Figure 36 . Calcomp output of BASEL program using resistivity logs form ST.Louis oil Field, Oklahoma.

*Locations of possible graben structure.



(A)

STRUCTURE CONTOUR MAP



(B)

THREE-DIMENSIONAL CROSS SECTION
(configuration)

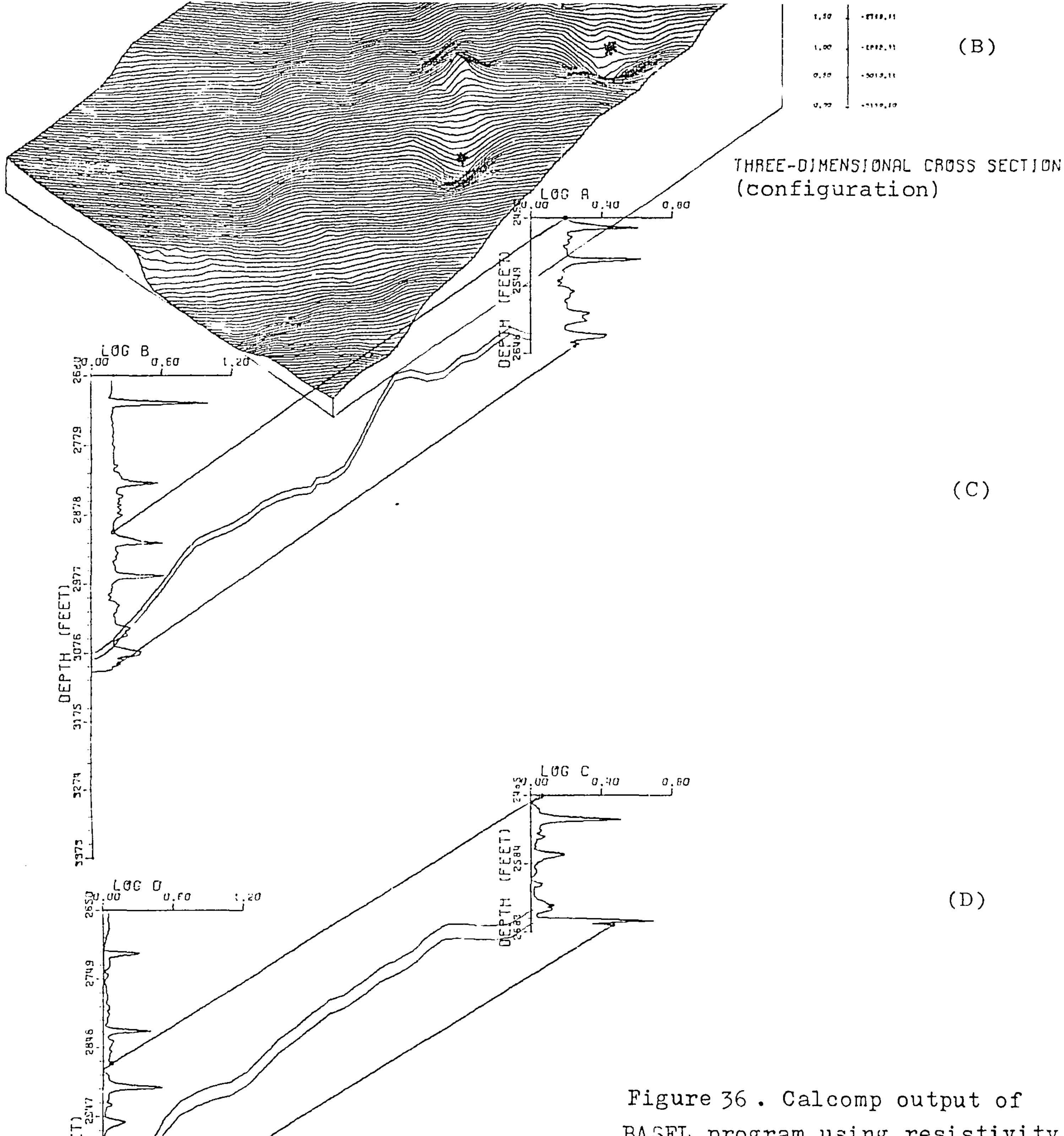
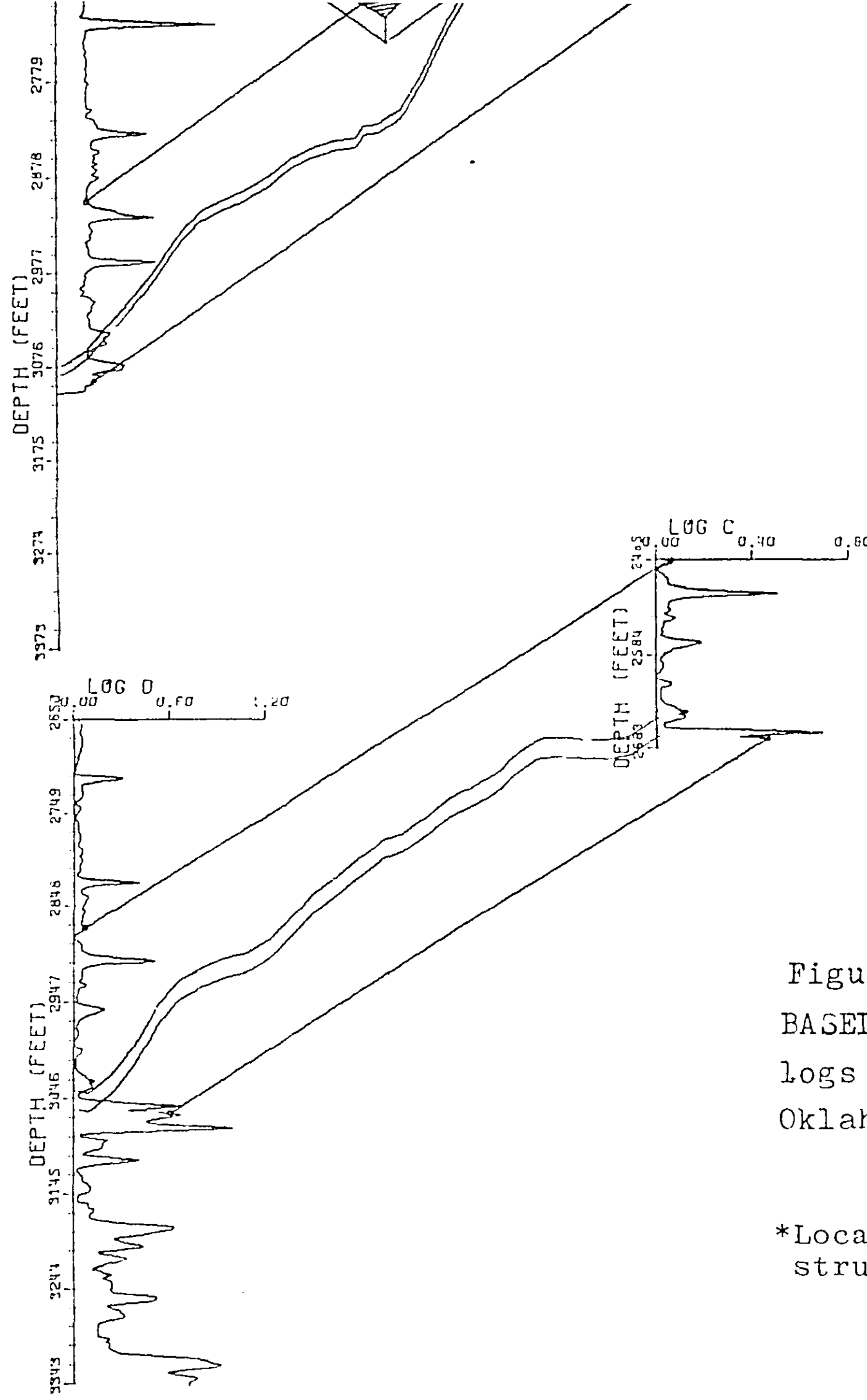


Figure 36 . Calcomp output of
BASEL program using resistivity



(C)

(D)

Figure 36 . Calcomp output of BASEL program using resistivity logs form ST.Louis oil Field, Oklahoma.

*Locations of possible graben structure.

RESISTIVITY LOGS FROM ST LOUIS OIL FIELD, OKLAHOMA

MAXIMUM CORRELATION IS 0.80

AT A LAG OF 112

WHEN LONG LOG IS STRETCHED 1.50 TIMES

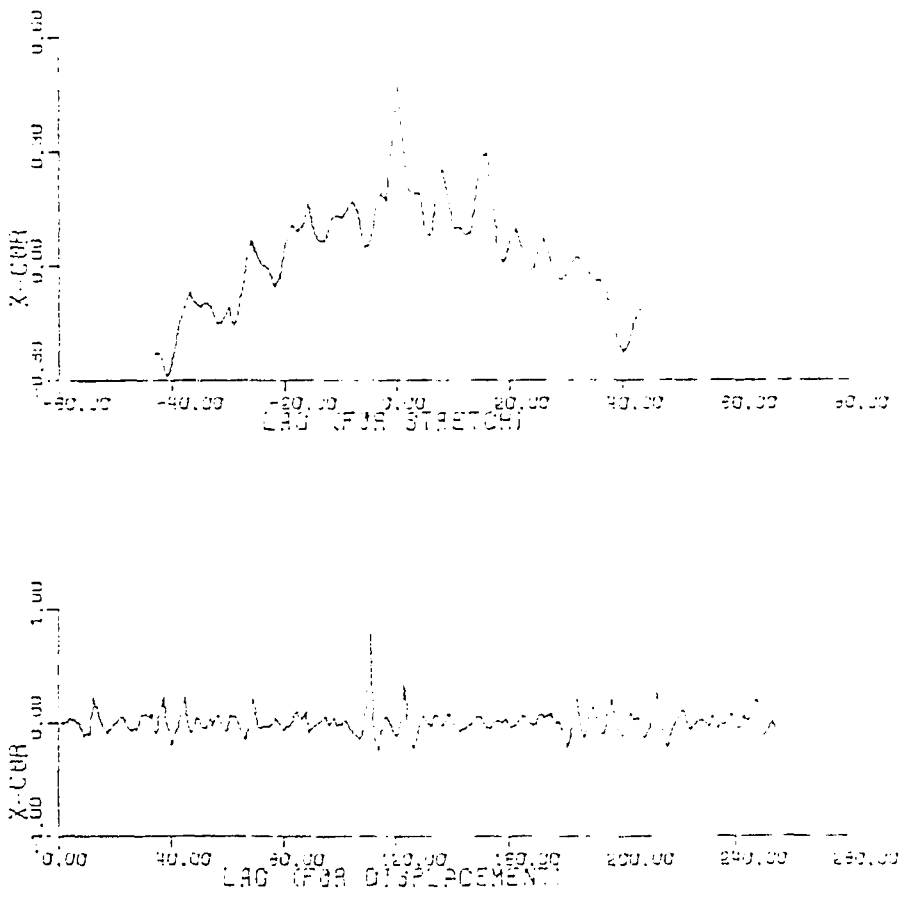


Figure 36. Cont.

2. Automatic correlation of four resistivity logs: This procedure consists of visually establishing a lithostratigraphic unit at each well site, then correlating these units by the subprogram COR4WELL. The resistivity logs (Figure 37) are digitized at two foot intervals. The long logs (long segments or windows) are plotted at a vertical scale equal to the length of the segment divided by seven (7 in., the length of the vertical axis). The units of this axis are considered as a depth scale for plotting the short logs (short segments or windows). Several segments of various lengths from logs A and C are cross-correlated with logs B and D (refer to Figures 4 and 29) and vice versa until the maximum value of the correlation function is reached. However, this procedure consumes a considerable amount of time in case there are more than four logs to correlate.

The last step in this procedure is the initiation of the two-dimensional cross section that symbolizes the subsurface structure in the prospecting area (Figure 36).

3. The final procedure in the BASEL algorithm is to convert the cross section thus obtained to a three-dimensional configuration.

Discussion of the Results

1. Structure map. The parallelism encountered in the contrast between the structure map in Figure 36 and that of Figure 38 demonstrates the accuracy of the subroutine SYMAP and the program CONTOUR.

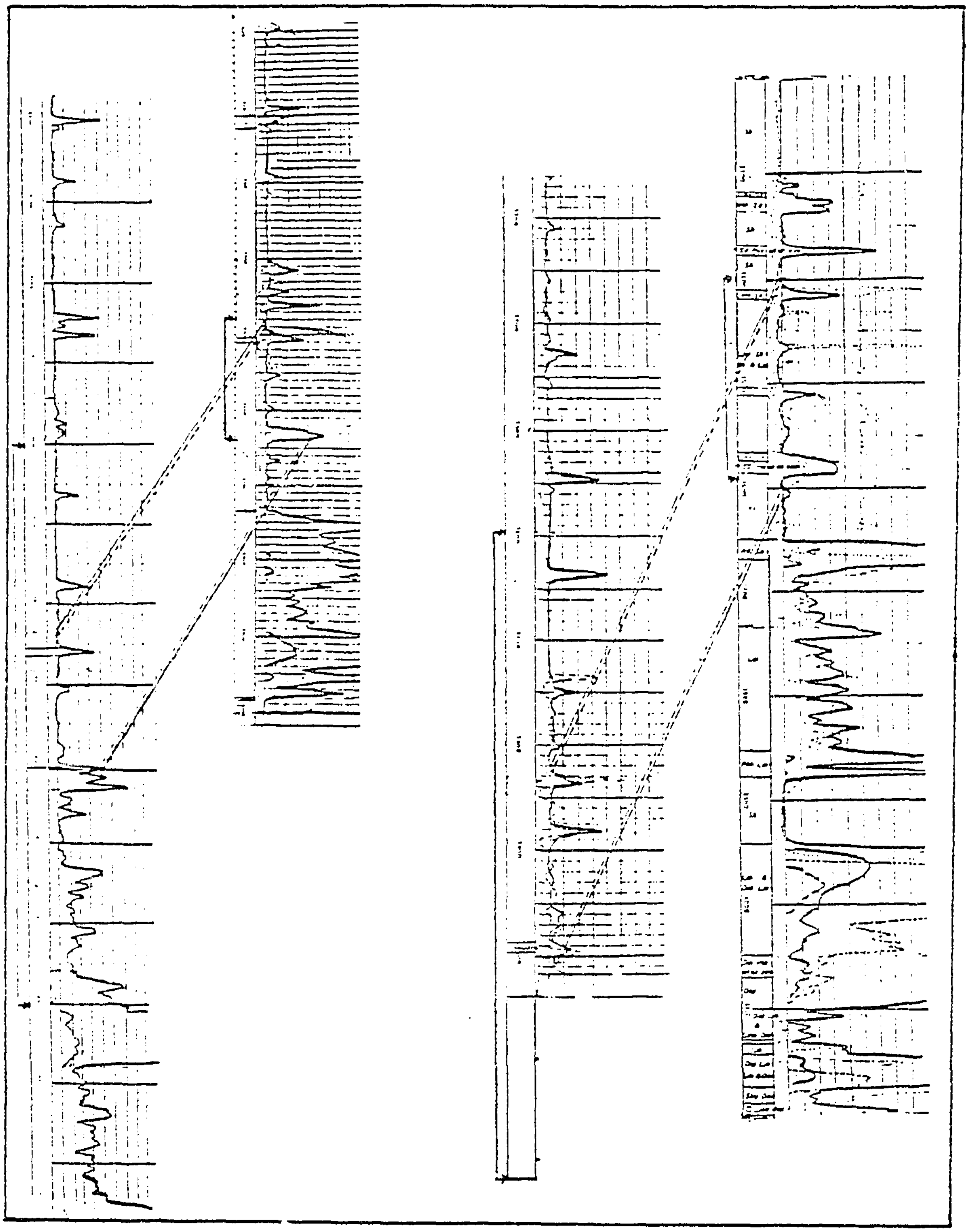


Figure 37. Resistivity logs from St. Louis Oil Field, Pottawatomi County, Oklahoma. Dashed lines indicate visual correlation while solid lines imply computer correlation. Arrows indicate the boundaries of windows (segment) used in automatic correlation.

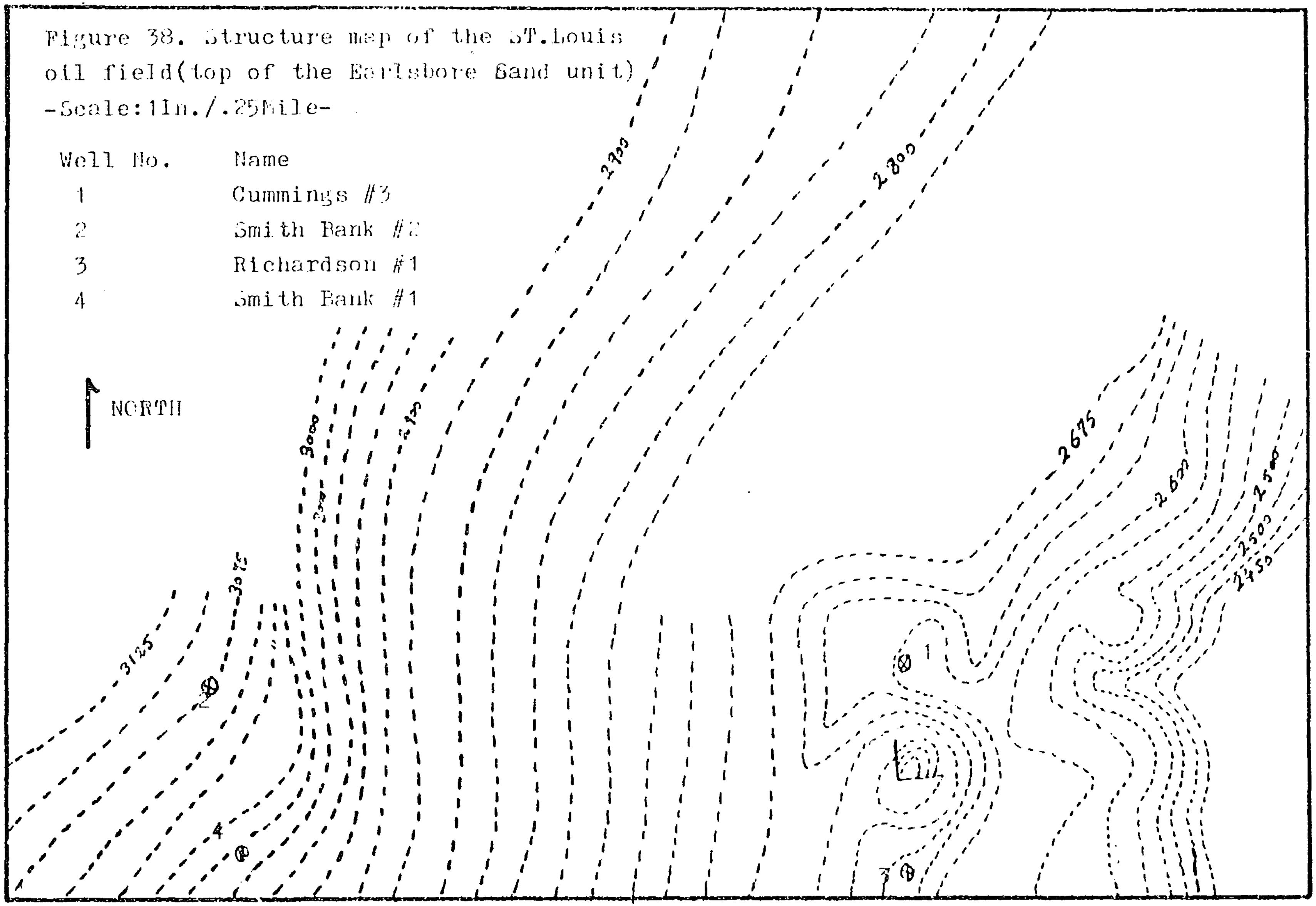


Figure 38. Structure map of the ST.Louis oil field(top of the Earlsbore Sand unit) -Scale:1In./.25Mile-

2. Cross-section. The program illustrated excellent success in correlating the four resistivity logs. In Figure 37, the computer correlation (continuous lines) matches the geological correlation (dashed lines) very well. Also, the slope of the beds corresponds to the inclination of the correlated segments in Figure 36. Finally, the subsurface structure of the investigation site in Figures 39 and 40 is similar to the structure illustrated in Figure 36-C and D.

3. The sinkhole-shape features on the three-dimensional configuration of Figure 36-B (marked by *) may indicate graben structures (blocks that have been down-thrown along faults) or tight synclines.

Analysis of Gamma Logs from North Dakota

Objectives of the Analysis

The goal of this investigation is similar to that discussed in the previous section, that is, to inspect the lateral continuity of the coal beds, the structure, and the configuration of these beds.

Description of the Study Area

1. Location. The site of investigation is in the drainage basin of the Knife River, the Falkirk (Underwood) and center areas of McLean and Oliver counties (Figure 41).

2. Geologic setting. The sedimentary column in the study area consists of 11,000-14,000 feet (3,300-4,200 m)

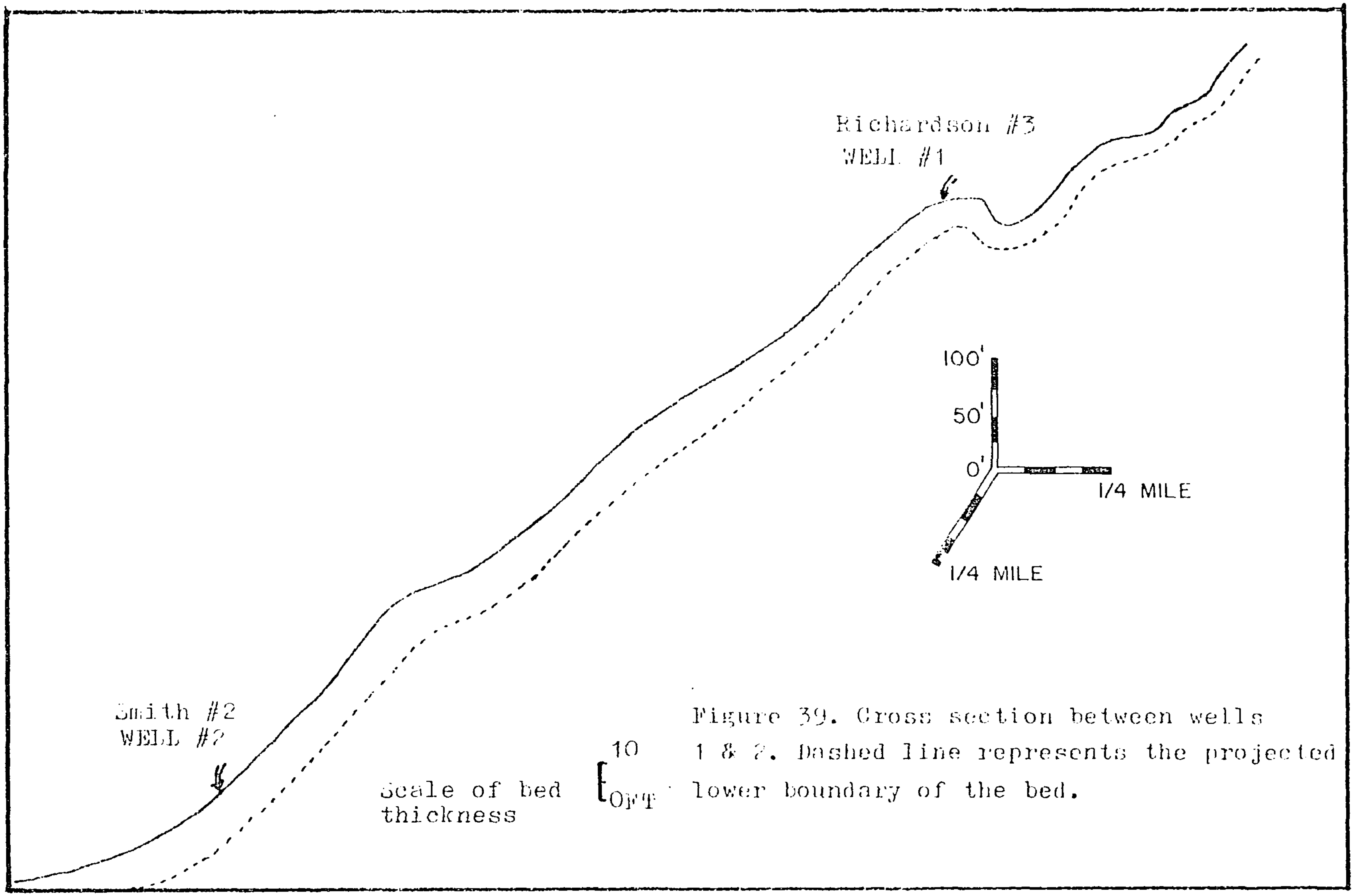


Figure 39. Cross section between wells 1 & 2. Dashed line represents the projected lower boundary of the bed.

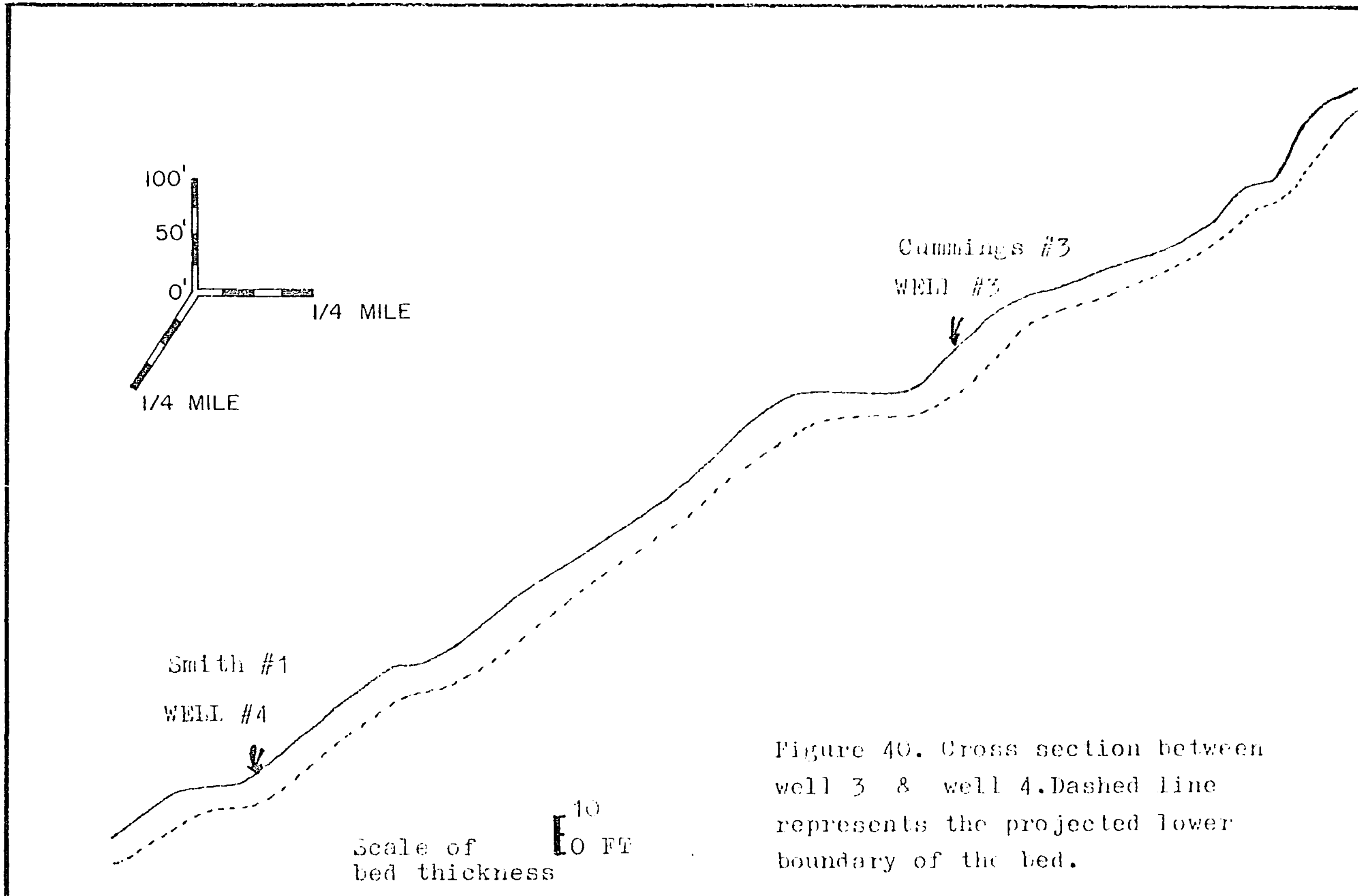


Figure 40. Cross section between well 3 & well 4. Dashed line represents the projected lower boundary of the bed.

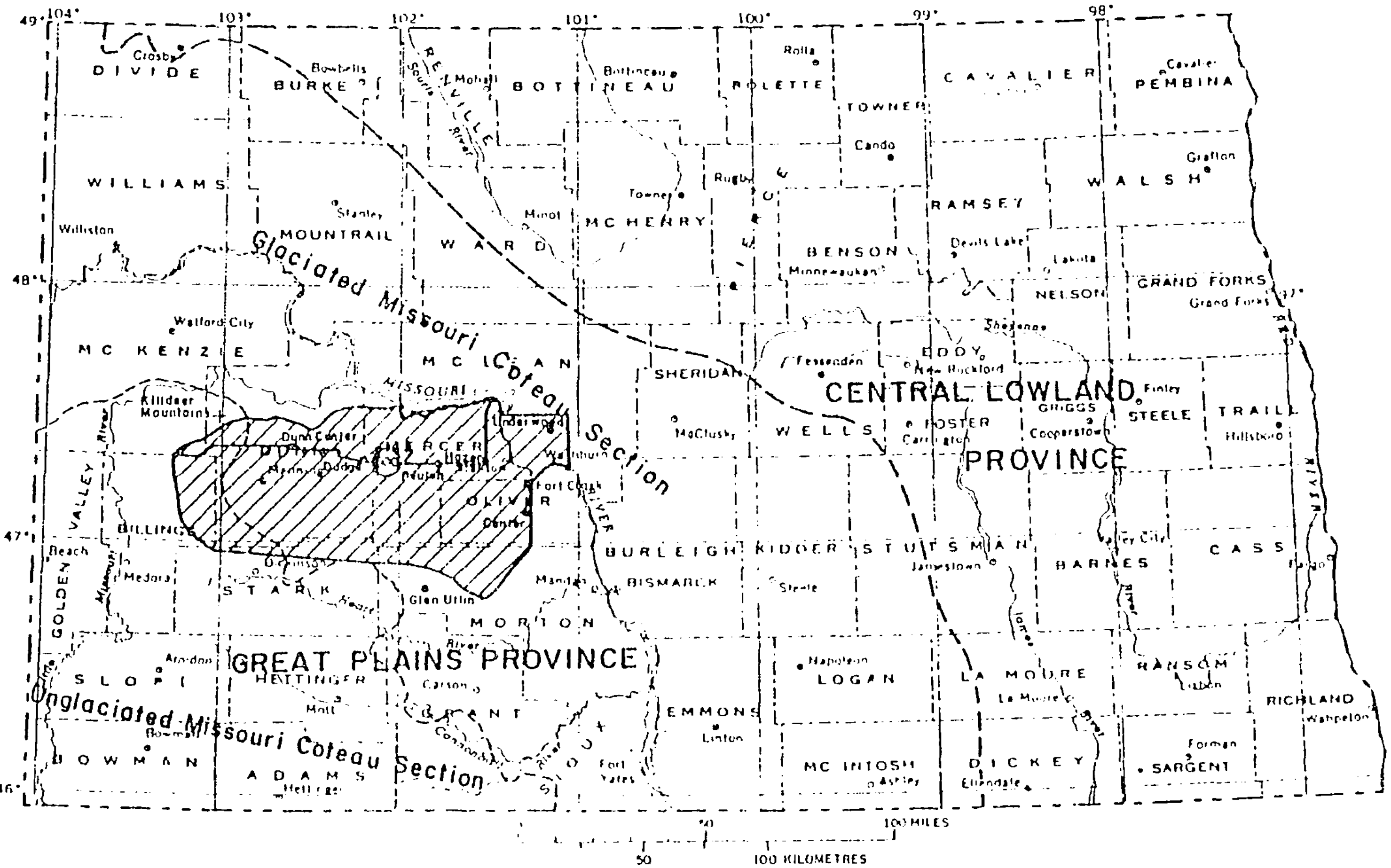


Figure 41. Location of the investigation site in North Dakota

of sedimentary rocks ranging from Quaternary to Cambrian. There are eight major coal zones of variable thickness and number of coal seams. Two zones are considered in this analysis, Kinneman Creek Bed and Hagel Bed, because of their lateral continuity in the study area and their appearance on all the gamma logs employed in this study.

Analysis Methodology

1A. Automatic drawing of the structure map on top of the Kinneman Creek Bed: The control points are deduced from 41 wells (Table 2) drilled in the site of investigation by the North Dakota Geological Survey (Groenewold and Hemish, 1979). The structure map drawn on top of the Kinneman Creek coal bed is shown in Figure 42.

1B. Automatic drawing of the structure map on top of the Hagel coal bed: The same logs are used in this map. The output is illustrated in Figure 43.

2. Automatic correlation of four gamma logs: The lithostratigraphic units of each well are determined visually (Figure 44). The subprogram COR4WELL correlates these logs and generates the cross sections of the study area. These cross sections are shown in Figures 42 and 43 for the Kinneman Creek beds and the Hagel beds, respectively.

3. The configuration of the Kinneman Creek beds and the Hagel beds are shown in Figures 42 and 43, respectively.

Table 2. List of the gamma wells used in analyzing the structure and coal distribution in the Knife River Basin, North Dakota.

Well Name	Location	Cross Section
L-9	T143N-R86W	B-B'
NDSWC-3748	T143N-R86W	B-B'
HB-39	T144N-R87W	B-B'
Reap-13	T144N-R87W	B-B'
HB-82	T144N-R87W	B-B'
HB-83	T144N-R88W	B-B'
Reap-12	T144N-R88W	B-B'
M74-116	T144N-R88W	B-B'
NDSWC-3755	T144N-R88W	B-B'
M74-229	T144N-R87W	B-B'
M74-226	T144N-R87W	B-B'
L-12	T146N-R86W	C-C'
Reap-16	T146N-R86W	C-C'
Reap-9	T145N-R86W	C-C'
Reap-15	T145N-R86W	C-C'
M74-184	T145N-R86W	C-C'
M74-89	T145N-R87W	C-C'
M74-88	T145N-R87W	C-C'
M74-106	T145N-R87W	C-C'
Reap-8	T144N-R86W	C-C'
Reap-14	T144N-R87W	C-C'
HB-45	T144N-R86W	C-C'
HB-43	T144N-R86W	C-C'
HB-113	T144N-R86W	C-C'
NDSWC-3652	T144N-R87W	C-C'
Reap-4	T143N-R85W	C-C'
M74-184	T146N-R86W	D-D'
L-13	T146N-R87W	D-D'
M74-178	T146N-R87W	D-D'
M74-179	T146N-R88W	D-D'
B74-77	T146N-R88W	D-D'
M74-109	T145N-R88W	D-D'
M74-108	T145N-R88W	D-D'
M74-45	T145N-R88W	D-D'
B74-78	T145 -R88W	D-D'
M74-77	T145 -R88W	D-D'
M74-161	T145 -R882	D-D'

Table 2. (cont.)

Well Name	Location	Cross Section
L-12	T146N-R86W	K-K'
G-169 58	T146N-R87W	K-K'
M74-20	T146N-R87W	K-K'
M74-2	T146N-R87W	K-K'

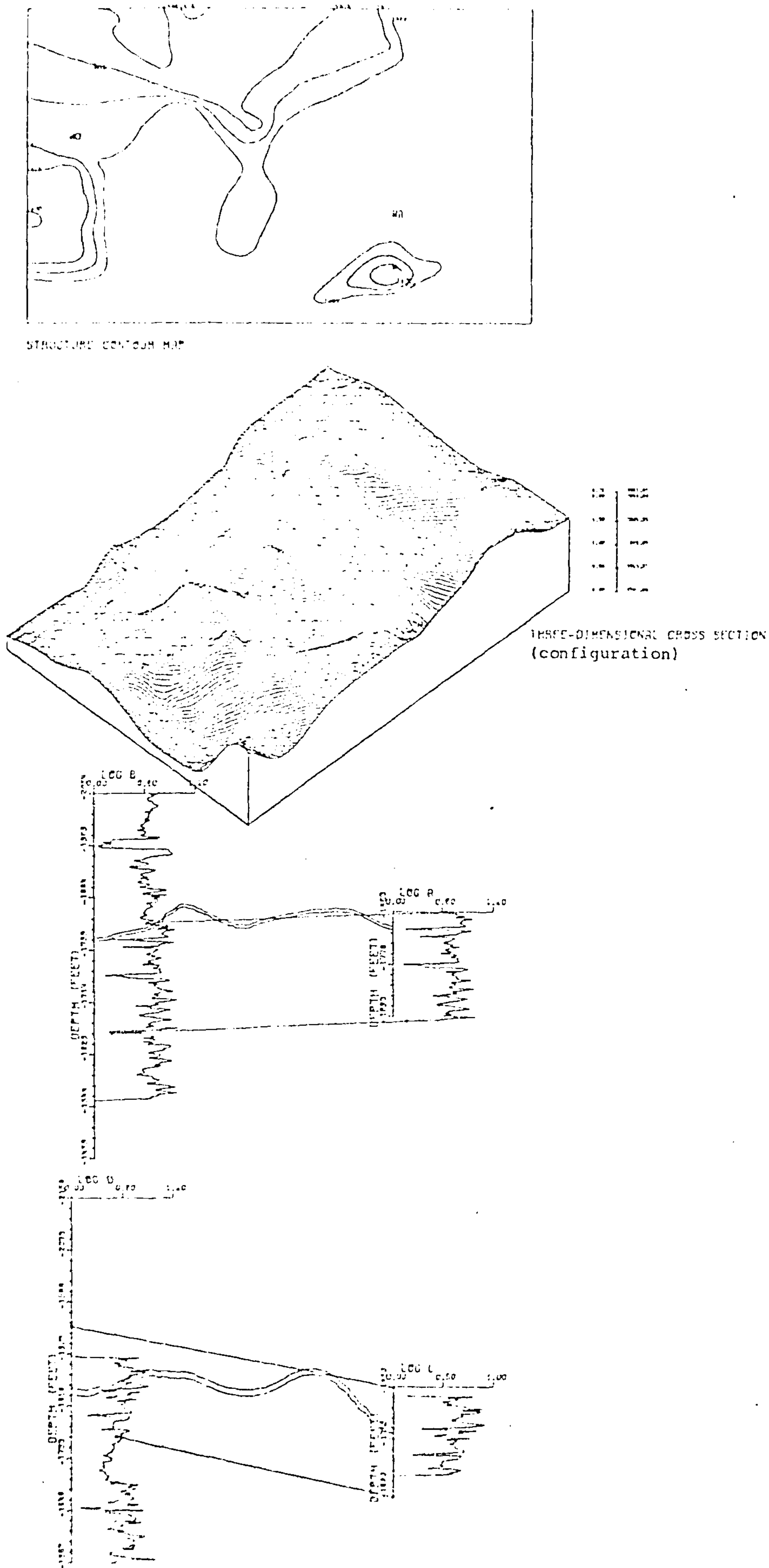
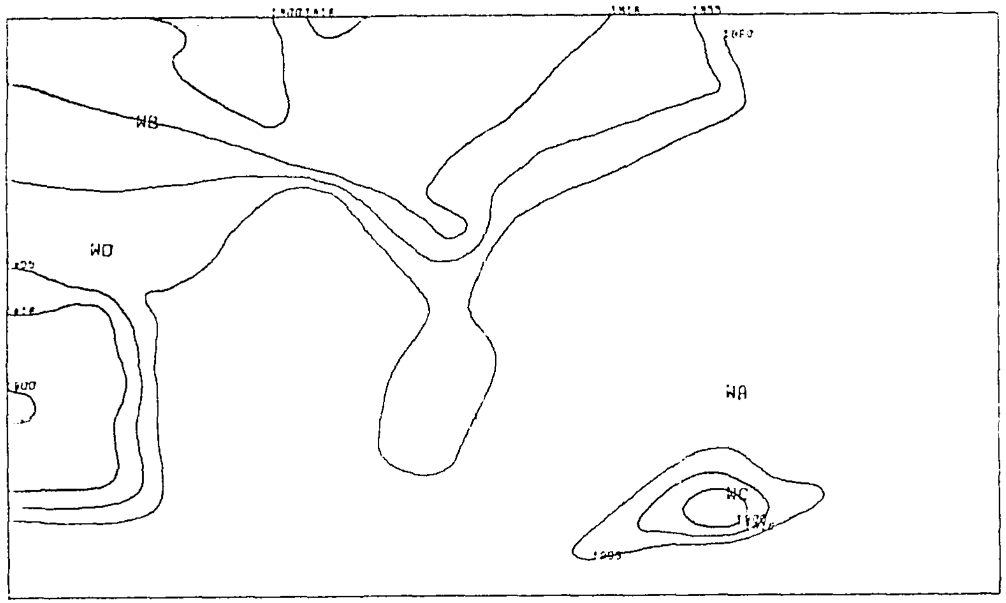
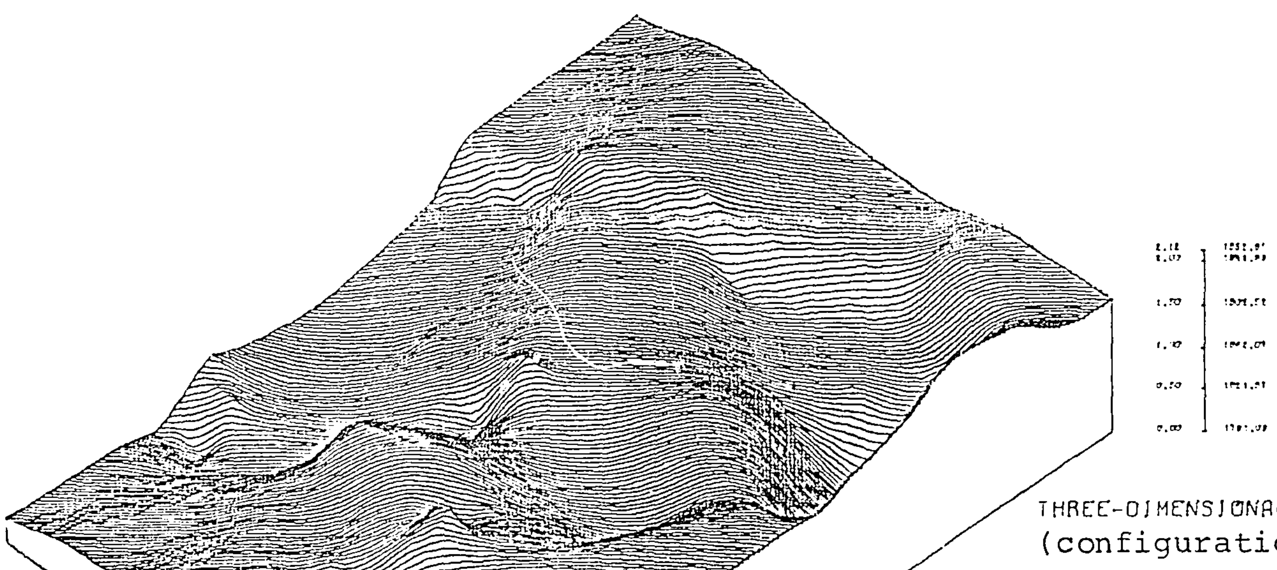


Figure 42. Calcomp output of FACEL program using gamma logs from Knife River Basin (Hanneman Creek coal bed), North Dakota.

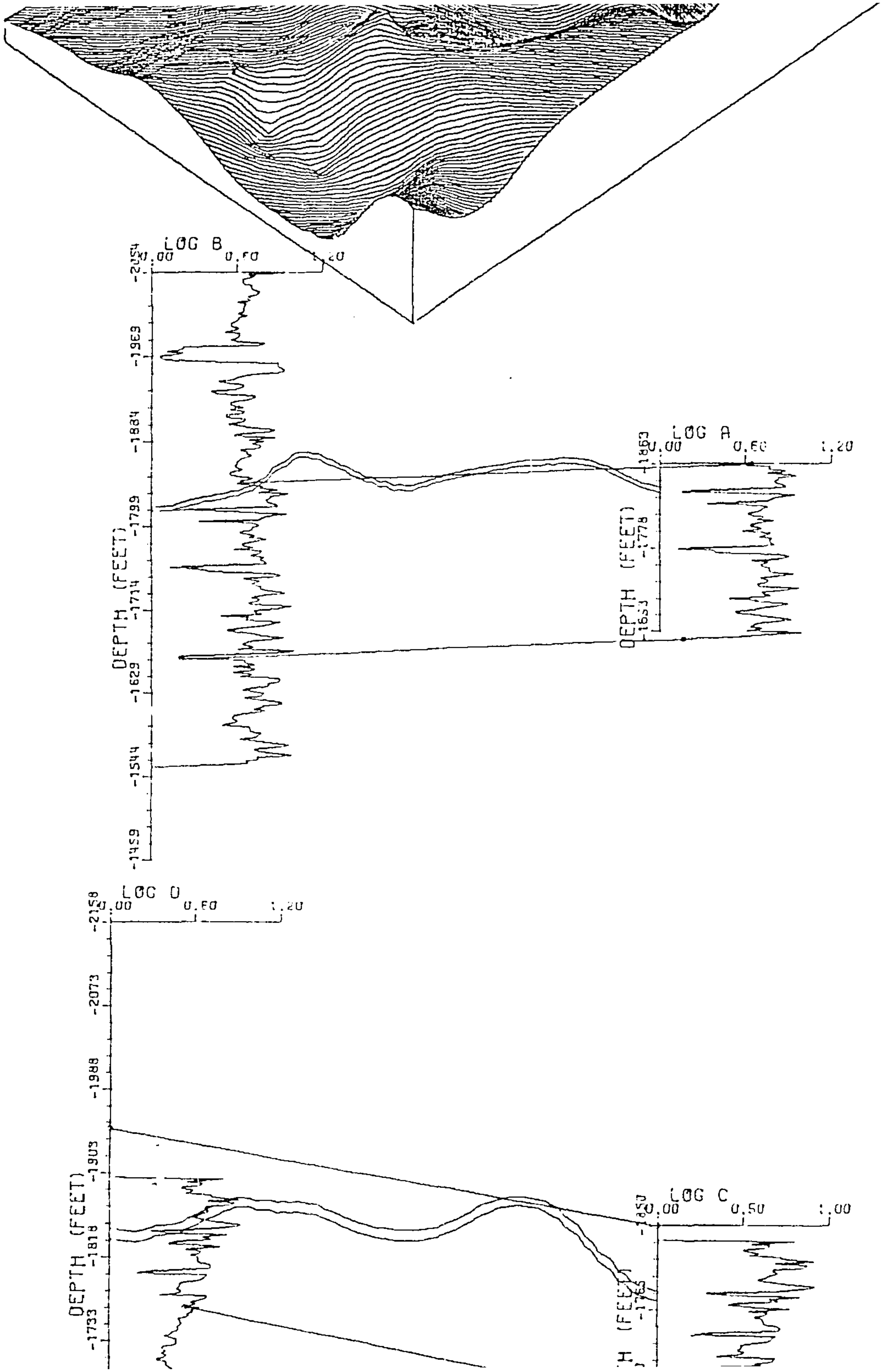


STRUCTURE CONTOUR MAP



THREE-DIMENSIONAL CROSS SECTION
(configuration)

THREE-DIMENSIONAL CROSS SECTION
(configuration)



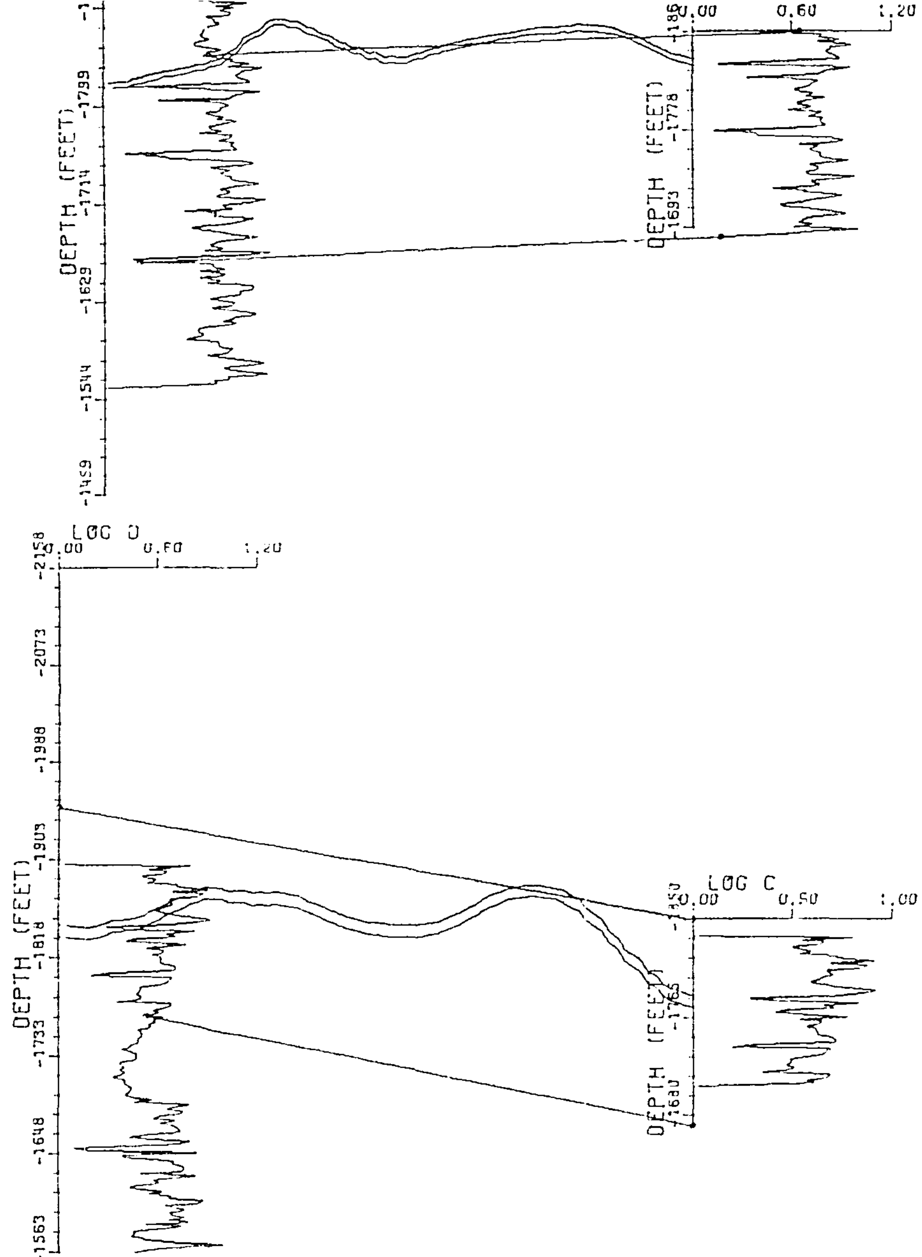


Figure 42. Calcomp output of BASEL program using gamma logs from Knife River Basin(Kinneman Creek coal bed), North Dakota.

GAMMA LOGS FROM NORTH DAKOTA

MAXIMUM CORRELATION IS 0.65

AT A LAG OF 106

WHEN LONG LOG IS STRETCHED 1.50 TIMES

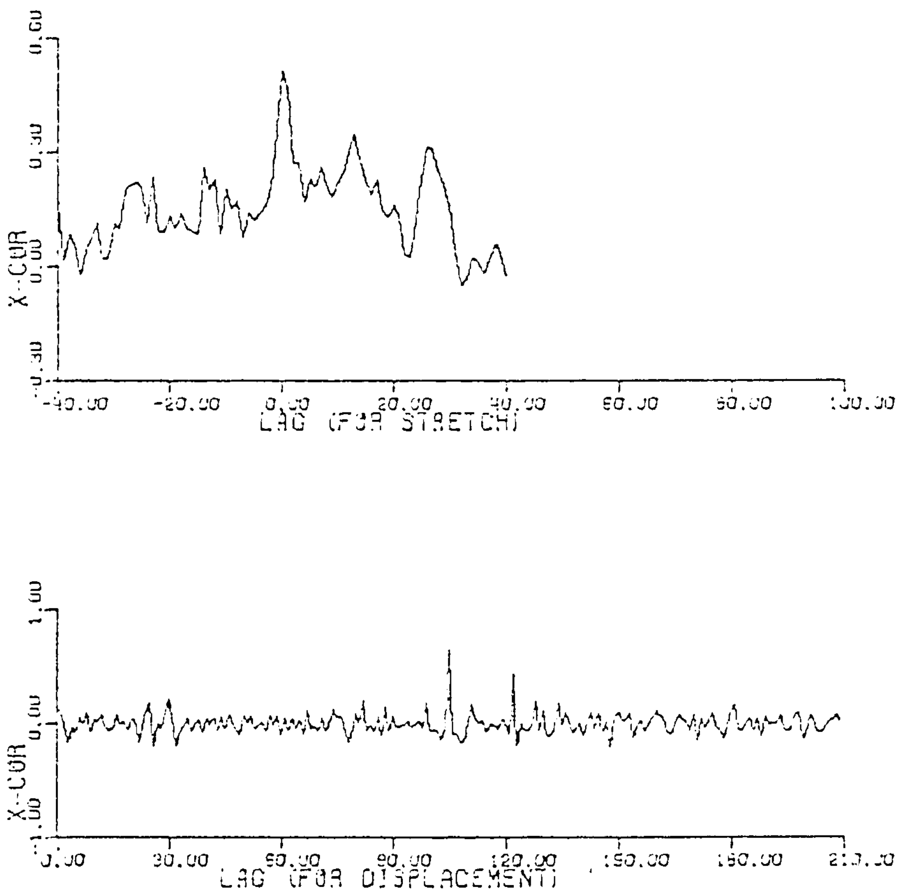
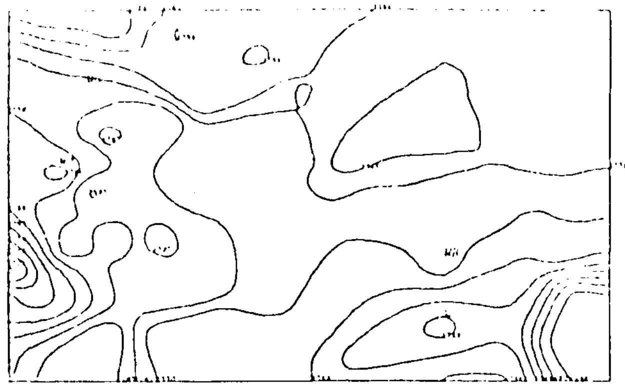
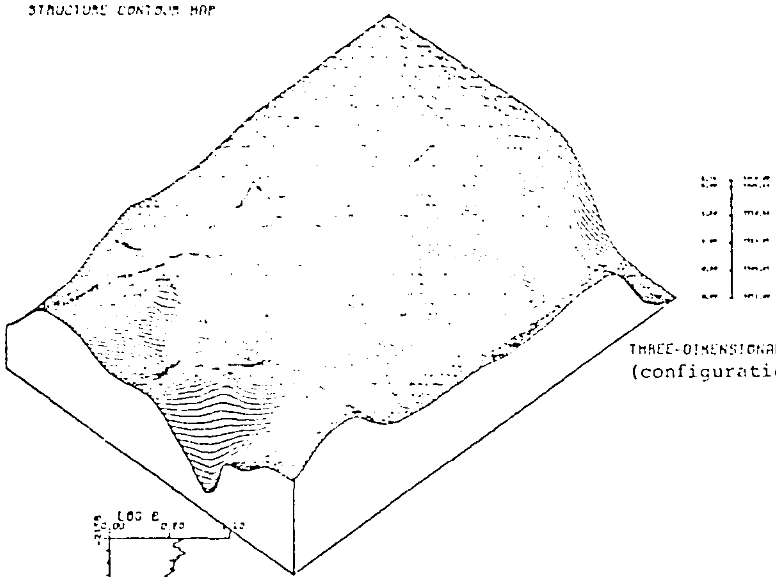


Figure 42. Cont.



STRUCTURE CONTOUR MAP



THREE-DIMENSIONAL CROSS SECTION
(configuration)

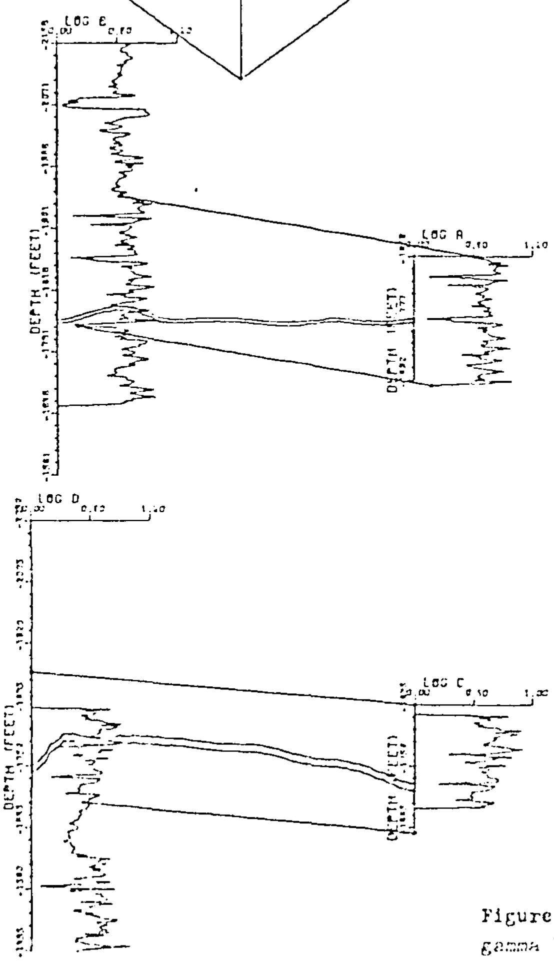
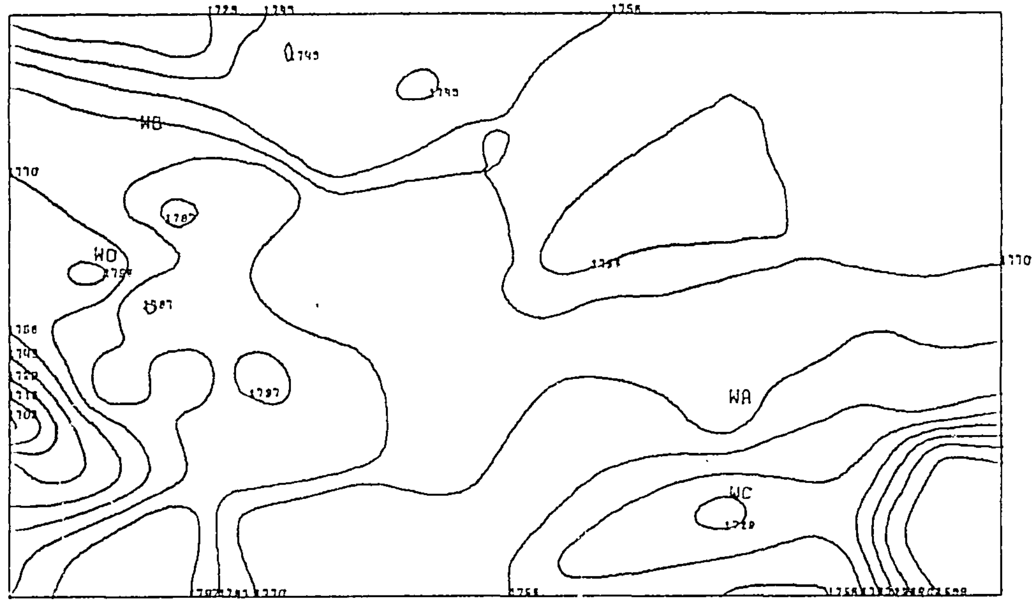
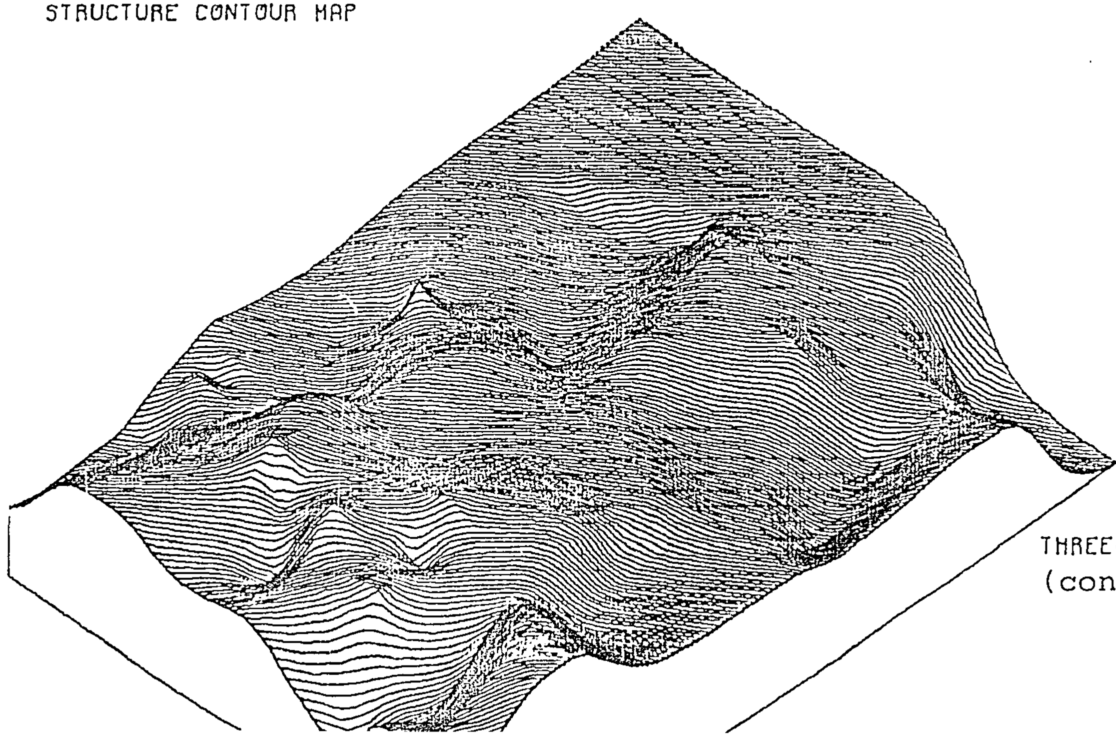


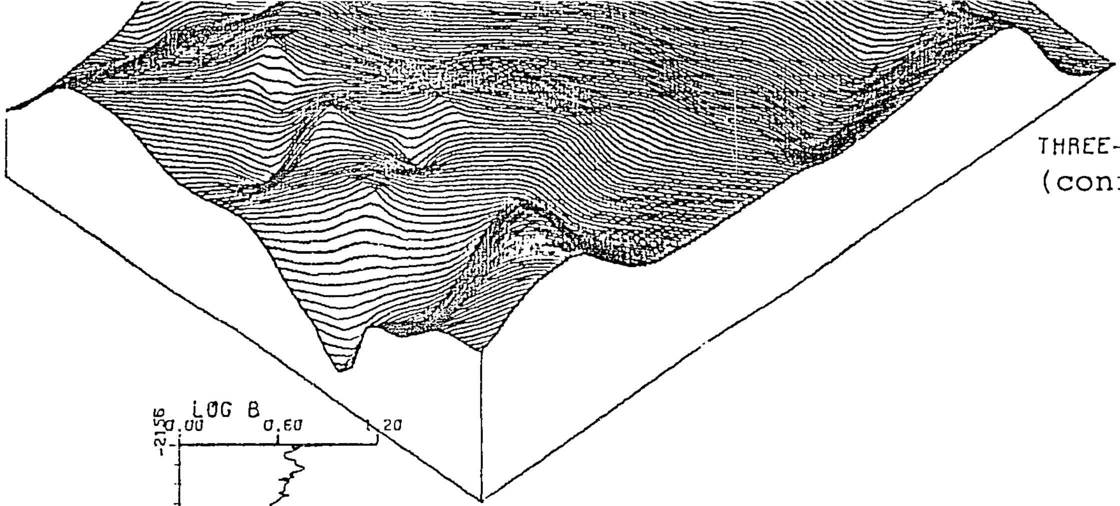
Figure 43. Calcomp output using gamma logs(Hagel coal bed) from Knife River Basin, North Dakota.



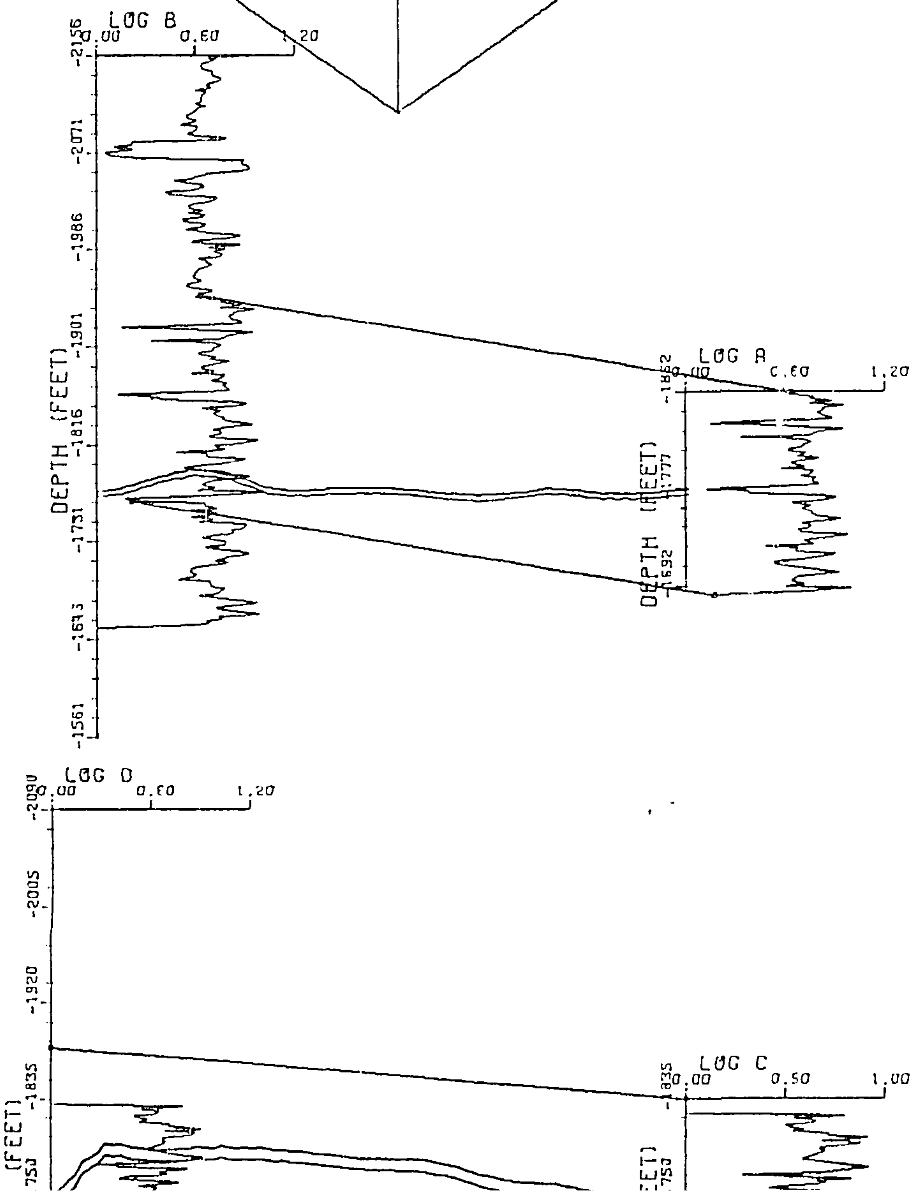
STRUCTURE CONTOUR MAP



THREE-DIMENSIONAL CROSS SECTION
(configuration)



THREE-DIMENSIONAL CROSS SECTION
(configuration)



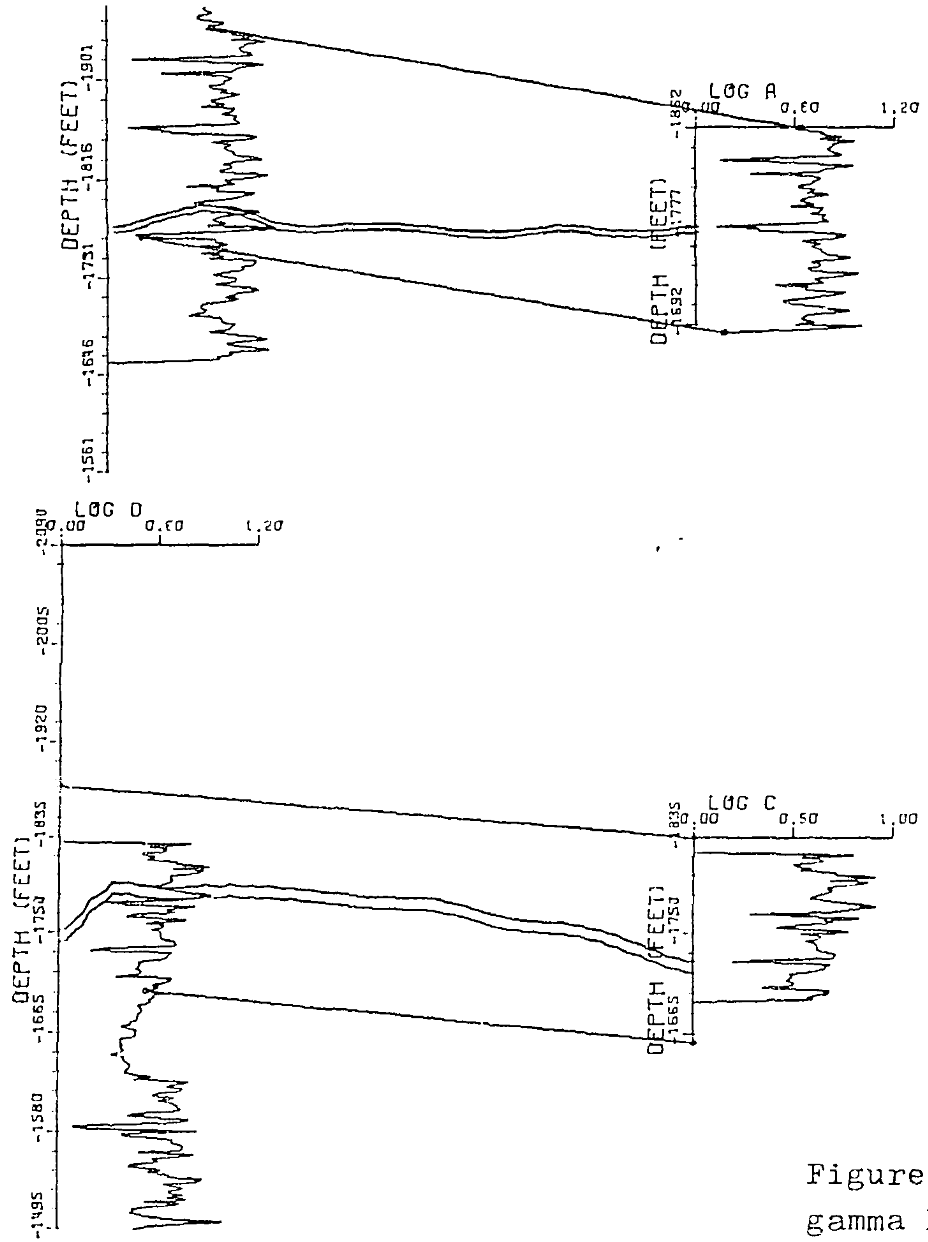


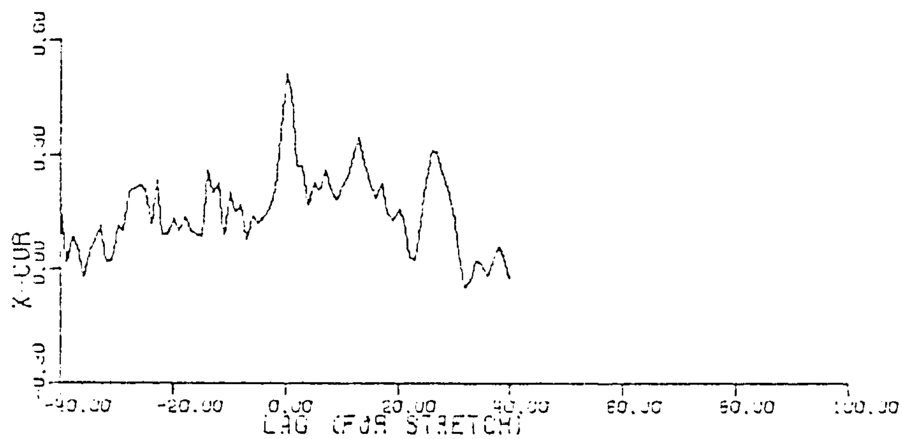
Figure 43. Calcomp output using gamma logs(Hagel coal bed) from Knife River Basin, North Dakota.

GAMMA LOGS FROM NORTH DAKOTA

MAXIMUM CORRELATION IS 0.65

AT A LAG OF 106

WHEN LONG LOG IS STRETCHED 1.50 TIMES



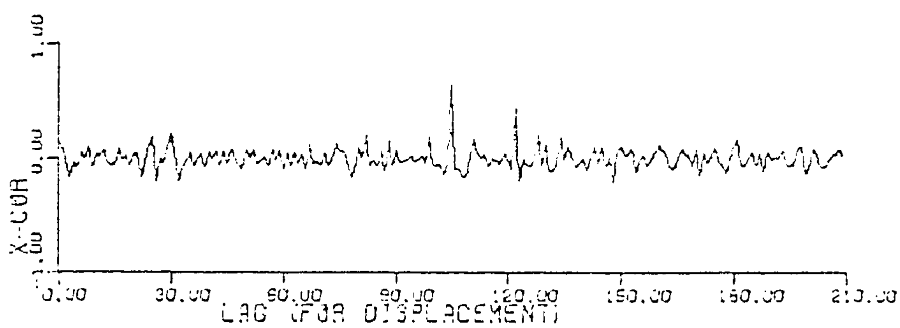


Figure 43. Cont.

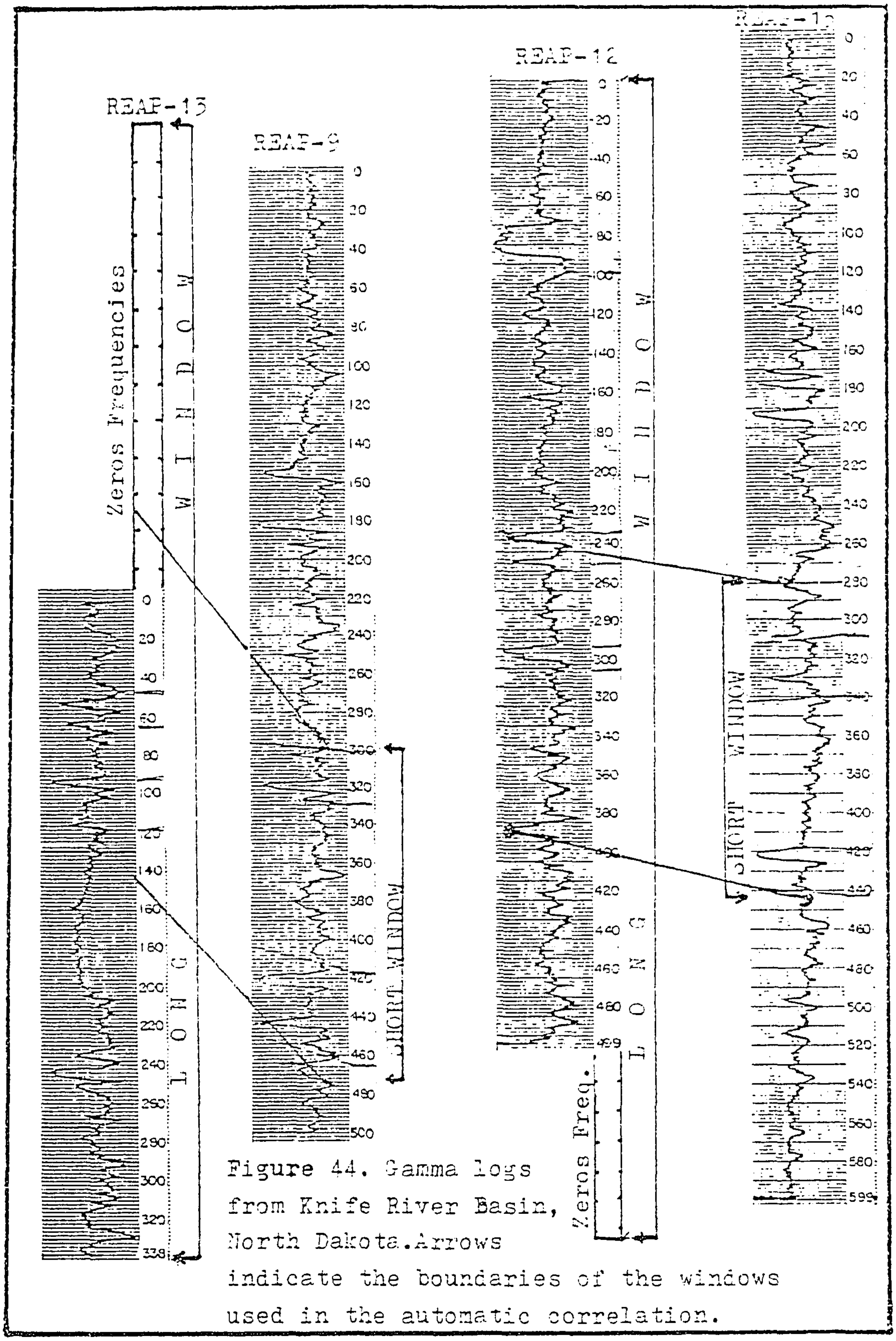


Figure 44. Gamma logs from Knife River Basin, North Dakota. Arrows indicate the boundaries of the windows used in the automatic correlation.

Discussion of Results

1. Structure map. Comparing the maps shown in Figures 42 and 43 with those indicated in Figures 45 and 46, one recognizes the similarity between the outputs of the automatic drawing and the conventional method.

2. Cross section. The cross sections established by the BASEL program (Figures 42 and 43) correspond to the cross sections provided by the conventional method (Figures 47 and 48) which prove the efficiency of the BASEL program in providing a rapid and accurate method of correlation and mapping of subsurface structures.

3. The cross-correlation provided by the subprogram COR4WELL is very much similar to that established by the conventional method.

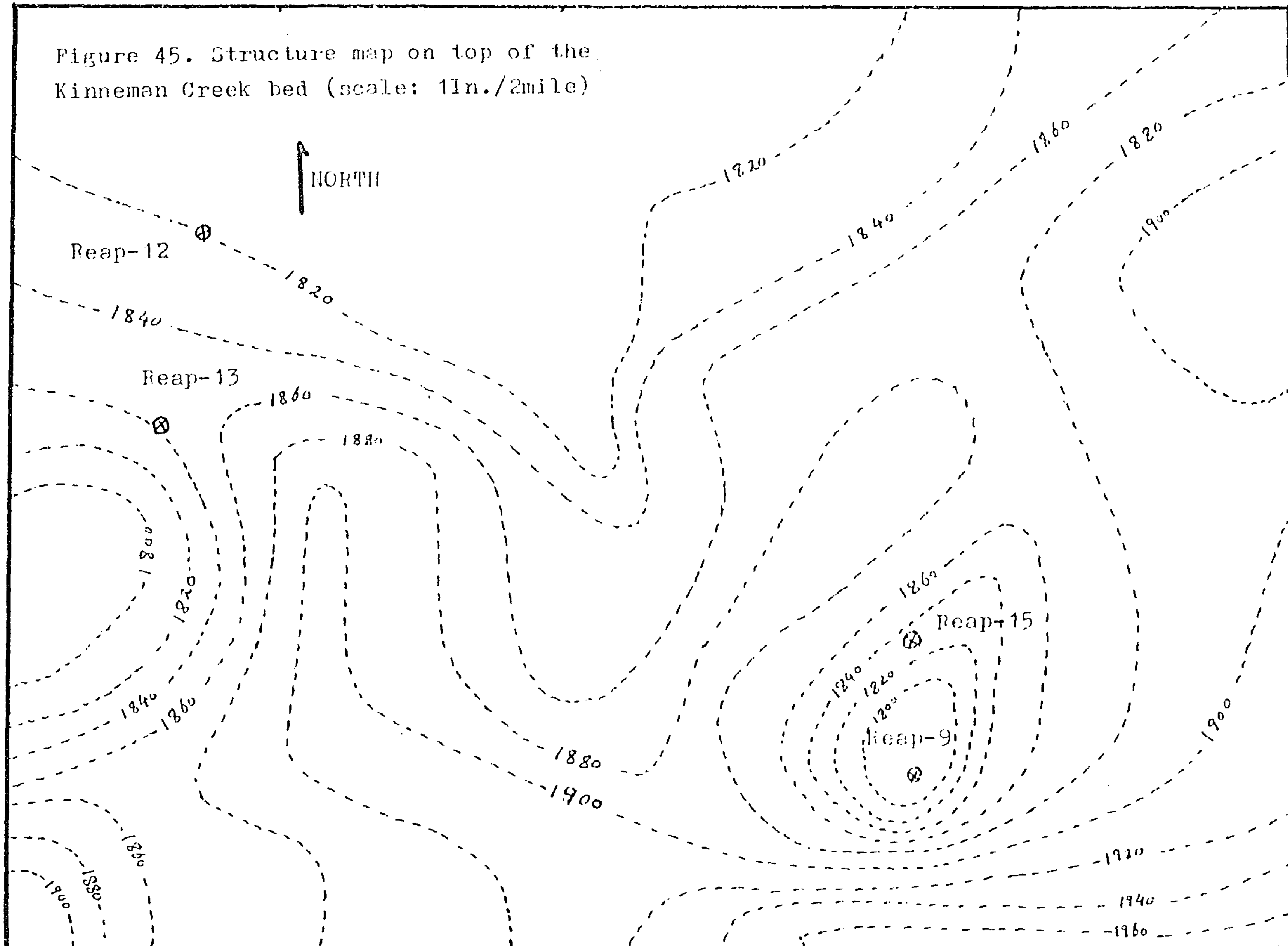
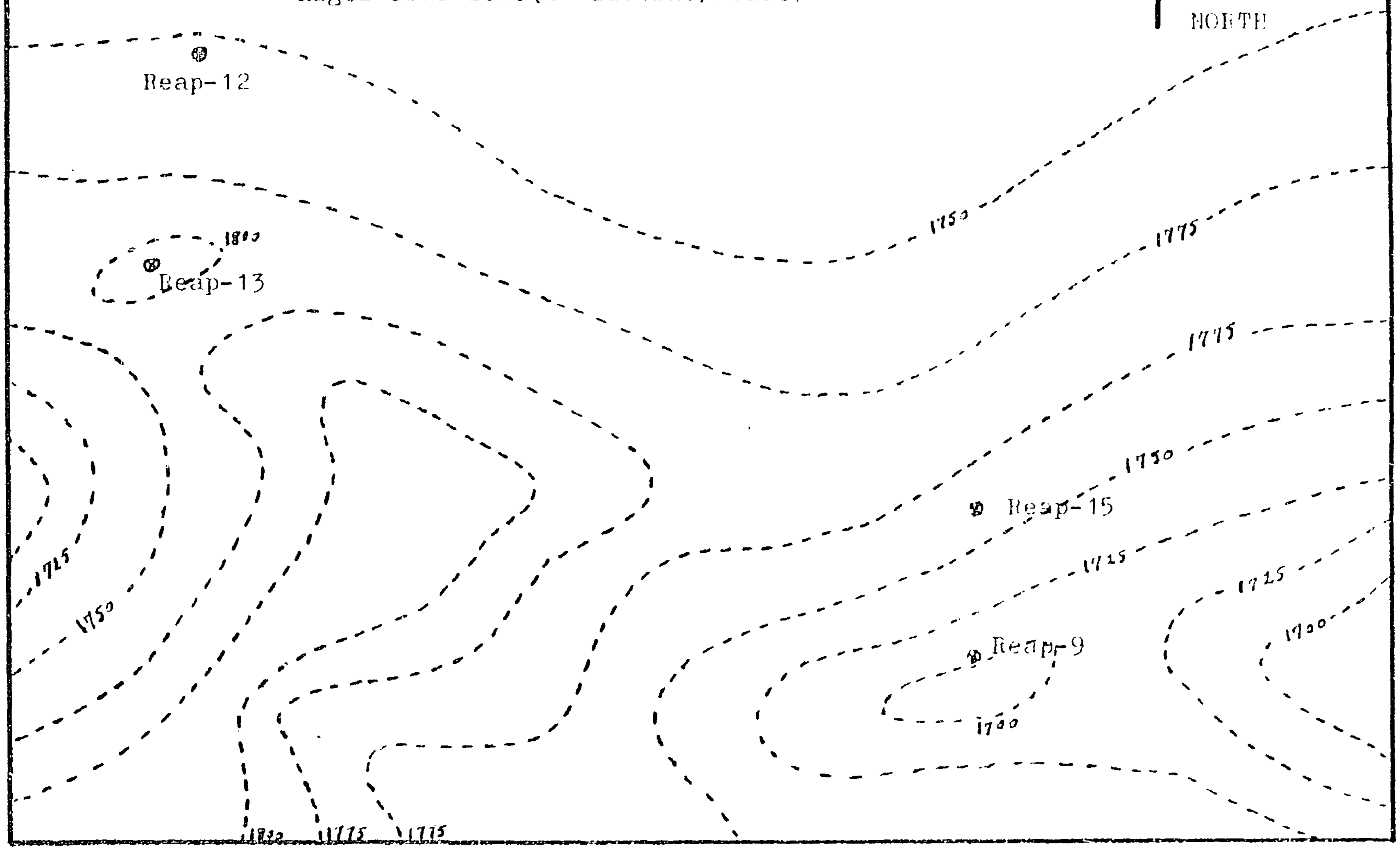


Figure 45. Structure map on top of the Kinneman Creek bed (scale: 1In./2mile)

Figure 46. Structure map on top of the Hagel coal bed.(scale:1in./2mile)



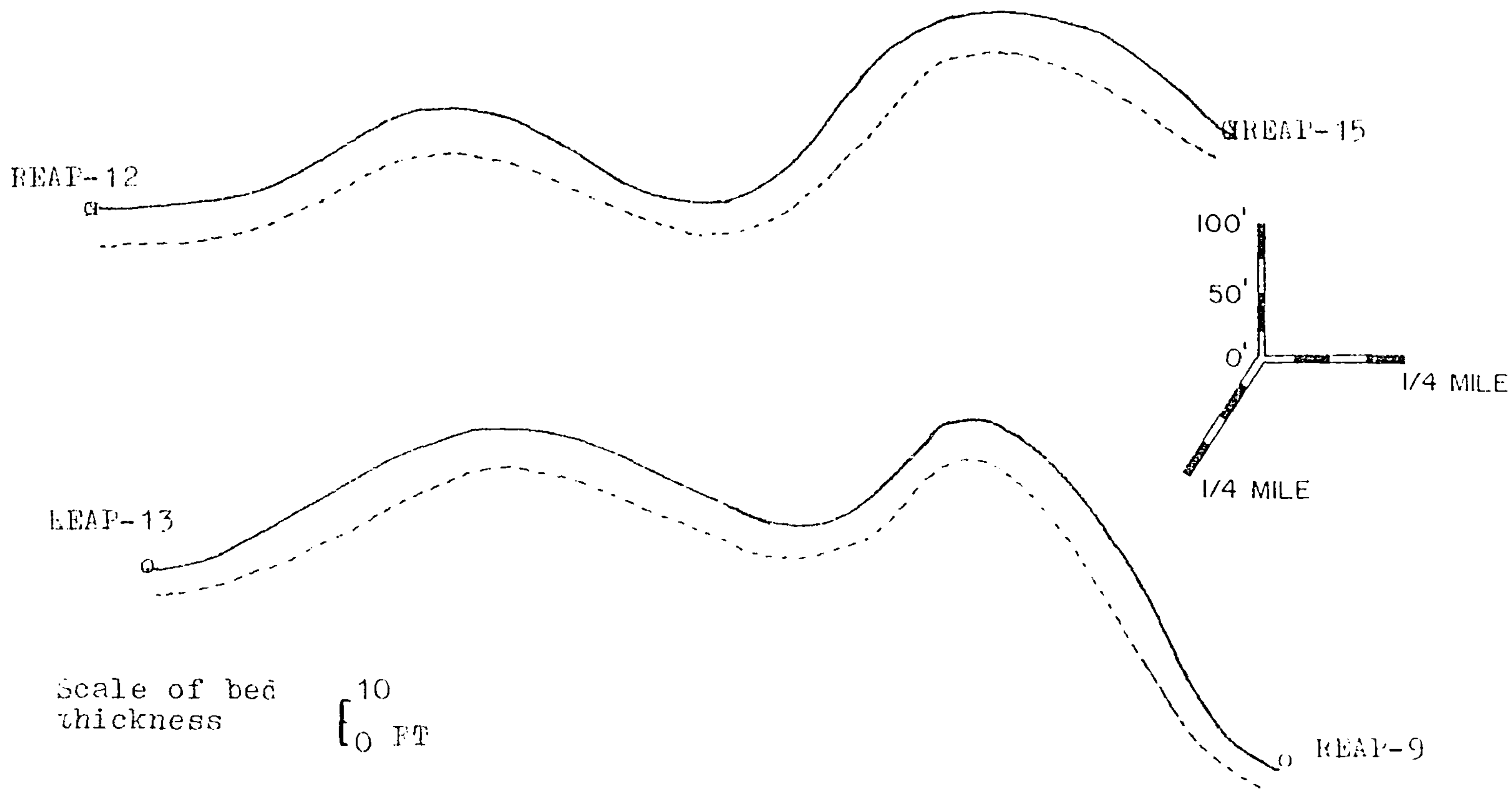


Figure 47. Cross section between wells 12 & 15 and 13 & 9. Dashed line represent the projected lower boundary of the correlated bed(refer to Fig.45), North Dakota.

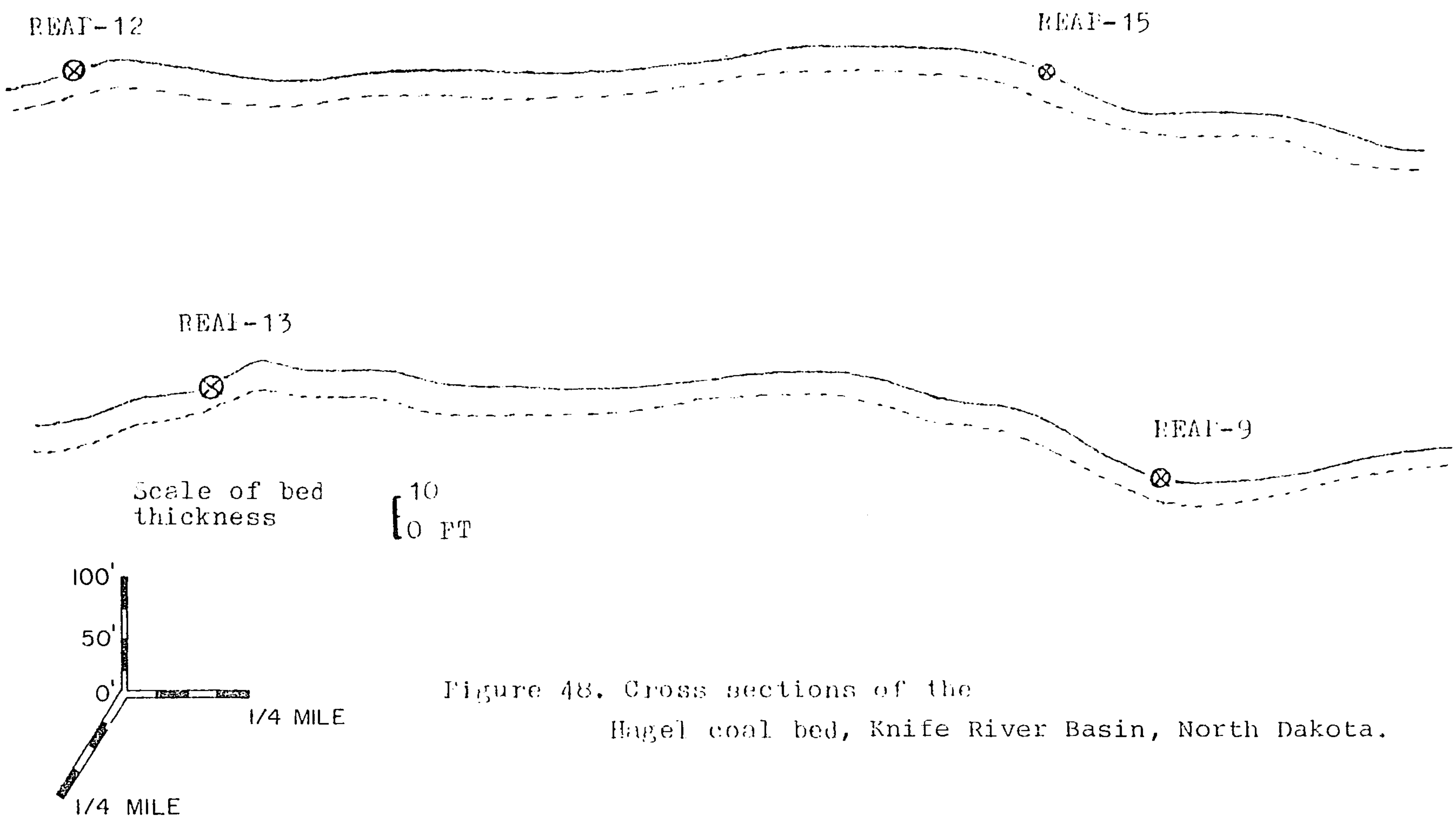


Figure 48. Cross sections of the Hagel coal bed, Knife River Basin, North Dakota.

CHAPTER IX

APPLICATION OF THIS RESEARCH TO THE EXPLORATION OF OIL, GAS, AND GEOTHERMAL ZONES

Quantitative lithostratigraphic correlation is of economic importance as a technique in the search for fossil fuels. Oil, gas, coal, and geothermal reservoirs occur in certain zones representing particular depositional environments and lithologies. The BASEL computer technique provides a tool for locating these critical zones. The algorithm thus forms the cornerstone for many theoretical and applied studies in exploration of petroleum reservoirs, locating coal seams, and deducing geothermal zones.

Application of BASEL Technique in Petroleum Exploration

Well logging technique is considered an important aspect of oil exploration and development programs. The implementation of the BASEL technique in these programs contributes a systematic and standard research tool that saves tremendous amounts of geologists' and engineers' time, in obtaining accurate results identical to those deduced by conventional methods.

The introduction of the three-dimensional display illustrates the configuration of the correlated reservoir bed or formation, thereby marking positions of synclines, anticlines, monoclines, erosional surfaces, and other structural features which are considered important in locating a drilling site. Simultaneous automatic correlation of four logs offers a rapid method for delineating the boundaries of the investigated formation under consideration, with the bedlines showing the structure of the correlated formation in two dimensions. This information is provided to geologists within a short time either by a computer plotter output or on a computer terminal screen.

Application of BASEL Technique in Coal and Mineral Exploration

Following the success of automatic lithostratigraphic correlation techniques in petroleum exploration, several government research centers as well as coal companies introduced these techniques in exploration programs.

The United States Bureau of Mines is involved in a number of projects to illustrate the capability of computer graphics techniques for engineering and management of coal mines (Smith, 1976). The Office of Coal Research, together with the United States Bureau of Mines, supports research that furnishes computer algorithms. These computer programs are made accessible to the mining industry (Manuel, et al., 1974, Office of Coal Research, 1975).

The United States Geological Survey has implemented computer and interactive computer graphics systems in the search for coal reserves. The Survey established the computer-based National Coal Resources Data System, which supplies an extensive data base for coal resources information in the United States (Cargill and others, 1976) (Figure 49).

The contribution of the BASEL technique to coal exploration is confined to the automatic correlation of several types of logs such as gamma ray, density, neutron and others (Figure 50). The application of this technique extends to areas where coal is in the stratigraphic column with oil reservoirs either on land or off-shore (Figure 51). In the case of complicated coal formations (limited lateral extent, abrupt pinchout of coal bed), correlated logs should be located on a short distance in order to locate the boundaries of the seam (Figure 52).

Another application of the BASEL technique is its ability to demonstrate the structural configuration of coal seams. In order to display the distribution of the coal seam or ore body in a mine, several seams or zones are correlated to produce several three-dimensional configurations. These illustrations are stacked vertically to demonstrate a block diagram of a mine (Figures 53 and 54).

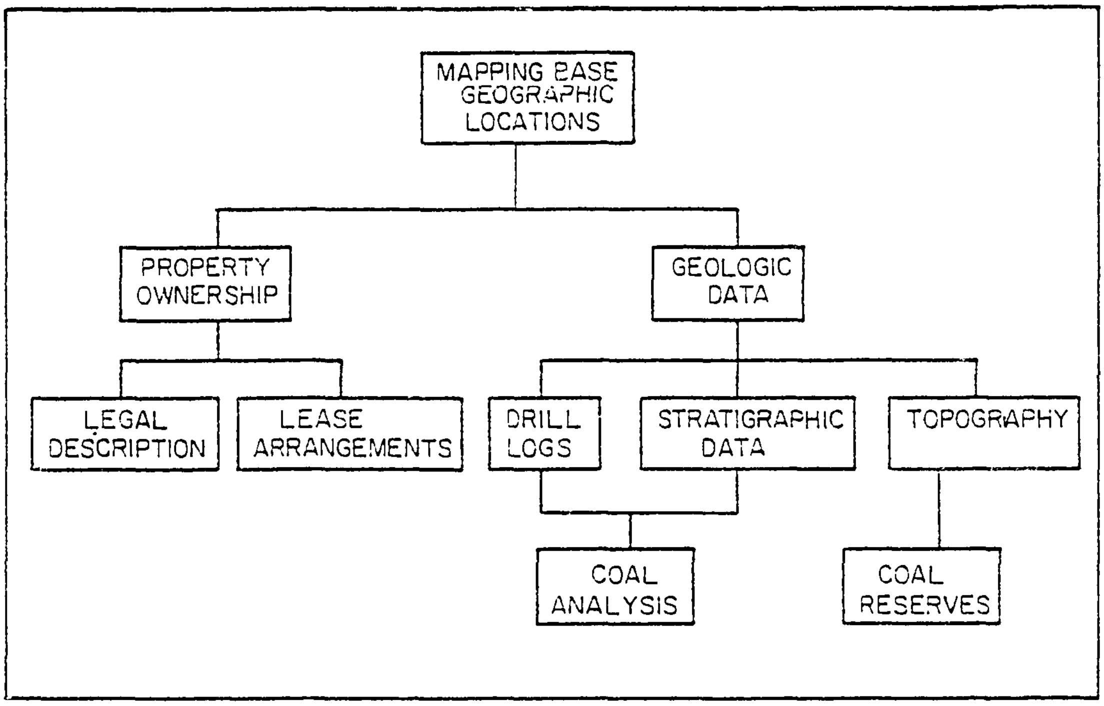


Figure 49. Block diagram of a coal data base (After Smith, 1976)

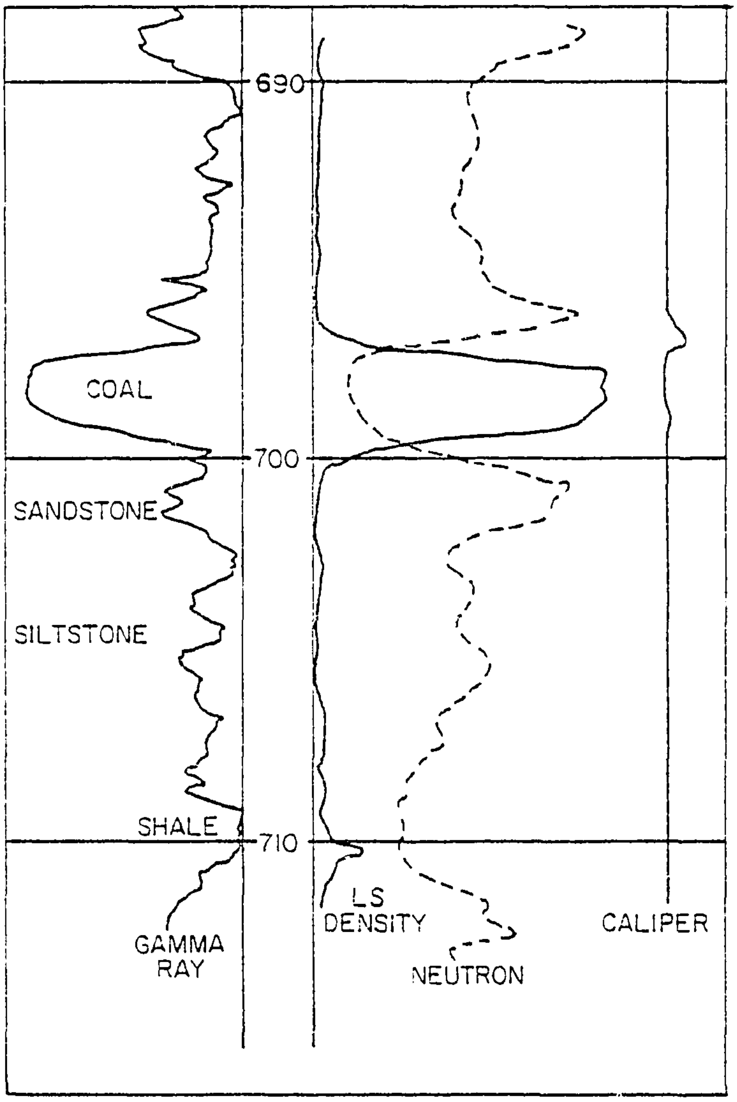


Figure 50. Four-log presentation on 100-1 scale suitable for identifying lithology, coal and for correlation (After Reeves, 1976).

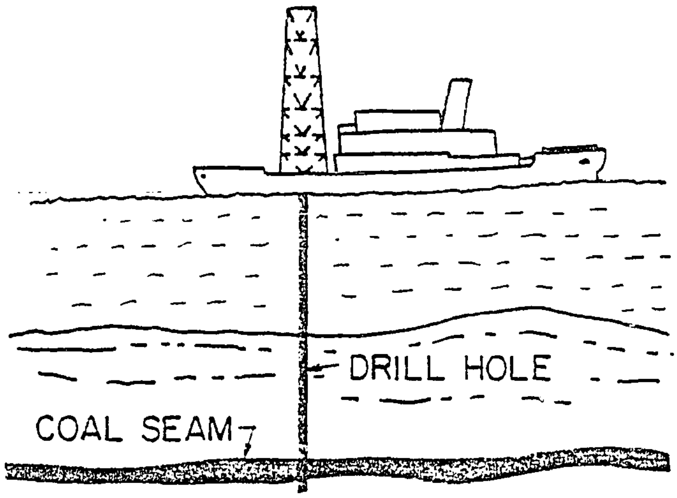


Figure 51. Cross-section of North Sea Offshore Coal Exploration and the use of the well logs systems (After Svendsen, 1976).

Vertical scale 1:1000
Horizontal scale none (avg hole distance = 1 km)

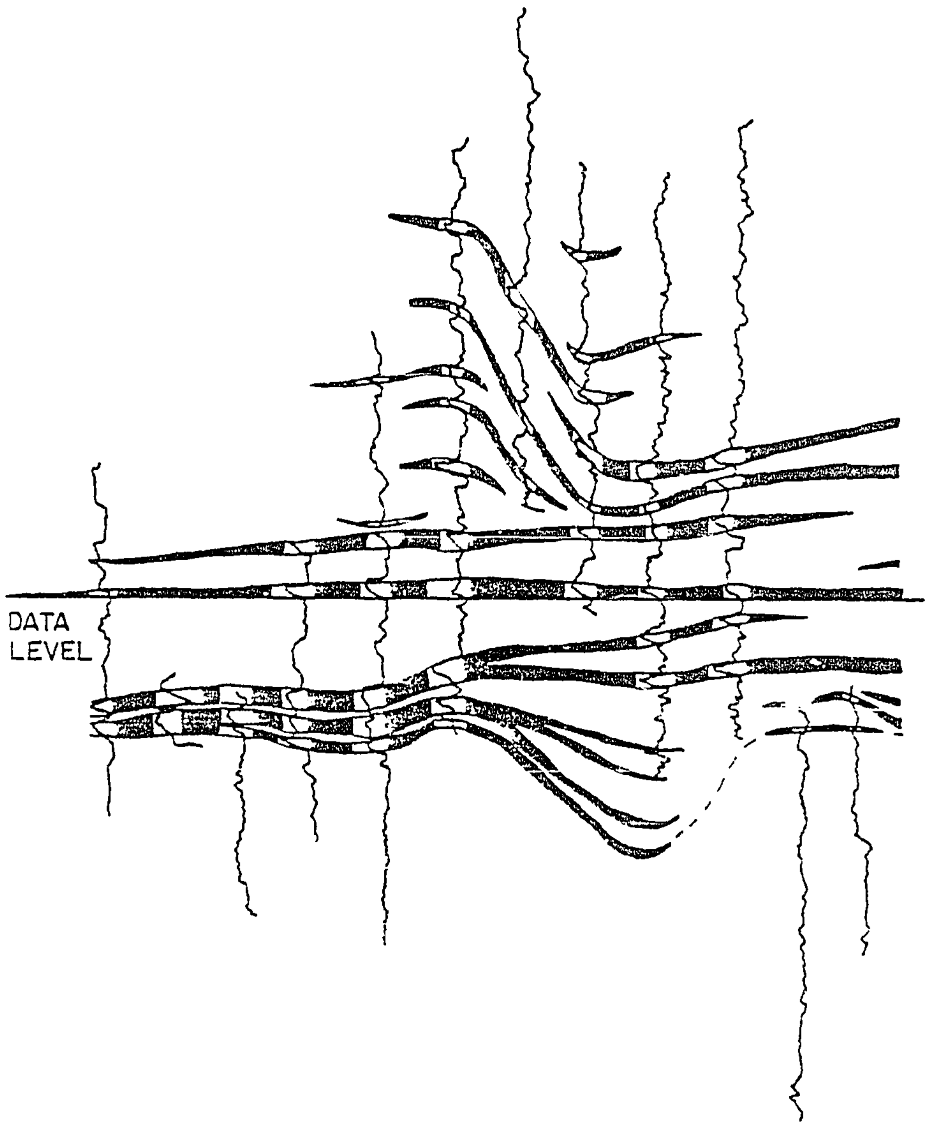


Figure 52. Example of log correlation in complicated coal formations (logs are lined up according to the data level indicated) (After Lavers and Smits, 1976).

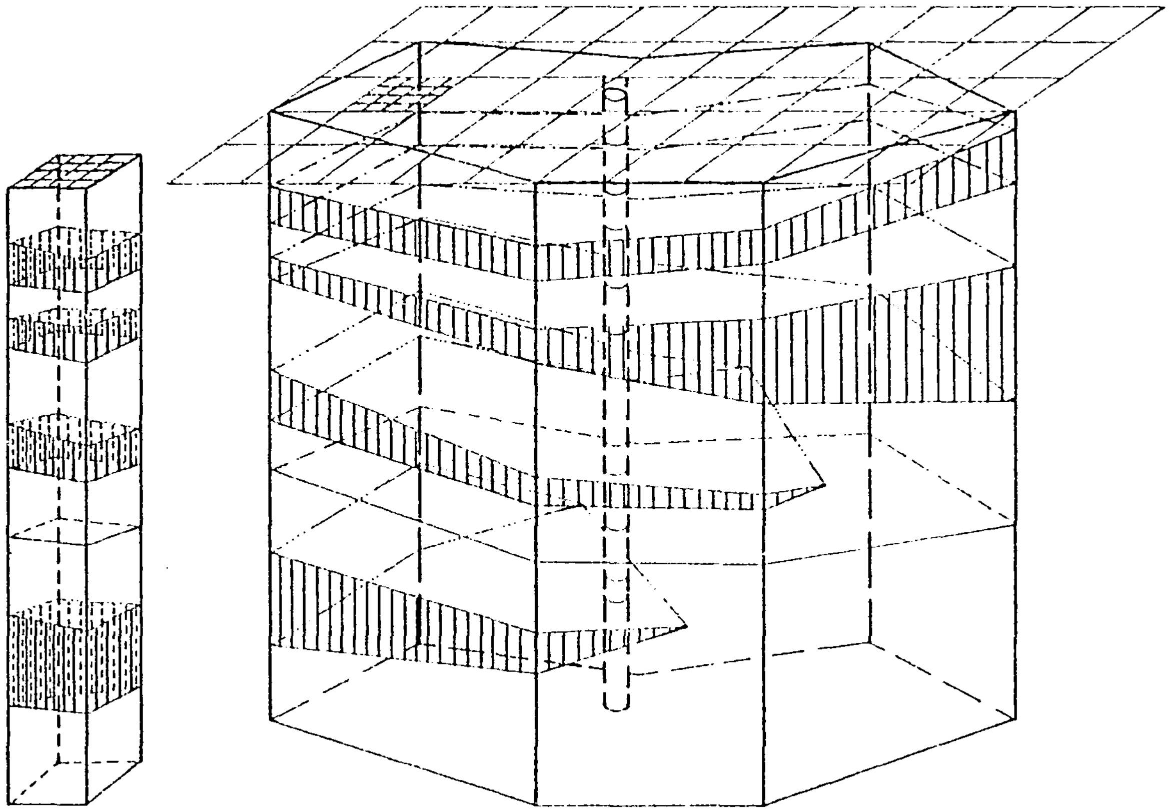


Figure 53. Schematic diagram showing the distribution of a lignite deposit model with four seams. The central borehole represents the mine shaft (Modified after Noigt, 1976).

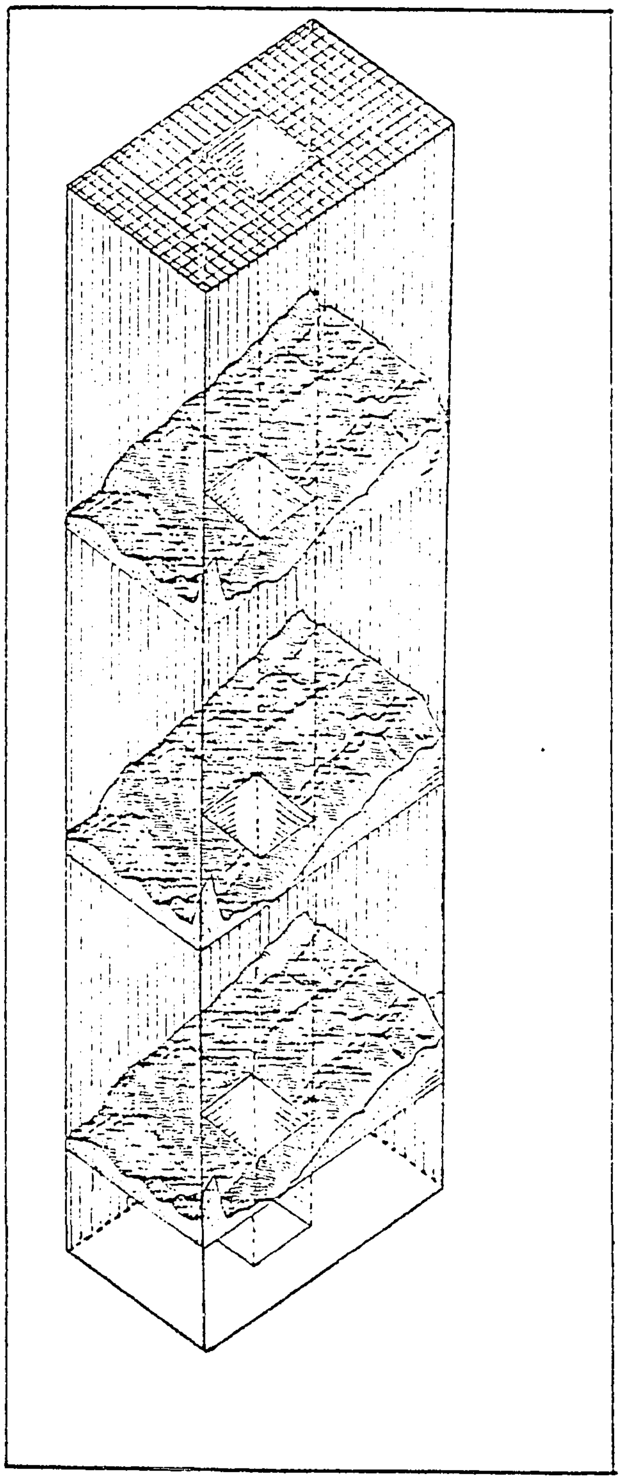


Figure 54. Block diagram showing the configuration of three coal beds. The central square represents a mining shaft.

Delineating Geothermal Zones

The introduction of well logging techniques to the exploration of geothermal zones is still in its early age. Ershaghi and others (1979) conducted a research in the Cerro Prieto Geothermal Field in Mexico to study the feasibility of utilizing well logging methods of interpretation to deduce geothermal zones.

In the BASEL method, correlation of spontaneous potential logs, SP, or deep induction logs, ILD, serves as a tool to locate hydrothermal zones.

CHAPTER X

DISCUSSION OF RESULTS

The applications of the BASEL computer model introduced in the previous chapters demonstrate the efficiency and effectiveness of this model in providing a detailed and descriptive method for the correlation of lithostratigraphic units and the prediction of subsurface structure in the study area.

The highlights of results obtained from the application of the BASEL program are described in this chapter.

A. Correlation of well logs: A reliable correlation of four well logs is accomplished if the four logs satisfy the following specifications.

1. Evaluation of logs for nonstationary (moving average) series: If one or more of the correlated logs are nonstationary, the maximum value of the correlation function $\phi(S,\tau)$ in Equation (32) may correspond to values of τ (displacement) and S (stretch) which do not correctly correlate the two series of each pair of logs. Therefore, the nonstationary series should be filtered before calculating their power spectra. For example, in the BASEL program without the subroutine DERIVA in the subprogram COR4WELL, an optional

elective to filter the original data in the case of nonstationary series, the correlation would not be correct.

2. It is essential in the BASEL algorithm to have the same number of points in the two short logs. The same applies for the long logs. However, this program could be modified to use unequal numbers of points. In this study, several numbers of input data points (various length of windows) were investigated. The results indicate that the length of the short logs are generally suitable if they have 1/4 to 1/3 of the number of data points of the long logs.

3. If the number of points for either the short or long logs is insufficient, the series may be lengthened by adding zeros before computing the power spectra. In this investigation, zero frequencies were added to lengthen the gamma logs (Figure 42, logs B, C, and D) and one of the resistivity logs (Figure 36, log B).

4. It is stated in Chapters IV and V that the magnitude of the correlation coefficient is between -1 and +1. The results obtained from this research indicate that:

a. If $\phi(S,\tau)$ is less than .30, then the correlation probably is not a geologic correlation.

b. If $\phi(S,\tau)$ is equal to or greater than .70, then the correlation is probably a geologic correlation (the detailed pictures are not included in the text because of space limits).

5. The manner in which the four logs are located (Figures 4 and 29) results in accurate plotting of the tie-

lines, the bed lines, the structure map, and the three-dimensional configuration.

6. The BASEL program will not accept logs of different types (gamma, resistivity, etc.), scale, or digitizing interval.

7. The BASEL program requires that the depth of the wells introduced into the input data be positive values in case the structure studied is below sea level (Figure 36), while the depth values are negative if the structure is above sea level (the case of coal beds in this study, Figures 42 and 43).

B. Drawing of the structure map: The depth of the bed is read as a positive value if the formation is located below sea level, and is read as a negative value if the formation is located above sea level. Particular attention should be exercised in arranging the input data for drawing the contour map to avoid any dislocation of the wells or rotation of the map.

CHAPTER XI

CONCLUSIONS AND RECOMMENDATIONS

The following may be concluded from the study:

1. Lithostratigraphic correlation of digitized well logs provides insight into those problems which visual correlation has failed to resolve. The computer model BASEL, developed in this investigation, demonstrated efficiently its competency to automatically correlate four well logs from four well sites, predict the subsurface structure by establishing cross sections and a three-dimensional display.

2. The study illustrates the similarity between the BASEL output structure map and the map produced by conventional methods. The introduction of the BASEL algorithm shows an automatic method of producing maps which eliminates perceptive differences resulting from producing similar output utilized in conventional methods.

3. The subprogram COR4WELL succeeded in providing automatic correlation of lithostratigraphic units similar to visual correlation. It also correlated four well logs simultaneously, thus reducing the amount of computer time.

4. The BASEL model has the ability of producing structure maps and cross sections by performing automatic correlation of four wells at a time, storing the output, moving to another adjacent set of four wells and so on until the total area under consideration is covered.

5. The two-dimensional cross section established in this study illustrated the subsurface structure of the investigated field. The output of the BASEL program was similar to the output obtained from conventional methods.

6. The three-dimensional illustration demonstrated the configuration and the lateral continuity of the oil reservoir in the St. Louis oil field, Oklahoma, and the coal beds in the drainage basin of the Knife River as well as the Falkirk and central areas of McLean and Oliver Counties, North Dakota. The outputs of the BASEL program based on data provided from these two locations were identical to the output produced by the conventional method.

7. The mathematical correlation gave an average measure of similarity between features of entire sections to be compared. Therefore, the computer-established cross-correlation may not always agree fully with the geologically selected sections which is made on the basis of an individual feature.

Recommendations

The following are recommended for further research to improve the quality of the computer model BASEL.

1. In this research, normal distribution was implemented to measure the cross-correlation coefficient. However, another type of distribution such as β and γ may be tested to improve the quality of correlation.

2. It is advised to account for the variation in petrophysical characteristics of the oil field. Such petrophysical properties (porosity, oil saturation and others) should be introduced into the program BASEL.

3. It is recommended that an automatic zonation technique be implemented to establish the lithostratigraphic units of each log. Then these units are cross-correlated using the subprogram COR4WELL.

4. A square window was used in this research. Yet, there are several types of windows that may be tested to improve the segmentation procedure which might ultimately improve the quality of correlation.

5. It is recommended that the length of the short logs be 1/4 to 1/3 of the number of data points of the long logs.

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APPENDIX I

List of BASEL Program

Program BASEL consists of three programs (see Appendix 2), DATASWC, WELLRC and DRIVER; two computer packages SYMAP and SYMVU; and two subprograms CONTOUR and COR4WELL. These programs and subprograms use 24 subroutines. The programs and subprograms constructed in the program BASEL are overlaped (linked) together to reduce the interference of the computer operator in the plotting process. However, the program BASEL requires the reactivation of the plotter twice during the plottings operation.

```
*******************************************************************************
*                                                                           ***
*       PROGRAM BASEL IS DEVELOPED BY M. MUMMTAZ NAJJAR-BAWAB AT            ***
*  THE DEPARTMENT OF GEOLOGICAL ENGINEERING, UNIVERSITY OF                  ***
*  OKLAHOMA .                                                               ***
*       PROGRAM BASEL SIMULTANEOUSLY CORRELATES FOUR WELL LOGS              ***
*  (A,B,C, AND D) OF ONE TYPE REPRESENTING FOUR WELL SITES.  IT             ***
*  ILLUSTRATES THE STRUCTURE CONFINED BETWEEN THESE LOGS IN TWO             ***
*  AND THREE DIMENSIONS.  THIS STRUCTURE IS PROJECTED FROM THE              ***
*  MAP DRAWN AUTOMATICALLY.  THE CONTROL POINTS OF THIS MAP ARE             ***
*  FROM THE AUTOMATIC CORRELATION OF THE LOGS A, B, C, AND D;               ***
*  AND THE VISUAL CORRELATION OF THE OTHER LOGS IN THE AREA.                ***
*       LINE PRINTER OUTPUT CONTAINS LIST OF THE INPUT DATA                 ***
*  (CONTROL POINTS, LOCATIONS OF THE LOGS A, B, C, AND D; STRUC-            ***
*  TURE MAP OF THE CORRELATED BED AND ITS LEGEND, DATA OF THE               ***
*  LOGS A, B, C, AND D), COEFFICIENTS OF THE CROSS-CORRELATION              ***
*  FUNCTION OF POWER SPECTRA, OPTIMUM STRETCH AND DISPLACEMENT              ***
*  VALUES.  THE RESULTS OF THE INTERMEDIATE STEPS IN THE CORRE-             ***
*  LATION PROCESS ARE PRINTED AS OPTIONAL.                                  ***
*       CALCOMP PLOTTER OUTPUT CONSISTS OF THE STRUCTURE MAP AND            ***
*  THE THREE-DIMENSIONAL CONFIGURATION OF CORRELATED BED, THE IN-           ***
*  INTIAL LOGS (A,B,C,D) WITH THE TIE LINES (STRAIGHT LINES)                ***
*  CONNECTING THE EQUIVALENT SEGMENTS OF THE LOGS, AND THE BED-             ***
*  LINES (WAVING LINES) INDICATING THE TWO DIMENSIONS CROSS SEC-            ***
*  TION OF THE CORRELATED BED.                                              ***
*                                                                           ***
* INPUT CARDS :                                                             ***
*  1. X AND Y COORDINATE CARDS (THE CONTROL POINTS OF THE STRUC-            ***
*       TURE MAP, SYMAP).                                                   ***
*     REQUIRED : COORDINATES FOR EACH LOCATION.                             ***
*     ORDER : Y COORDINATE THEN,X COORDINATE ON EACH CARD.                  ***
*     FORMAT (10X,2F10.0)                                                   ***
*  2. SIGNAL CARD.                                                          ***
*     EXCLAIMATION POINTS IN COLUMNS 1-2.                                   ***
*  3. DEPTH VALUES FOR CONTOUR MAP.                                         ***
*     REQUIRED : POSITIVE VALUES (IF THE STRUCTURE IS BELOW SEA             ***
*                LEVEL),                                                    ***
*                NEGATIVE VALUES (IF THE STRUCTURE IS ABOVE SEA             ***
*                LEVEL),                                                    ***
*                A VALUE FOR EVERY (X,Y) PAIR IN THE COORDINATE             ***
*                CARDS.                                                     ***
*     FORMAT (10X,F10.0)                                                    ***
```

```
*   4. SIGNAL CARD.                                                        ***
*   5. SYMAP TITLE CARDS.                                                  ***
*      REQUIRED : THREE CARDS.                                             ***
*      FORMAT (20A4)                                                       ***
*   6. SIGNAL CARD.                                                        ***
*   7. LOCATION OF WELLS.                                                  ***
*      SEQUENCE NUMBER OF THE (X,Y) COORDINATE PAIR CORRESPONDING         ***
*      TO EACH WELL.                                                       ***
*      FORMAT (4I10)                                                       ***
*   8. HEIGHT OF 3-DIMENSIONAL COUNTOUR MAP.                               ***
*      REQUIRED : POSITIVE VALUE LESS THAN OR EQUAL TO 11.0.               ***
*      FORMAT (F10.4)                                                      ***
*   9. CORAWELL TITLE CARD.                                                ***
*      FORMAT (20A4)                                                       ***
*  10. CORAWELL CONTROL VARIABLES.                                         ***
*      LS = NUMBER OF DATA POINTS OF THE SHORT LOGS.                       ***
*      LL = NUMBER OF DATA POINTS OF THE LONG LOGS.                        ***
*      IDER = 1  DERIVATIVE IS REQUIRED TO COMPUTE POWER SPECTRA.         ***
*           = 0  DERIVATIVE IS NOT REQUIRED.                               ***
*      IORG = 1  ORIGINAL DATA IS REQUIRED FOR STRETCHING AND             ***
*                FOLLOWING CORRELATION.                                    ***
*           = 0  DERIVATIVE DATA IS REQUIRED FOR STRETCHING AND           ***
*                FOLLOWING CORRELATION.                                    ***
*      SMAX = MAXIMUM ANTICIPATED STRETCH VALUE.  TYPICAL VALUE           ***
*           = 2.0                                                          ***
*      SINT = DIGITIZATION OF THE INTERVALS IN FEET.                       ***
*      PRALL = (IF NONZERO, DERIVATIVES OF LOG DATA, POWER SPEC-          ***
*              TRA AND INTERPOLATED SPECTRA ARE ALL PRINTED OUT).         ***
*      FORMAT (4I3,3F5.0)                                                  ***
*  11. LOG DEPTHS.                                                         ***
*      DEPTHS OF LOG A, LOG B, LOG C, LOG D.                               ***
*      DEPTHA = DEPTH OF LOG A.                                            ***
*      DEPTHB = DEPTH OF LOG B.                                            ***
*      DEPTHC = DEPTH OF LOG C.                                            ***
*      DEPTHD = DEPTH OF LOG D.                                            ***
*      REQUIRED : POSITIVE VALUES (IF THE STRUCTURE IS BELOW SEA          ***
*                 LEVEL),                                                  ***
*                 NEGATIVE VALUES (IF THE STRUCTURE IS ABOVE SEA          ***
*                 LEVEL).                                                  ***
*      FORMAT (4F10.2)                                                     ***
*  12. THICKNESS OF BEDS.                                                  ***
*      THICAB = THICKNESS OF BED BETWEEN WELL A AND WELL B.               ***
*      THICCD = THICKNESS OF BED BETWEEN WELL C AND WELL D.               ***
*      FORMAT (2F10.2)                                                     ***
*  13. DATA VALUES OF FOUR LOGS.                                           ***
*      LOG A     WELL A, SHORT LOG                                         ***
*      LOG B     WELL B, LONG LOG                                          ***
*      LOG C     WELL C, SHORT LOG                                         ***
*      LOG D     WELL D, LONG LOG                                          ***
*      FORMAT (F10.3)                                                      ***
*                                                                          ***
******************************************************************************
```

```
C***********************************************************************
C*
C*   PROGRAM   DATASWC
C*
C***********************************************************************
C
C   THIS PROGRAM PREPARES INPUT DATA FOR SYMAP, WELLRC, AND COP4WELL.
C
      DIMENSION CARD(20)
      DATA S /'    '/
C
C   B-DATA (SYMAP)
C
      WRITE (1,45)
    5 READ (5,70) CARD
      IF (CARD(1) .EQ. S) GO TO 10
      WRITE (1,70) CARD
      GO TO 5
C
C   E-VALUES (SYMAP)
C
   10 WRITE (1,50)
   15 READ (5,70) CARD
      IF (CARD(1) .EQ. S) GO TO 20
      WRITE (1,70) CARD
      GO TO 15
C
C   F-MAP (SYMAP)
C
   20 WRITE (1,55)
   25 READ (5,70) CARD
      IF (CARD(1) .EQ. S) GO TO 30
      WRITE (1,70) CARD
      GO TO 25
   30 WRITE (1,60)
C
C   WELLRC
C
      READ (5,70) CARD
      WRITE (2,70) CARD
   35 CONTINUE
      READ(5,70) CARD
      WRITE(2,70) CARD
C
C   COP4WELL
C
   40 READ (5,70,END=95) CARD
      WRITE (3,70) CARD
      GO TO 40
C
C   FORMATS
C
   45 FORMAT ( 'B-DATA POINTS',11X,'N')
   50 FORMAT ('99999',/,'E-VALUES',16X,'N',12X,'-1.')
   55 FORMAT ('99999',/,'F-MAP')
   60 FORMAT (4X,'3',6X,'10.',/,3X,'21',23X,'11',/,3X,'28',/,
     @'99999',/,'999999')
   70 FORMAT (20A4)
   95 END FILE 1
      END FILE 2
```

```
END FILE 3
STOP
END
```

```
C***********************************************************************
C*
C*     PROGRAM   WELLSC
C*
C*    THIS PROGRAM IS FOR THE PREPARATION OF THE DATA GENERATED BY
C*    SYMAP TO ALLOCATE THE POSITION OF THE WELLS ON THE STRUCTURE MAP
C*    OF THE BASEL PROGRAM OUTPUT.
C*
C***********************************************************************
C
      INTEGER COL(500), ROW(500), POINT(4), DUMMY(133), AST, BLNK
      DATA AST /'*'/, BLNK /' '/
C
C   DETERMINE THE NUMBER OF ROWS AND COLUMNS IN THE CONTOUR MAP.
C
      JY = 0
    5 READ(8,40) DUMMY
      IF (DUMMY(2) .EQ. AST) GO TO 6
      GO TO 5
    6 DO 7 I = 3,133
      IF (DUMMY(I) .EQ. AST) GO TO 9
      IX = I -2
    7 CONTINUE
    9 READ(8,40) DUMMY
      IF (DUMMY(2) .EQ. AST) GO TO 10
      IF (DUMMY(1) .EQ. BLNK) JY = JY+1
      GO TO 9
C
C   DETERMINE THE ROW AND COLUMN LOCATION OF EACH WELL.
C
   10 READ (7,25,END=15) (ROW(IN),COL(IN), IN = 1,500)
   15 CONTINUE
      READ (5,26) POINT
      DO 20 I = 1,4
      IF (COL(POINT(I)).GT.IX) COL(POINT(I)) = IX
      IF (ROW(POINT(I)).GT.JY) ROW(POINT(I)) = JY
      IF (COL(POINT(I)) .LT. 1) COL(POINT(I)) = 1
      IF (ROW(POINT(I)) .LT. 1) ROW(POINT(I)) = 1
      WRITE (9,25)  ROW(POINT(I)),COL(POINT(I))
   20 CONTINUE
      WRITE(9,25) JY, IX
      ENDFILE 9
C
C   CREATE SYSIN DATASET FOR SYMVU
C
      READ (5,30) VUHT
   25 FORMAT (2I10)
   26 FORMAT (4I10)
   30 FORMAT (F10.4)
      WRITE (2,35) JY,IX,VUHT
      DO 14 I = 1,4
      WRITE (2,25) ROW(POINT(I)),COL(POINT(I))
   14 CONTINUE
      END FILE 2
   35 FORMAT(' ',/,
     @       2I4,7X,'4',31X,'8',' 1 1',11X,'4',3X,'1',/,
     @       '  45. 45.0',' 10.0',F10.4)
   40 FORMAT(133A1)
      STOP
      END
```

```
C***********************************************************************
C*                                                                     *
C*  DRIVER PROGRAM FOR BASEL                                           *
C*                                                                     *
C*  THIS PROGRAM CALLS EACH OF THE THREE SUBPROGRAMS AS SUBROUTINES    *
C*  COPAWL(COPA-WELL), CONTUR(CONTOUR), AND SYMVU(SYMVU).              *
C*                                                                     *
C***********************************************************************
C
      COMMON /ARRAY/X(132,132)
      CALL PLOT (0.0,-29.5,-3)
      CALL CONTUR
      CALL PLOT (0.0,-29.5,-3)
      CALL COPAWL
      CALL SYMBOL (10.,18.,.15,'THREE-DIMENSIONAL CROSS SECTION',0.,31)
      CALL PLOT (-2.0,13.0,-3)
      CALL FACTOR (.80)
      CALL SYMVU
      STOP
      END
```

```
C*************************************************************************
C*
C*    CONTOUR
C*
C*    SUBPROGRAM CONTOUR COPIES THE DATA FROM THE SYMAP OUTPUT IN ORDER
C*    TO DRAW THE STRUCTURE MAP ON THE CALCOMP OUTPUT OF THE LABEL
C*    PROGRAM.
C*
C*    THE PROGRAM WAS DEVELOPED BY PATRICK BRADY, JUNE 1975, AND MOD-
C*    IFIED BY THIS RESEARCH IN APRIL 1980 AT THE UNIVERSITY OF
C*    OKLAHOMA.
C*
C*************************************************************************
C
      SUBROUTINE CONTUR
C
      COMMON /ARRAY/SMUTH(132,132)
      DIMENSION CONTA(132,132), IWLX(4), IWLY(4)
C
      CALL PLOT (10.0,23.0,-3)
C
      DO 4 I= 1,4
      READ (9,3) IALY(I), IALX(I)
    3 FORMAT (2I10)
    4 CONTINUE
      READ (9,3) JY, IX
      NUM = 10
      MM=JY+1
      READ (8) DUMMY
      DO 6 M = 1,JY
      READ(8) (CONTA(J,MM-M),J = 1,IX)
    6 CONTINUE
      CALL SMOOTH(CONTA,SMUTH,IX,JY)
      CALL CANTUR(CONTA,132,132,IX,JY,NUM,TEMP)
      CALL WELL (IALX,IALY,TEMP,JY,IX)
      REWIND 8
      REWIND 9
      RETURN
      END
C
C
      SUBROUTINE CANTUR(Z,IDIM,JDIM,M,N,NUM,TEMP)
C
      REAL LOW
      DIMENSION        Z(IDIM,JDIM)
C
C THIS ROUTINE FINDS THE BEGINNINGS OF ALL CONTOUR LINES AT LEVEL CV.
C FIRST THE EDGES ARE SEARCHED FOR LINES INTERSECTING THE EDGE (OPEN
C LINES) THEN THE INTERIOR IS SEARCHED FOR LINES WHICH DO NOT INTERSECT
C THE EDGE (CLOSED LINES).  BEGINNINGS ARE STORED IN IR TO PREVENT RE-
C TRACING OF LINES.  IF IR IS FILLED, THE SEARCH IS STOPPED FOR THIS CV.
C
      COMMON/CANTR/IX,IY,IDX,IDY,IS,ISS,KEY,NP,CV,MM,NN,
     -              INX(8),INY(8),IR(100),NR
      MM=M
      NN=N
      M2=M-2
      N2=N-2
      RX=M
      RY=N
```

```
C
C     DETERMINE DATA LIMITS
C
      LOW=1.0E70
      HIGH=-1.0E70
      DO 20 I=1,M
      DO 20 J=1,N
      IF(Z(I,J).LT.HIGH) GO TO 10
      HIGH=Z(I,J)
      HIGHI=I-1
      HIGHJ=J-1
10    IF(Z(I,J).GT.LOW) GO TO 20
      LOW=Z(I,J)
      RLOWI=I-1
      RLOWJ=J-1
20    CONTINUE
      CALL SYMBOL (0.0,0.5,.15,'STRUCTURE CONTOUR MAP',0.0,21)
      CALL PLOT (0.0,1.0,-3)
C
C     BOUNDRY
C
      TEMP=10./(AMAX0(M,N)-1.0)
      CALL FACTOR(TEMP)
      CALL PLOT (-1.0,-1.0,-3)
      CALL PLOT (1.0,1.0,3)
      CALL PLOT(1.,FY,2)
      CALL PLOT(FX,FY,2)
      CALL PLOT(FX,1.,2)
      CALL PLOT(1.,1.,2)
      STEP=(HIGH-LOW)/FLOAT(NUM)
C
C     NUM CONTOUR LINES
C
      DO 100 INUM=1,NUM
      KEY=0
      CV=LOW+STEP*FLOAT(INUM-1)
      NP = 0
      ISS=0
C
C     EDGES
C
      DO 2 IP1=2,M
      I=IP1-1
      IF(Z(I,1).GE.CV.OR.Z(IP1,1).LT.CV) GO TO 1
      IX=IP1
      IY=1
      IDX=-1
      IDY=0
      IS=1
      CALL DRCNTR (Z,IDIM,JDIM)
    1 IF(Z(IP1,N).GE.CV.OR.Z(I,N).LT.CV) GO TO 2
      IX=I
      IY=N
      IDX=1
      IDY=0
      IS=5
      CALL DRCNTR (Z,IDIM,JDIM)
    2 CONTINUE
      DO 4 JP1=2,N
      J=JP1-1
```

```
      IF(Z(M,J).GE.CV.OR.Z(M,JP1).LT.CV) GO TO 3
      IX=M
      IY=JP1
      IDX=0
      IDY=-1
      IS=7
      CALL DRCNTR (Z,IDIM,JDIM)
    3 IF(Z(1,JP1).GE.CV.OR.Z(1,J).LT.CV) GO TO 4
      IX=1
      IY=J
      IDX=0
      IDY=1
      IS=3
      CALL DRCNTR (Z,IDIM,JDIM)
    4 CONTINUE
      ISS = 1
C
C    INTERIOR
C
      DO 104 JP1=3,N
         J = JP1-1
         DO 103 IP1=2,M
            I = IP1-1
            IF (Z(I,J).GE.CV .OR. Z(IP1,J).LT.CV) GO TO 103
            IXY = IP1*100+J
            IF (NP .EQ. 0) GO TO 102
            DO 101 K=1,NP
               IF (IR(K) .EQ. IXY) GO TO 103
  101       CONTINUE
  102       NP = NP+1
            IF (NP .GT. MP) GO TO 105
            IR(NP) = IXY
            IX = IP1
            IY = J
            IDX = -1
            IDY = 0
            IS = 1
            CALL DRCNTR (Z,IDIM,JDIM)
  103    CONTINUE
  104 CONTINUE
  100 CONTINUE
  105 CALL PLOT (1.0,1.0,-3)
      RETURN
      END
C
C
      SUBROUTINE DRCNTR (Z,IDIM,JDIM)
C
      DIMENSION        Z(IDIM,JDIM)
C
C THIS ROUTINE TRACES A CONTOUR LINE WHEN GIVEN THE BEGINNING BY CANTUR.
C X=1. AT Z(1,J), X=FLOAT(M) AT Z(M,J). X TAKES ON NON-INTEGER VALUES.
C Y=1. AT Z(I,1), Y=FLOAT(N) AT Z(I,N). Y TAKES ON NON-INTEGER VALUES.
C
      COMMON/CANTR/IX,IY,IDX,IDY,IS,ISS,KEY,NP,CV,M,N,
     -            INX(8),INY(8),IR(100),NR
      LOGICAL          IPEN        ,IPENC
      C(P1,P2) = (P1-CV)/(P1-P2)
C
      IF(KEY.GT.0) GO TO 100
```

```
      KEY=1
      IOFFP=0
      SPVAL=0.
      IPEN=.TRUE.
      IPENO=.TRUE.
C
C     CONTOUR GENERATION
C
  100 IF (IOFFP .EQ. 0) GO TO 101
      ASSIGN 110 TO JUMP1
      ASSIGN 115 TO JUMP2
      GO TO 102
  101 ASSIGN 112 TO JUMP1
      ASSIGN 116 TO JUMP2
  102 IX0 = IX
      IY0 = IY
      IS0 = IS
      IF (IOFFP .EQ. 0) GO TO 103
      IX2 = IX+INX(IS)
      IY2 = IY+INY(IS)
      IPEN = Z(IX,IY).NE.SPVAL .AND. Z(IX2,IY2).NE.SPVAL
      IPENO = IPEN
  103 IF (IDX .EQ. 0) GO TO 104
      Y = IY
      ISUB = IX+IDX
      X = C(Z(IX,IY),Z(ISUB,IY))*FLOAT(IDX)+FLOAT(IX)
      GO TO 105
  104 X = IX
      ISUB = IY+IDY
      Y = C(Z(IX,IY),Z(IX,ISUB))*FLOAT(IDY)+FLOAT(IY)
  105 IF (IPEN) CALL PLOT (X,Y,3)
  106 IS = IS+1
      IF (IS .GT. 8) IS = IS-8
      IDX = INX(IS)
      IDY = INY(IS)
      IX2 = IX+IDX
      IY2 = IY+IDY
      IF (ISS .NE. 0) GO TO 107
      IF (IX2.GT.M .OR. IY2.GT.N .OR. IX2.LT.1 .OR. IY2.LT.1) GO TO 119
  107 IF (CV-Z(IX2,IY2)) 108,108,109
  108 IS = IS+4
      IX = IX2
      IY = IY2
      GO TO 106
  109 IF (IS/2*2 .EQ. IS) GO TO 106
      GO TO JUMP1,(110,112)
  110 ISBIG = IS+(8-IS)/4*8
      IX3 = IX+INX(ISBIG-1)
      IY3 = IY+INY(ISBIG-1)
      IX4 = IX+INX(ISBIG-2)
      IY4 = IY+INY(ISBIG-2)
      IPENO = IPEN
      IF (ISS .NE. 0) GO TO 111
      IF (IX3.GT.M .OR. IY3.GT.N .OR. IX3.LT.1 .OR. IY3.LT.1) GO TO 119
      IF (IX4.GT.M .OR. IY4.GT.N .OR. IX4.LT.1 .OR. IY4.LT.1) GO TO 119
  111 IPEN = Z(IX,IY).NE.SPVAL .AND. Z(IX2,IY2).NE.SPVAL .AND.
     1         Z(IX3,IY3).NE.SPVAL .AND. Z(IX4,IY4).NE.SPVAL
  112 IF (IDX .EQ. 0) GO TO 113
      Y = IY
      ISUB = IX+IDX
```

```
      X = C(Z(IX,IY),Z(ISUB,IY))*FLOAT(IDX)+FLOAT(IX)
      GO TO 114
  113 X = IX
      ISUB = IY+IDY
      Y = C(Z(IX,IY),Z(IX,ISUB))*FLOAT(IDY)+FLOAT(IY)
  114 GO TO JUMP2,(115,116)
  115 IF (.NOT.IPEN) GO TO 117
      IF (IPENO) GO TO 116
C
C   END OF LINE SEGMENT
C
      CALL PLOT (X,Y,2)
      CALL PLOT (XOLD,YOLD,3)
C
C   CONTINUE LINE SEGMENT
C
  116 CALL PLOT (X,Y,2)
  117 XOLD = X
      YOLD = Y
      IF (IS .NE. 1) GO TO 118
      NP = NP+1
      IF (NP .GT. NR) GO TO 119
      IT(NP) = IX*100+IY
  118 IF (ISS .EQ. 0) GO TO 106
      IF (IX.NE.IX0 .OR. IY.NE.IY0 .OR. IS.NE.IS0) GO TO 106
C
C   END OF LINE
C
  119 CALL PLOT (X,Y,2)
      CALL NUMBER (X,Y,1.0,CV,0.0,-1)
      RETURN
      END
C
C
      BLOCK DATA
      COMMON/CONTR/IX,IY,IDX,IDY,IS,ISS,KEY,NP,CV,M,N,
     -              INX(8),INY(8),IT(100),NR
      DATA INX(1),INX(2),INX(3),INX(4),INX(5),INX(6),INX(7),INX(8)/
     -     -1,-1,0,1,1,1,0,-1/
      DATA INY(1),INY(2),INY(3),INY(4),INY(5),INY(6),INY(7),INY(8)/
     -     0,1,1,1,0,-1,-1,-1/
      DATA NR/100/
      END
C
C
      SUBROUTINE SMOOTH (IN,OUT,M,N)
C
C   PATRICK J BRADY...AUGUST 1973
C   SUBROUTINE TO SMOOTH A TWO DIMENSIONAL FIELD
C   IN...INPUT ARRAY
C   OUT...OUTPUT ARRAY
C   BOTH ARRAYS DIMENSIONED TO M X N
      REAL IN
      DIMENSION IN(132,132),OUT(132,132)
C
C   INITIALIZATION
      MM=M-1
      NN=N-1
      DO 10 I=1,M
      DO 10 J=1,N
```

```
      OUT(I,J)=.25*IN(I,J)
      IN(I,J)=.125*IN(I,J)
10    CONTINUE
C
C   SMOOTH THE INTERIOR FIELD
      DO 20 I=2,MM
      IL=I-1
      IG=I+1
      DO 20 J=2,NN
      JL=J-1
      JG=J+1
      OUT(I,J)=OUT(I,J)+IN(IL,J)+IN(IG,J)+IN(I,JL)+IN(I,JG)+
     -.5*(IN(IL,JL)+IN(IL,JG)+IN(IG,JL)+IN(IG,JG))
20    CONTINUE
C
C   SMOOTH THE EDGES
      DO 30 I=2,MM
      IL=I-1
      IG=I+1
      OUT(I,1)=2.*OUT(I,1)+IN(IL,1)+IN(IG,1)+IN(I,2)+
     -.5*(IN(IL,2)+IN(IG,2))
      OUT(I,N)=2.*OUT(I,N)+IN(IL,N)+IN(IG,N)+IN(I,NN)+
     -.5*(IN(IL,NN)+IN(IG,NN))
30    CONTINUE
      DO 40 I=2,NN
      IL=I-1
      IG=I+1
      OUT(1,I)=2.*OUT(1,I)+IN(1,IL)+IN(1,IG)+IN(2,I)+
     -.5*(IN(2,IL)+IN(2,IG))
      OUT(M,I)=2.*OUT(M,I)+IN(M,IL)+IN(M,IG)+IN(MM,I)+
     -.5*(IN(MM,IL)+IN(MM,IG))
40    CONTINUE
C
C   SMOOTH THE CORNERS
      OUT(1,1)=2.750*OUT(1,1)+IN(1,2)+IN(2,1)+.5*IN(2,2)
      OUT(M,1)=2.750*OUT(M,1)+IN(MM,1)+IN(M,2)+.5*IN(MM,2)
      OUT(1,N)=2.750*OUT(1,N)+IN(1,NN)+IN(2,N)+.5*IN(2,NN)
      OUT(M,N)=2.750*OUT(M,N)+IN(MM,N)+IN(M,NN)+.5*IN(MM,NN)
C
C   RETURN VALUES IN THE IN ARRAY
      DO 50 I=1,M
      DO 50 J=1,N
      IN(I,J)=OUT(I,J)
50    CONTINUE
      RETURN
      END
C
C
      SUBROUTINE WELL (IC,IR,TEMP,JY,IM)
C
C   PLOT LOCATIONS OF WELLS.
C
      DIMENSION IC(4), IR(4), WL(4)
      DATA WL/ '+A','+B','+C','+D'/
      REWIND 9
      CALL FACTOR (1.0)
      YM = (JY+1)*TEMP
      WRITE (6,10)
      DO 5 I = 1,4
      X = (IC(I)-1)*TEMP
```

```
      Y = (IR(I)-1)*TEMP
      CALL SYMBOL (X, YY-Y, .123, WL(I), 0.0, 2)
      WRITE (9,15) IR(I), IC(I), Y,X
      WRITE (6,20) WL(I),IR(I),IC(I),Y,X
    5 CONTINUE
      WRITE (9,15) JY, IX
      WRITE (6,25) JY, IX
      END FILE 9
   10 FORMAT ('1','WELL POSITION DATA FROM SYMAP',//
     &        7X,'WELL',7X,'ROW',4X,'COLUMN',4X,'Y-COOR',4X,'X-COOR',/)
   15 FORMAT (2I10,2F10.2)
   20 FORMAT (9X,A2,2I10,2F10.2)
   25 FORMAT (1X,/' NUMBER OF ROWS = ',I3,'   NUMBER OF COLUMNS = ',I3)
      RETURN
      END
```

```
C***********************************************************************
C*                                                                     *
C*  CORAWELL                                                           *
C*                                                                     *
C*  SUBPROGRAM CORAWELL CORRELATES FOUR LOGS OF ONE TYPE REPRESENTING  *
C*  FOUR DIFFERENT WELLS.  THIS PROGRAM IS MODIFIED FROM THE PROGRAM   *
C*  SPECOR INTRODUCED BY KWON AND OTHERS, 1978.  THE CORRELATION PRO-  *
C*  CEDURE CONSISTS OF CONSTRUCTING TWO COMPLEX SERIES (A,B) REPRE-    *
C*  SENTING WELL 1 AND WELL 2, AND SERIES (C,D) REPRESENTING WELL 3 AND*
C*  WELL 4.  THEN ADDING THE CROSS-CORRELATION FUNCTION OF SERIES A    *
C*  AND B TO THE CROSS-CORRELATION OF SERIES C AND D. CROSS-CORRELATION*
C*  OF POWER SPECTRA IDENTIFIES THE DIRECTION AND AMOUNT OF STRETCH    *
C*  BETWEEN FOUR WELLS AND CROSS-CORRELATION OF STRETCHED LOGS DE-     *
C*  TERMINES RELATIVE DISPLACEMENT.                                    *
C*                                                                     *
C***********************************************************************
C
      SUBROUTINE CORAWL
C
      REAL*8 LONG,SHORT
      DIMENSION RLOG1(800),RLOG2(800),YIP1(800),YIP2(800)
      DIMENSION CLOG1(800),CLOG2(800),WORK(1600), XC(4)
      DIMENSION XCORL(100),XCORS(100),ITITLE(20)
      COMPLEX CLOG1,CLOG2,YIP1,YIP2,CONST
      DATA LONG /5H LONG/
      DATA SHORT /5HSHORT/
C
C   INITIALIZE ALL ARRAYS TO ZERO.
C
      DO 10 I=1,800
      RLOG2(I)=0.0
      RLOG1(I)=RLOG2(I)
      WORK(I+800)=0.0
      WORK(I)=WORK(I+800)
      CLOG1(I)=CMPLX(0.0,0.0)
      CLOG2(I)=CLOG1(I)
      YIP1(I)=CMPLX(0.0,0.0)
      YIP2(I)=YIP1(I)
 10   CONTINUE
      DO 20 I=1,100
      XCORS(I)=0.0
 20   XCORL(I)=XCORS(I)
C
C   READ AND WRITE PARAMETERS AND LOG DATA.
C
      READ(5,298) (ITITLE(I),I=1,20)
      READ(5,301) LS,LL,IDEP,IORG,SMAX,SINT,PRALL
      READ(5,297) DEPTHA,DEPTHB,DEPTHC,DEPTHD
      DO 17 I = 1,4
      READ(9,296) XC(I)
 17   CONTINUE
      REWIND 9
      READ(5,297) THICAB,THICCD
      READ(5,302) (RLOG1(I),I=1,LS)
      READ(5,302) (RLOG2(I),I=1,LL)
      READ(5,302) (WORK(I),I=1,LS)
C
C   KEEP THE ORIGINAL DATA IN UNIT14 FOR PLOT.
C
      WRITE(14) (RLOG1(I),I=1,LS)
```

```
      WRITE(14) (FLOG2(I),I=1,LL)
      WRITE(14) (WORK(I),I=1,LS)
C
C     CONSTRUCT COMPLEX SERIES.
C
      DO 30 I=1,LS
   30 CLOG1(I)=CMPLX(FLOG1(I),WORK(I))
      READ(5,302)(WORK(I),I=1,LL)
      WRITE(14) (WORK(I),I=1,LL)
      DO 40 I=1,LL
   40 CLOG2(I)=CMPLX(FLOG2(I),WORK(I))
C
C     KEEP THE COMPLEX SERIES IN UNIT13 FOR CORRELATION.
C
      WRITE(13) (CLOG1(I),I=1,LS)
      WRITE(13) (CLOG2(I),I=1,LL)
      WRITE(6,299) (ITITLE(I),I=1,20)
      WRITE(6,303) LS,LL,IDER,IORG,SMAX,SINT,DEPTHA,DEPTHB,DEPTHC,DEPTHD
     1,THICAB,THICCD
      WRITE(6,304)
      DO 50 I=1,LS
   50 WRITE(6,305) I,CLOG1(I),CLOG2(I)
      LS1=LS+1
      DO 60 I=LS1,LL
   60 WRITE(6,306) I,CLOG2(I)
C
C     CHECK WHETHER DERIVATIVE IS WANTED.
C
      IF(IDER.EQ.0) GO TO 100
      CALL DERIVA  (CLOG1,LS)
      CLOG1(LS+1)=CMPLX(0.0,0.0)
      CALL DERIVA  (CLOG2,LL)
      IF (PRALL.EQ.0.0) GO TO 90
      WRITE(6,307)
      DO 70 I=1,LS
   70 WRITE(6,305) I,CLOG1(I),CLOG2(I)
      LS1=LS+1
      DO 80 I=LS1,LL
   80 WRITE(6,306) I,CLOG2(I)
   90 CONTINUE
      WRITE(13) (CLOG1(I),I=1,LS)
      WRITE(13) (CLOG2(I),I=1,LL)
  100 CONTINUE
C
C     FOURIER TRANSFORM OF COMPLEX SERIES.
C
      CALL FOURT (CLOG1,LL,1,-1,1,WORK)
      CALL FOURT (CLOG2,LL,1,-1,1,WORK)
      NYQ=LL/2+1
      CONST=-0.5*CMPLX(0.0,1.0)
C
C     COMPUTE POWER SPECTRA OF FOUR LOGS (THE SECOND HALF OF
C     THE SPECTRA IS IGNORED).
C     CONSTRUCT COMPLEX SERIES OF POWER SPECTRA.
C
      DO 110 I=2,NYQ
      YIP1(I)=0.5*(CLOG1(I)+CONJG(CLOG1(LL-I+2)))
      YIP2(I)=CONST*(CLOG1(I)-CONJG(CLOG1(LL-I+2)))
      XREAL=(REAL(YIP1(I))**2+AIMAG(YIP1(I))**2)/FLOAT(LL)
      XIMAG=(REAL(YIP2(I))**2+AIMAG(YIP2(I))**2)/FLOAT(LL)
```

```
      CLOG1(I-1)=CMPLX(XREAL,XIMAG)
  110 CONTINUE
      DO 120 I=2,NYQ
      YIP1(I)=0.5*(CLOG2(I)+CONJG(CLOG2(LL-I+2)))
      YIP2(I)=CONST*(CLOG2(I)-CONJG(CLOG2(LL-I+2)))
      XREAL=(REAL(YIP1(I ))**2+AIMAG(YIP1(I))**2)/FLOAT(LL)
      XIMAG=(REAL(YIP2(I))**2+AIMAG(YIP2(I))**2)/FLOAT(LL)
      CLOG2(I-1)=CMPLX(XREAL,XIMAG)
  120 CONTINUE
      IF(PRALL.EQ.0.0) GO TO 140
      NN=NYQ-1
      WRITE(6,308)
      DO 130 I=1,NN
  130 WRITE(6,309) I,CLOG1(I),CLOG2(I)
  140 CONTINUE
C
C     TRANSFORM THE FREQUENCIES INTO A LOGARITHMIC SCALE.
C
      DO 145 I=1,NN
  145 WORK(I)=ALOG10(FLOAT(I))
C
C     OBTAIN EQUALLY SPACED POWER SPECTRA USING LAGRANGE'S
C     INTERPOLATION METHOD.
C
      JLAST=NN-2
      DELT=0.01
      CALL INTPL3  (WORK,CLOG1,CLOG2,YIP1,YIP2,10,JLAST,NLAST,DELT)
      IF(PRALL.EQ.0.0) GO TO 155
      WRITE(6,310)
      DO 150 I=1,NLAST
  150 WRITE(6,305) I,YIP1(I),YIP2(I)
  155 CONTINUE
C
C     NORMALIZE MAGNITUDE OF EACH POWER SPECTRA.
C
      CALL NORMAL (YIP1,RLOG1,RLOG2,NLAST)
      CALL NORMAL (YIP2,RLOG1,RLOG2,NLAST)
C
C     CROSS-CORRELATE INTERPOLATED POWER SPECTRA TO OBTAIN
C     STRETCH VALUES.
C
      LAGMAX=ALOG10(SMAX)/DELT+1.5
      CALL CROSS1 (YIP1,YIP2,XCORL,NLAST,LAGMAX)
      CALL CROSS1 (YIP2,YIP1,XCORS,NLAST,LAGMAX)
      WRITE(6,313)
      DO 160 I=1,LAGMAX
      K1=-I+1
      K2=I-1
  160 WRITE(6,312) K1,XCORL(I),K2,XCORS(I)
      WRITE(6,311)
      LAGTOT=2*LAGMAX-1
      DO 170 I=1,LAGMAX
      WORK(I)=FLOAT(-LAGMAX+I)
  170 RLOG1(I)=XCORL(LAGMAX-I+1)
      DO 180 I=2,LAGMAX
      WORK(LAGMAX+I-1)=FLOAT(I-1)
  180 RLOG1(LAGMAX+I-1)=XCORS(I)
C
C     KEEP THE CROSS-CORRELATION FUNCTION OF SPECTRA IN UNIT13
C     FOR PLOT.
```

```
C
      WRITE(14) (WORK(I),I=1,LAGTOT)
      WRITE(14) (RLOG1(I),I=1,LAGTOT)
C
C   FIND THE MAXIMUM PEAK IN THE CORRELATION FUNCTION OF POWER SPECTRA
C   AND COMPUTE CORRESPONDING STRETCH FACTOR.
C
      CALL MAX (RLOG1,1,LAGTOT,I1,PCMAX1)
      XLAG1=WORK(I1)
      DEL1=ABS(XLAG1)*DELT
      ST1=10.**DEL1
C
C   FIND SECOND PEAK IN THE CORRELATION FUNCTION OF POWER SPECTRA
C   AND COMPUTE CORRESPONDING STRETCH FACTOR.
C
      CALL SCAN (RLOG1,I1,LAGTOT)
      CALL MAX (RLOG1,1,LAGTOT,I2,PCMAX2)
      XLAG2=WORK(I2)
      DEL2=ABS(XLAG2)*DELT
      ST2=10.**DEL2
C
C   FROM TWO PEAK VALUES, FIND THE OPTIMUM DISPLACEMENT AND STRETCH.
C
      IF(XLAG1.GT.0.0) GO TO 190
C
C   STRETCHING AND CORRELATING THE FIRST PEAK ASSUMES THE LONG LOG
C   (LOG2) IS STRETCHED.
C
      WRITE(6,315) ST1
      CALL STXC1 (CLOG1,CLOG2,WORK,RLOG1,LS,LL,ST1,VL1,ID1,
     1CMAX1,IDEF,IORG)
      IF (XLAG2.GT.0.0) GO TO 210
      GO TO 200
C
C   STRETCHING AND CORRELATING THE FIRST PEAK ASSUMES THE SHORT
C   (LOG1) IS STRETCHED.
C
 190  WRITE(6,314) ST1
      CALL STXC2 (CLOG1,CLOG2,WORK,RLOG1,LS,LL,ST1,VL1,ID1,
     1CMAX1,IDEF,IORG)
      IF(XLAG2.GT.0.0) GO TO 210
C
C   STRETCHING AND CORRELATING THE SECOND PEAK ASSUMES THE LONG LOG
C   (LOG2) IS STRETCHED.
C
 200  WRITE(6,317) ST2
      CALL STXC1 (CLOG1,CLOG2,WORK,RLOG2,LS,LL,ST2,VL2,ID2,
     1CMAX2,IDEF,IORG)
      GO TO 220
C
C   STRETCHING AND CORRELATING THE SECOND PEAK ASSUMES THE SHORT LOG
C   (LOG1) IS STRETCHED.
C
 210  WRITE(6,316) ST2
      CALL STXC2 (CLOG1,CLOG2,WORK,RLOG2,LS,LL,ST2,VL2,ID2,
     1CMAX2,IDEF,IORG)
C
C   COMPARE THE COEFICIENTS OBTAINED FROM CORRELATIONS TWO SETS OF
C   STRETCHED LOGS.
C
```

```
 220  IF(CMAX1.LT.CMAX2) GO TO 230
      CMAX=CMAX1
      ST=ST1
      ML=ML1
      ID=ID1
      WRITE(14) (FLOG1(I),I=1,ML)
      IF(XLAG1.GT.0.0) GO TO 240
      GO TO 250
 230  CMAX=CMAX2
      ST=ST2
      ML=ML2
      ID=ID2
      WRITE(14) (FLOG2(I),I=1,ML)
 240  IF(XLAG2.GT.0.0) GO TO 250
      GO TO 260
C
C   THE FINAL RESULT SUGGESTS THAT THE SHORT LOG (LOG1) IS STRETCHED.
C   PLOT THE CORRELATION RESULT.
 250  ID=FLOAT(ID)/ST+0.5
C
      WRITE(6,318) ST,CMAX,ID
      IDEND=FLOAT(ID)+(FLOAT(LS)/ST)
      BDS1 = THICAB
      FACT1 = BDS1 - THICAB * ST
      BDS2 = THICCD
      FACT2 = BDS2 -THICCD*ST
C
C   PLOT INITIAL LOG DATA AND CORRELATION RESULTS.
C
      CALL PLOTRS  (FLOG1,FLOG2,CLOG1,CLOG2,WORK,YIP1,LS,LL,SINT,ST,
     1ID,IDEND,CMAX,ITITLE,SHORT,DEPTHA,DEPTHB,DEPTHC,DEPTHD,XC,
     1FACT1,FACT2,BDS1,BDS2)
      GO TO 270
 260  WRITE(6,319) ST,CMAX,ID
      IDEND=FLOAT(ID)+(FLOAT(LS)*ST)
      BDS1 = THICAB*ST
      FACT1 = BDS1 - THICAB
      BDS2 = THICCD*ST
      FACT2 = BDS2 - THICCD
C
C   PLOT INITIAL LOG DATA AND CORRELATION RESULTS.
C
      CALL PLOTRS  (FLOG1,FLOG2,CLOG1,CLOG2,WORK,YIP1,LS,LL,SINT,ST,
     1ID,IDEND,CMAX,ITITLE,LONG,DEPTHA,DEPTHB,DEPTHC,DEPTHD,XC,
     1FACT1,FACT2,BDS1,BDS2)
C
C   PLOT BOTH CORRELATION FUNCTIONS OF POWER SPECTRA AND
C   STRETCHED LOGS.
C
  270 CALL PLTCOR (FLOG1,FLOG2,YIP1,YIP2,LL,LS,ML,LAGTOT)
      REWIND 13
      REWIND 14
C
C   FORMATS.
C
 296  FORMAT(30X,F10.2)
 297  FORMAT(4F10.0)
 298  FORMAT(20A4)
 299  FORMAT('1','COR4WELL',//1X,20A4,//)
 301  FORMAT(4I5,3F5.0)
```

```
302  FORMAT(F10.3)
303  FORMAT(3X,'LS=',I5,3X,'LL=',I5,3X,'IDER=',I2,3X,'IORG=',I2,
    13X,'SMAX=',F5.1,3X,'SINT=',F5.1,/,3X,'DEPTH OF LOG A=',
    1F9.1,' FEET',/3X,'DEPTH OF LOG B =',F9.1 ,' FEET',/
    13X,'DEPTH OF LOG C =',F9.1,' FEET',/3X,'DEPTH OF LOG D =',
    1F9.1,' FEET',/
    13X,'THICKNESS OF A - B BED = ',F10.2,/
    13X,'THICKNESS OF C - D BED = ',F10.2)
304  FORMAT(1H0,15X,'INPUT  DATA',//,15X,'LOG A',15X,'LOG B',/)
305  FORMAT(I5,4F10.3)
306  FORMAT(I5,20X,2F10.3)
307  FORMAT(//,15X,'DERIVATIVED DATA',//,15X,'LOG A',15X,'LOG B',/)
308  FORMAT(//,15X,'POWER SPECTRUM',//,12X,'LOG A',5X,'LOG B',
    15X,'LOG C',5X,'LOG D',/)
309  FORMAT(I5,4F10.3)
310  FORMAT(//,10X,'INTERPOLATED POWER SPECTRUM  (  START FROM 10TH OF
    1ORIGINAL  )',//,10X,'LOG A',5X,'LOG B',5X,'LOG C',5X,'LOG D')
311  FORMAT(///,'  STRETCH FACTOR FOUND FROM CORRELATION OF POWER'
    1,' SPECTRA')
312  FORMAT(10X,I5,F15.3,22X,I5,F15.3)
313  FORMAT(//,20X,'       NORMALIZED CORRELATION COEFFICIENTS',/,
    110X,'( ASSUME LONG LOG IS STRETCHED )',10X,
    1'(  ASSUME SHORT LOG IS STRETCHED )',//,8X,'LAG NUMBER',
    15X,'VALUE OF COEFFICIENT',7X,'LAG NUMBER',5X,
    1'VALUE OF COEFFICIENT',/)
314  FORMAT(//,'  FIRST CHOICE  - SHORT LOG IS STRETCHED',F6.2,
    1'  TIMES')
315  FORMAT(//,'  FIRST CHOICE  - LONG LOG IS STRETCHED',F6.2,
    1'  TIMES')
316  FORMAT(/,'  SECOND CHOICE - SHORT LOG IS STRETCHED',F6.2,
    1'  TIMES')
317  FORMAT(/,'  SECOND CHOICE - LONG LOG IS STRETCHED',F6.2,
    1'  TIMES')
318  FORMAT(///,'  FINAL RESULT SUGGESTS THAT SHORT LOG IS STRETCHED',
    1F5.2,'  TIMES',//,'  MAXIMUM CORRELATION IS',F6.3,' AT A LAG OF',
    1I5)
319  FORMAT(///,'  FINAL RESULT SUGGESTS THAT LONG LOG IS STRETCHED',
    1F5.2,'  TIMES',//,'  MAXIMUM CORRELATION IS',F6.3,' AT A LAG OF',
    1I5)
     RETURN
     END
C
C
     SUBROUTINE REDLIN (SC2,SC4,DPTH2,DPTH4,XC2,XC4,FACT1,FACT2,PDS1,
    1PDS2)
C
C  PLOT CROSS-SECTION OF BEDS BETWEEN WELLS.
C
     COMMON /ARRAY/ STORE(132,132)
     DIMENSION X(132), Z(132)
     INTEGER COL(4), ROW(4)
C
C   READ POSITIONS OF WELLS AND MAP COORDINATES.
C
     READ(9,6) (ROW(I), COL(I), I=1,4)
     READ (9,6) JY, IX
   6 FORMAT(2I10)
     READ (8) DUMMY
     DO 9 I= 1,JY
     READ(8) (STORE(J,I), J=1,IX)
```

```
    9 CONTINUE
      REWIND 8
      REWIND 9
C
C   INITIALIZE VARIABLES FOR 1ST BED.
C
      IS = 2
      IE = 1
      DPTH = -DPTH2
      SC = SC2
      YCC = 15.0
      XCC = XC2
      FACT = FACT1
      BDS = BDS1
C
C   PLOT BED LINES.
C
      DO 24 K = 1,2
      ISTRT = COL(IS)
      IEND = COL(IE)
      SEG = FLOAT(ROW(IE)-ROW(IS))/(IEND-ISTRT)
      XINC = SQRT(1+SEG*SEG)
      JJ =1
      IR = ROW(IS)
      ASG = ABS(SEG)
      X(JJ) = 0.0
      Y = IR
      Z(JJ) = STORE(ISTRT,IR)
      ISTRT = ISTRT+1
      DO 14 J = ISTRT,IEND
      JJ = JJ+1
      IR = Y
   12 Z(JJ) = STORE(J,IR)-(STORE(J,IR)-STORE(J,IR+1))*ASG
      Y = Y+SEG
      X(JJ) = X(JJ-1) + XINC
   14 CONTINUE
      X(JJ+1) = 0.0
      X(JJ+2) = X(JJ)*IX/(10.0*FLOAT(JJ))
      Z(JJ+1) = DPTH
      Z(JJ+2) = SC
      CALL TLINE (XCC,YCC,X,Z,JJ,1,0.0)
      FACT = FACT/JJ
      DO 31 I = 1, JJ
      Z(I) = Z(I) - BDS + FACT*I
   31 CONTINUE
      CALL TLINE (XCC,YCC,X,Z,JJ,1,0.0)
C
C   INITIALIZE VARIABLES FOR 2ND BED.
C
      IS = 4
      IE = 3
      DPTH = -DPTH4
      SC = SC4
      YCC = 7.25
      XCC = XC4
      FACT = FACT2
      BDS = BDS2
   24 CONTINUE
      RETURN
      END
```

```
C
C
      SUBROUTINE CROSS1 (A,B,C,L,ML)
C
C    NORMALIZED CROSS-CORRELATION WITH A VARIABLE WINDOW SIZE.
C
      DIMENSION A(300),B(300),C(100)
      COMPLEX A,B,ATOT,BTOT,AB,CNUM
      BTOT=0.0
      ATOT=BTOT
      BSQ=0.0
      ASQ=BSQ
      DO 1 I=1,L
      ATOT=ATOT+CONJG(A(I))
      BTOT=BTOT+B(I)
      XSQ=REAL(A(I)*CONJG(A(I)))
      YSQ=REAL(B(I)*CONJG(B(I)))
      ASQ=ASQ+XSQ
  1   BSQ=BSQ+YSQ
      DO 2 J=1,ML
      AB=CMPLX(0.0,0.0)
      N=L-J+1
      DO 3 K=1,N
  3   AB=AB+(CONJG(A(K+J-1))*B(K))
      CNUM=AB-(ATOT*BTOT/FLOAT(N))
      XTOT=REAL(ATOT*CONJG(ATOT))
      YTOT=REAL(BTOT*CONJG(BTOT))
      CDEN=(ASQ-(XTOT/FLOAT(N)))*(BSQ-(YTOT/FLOAT(N)))
      IF(CDEN.LE.0.0) GO TO 10
      CDEN=SQRT(CDEN)
      GO TO 20
 10   CDEN=100000000.
 20   C(J)=REAL(CNUM)/CDEN
      ATOT=ATOT-CONJG(A(J))
      BTOT=BTOT-B(L-J+1)
      TASQ=REAL(A(J)*CONJG(A(J)))
      TBSQ=REAL(B(L-J+1)*CONJG(B(L-J+1)))
      ASQ=ASQ-TASQ
      BSQ=BSQ-TBSQ
  2   CONTINUE
      RETURN
      END
C
C
      SUBROUTINE CROSS2 (A,B,C,L1,L2,ML)
C
C    NORMALIZED CROSS-CORRELATION WITH A FIXED WINDOW SIZE.
C
      DIMENSION A(300),B(300),C(300)
      COMPLEX A,B,ATOT,BTOT,AB,CNUM
      BTOT=0.0
      ATOT=BTOT
      BSQ=0.0
      ASQ=BSQ
      DO 1 I=1,L1
      ATOT=ATOT+CONJG(A(I))
      BTOT=BTOT+B(I)
      XSQ=REAL(A(I)*CONJG(A(I)))
      YSQ=REAL(B(I)*CONJG(B(I)))
      ASQ=ASQ+XSQ
```

```
 1    BSQ=BSQ+YSQ
      ML=L2-L1+1
      DO 2 J=1,ML
      AB=CMPLX(0.0,0.0)
      DO 3 K=1,L1
 3    AB=AB+(CONJG(A(K))*B(K+J-1))
      CNUM=AB-(ATOT*BTOT/FLOAT(L1))
      XTOT=REAL(ATOT*CONJG(ATOT))
      YTOT=REAL(BTOT*CONJG(BTOT))
      CDEN=(ASQ-(XTOT/FLOAT(L1)))*(BSQ-(YTOT/FLOAT(L1)))
      IF(CDEN.LE.0.0) GO TO 10
      CDEN=SQRT(CDEN)
      GO TO 20
 10   CDEN=10000000.
 20   C(J)=REAL(CNUM)/CDEN
      BTOT=BTOT-B(J)+B(L1+J)
      TBSQ=REAL(B(J)*CONJG(B(J)))
      TCSQ=REAL(B(L1+J)*CONJG(B(L1+J)))
      BSQ=BSQ-TBSQ+TCSQ
 2    CONTINUE
      RETURN
      END
C
C
      SUBROUTINE DERIVA  (A,N)
C
C   REPLACE LOG DATA BY THEIR FIRST DERIVATIVE.
C
      DIMENSION A(800)
      COMPLEX A
      N=N-1
      DO 10 I=1,N
 10   A(I)=A(I+1)-A(I)
      RETURN
      END
C
C
      SUBROUTINE FOURT(DATA,NN,NDIM,ISIGN,IFORM,WORK)
C
C   SUBROUTINE FOURT IS A FAST FOURIER TRANSFORM ALGORITHM FOR
C   ANY NUMBER OF DATA.  IT WAS WRITTEN BY NORMAN BRENNER AT THE
C   MIT LINCOLN LABORATORY, 1967.
C
      DIMENSION DATA(1600),NN(10),IFACT(32),WORK(1600)
      TWOPI=6.283185307
      IF(NDIM-1)920,1,1
 1    NTOT=2
      DO 2 IDIM=1,NDIM
      IF(NN(IDIM))920,920,2
 2    NTOT=NTOT*NN(IDIM)
C
C       MAIN LOOP FOR EACH DIMENSION.
C
      NP1=2
      DO 910 IDIM=1,NDIM
      N=NN(IDIM)
      NP2=NP1*N
      IF(N-1)920,900,5
C
C       FACTOR N.
```

```
C
 5    M=N
      NTWO=NP1
      IF=1
      IDIV=2
 10   IQUOT=M/IDIV
      IREM=M-IDIV*IQUOT
      IF(IQUOT-IDIV)50,11,11
 11   IF(IREM)20,12,20
 12   NTWO=NTWO+NTWO
      M=IQUOT
      GO TO 10
 20   IDIV=3
 30   IQUOT=M/IDIV
      IREM=M-IDIV*IQUOT
      IF(IQUOT-IDIV)60,31,31
 31   IF(IREM)40,32,40
 32   IFACT(IF)=IDIV
      IF=IF+1
      M=IQUOT
      GO TO 30
 40   IDIV=IDIV+2
      GO TO 30
 50   IF(IREM)60,51,60
 51   NTWO=NTWO+NTWO
      GO TO 70
 60   IFACT(IF)=M
C
C      SEPARATE FOUR CASES--
C         1. COMPLEX TRANSFORM OR REAL TRANSFORM FOR THE 4TH,5TH,ETC.
C            DIMENSIONS.
C         2. REAL TRANSFORM FOR THE 2ND OR 3RD DIMENSION. METHOD--
C            TRANSFORM HALF THE DATA, SUPPLYING THE OTHER HALF BY CON-
C            JUGATE SYMMETRY.
C         3. REAL TRANSFORM FROM THE 1ST DIMENSION, N ODD. METHOD--
C            TRANSFORM HALF THE DATA AT EACH STAGE, SUPPLYING THE OTHER
C            HALF BY CONJUGATE SYMMETRY.
C         4. REAL TRANSFORM FOR THE 1ST DIMENSION, N EVEN. METHOD--
C            TRANSFORM A COMPLEX ARRAY OF LENGTH N/2 WHOSE REAL PARTS
C            ARE THE EVEN NUMBERED REAL VALUES AND WHOSE IMAGINARY PARTS
C            ARE THE ODD NUMBERED REAL VALUES. SEPARATE AND SUPPLY
C            THE SECOND HALF BY CONJUGATE SYMMETRY.
C
 70   NON2=NP1*(NP2/NTWO)
      ICASE=1
      IF(IDIM-4)71,90,90
 71   IF(IFORM)72,72,90
 72   ICASE=2
      IF(IDIM-1)73,73,90
 73   ICASE=3
      IF(NTWO-NP1)90,90,74
 74   ICASE=4
      NTWO=NTWO/2
      N=N/2
      NP2=NP2/2
      NTOT=NTOT/2
      I=3
      DO 80 J=2,NTOT
      DATA(J)=DATA(I)
 80   I=I+2
```

```
 90   I1RNG=NP1
      IF(ICASE-2)100,95,100
 95   I1RNG=NP0*(1+NPREV/2)
C
C      SHUFFLE ON THE FACTORS OF TWO IN N.  AS THE SHUFFLING
C      CAN BE DONE BY SIMPLE INTERCHANGE, NO WORKING ARRAY IS NEEDED.
C
100   IF(NTWO-NP1)600,600,110
110   NP2HF=NP2/2
      J=1
      DO 150 I2=1,NP2,NON2
      IF(J-I2)120,130,130
120   I1MAX=I2+NON2-2
      DO 125 I1=I2,I1MAX,2
      DO 125 I3=I1,NTOT,NP2
      J3=J+I3-I2
      TEMPR=DATA(I3)
      TEMPI=DATA(I3+1)
      DATA(I3)=DATA(J3)
      DATA(I3+1)=DATA(J3+1)
      DATA(J3)=TEMPR
125   DATA(J3+1)=TEMPI
130   M=NP2HF
140   IF(J-M)150,150,145
145   J=J-M
      M=M/2
      IF(M-NON2)150,140,140
150   J=J+M
C
C      MAIN LOOP FOR FACTORS OF TWO.  PERFORM FOURIER TRANSFORMS OF
C      LENGTH FOUR, WITH ONE OF LENGTH TWO IF NEEDED.  THE TWIDDLE FACTOR
C      W=EXP(ISIGN*2*PI*SQRT(-1)*M/(4*MMAX)).  CHECK FOR W=ISIGN*SQRT(-1)
C      AND REPEAT FOR W=ISIGN*SQRT(-1)*CONJUGATE(W).
C
      NON2T=NON2+NON2
      IPAR=NTWO/NP1
310   IF(IPAR-2)350,330,320
320   IPAR=IPAR/4
      GO TO 310
330   DO 340 I1=1,I1RNG,2
      DO 340 J3=I1,NON2,NP1
      DO 340 K1=J3,NTOT,NON2T
      K2=K1+NON2
      TEMPR=DATA(K2)
      TEMPI=DATA(K2+1)
      DATA(K2)=DATA(K1)-TEMPR
      DATA(K2+1)=DATA(K1+1)-TEMPI
      DATA(K1)=DATA(K1)+TEMPR
340   DATA(K1+1)=DATA(K1+1)+TEMPI
350   MMAX=NON2
360   IF(MMAX-NP2HF)370,600,600
370   LMAX=MAX0(NON2T,MMAX/2)
      IF(MMAX-NON2)405,405,380
380   THETA=-TWOPI*FLOAT(NON2)/FLOAT(4*MMAX)
      IF(ISIGN)400,390,390
390   THETA=-THETA
400   WR=COS(THETA)
      WI=SIN(THETA)
      WSTPR=-2.*WI*WI
      WSTPI=2.*WR*WI
```

```
405   DO 570 L=NON2,LMAX,NON2T
      M=L
      IF(MMAX-NON2)420,420,410
410   W2R=WR*WR-WI*WI
      W2I=2.*WR*WI
      W3R=W2R*WR-W2I*WI
      W3I=W2R*WI+W2I*WR
420   DO 530 I1=1,I1RNG,2
      DO 530 J3=I1,NON2,NP1
      KMIN=J3+IPAR*M
      IF(MMAX-NON2)430,430,440
430   KMIN=J3
440   KDIF=IPAR*MMAX
450   KSTEP=4*KDIF
      DO 520 K1=KMIN,NTOT,KSTEP
      K2=K1+KDIF
      K3=K2+KDIF
      K4=K3+KDIF
      IF(MMAX-NON2)460,460,480
460   U1R=DATA(K1)+DATA(K2)
      U1I=DATA(K1+1)+DATA(K2+1)
      U2R=DATA(K3)+DATA(K4)
      U2I=DATA(K3+1)+DATA(K4+1)
      U3R=DATA(K1)-DATA(K2)
      U3I=DATA(K1+1)-DATA(K2+1)
      IF(ISIGN)470,475,475
470   U4R=DATA(K3+1)-DATA(K4+1)
      U4I=DATA(K4)-DATA(K3)
      GO TO 510
475   U4R=DATA(K4+1)-DATA(K3+1)
      U4I=DATA(K3)-DATA(K4)
      GO TO 510
480   T2R=W2R*DATA(K2)-W2I*DATA(K2+1)
      T2I=W2R*DATA(K2+1)+W2I*DATA(K2)
      T3R=WR*DATA(K3)-WI*DATA(K3+1)
      T3I=WR*DATA(K3+1)+WI*DATA(K3)
      T4R=W3R*DATA(K4)-W3I*DATA(K4+1)
      T4I=W3R*DATA(K4+1)+W3I*DATA(K4)
      U1R=DATA(K1)+T2R
      U1I=DATA(K1+1)+T2I
      U2R=T3R+T4R
      U2I=T3I+T4I
      U3R=DATA(K1)-T2R
      U3I=DATA(K1+1)-T2I
      IF(ISIGN)490,500,500
490   U4R=T3I-T4I
      U4I=T4R-T3R
      GO TO 510
500   U4R=T4I-T3I
      U4I=T3R-T4R
510   DATA(K1)=U1R+U2R
      DATA(K1+1)=U1I+U2I
      DATA(K2)=U3R+U4R
      DATA(K2+1)=U3I+U4I
      DATA(K3)=U1R-U2R
      DATA(K3+1)=U1I-U2I
      DATA(K4)=U3R-U4R
520   DATA(K4+1)=U3I-U4I
      KMIN=4*(KMIN-J3)+J3
      KDIF=KSTEP
```

```
      IF(KDIF-NP2)450,530,530
  530 CONTINUE
      M=MMAX-M
      IF(ISIGN)540,550,550
  540 TEMPR=WR
      WR=-WI
      WI=-TEMPR
      GO TO 560
  550 TEMPR=WR
      WR=WI
      WI=TEMPR
  560 IF(M-LMAX)565,565,410
  565 TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR
  570 WI=WI*WSTPR+TEMPR*WSTPI+WI
      IPAR=3-IPAR
      MMAX=MMAX+MMAX
      GO TO 360
C
C      MAIN LOOP FOR FACTORS NOT EQUAL TO TWO. APPLY THE TWIDDLE FACTOR
C      W=EXP(ISIGN*2*PI*SQRT(-1)*(J2-1)*(J1-J2)/(NP2*IFP1)), THEN
C      PERFORM A FOURIER TRANSFORM OF LENGTH IFACT(IF),MAKING USE OF
C      CONJUGATE SYMMETRIES.
C
  600 IF(NTWO-NP2)605,700,700
  605 IFP1=NON2
      IF=1
      NP1HF=NP1/2
  610 IFP2=IFP1/IFACT(IF)
      J1RNG=NP2
      IF(ICASE-3)612,611,612
  611 J1RNG=(NP2+IFP1)/2
      J2STP=NP2/IFACT(IF)
      J1RG2=(J2STP+IFP2)/2
  612 J2MIN=1+IFP2
      IF(IFP1-NP2)615,640,640
  615 DO 635 J2=J2MIN,IFP1,IFP2
      THETA=-TWOPI*FLOAT(J2-1)/FLOAT(NP2)
      IF(ISIGN)625,620,620
  620 THETA=-THETA
  625 SINTH=SIN(THETA/2.)
      WSTPR=-2.*SINTH*SINTH
      WSTPI=SIN(THETA)
      WR=WSTPR+1.
      WI=WSTPI
      J1MIN=J2+IFP1
      DO 635 J1=J1MIN,J1RNG,IFP1
      I1MAX=J1+I1RNG-2
      DO 630 I1=J1,I1MAX,2
      DO 630 I3=I1,NTOT,NP2
      J3MAX=I3+IFP2-NP1
      DO 630 J3=I3,J3MAX,NP1
      TEMPR=DATA(J3)
      DATA(J3)=DATA(J3)*WR-DATA(J3+1)*WI
  630 DATA(J3+1)=TEMPR*WI+DATA(J3+1)*WR
      TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR
  635 WI=TEMPR*WSTPI+WI*WSTPR+WI
  640 THETA=-TWOPI/FLOAT(IFACT(IF))
      IF(ISIGN)650,645,645
```

```
645   THETA=-THETA
650   SINTH=SIN(THETA/2.)
      WSTPR=-2.*SINTH*SINTH
      WSTPI=SIN(THETA)
      KSTEP=2*N/IFACT(IF)
      KRANG=KSTEP*(IFACT(IF)/2)+1
      DO 698 I1=1,I1RNG,2
      DO 698 I3=I1,NTOT,NP2
      DO 690 KMIN=1,KRANG,KSTEP
      J1MAX=I3+J1RNG-IFP1
      DO 680 J1=I3,J1MAX,IFP1
      J3MAX=J1+IFP2-NP1
      DO 680 J3=J1,J3MAX,NP1
      J2MAX=J3+IFP1-IFP2
      K=KMIN+(J3-J1+(J1-I3)/IFACT(IF))/NP1HF
      IF(KMIN-1)655,655,665
655   SUMR=0.
      SUMI=0.
      DO 660 J2=J3,J2MAX,IFP2
      SUMR=SUMR+DATA(J2)
660   SUMI=SUMI+DATA(J2+1)
      WORK(K)=SUMR
      WORK(K+1)=SUMI
      GO TO 680
665   KCONJ=K+2*(N-KMIN+1)
      J2=J2MAX
      SUMR=DATA(J2)
      SUMI=DATA(J2+1)
      OLDSR=0.
      OLDSI=0.
      J2=J2-IFP2
670   TEMPR=SUMR
      TEMPI=SUMI
      SUMR=TWOWR*SUMR-OLDSR+DATA(J2)
      SUMI=TWOWR*SUMI-OLDSI+DATA(J2+1)
      OLDSR=TEMPR
      OLDSI=TEMPI
      J2=J2-IFP2
      IF(J2-J3)675,675,670
675   TEMPR=WR*SUMR-OLDSR+DATA(J2)
      TEMPI=WI*SUMI
      WORK(K)=TEMPR-TEMPI
      WORK(KCONJ)=TEMPR+TEMPI
      TEMPR=WR*SUMI-OLDSI+DATA(J2+1)
      TEMPI=WI*SUMR
      WORK(K+1)=TEMPR+TEMPI
      WORK(KCONJ+1)=TEMPR-TEMPI
680   CONTINUE
      IF(KMIN-1)685,685,686
685   WR=WSTPR+1.
      WI=WSTPI
      GO TO 690
686   TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR
      WI=TEMPR*WSTPI+WI*WSTPR+WI
690   TWOWR=WR+WR
      IF(ICASE-3)692,691,692
691   IF(IFP1-NP2)695,692,692
692   K=1
      I2MAX=I3+NP2-NP1
```

```
      DO 693 I2=I3,I2MAX,NP1
      DATA(I2)=WORK(K)
      DATA(I2+1)=WORK(K+1)
  693 K=K+2
      GO TO 698
C
C      COMPLETE A REAL TRANSFORM IN THE 1ST DIMENSION, N ODD, BY CON-
C      JUGATE SYMMETRIES AT EACH STAGE.
C
  695 J3MAX=I3+IFP2-NP1
      DO 697 J3=I3,J3MAX,NP1
      J2MAX=J3+NP2-J2STP
      DO 697 J2=J3,J2MAX,J2STP
      J1MAX=J2+J1RG2-IFP2
      J1CNJ=J3+J2MAX+J2STP-J2
      DO 697 J1=J2,J1MAX,IFP2
      K=1+J1-I3
        DATA(J1)=WORK(K)
      DATA(J1+1)=WORK(K+1)
      IF(J1-J2)697,697,696
  696 DATA(J1CNJ)=WORK(K)
      DATA(J1CNJ+1)=-WORK(K+1)
  697 J1CNJ=J1CNJ-IFP2
  698 CONTINUE
      IF=IF+1
      IFP1=IFP2
      IF(IFP1-NP1)700,700,610
C
C      COMPLETE A REAL TRANSFORM IN THE 1ST DIMENSION, N EVEN, BY CON-
C      JUGATE SYMMETRIES.
C
  700 GO TO (900,800,900,701),ICASE
  701 NHALF=N
      N=N+N
      THETA=-TWOPI/FLOAT(N)
      IF(ISIGN)703,702,702
  702 THETA=-THETA
  703 SINTH=SIN(THETA/2.)
      WSTPR=-2.*SINTH*SINTH
      WSTPI=SIN(THETA)
      WR=WSTPR+1.
      WI=WSTPI
      IMIN=3
      JMIN=2*NHALF-1
      GO TO 725
  710 J=JMIN
      DO 720 I=IMIN,NTOT,NP2
      SUMR=(DATA(I)+DATA(J))/2.
      SUMI=(DATA(I+1)+DATA(J+1))/2.
      DIFR=(DATA(I)-DATA(J))/2.
      DIFI=(DATA(I+1)-DATA(J+1))/2.
      TEMPR=WR*SUMI+WI*DIFR
      TEMPI=WI*SUMI-WR*DIFR
      DATA(I)=SUMR+TEMPR
      DATA(I+1)=DIFI+TEMPI
      DATA(J)=SUMR-TEMPR
      DATA(J+1)=-DIFI+TEMPI
  720 J=J+NP2
      IMIN=IMIN+2
      JMIN=JMIN-2
```

```
      TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR
      WI=TEMPR*WSTPI+WI*WSTPR+WI
  725 IF(IMIN-JMIN)710,730,740
  730 IF(ISIGN)731,740,740
  731 DO 735 I=IMIN,NTOT,NP2
  735 DATA(I+1)=-DATA(I+1)
  740 NP2=NP2+NP2
      NTOT=NTOT+NTOT
      J=NTOT+1
      IMAX=NTOT/2+1
  745 IMIN=IMAX-2*NHALF
      I=IMIN
      GO TO 755
  750 DATA(J)=DATA(I)
      DATA(J+1)=-DATA(I+1)
  755 I=I+2
      J=J-2
      IF(I-IMAX)750,760,760
  760 DATA(J)=DATA(IMIN)-DATA(IMIN+1)
      DATA(J+1)=0.
      IF(I-J)770,780,780
  765 DATA(J)=DATA(I)
      DATA(J+1)=DATA(I+1)
  770 I=I-2
      J=J-2
      IF(I-IMIN)775,775,765
  775 DATA(J)=DATA(IMIN)+DATA(IMIN+1)
      DATA(J+1)=0.
      IMAX=IMIN
      GO TO 745
  780 DATA(1)=DATA(1)+DATA(2)
      DATA(2)=0.
      GO TO 900
C
C      COMPLETE A REAL TRANSFORM FOR THE 2ND OR 3RD DIMENSION BY
C      CONJUGATE SYMMETRIES.
C
  800 IF(I1RNG-NP1)805,900,900
  805 DO 860 I3=1,NTOT,NP2
      I2MAX=I3+NP2-NP1
      DO 860 I2=I3,I2MAX,NP1
      IMIN=I2+I1RNG
      IMAX=I2+NP1-2
      JMAX=2*I3+NP1-IMIN
      IF(I2-I3)820,820,810
  810 JMAX=JMAX+NP2
  820 IF(IDIM-2)850,850,830
  830 J=JMAX+NP0
      DO 840 I=IMIN,IMAX,2
      DATA(I)=DATA(J)
      DATA(I+1)=-DATA(J+1)
  840 J=J-2
  850 J=JMAX
      DO 860 I=IMIN,IMAX,NP0
      DATA(I)=DATA(J)
      DATA(I+1)=-DATA(J+1)
  860 J=J-NP0
C
C      END OF LOOP ON EACH DIMENSION.
```

```
C
 900   NP0=NP1
       NP1=NP2
 910   NPREV=N
 920   RETURN
       END
C
C
       SUBROUTINE IAXIS (X,Y,ZLEN,STRT,DEL)
C
C   SUBROUTINE TO PLOT INTEGER NUMBERED AXIS.
C
       ALEN = AINT(ZLEN+.5)
       CALL PLOT (X,Y,3)
       CALL PLOT (X,Y-ALEN,2)
       LEN = ALEN
       YY = Y
       XX = X - .05
       XXX = X-.1
       VAL = STRT
       DO 10 I = 1,LEN
       CALL PLOT (X,YY,3)
       CALL PLOT (XXX,YY,2)
       CALL NUMBER (XXX-.05,YY-.1,.1,VAL,90.,-1)
       VAL = VAL+DEL
       DO 5 J = 1,4
       YY = YY-.2
       CALL PLOT (X,YY,3)
       CALL PLOT (XX,YY,2)
     5 CONTINUE
       YY = YY-.2
    10 CONTINUE
       CALL PLOT (X,YY,3)
       CALL PLOT (XXX,YY,2)
       CALL NUMBER (XXX-.05,YY-.1,.1,VAL,90.,-1)
       YSYM = ALEN/2.+1.2
       CALL SYMBOL (X-0.3,Y-YSYM,0.15,'DEPTH (FEET)',90.,12)
       RETURN
       END
C
C
       SUBROUTINE INTPL3  (X,CLOG1,CLOG2,YIP1,YIP2,JSTART,JLAST,NLAST,
      1DELT)
C
C   INTERPOLATE EQUALLY SPACED SAMPLES USING A LAGRANGE'S
C   3RD DEGREE POLYNOMIAL.
C
       DIMENSION X(1600),CLOG1(800),CLOG2(800),YIP1(800),YIP2(800)
       COMPLEX CLOG1,CLOG2,YIP1,YIP2
       NSEQ=1
       DO 1 J=JSTART,JLAST
 2     TXIP=FLOAT(NSEQ-1)*DELT+1.0
       IF(X(J).LE.TXIP.AND.X(J+1).GE.TXIP) GO TO 3
       GO TO 1
 3     A1=X(J-1)-X(J)
       A2=X(J-1)-X(J+1)
       A3=X(J-1)-X(J+2)
       A4=-A1
       A5=X(J)-X(J+1)
       A6=X(J)-X(J+2)
```

```
      A7=-A2
      A8=-A5
      A9=X(J+1)-X(J+2)
      A10=-A3
      A11=-A6
      A12=-A9
      C1=1.0/(A1*A2*A3)
      C2=1.0/(A4*A5*A6)
      C3=1.0/(A7*A8*A9)
      C4=1.0/(A10*A11*A12)
      B1=TXIP-X(J-1)
      B2=TXIP-X(J)
      B3=TXIP-X(J+1)
      B4=TXIP-X(J+2)
      P1=B2*B3*B4
      P2=B1*B3*B4
      P3=B1*B2*B4
      P4=B1*B2*B3
      YIP1(NSEG)=(C1*P1*CLOG1(J-1))+(C2*P2*CLOG1(J))+
     1(C3*P3*CLOG1(J+1))+(C4*P4*CLOG1(J+1))
      YIP2(NSEG)=(C1*P1*CLOG2(J-1))+(C2*P2*CLOG2(J))+
     1(C3*P3*CLOG2(J+1))+(C4*P4*CLOG2(J+2))
      NSEG=NSEG+1
      GO TO 2
 1    CONTINUE
      NLAST=NSEG-1
      RETURN
      END
C
C
      SUBROUTINE MAX (A,M,N,ID,AMAX)
C
C   FIND THE MAXIMUM (AMAX) AND ITS POSITION (ID).
C
      DIMENSION A(800)
      AMAX=A(M)
      ID=M
      DO 1 I=M,N
      IF(A(I).GT.AMAX) GO TO 2
      GO TO 1
 2    AMAX=A(I)
      ID=I
 1    CONTINUE
      RETURN
      END
C
C
      SUBROUTINE NORM (X,Y,N,M)
C
C  NORMALIZE LOG DATA TO FIT THE SCALE OF PLOT.
C
      DIMENSION X(800),Y(800)
      IMIN=1
      IMAX=IMIN
      JMIN=1
      JMAX=JMIN
      DO 1 I=1,M
      IF ( X(I).GT.X(IMAX)) IMAX=I
      IF ( X(I).LT.X(IMIN)) IMIN=I
 1    CONTINUE
```

```
      DO 2 J=1,M
      IF ( Y(J).GT.Y(JMAX)) JMAX=J
      IF ( Y(J).LT.Y(JMIN)) JMIN=J
  2   CONTINUE
      ZMAX=AMAX1( X(IMAX), Y(JMAX))
      ZMIN=AMIN1( X(IMIN), Y(JMIN))
      DIFF=ZMAX-ZMIN
      DO 3 I=1,N
  3   X(I)=(X(I)-ZMIN)/DIFF
      DO 4 J=1,M
  4   Y(J)=(Y(J)-ZMIN)/DIFF
      RETURN
      END
C
C
      SUBROUTINE NORMAL (X,XR,XI,N)
C
C   NORMALIZE LOG DATA TO BE CORRELATED WITH THE SAME WEIGHT.
C
      DIMENSION X(800),XR(800),XI(800)
      COMPLEX X
      IMINR=1
      IMAXR=IMINR
      IMINI=1
      IMAXI=IMINI
      DO 1 I=1,N
      XR(I)=REAL(X(I))
      IF(XR(I).GT.XR(IMAXR)) IMAXR=I
      IF(XR(I).LT.XR(IMINR))  IMINR=I
      XI(I)=AIMAG(X(I))
      IF(XI(I).GT.XI(IMAXI)) IMAXI=I
      IF(XI(I).LT.XI(IMINI)) IMINI=I
  1   CONTINUE
      XMAXR=XR(IMAXR)
      XMINR=XR(IMINR)
      XMAXI=XI(IMAXI)
      XMINI=XI(IMINI)
      DIFFR=XMAXR-XMINR
      DIFFI=XMAXI-XMINI
      DO 2 I=1,N
      XR(I)=(XR(I)-XMINR)/DIFFR
      XI(I)=(XI(I)-XMINI)/DIFFI
      X(I)=CMPLX(XR(I),XI(I))
  2   CONTINUE
      RETURN
      END
C
C
      SUBROUTINE PLCTRS   (RLOG1,RLOG2,RLOG3,RLOG4,X,XCOR,LS,LL,SINT,
     &ST,ID,IDEND,CMAX, ITITLE,CHOICE,DEPTHA,DEPTHB,DEPTHC,DEPTHD,XC,
     &FACT1,FACT2,BDS1,BDS2)
C
C  PLOT THE INITIAL LOG DATA AND TIE LINES CONNECTING
C  EQUIVALENT PARTS OF THE LOGS.
C
      REAL*8 CHOICE
      DIMENSION RLOG1(800),RLOG2(800),RLOG3(800),RLOG4(800),X(1600)
      DIMENSION ITITLE(20),XCOR(800), XC(4)
      REWIND 14
      LSP1=LS+1
```

```
      LLP1=LL+1
      DO 5 I = 1,4
    5 CONTINUE
      READ(14)  (FLOG1(I),I=1,LSP1)
      READ(14)  (FLOG2(I),I=1,LLP1)
      READ(14)  (FLOG3(I),I=1,LSP1)
      READ(14)  (FLOG4(I),I=1,LLP1)
      CALL NORM (FLOG1,FLOG2,LS,LL)
      CALL NORM (FLOG3,FLOG4,LS,LL)
C
C    LOG B.
C
      DO 10 I=1,LL
   10 X(I)=FLOAT(I-1)*SINT+DEPTHB
      X(LL+1) = X(1)
      X(LL+2) = INT((X(LL)-X(1))/7.0+.5)
      CALL SCALE (FLOG2,2.0,LL,1)
      CALL AXIS (XC(2),15.0,'LOG B',5,2.0,0.0,FLOG2(LL+1),FLOG2(LL+2))
      CALL IAXIS (XC(2),15.0,7.0,X(LL+1),X(LL+2))
      SC2 = X(LL+2)
      CALL TLINE(XC(2),15.0,X,FLOG2,LL,1,-90.0)
      X2S=(X(ID)-X(LL+1))/X(LL+2)
      X2L=(X(IDEND)-X(LL+1))/X(LL+2)
C
C    LOG A.
C
      DO 20 I=1,LS
   20 X(I)=FLOAT(I-1)*SINT+DEPTHA
      SLENTH=7.0*FLOAT(LS-1)/FLOAT(LL-1)
      ALENTH = INT(SLENTH + 0.5)
      X(LS+1) = X(1)
      X(LS+2) = SC2
      YC1 = (DEPTHB-DEPTHA)/SC2
      CALL SCALE(FLOG1,2.0,LS,1)
      CALL AXIS(XC(1),15.+YC1,'LOG A',5,2.,0.,FLOG1(LS+1),FLOG1(LS+2))
      CALL IAXIS (XC(1),15.+YC1,SLENTH,X(LS+1),X(LS+2))
      CALL TLINE(XC(1),15.0+YC1,X,FLOG1,LS,1,-90.0)
      X1S=(X(1)-X(LS+1))/X(LS+2)
      X1L=(X(LS)-X(LS+1))/X(LS+2)
C
C    LOG D.
C
      DO 11 I = 1,LL
   11 X(I) = FLOAT(I-1)*SINT + DEPTHD
      X(LL+1) = X(1)
      X(LL+2) = INT((X(LL)-X(1))/7.0+.5)
      CALL SCALE(FLOG4,2.0,LL,1)
      CALL AXIS(XC(4),7.25,'LOG D',5,2.0,0.,FLOG4(LL+1),FLOG4(LL+2))
      CALL IAXIS (XC(4),7.25,7.0,X(LL+1),X(LL+2))
      SC4 = X(LL+2)
      CALL TLINE (XC(4),7.25,X,FLOG4,LL,1,-90.0)
      X4S=(X(ID)-X(LL+1))/X(LL+2)
      X4L=(X(IDEND)-X(LL+1))/X(LL+2)
C
C    LOG C.
C
      DO 21 I = 1,LS
   21 X(I) = FLOAT(I-1)*SINT + DEPTHC
      SLENTH=7.0*FLOAT(LS-1)/FLOAT(LL-1)
      ALENTH = INT(SLENTH + 0.5)
```

```
      X(LS+1) = X(1)
      X(LS+2) = SC4
      YC3 = (DEPTHD-DEPTHC)/SC4
      CALL SCALE(FLOG3,2.0,LS,1)
      CALL AXIS(XC(3),7.25+YC3,'LOG C',5,2.0,0.,FLOG3(LS+1),FLOG3(LS+2))
      CALL IAXIS (XC(3),7.25+YC3,SLENTH,X(LS+1),X(LS+2))
      CALL TLINE(XC(3),7.25+YC3,X,FLOG3,LS,1,-90.0)
      X3S=(X(1)-X(LS+1))/X(LS+2)
      X3L=(X(LS)-X(LS+1))/X(LS+2)
C
C    PLOT TITLES AND CORRELATION INFORMATION.
C
      CALL SYMBOL (-8.5,9.9,.12,ITITLE,0.0,80)
      CALL SYMBOL (-8.5,9.5,.12,'MAXIMUM CORRELATION IS ',0.,23)
      CALL NUMBER (999.,9.5,.12,CMAX,0.,2)
      CALL SYMBOL (-8.5,9.1,.12,'AT A LAG OF ',0.,12)
      XLAG=FLOAT(ID)
      CALL NUMBER (999.,9.1,.12,XLAG,0.,-1)
      CALL SYMBOL (-8.5,8.7,.12,'WHEN ',0.0,5)
      CALL SYMBOL (999.,8.7,.12,CHOICE,0.0,5)
      CALL SYMBOL (999.,8.7,.12,' LOG IS STRETCHED ',0.,18)
      ST=ST+0.F
C
C    PLOT TIE LINES.
C
      CALL NUMBER (999.,8.7,.12,ST,0.,2)
      CALL SYMBOL (999.,8.7,.12,' TIMES',0.,6)
      Y1S=FLOG1(1)/FLOG1(LS+2)+XC(1)
      CALL SYMBOL (Y1S,15.0-X1S+YC1,.06,1,0.0,-1)
      Y2S=FLOG2(ID)/FLOG2(LL+2) + XC(2)
      CALL SYMBOL (Y2S,15.0-X2S,.06,1,0.0,-2)
      Y1L=FLOG1(LS)/FLOG1(LS+2)+XC(1)
      CALL SYMBOL (Y1L,15.0-X1L+YC1,.06,1,0.0,-1)
      Y2L=FLOG2(IDEND)/FLOG2(LL+2) + XC(2)
      CALL SYMBOL (Y2L,15.0-X2L,.06,1,0.0,-2)
      Y3S=FLOG3(1)/FLOG3(LS+2)+XC(3)
      CALL SYMBOL (Y3S,7.25-X1S+YC3,.06,1,0.0,-1)
      Y4S=FLOG4(ID)/FLOG4(LL+2) +XC(4)
      CALL SYMBOL (Y4S,7.25-X2S,.06,1,0.0,-2)
      Y3L=FLOG3(LS)/FLOG3(LS+2)+XC(3)
      CALL SYMBOL (Y3L,7.25-X3L+YC3,.06,1,0.0,-1)
      Y4L=FLOG4(IDEND)/FLOG4(LL+2) + XC(4)
      CALL SYMBOL (Y4L,7.25-X2L,.06,1,0.0,-2)
C
C    PLOT BED LINES.
C
      CALL BEDLIN (SC2,SC4,DEPTHB,DEPTHD,XC(2),XC(4),FACT1,FACT2,BDS1,
     &BDS2)
      RETURN
      END
C
C
      SUBROUTINE PLTCCP  (CLOG1,CLOG2,X,XCOR,LL,LS,ML,LAGTOT)
C
C  PLOT THE NORMALIZED CROSS-CORRELATION FUNCTION OF INTERPOLATED POWER
C  SPECTRA AND THE NORMALIZED CROSS-CORRELATION FUNCTION OF THE STRETCH
C  -ED LOGS WITH THE OPTIMUM STRETCH.
C
      DIMENSION CLOG1(800),CLOG2(800),X(800),XCOR(800)
      CALL FACTOR (0.6)
```

```
      REWIND 14
      LSP1=LS+1
      LLP1=LL+1
      READ(14)   (CLOG1(I),I=1,LSP1)
      READ(14)   (CLOG2(I),I=1,LLP1)
      READ(14)   (CLOG1(I),I=1,LSP1)
      READ(14)   (CLOG2(I),I=1,LLP1)
      READ(14)   (X(I),I=1,LAGTOT)
      READ(14)   (XCOR(I),I=1,LAGTOT)
      CALL SCALE(X,7.0,LAGTOT,1)
      CALL AXIS(-10.,5.,'LAG (FOR STRETCH)',-17,7.0,0.0,X(LAGTOT+1),
     1X(LAGTOT+2))
      CALL SCALE(XCOR,3.,LAGTOT,1)
      CALL AXIS(-10.,5.,'X-COR',5,3.0,90.,XCOR(LAGTOT+1),XCOR(LAGTOT+2))
      CALL TLINE(-10.,5.,X,XCOR,LAGTOT,1,0.)
      READ(14)   (XCOR(I),I=1,ML)
      DO 6 I=1,ML
    6 X(I)=FLOAT(I-1)
      XCOR(ML+1) = -1.0
      XCOR(ML+2) = 1.0
      CALL AXIS(-10.,1.,'X-COR',5,2.0,90.,XCOR(ML+1),XCOR(ML+2))
      CALL SCALE(X,7.0,ML,1)
      CALL AXIS(-10.,1.0,'LAG (FOR DISPLACEMENT)',-22,7.0,0.0,X(ML+1),
     1X(ML+2))
      CALL TLINE(-10.,1.0,X,XCOR,ML,1,0.)
      CALL FACTOR(1.)
      RETURN
      END
C
C
      SUBROUTINE SCAN (A,ID,LAGMAX)
C
C    SCAN CORRELATION COEFFICIENTS TO DETERMINE SECOND BEST
C    STRETCH FACTOR.
C
      DIMENSION A(800)
      ID1=ID+1
      LMAX=LAGMAX-1
      IF (ID1.GE.LAGMAX) GO TO 3
      DO 1 I=ID1,LMAX
      IF ((A(I+1)-A(I)).LT.0.0) GO TO 2
      GO TO 4
 2    A(I)=-1.0
      IF(I.EQ.LMAX) A(LAGMAX)=-1.0
 1    CONTINUE
 3    A(ID1)=-1.0
 4    LAST=ID-2
      IF (LAST.LT.1) GO TO 7
      DO 5 J=1,LAST
      K=ID-J
      IF((A(K-1)-A(K)).LT.0.0) GO TO 6
      GO TO 8
 6    A(K)=-1.0
      IF(K.EQ.2) A(1)=-1.0
 5    CONTINUE
 7    A(ID-1)=-1.0
 8    A(ID)=0.0
      RETURN
      END
C
```

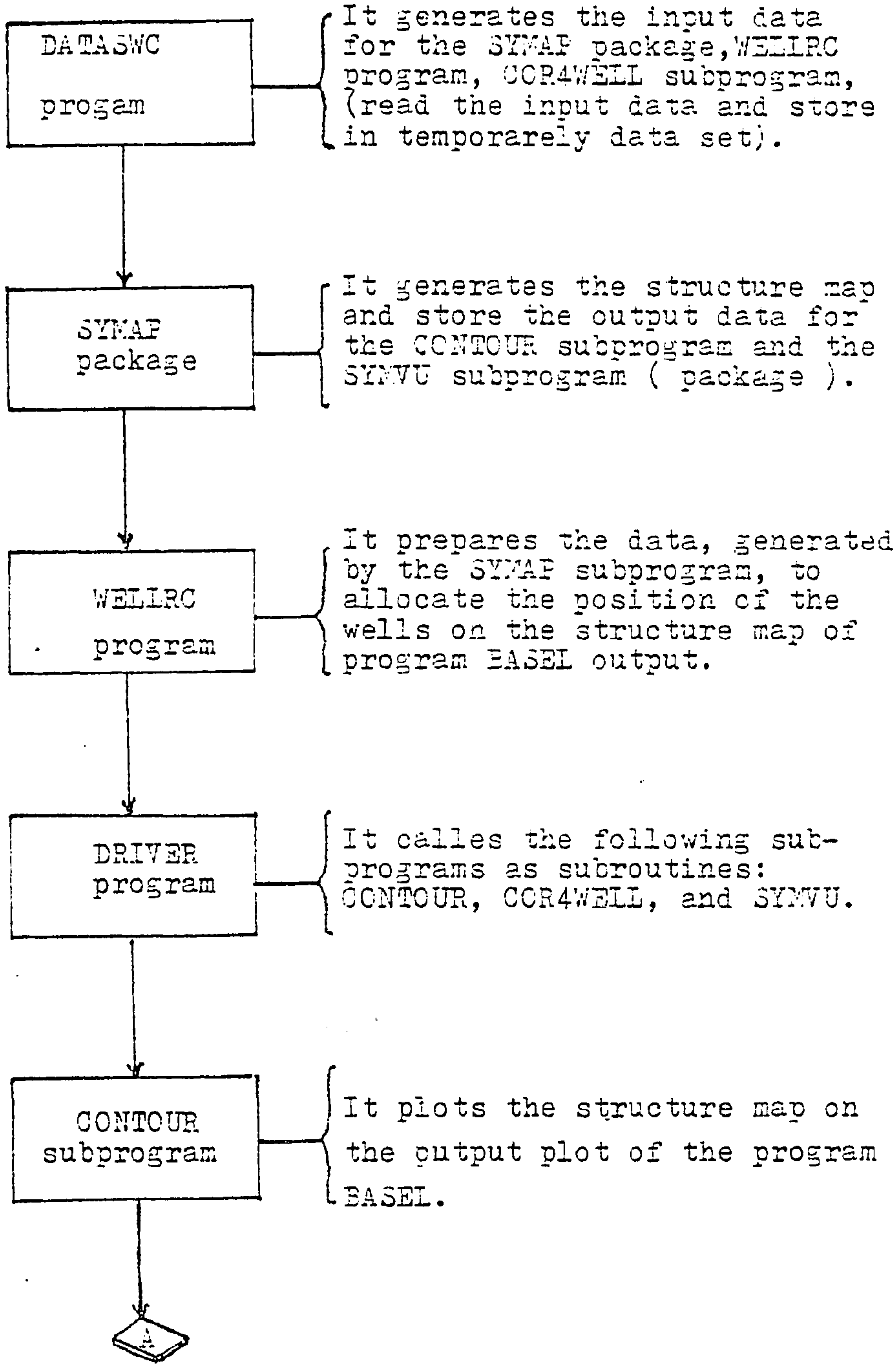
```
C
      SUBROUTINE STRTCH  (A,WORK,N,M)
C
C   INTERPOLATE TIME SERIES DATA WITH N VALUES TO A SERIES WITH
C   M VALUES IN THE FREQUENCY DOMAIN.
C
      DIMENSION WORK(1600),A(800)
      COMPLEX A
      CALL FOURT (A,N,1,-1,1,WORK)
      IF(N.EQ.M) GO TO 50
      K=FLOAT(N)/2.+1.5
      MN=M-N
      K2=K+MN-1
      DO 10 I=K,N
 10   A(M+K-I)=A(N+K-I)
      IF(N/2*2.EQ.N) GO TO 20
      GO TO 30
  20  A(K+MN)=A(K)/2
      A(K)=A(K+MN)
      K=K+1
      IF(M.EQ.(N+1)) GO TO 50
 30   CONTINUE
      DO 40 I=K,K2
 40   A(I)=0.0
 50   CALL FOURT (A,M,1,1,1,WORK)
      DO 60 I=1,M
      A(I)= A(I)/FLOAT(N)
 60   CONTINUE
      RETURN
      END
C
C
      SUBROUTINE STXC1 (CLOG1,CLOG2,WORK,XCOR,LS,LL,ST,ML1,ID1,
     1CMAX1,IDER,IORG)
C
C   STRETCH THE SHORT LOG (LOG1) BY THE FFT INTERPOLATION
C   METHOD AND CROSS-CORRELATE WITH THE LONG LOG (LOG2).
C   FIND THE MAXIMUM CORRELATION COEFFICIENT.
C
      DIMENSION CLOG1(800),CLOG2(800),WORK(1600),XCOR(800)
      COMPLEX CLOG1,CLOG2
      REWIND 13
      LSP1=LS+1
      LLP1=LL+1
      READ(13)  (CLOG1(I),I=1,LSP1)
      READ(13)  (CLOG2(I),I=1,LLP1)
      IF (IDER.EQ.0.OR.IORG.NE.0) GO TO 1
      READ(13)  (CLOG1(I),I=1,LS)
      READ(13)  (CLOG2(I),I=1,LL)
 1    M=FLOAT(LS)*ST+0.5
      CALL NORMAL (CLOG1,WORK,XCOR,LS)
      CALL NORMAL (CLOG2,WORK,XCOR,LL)
      CALL STRTCH  (CLOG1,WORK,LS,M)
      CALL CROSS2 (CLOG1,CLOG2,XCOR,M,LL,ML1)
      CALL MAX (XCOR,1,ML1,ID1,CMAX1)
      RETURN
      END
C
C
      SUBROUTINE STXC2 (CLOG1,CLOG2,WORK,XCOR,LS,LL,ST,ML2,ID2,
```

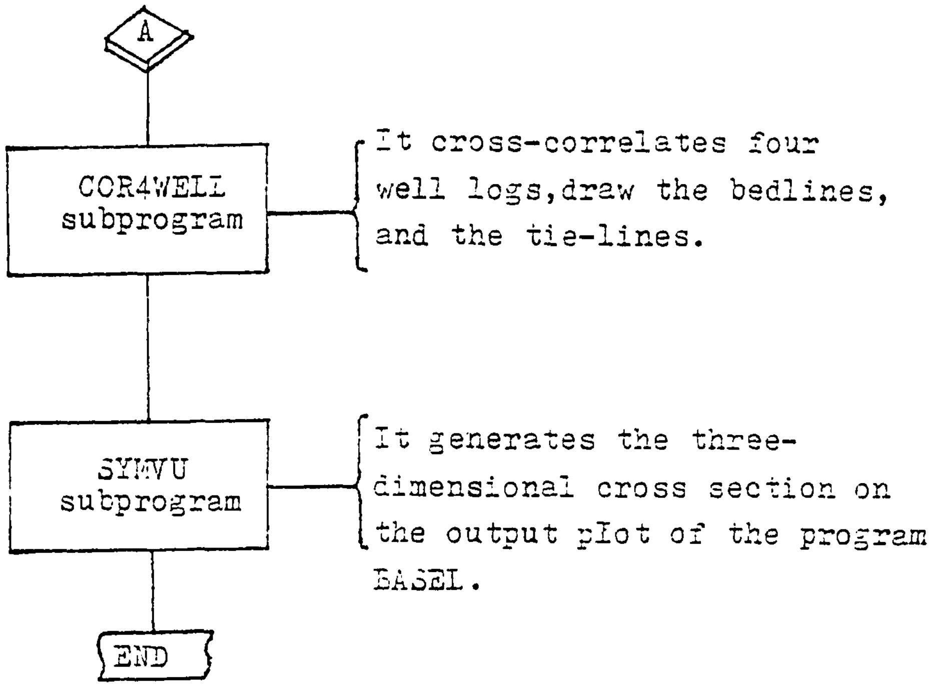
```
     1CMAX2,IDEP,IORG)
C
C   STRETCH THE LONG LOG (LOG2) BY THE FFT INTERPOLATION
C   METHOD AND CROSS-CORRELATE WITH THE SHORT LOG (LOG1)
C   FIND THE MAXIMUM CORRELATION COEFFICIENT.
C
      DIMENSION CLOG1(800),CLOG2(800), WORK(1600),XCOR(800)
      COMPLEX CLOG2,CLOG1
      REWIND 13
      LSP1=LS+1
      LLP1=LL+1
      READ(13)  (CLOG1(I),I=1,LSP1)
      READ(13)  (CLOG2(I),I=1,LLP1)
      IF (IDEP.EQ.0.OR.IORG.NE.0) GO TO 1
      READ(13)  (CLOG1(I),I=1,LS)
      READ(13)  (CLOG2(I),I=1,LL)
 1    M=FLOAT(LL)*ST+0.5
      CALL NORMAL (CLOG1,WORK,XCOR,LS)
      CALL NORMAL (CLOG2,WORK,XCOR,LL)
      CALL STRTCH  (CLOG2,WORK,LL,M)
      CALL CROSS2 (CLOG1,CLOG2,XCOR,LS,M,ML2)
      CALL MAX (XCOR,1,ML2,ID2,CMAX2)
      RETURN
      END
C
C
      SUBROUTINE TLINE (XORG,YORG,X,Y,NP,K,ANG)
C
C   THIS SUBROUTINE IS PROVIDED FOR THE ROTATION AND THE TRANSLATION
C   OF THE WELL LOG PLOTS.
C  LOG PLOTS.
C
      DIMENSION X(1), Y(1)
      KA= IABS(K)
      NN= NP*KA+1
      XS= X(NN)
      XD= X(NN+KA)
      YS= Y(NN)
      YD= Y(NN+KA)
      II= 3
      N= 1
      CO= COS(ANG/180.*3.14159)
      SI= SIN(ANG/180.*3.14159)
   25 XX= (X(N)-XS)/XD
      YY= (Y(N)-YS)/YD
      XN= CO*XX - SI*YY + XORG
      YN= SI*XX + CO*YY + YORG
      CALL PLOT (XN,YN,II)
      II= 2
      N= N+KA
      IF (N.LT.NN) GO TO 25
      CALL PLOT (XN,YN,3)
      RETURN
      END
```

APPENDIX II

Flow Diagram of the Program BASEL

FLOW DIAGRAM OF BASEL PROGRAM




A
COR4WELL
subprogram
It cross-correlates four
well logs,draw the bedlines,
and the tie-lines.
SYMVU
subprogram
It generates the three-
dimensional cross section on
the output plot of the program
BASEL.
END

APPENDIX III

Input cards of the program BASEL-test case-

The input data consist of four density logs (Rudman and others, 1978). These logs are digitized at two foot intervals. Input cards are:

1. Y and X coordinates of control points of the structure map: These coordinates should be entered as Y and X according to the FORMAT (10X, 2F10.0).

2. Signal card: Exclamation points in column 1-2. This card indicates the end of the data introduced as Y and X coordinates.

3. Depth value for each of the control points of the structure map: These depth values are entered either as positive numbers; if the structure studies are below sea level; or negative numbers, if the structure is above sea level. FORMAT (10X, F10.0).

4. Signal card: as in 2 indicating the end of the depth values.

5. SYMAP title cards: required three cards:

   a. name of the structure map

   b. scale of the map

   c. size of the map

These cards are introduced according to the FORMAT (20A4) or they may be left blank.

6. Signal card: implies the end of the SYMAP data.

7. Location of wells: sequence number of the (X, Y) coordinate pair corresponding to each well. FORMAT (4I10)

8. Height of three-dimensional cross section: It represents the required exaggeration of the vertical scale. This value is a positive number confined between 1 and 11. FORMAT (F10.4)

9. COR4WELL title card: It contains information required to be printed on the calcomp output. FORMAT (20A4)

10. COR4WELL control variables

LS = number of data points of the short logs.

LL = number of data points of the long logs.

IDER = 1 Derivative is wanted to compute power spectra.

= 0 Derivative is not wanted.

IORG = 1 Original data is wanted for stretching and following correlation.

= 0 Derivative data is wanted for stretching and following correlation.

SMAX = Maximum anticipated stretch value. This value is determined according to the change of bed thickness between the correlated wells (i.e., if the thickness is 20 feet on one side and 10 feet on the other so SMAX = 2).

SINT = Digitization of the intervals in feet.

PRALL = If nonzero, derivatives of log data, power spectra, and interpolated spectra are all printed out.

FORMAT (4I5, 3F5.0).

11. Log depths: These values indicate the depth or the height of the correlated segments below or above the sea level respectively. The data is entered as log A, log B, log C, and log D. These values are either positive numbers, if the structure is below the sea level; or negative values, if the structure is above the sea level. FORMAT (4F10.2).

12. Thickness of beds:

THICAB = Thickness of the correlated bed between well A and well B.

THICCD = Thickness of the correlated bed between well C and well D.

FORMAT (2F10.2)

13. Data values of four logs: These values are entered in the following order:

Log A well A, short log
Log B well B, long log
Log C well C, short log
Log D well D, long log
FORMAT (F10.3)

In order to further illustrate the order of the input cards, the following diagram is provided:

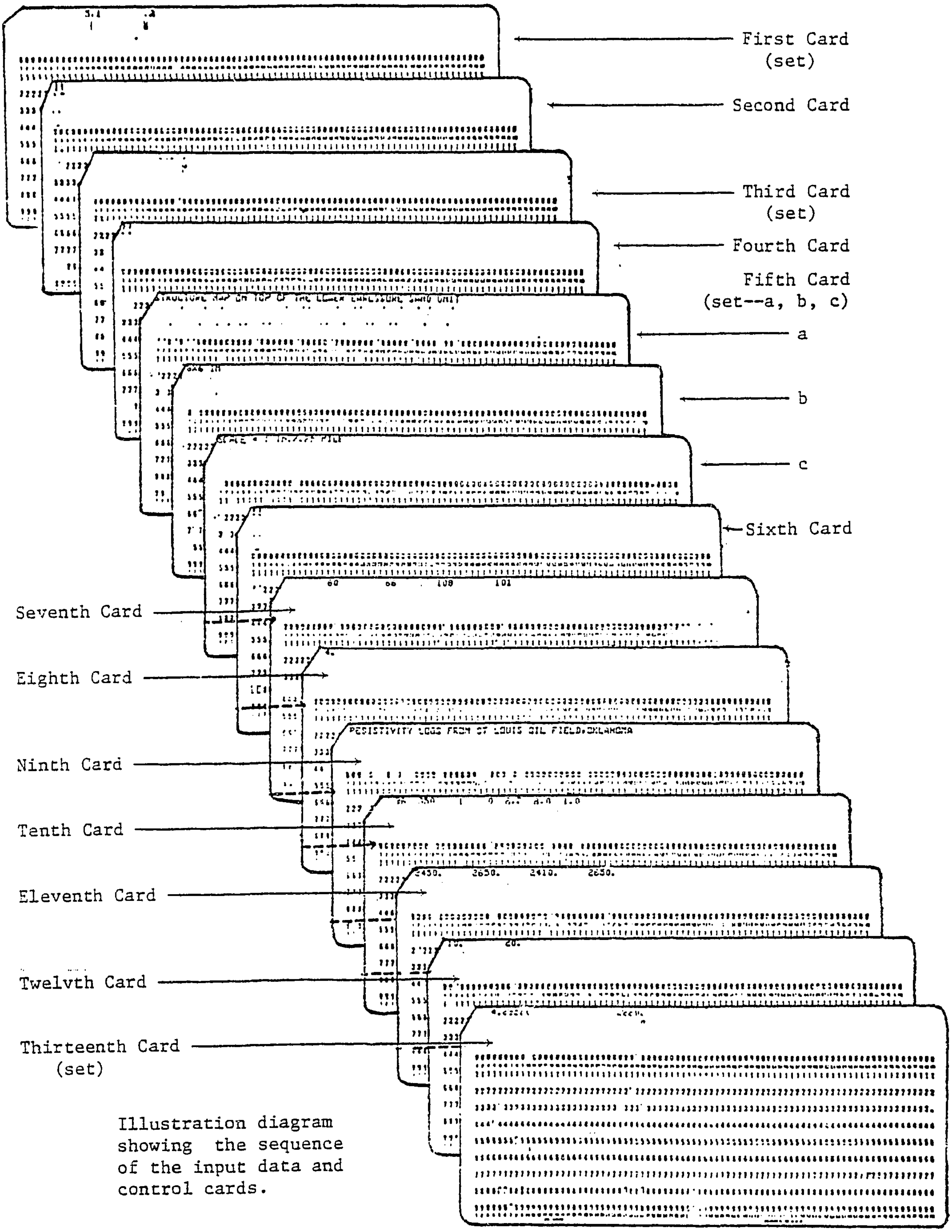


Illustration diagram showing the sequence of the input data and control cards.

The input data and the output print of the test data are given in the following pages. The calcomp output is illustrated in Figure 31.

SYMAP. VERSION 5.20

LABORATORY FOR COMPUTER GRAPHICS AND SPATIAL ANALYSIS
GRADUATE SCHOOL OF DESIGN
HARVARD UNIVERSITY
CAMBRIDGE, MASSACHUSETTS 02138
UNITED STATES OF AMERICA

TIME = 624.5

F-MAP

RESISTIVITY LOGS

FRAME SIZE: 10 X 6 IN.

SCALE: 4 IN. / MILE

ELECTIVE

```
    3 NUMBER OF VALUE CLASS INTERVALS IS 10
   21 SYMVU TAPE CREATED AND DATA POINTS PUNCHED
   28 POINT DISTRIBUTION COEFFICIENT

 0.054688 MINUTES FOR INPUT
```

B-DATA POINTS
----

273 DATA POINTS

E-VALUES
----

275 VALUES

MAP 1

RESISTIVITY LOGS
FRAME SIZE: 10 X 6 IN.
SCALE: 4 IN. / MILE

MAP WINDOW DISPLAYED IS
(0.0 , 0.0) (TOP-LEFT CORNER)
(5.962, 10.000) (BOTTOM-RIGHT CORNER)

MAP SCALE = 1.3000 (INCHES ON OUTPUT MAP)/(UNITS ON SOURCE MAP)

MAP SHOULD BE PRINTED AT 8.0 ROWS PER INCH AND 10.0 COLUMNS PER INCH

TRANSFORMATION FROM SOURCE COORDINATES TO PRINT CHARACTER LOCATION IS
ROW = DOWN COORDINATE * 10.4000
COLUMN = ACROSS COORDINATE * 13.0000

THERE ARE 273 VALID DATA VALUES

MINIMUM AND MAXIMUM VALID DATA VALUES ARE -3990.000 AND -3500.000

MEAN OF VALID DATA IS -3726.996

STANDARD DEVIATION OF VALID DATA IS 124.980

DATA POINTS FOR MAP

POINT	ROW	COLUMN	DATUM	VALUE	LEVEL
1)	0	0	1	-3925.00	2
2)	0	6	2	-3900.00	2
3)	0	13	3	-3900.00	2
4)	0	19	4	-3900.00	2
5)	0	26	5	-3800.00	4
6)	0	32	6	-3800.00	4
7)	0	39	7	-3750.00	5
8)	0	45	8	-3750.00	5
9)	0	52	9	-3750.00	5
10)	0	58	10	-3725.00	6
11)	0	65	11	-3700.00	6
12)	0	71	12	-3700.00	6
13)	0	78	13	-3700.00	6
14)	0	84	14	-3650.00	7
15)	0	91	15	-3650.00	7
16)	0	97	16	-3600.00	8
17)	0	104	17	-3600.00	8
18)	0	110	18	-3550.00	9
19)	0	117	19	-3550.00	9
20)	0	123	20	-3500.00	10
21)	0	130	21	-3500.00	10
22)	5	0	22	-3875.00	3
23)	5	6	23	-3850.00	3
24)	5	13	24	-3850.00	3

25)	5	19	25	-3850.00	3
26)	5	26	26	-3700.00	6
27)	5	32	27	-3650.00	7
28)	5	39	28	-3700.00	6
29)	5	45	29	-3700.00	6
30)	5	52	30	-3700.00	6
31)	5	58	31	-3700.00	6
32)	5	65	32	-3675.00	7
33)	5	71	33	-3675.00	7
34)	5	78	34	-3675.00	7
35)	5	84	35	-3675.00	7
36)	5	91	36	-3675.00	7
37)	5	97	37	-3650.00	7
38)	5	104	38	-3650.00	7
39)	5	110	39	-3650.00	7
40)	5	117	40	-3650.00	7
41)	5	123	41	-3600.00	8
42)	5	130	42	-3550.00	9
43)	10	0	43	-3825.00	4
44)	10	6	44	-3800.00	4
45)	10	13	45	-3800.00	4
46)	10	19	46	-3800.00	4
47)	10	26	47	-3750.00	5
48)	10	32	48	-3700.00	6
49)	10	39	49	-3700.00	6
50)	10	45	50	-3650.00	7
51)	10	52	51	-3650.00	7
52)	10	58	52	-3700.00	6
53)	10	65	53	-3675.00	7
54)	10	71	54	-3650.00	7
55)	10	78	55	-3650.00	7
56)	10	84	56	-3675.00	7
57)	10	91	57	-3650.00	7
58)	10	97	58	-3600.00	8
59)	10	104	59	-3600.00	8
60)	10	110	60	-3650.00	7
61)	10	117	61	-3600.00	8
62)	10	123	62	-3550.00	9
63)	10	130	63	-3500.00	10
64)	16	0	64	-3800.00	4
65)	16	6	65	-3750.00	5
66)	16	13	66	-3750.00	5
67)	16	19	67	-3750.00	5
68)	16	26	68	-3800.00	4
69)	16	32	69	-3750.00	5
70)	16	39	70	-3700.00	6
71)	16	45	71	-3650.00	7
72)	16	52	72	-3650.00	7
73)	16	58	73	-3700.00	6
74)	16	65	74	-3675.00	7
75)	16	71	75	-3650.00	7
76)	16	78	76	-3650.00	7
77)	16	84	77	-3675.00	7
78)	16	91	78	-3650.00	7
79)	16	97	79	-3600.00	8
80)	16	104	80	-3600.00	8
81)	16	110	81	-3650.00	7
82)	16	117	82	-3600.00	8
83)	16	123	83	-3550.00	9
84)	16	130	84	-3500.00	10
85)	21	0	85	-3825.00	4
86)	21	6	86	-3800.00	4
87)	21	13	87	-3800.00	4
88)	21	19	88	-3800.00	4
89)	21	26	89	-3850.00	3
90)	21	32	90	-3800.00	4

91)	21	39	91	-3700.00	6
92)	21	45	92	-3700.00	6
93)	21	52	93	-3700.00	6
94)	21	58	94	-3700.00	6
95)	21	65	95	-3675.00	7
96)	21	71	96	-3675.00	7
97)	21	78	97	-3675.00	7
98)	21	84	98	-3675.00	7
99)	21	91	99	-3650.00	7
100)	21	97	100	-3650.00	7
101)	21	104	101	-3650.00	7
102)	21	110	102	-3650.00	7
103)	21	117	103	-3600.00	8
104)	21	123	104	-3550.00	9
105)	21	130	105	-3500.00	10
106)	26	0	106	-3875.00	3
107)	26	6	107	-3850.00	3
108)	26	13	108	-3850.00	3
109)	26	19	109	-3850.00	3
110)	26	26	110	-3900.00	2
111)	26	32	111	-3850.00	3
112)	26	39	112	-3900.00	4
113)	26	45	113	-3775.00	5
114)	26	52	114	-3725.00	6
115)	26	58	115	-3750.00	5
116)	26	65	116	-3700.00	6
117)	26	71	117	-3700.00	6
118)	26	78	118	-3675.00	7
119)	26	84	119	-3600.00	8
120)	26	91	120	-3600.00	8
121)	26	97	121	-3600.00	8
122)	26	104	122	-3600.00	8
123)	26	110	123	-3600.00	8
124)	26	117	124	-3600.00	8
125)	26	123	125	-3550.00	9
126)	26	130	126	-3500.00	10
127)	31	0	127	-3830.00	4
128)	31	6	128	-3880.00	3
129)	31	13	129	-3850.00	2
130)	31	19	130	-3900.00	2
131)	31	26	131	-3950.00	1
132)	31	32	132	-3900.00	2
133)	31	39	133	-3850.00	3
134)	31	45	134	-3800.00	4
135)	31	52	135	-3750.00	5
136)	31	58	136	-3700.00	6
137)	31	65	137	-3700.00	6
138)	31	71	138	-3700.00	6
139)	31	78	139	-3700.00	6
140)	31	84	140	-3650.00	7
141)	31	91	141	-3650.00	7
142)	31	97	142	-3650.00	7
143)	31	104	143	-3600.00	8
144)	31	110	144	-3600.00	8
145)	31	117	145	-3550.00	9
146)	31	123	146	-3500.00	10
147)	31	130	147	-3500.00	10
148)	36	0	148	-3925.00	4
149)	36	6	149	-3825.00	4
150)	36	13	150	-3900.00	2
151)	36	19	151	-3950.00	1
152)	36	26	152	-3980.00	1
153)	36	32	153	-3980.00	1
154)	36	39	154	-3900.00	2
155)	36	45	155	-3850.00	3
156)	36	52	156	-3800.00	4

157)	36	58	157	-3750.00	5
158)	36	65	158	-3750.00	5
159)	36	71	159	-3750.00	5
160)	36	78	160	-3700.00	6
161)	36	84	161	-3650.00	7
162)	36	91	162	-3650.00	7
163)	36	97	163	-3650.00	7
164)	36	104	164	-3600.00	8
165)	36	110	165	-3650.00	7
166)	36	117	166	-3600.00	8
167)	36	123	167	-3550.00	9
168)	36	130	168	-3500.00	10
169)	42	0	169	-3875.00	3
170)	42	6	170	-3875.00	3
171)	42	13	171	-3950.00	1
172)	42	19	172	-3970.00	1
173)	42	26	173	-3980.00	1
174)	42	32	174	-3980.00	1
175)	42	39	175	-3950.00	1
176)	42	45	176	-3900.00	2
177)	42	52	177	-3850.00	3
178)	42	58	178	-3800.00	4
179)	42	65	179	-3800.00	4
180)	42	71	180	-3800.00	4
181)	42	78	181	-3750.00	5
182)	42	84	182	-3700.00	6
183)	42	91	183	-3700.00	6
184)	42	97	184	-3700.00	6
185)	42	104	185	-3650.00	7
186)	42	110	186	-3600.00	8
187)	42	117	187	-3650.00	7
188)	42	123	188	-3600.00	8
189)	42	130	189	-3500.00	10
190)	47	0	190	-3825.00	4
191)	47	6	191	-3825.00	4
192)	47	13	192	-3900.00	2
193)	47	19	193	-3910.00	2
194)	47	26	194	-3980.00	1
195)	47	32	195	-3980.00	1
196)	47	39	196	-3900.00	2
197)	47	45	197	-3850.00	3
198)	47	52	198	-3800.00	4
199)	47	58	199	-3750.00	5
200)	47	65	200	-3750.00	5
201)	47	71	201	-3750.00	5
202)	47	78	202	-3700.00	6
203)	47	84	203	-3650.00	7
204)	47	91	204	-3650.00	7
205)	47	97	205	-3650.00	7
206)	47	104	206	-3600.00	8
207)	47	110	207	-3650.00	7
208)	47	117	208	-3600.00	8
209)	47	123	209	-3550.00	9
210)	47	130	210	-3500.00	10
211)	52	0	211	-3860.00	3
212)	52	6	212	-3880.00	3
213)	52	13	213	-3890.00	2
214)	52	19	214	-3900.00	2
215)	52	26	215	-3950.00	1
216)	52	32	216	-3900.00	2
217)	52	39	217	-3850.00	3
218)	52	45	218	-3800.00	4
219)	52	52	219	-3750.00	5
220)	52	58	220	-3700.00	6
221)	52	65	221	-3750.00	5
222)	52	71	222	-3700.00	6

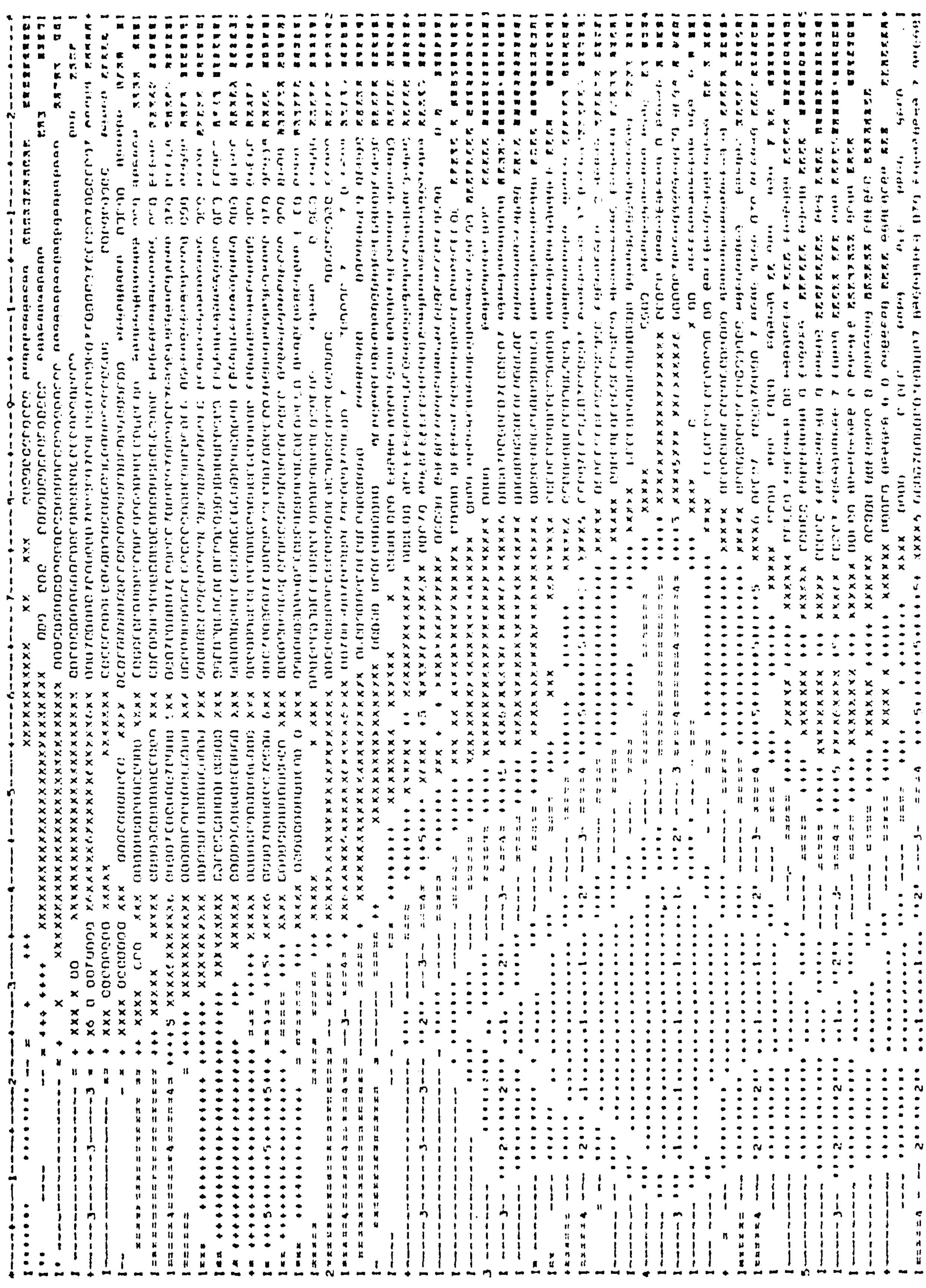
223)	52	78	223	-3650.00	7
224)	52	84	224	-3600.00	8
225)	52	91	225	-3650.00	7
226)	52	97	226	-3600.00	8
227)	52	104	227	-3550.00	9
228)	52	110	228	-3600.00	8
229)	52	117	229	-3550.00	9
230)	52	123	230	-3500.00	10
231)	52	130	231	-3500.00	10
232)	57	0	232	-3825.00	4
233)	57	6	233	-3825.00	4
234)	57	13	234	-3900.00	2
235)	57	19	235	-3910.00	2
236)	57	26	236	-3980.00	1
237)	57	32	237	-3980.00	1
238)	57	39	238	-3900.00	2
239)	57	45	239	-3850.00	3
240)	57	52	240	-3800.00	4
241)	57	58	241	-3750.00	5
242)	57	65	242	-3750.00	5
243)	57	71	243	-3750.00	5
244)	57	78	244	-3700.00	6
245)	57	84	245	-3650.00	7
246)	57	91	246	-3650.00	7
247)	57	97	247	-3650.00	7
248)	57	104	248	-3600.00	8
249)	57	110	249	-3650.00	7
250)	57	117	250	-3600.00	8
251)	57	123	251	-3650.00	7
252)	57	130	252	-3600.00	8
253)	62	0	253	-3550.00	9
254)	62	6	254	-3500.00	10
255)	62	13	255	-3875.00	3
256)	62	19	256	-3875.00	3
257)	62	26	257	-3900.00	2
258)	62	32	258	-3900.00	2
259)	62	39	259	-3980.00	1
260)	62	45	260	-3980.00	1
261)	62	52	261	-3950.00	1
262)	62	58	262	-3900.00	2
263)	62	65	263	-3850.00	3
264)	62	71	264	-3800.00	4
265)	62	78	265	-3800.00	4
266)	62	84	266	-3800.00	4
267)	62	91	267	-3750.00	5
268)	62	97	268	-3700.00	6
269)	62	104	269	-3700.00	6
270)	62	110	270	-3700.00	6
271)	62	117	271	-3650.00	7
272)	62	123	272	-3700.00	6
273)	62	130	273	-3650.00	7

POINT DISTRIBUTION COEFFICIENT IS 2.06

DISTRIBUTION IS RANDOM TO UNIFORM
AREA USED FOR CALCULATION IS 59.615
NUMBER OF POINTS USED FOR CALCULATION IS 252
MAP WINDOW USED FOR CALCULATION IS
(0.0 , 0.0) (TOP-LEFT CORNER)
(5.962, 10.000) (BOTTOM-RIGHT CORNER)

STANDARD SEARCH RADIUS IS 0.7537

0.460693 MINUTES FOR INITIAL CALCULATIONS



```
I     + = -  '''''''''' ............ '''''  ----   ===   +++++++++++++++ XXXXX    000000000000000  8888888 0000 8888888 0 0 88881
I++ X + + = -  ''''''''''  ............   '''    --- = ==== +        +++++++      XXXX 0         0000000        000000 00000 00000  881
6  0 8 8 X = ' ''' '''''          ........    ''''   ' -     - =======       ++++++     + XXXXXXXX    000000000000 00000       0000 000  6
I 8 0 8 8 X = - ' --  '''''''''''''' ..........     ... ' '''' -     ========= ++++++++  =      XXXXXX 000000000 X 00000000000 X 00001
+-----+-----1-----+-----2-----+-----3-----+-----4-----+-----5-----+-----6-----+-----7-----+-----8-----+-----9-----+-----1-----+-----1-----+-----2-----+-----+
SYMAP
```

1.127666 MINUTES FOR MAP

RESISTIVITY LOGS

FRAME SIZE: 10 X 6 IN.

SCALE: 4 IN. / MILE

DATA VALUE EXTREMES ARE -3980.00 -3500.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	-3980.00	-3932.00	-3884.00	-3836.00	-3788.00	-3740.00	-3692.00	-3644.00	-3596.00	-3548.00
MAXIMUM	-3932.00	-3884.00	-3836.00	-3788.00	-3740.00	-3692.00	-3644.00	-3596.00	-3548.00	-3500.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

```
LEVEL          1         2         3         4         5         6         7         8         9        10
         ===================================================================================================
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  888888888  888888888  888888888
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  888888888  888888888  888888888
SYMBOLS    ....1....  ''''2''''  ----3----  ====4====  ++++5++++  XXXX6XXXX  0000700000 888888888  888888888  888888888
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  888888888  888888888  888888888
           .........  '''''''''  ---------  =========  +++++++++  XXXXXXXXX  000000000  888888888  888888888  888888888
         ===================================================================================================
FREQ.         17        23        24        32        24        37        59        30        13        14
      1    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      2    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      3    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      4    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      5    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      6    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      7    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      8    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
      9    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
     10    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
     11    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
     12    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
     13    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I   I888881   I88888I
     14    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I              I88888I
     15    I..I..I   I''2''I   I--3--I   I==4==I   I++5++I   IXX6XXI   I00700I   I88888I
```

```
16  I..1..I  I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
17  I..1..I  I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
18           I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
19           I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
20           I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
21           I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
22           I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
23           I**2**I  I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
24                    I--3--I  I==4==I  I++5++I  IXX6XXI  IOO7OOI  I88888I
25                             I==4==I           IXX6XXI  IOO7OOI  I88888I
26                             I==4==I           IXX6XXI  IOO7OOI  I88888I
27                             I==4==I           IXX6XXI  IOO7OOI  I88888I
28                             I==4==I           IXX6XXI  IOO7OOI  I88888I
29                             I==4==I           IXX6XXI  IOO7OOI  I88888I
30                             I==4==I           IXX6XXI  IOO7OOI  I88888I
31                             I==4==I           IXX6XXI  IOO7OOI
32                             I==4==I           IXX6XXI  IOO7OOI
33                                               IXX6XXI  IOO7OOI
34                                               IXX6XXI  IOO7OOI
35                                               IXX6XXI  IOO7OOI
36                                               IXX6XXI  IOO7OOI
37                                               IXX6XXI  IOO7OOI
38                                                        IOO7OOI
39                                                        IOO7OOI
40                                                        IOO7OOI
41                                                        IOO7OOI
42                                                        IOO7OOI
43                                                        IOO7OOI
44                                                        IOO7OOI
45                                                        IOO7OOI
46                                                        IOO7OOI
47                                                        IOO7OOI
48                                                        IOO7OOI
49                                                        IOO7OOI
50                                                        IOO7OOI
51                                                        IOO7OOI
52                                                        IOO7OOI
53                                                        IOO7OOI
54                                                        IOO7OOI
55                                                        IOO7OOI
56                                                        IOO7OOI
57                                                        IOO7OOI
58                                                        IOO7OOI
59                                                        IOO7OOI

0.149414 MINUTES FOR HISTOGRAM
```

```
  1 MAPS HAVE BEEN PRODUCED
END OF JOB
```

WELL POSITION DATA FROM SYMAP

WELL	ROW	COLUMN	Y-COOR	X-COOR
+A	21	129	1.56	10.00
+B	31	1	2.34	0.0
+C	52	129	3.98	10.00
+D	52	1	3.98	0.0

NUMBER OF ROWS = 61 NUMBER OF COLUMNS = 129

COR4WELL

DEEP SEA DENSITY LOG: SHORT LOG STRETCHED 1.35 TIMES

LS= 130 LL= 350 IDER= 1 IORG= 0 SMAX= 2.0 SINT= 2.0
DEPTH OF LOG A= 3300.0 FEET
DEPTH OF LOG B = 3320.0 FEET
DEPTH OF LOG C = 3300.0 FEET
DEPTH OF LOG D = 3350.0 FEET
THICKNESS OF A - B BED = 20.00
THICKNESS OF C - D BED = 20.00

INPUT DATA

	LOG A		LOG B	
1	1.184	1.184	1.230	1.230
2	0.723	0.723	1.260	1.260
3	0.481	0.481	1.250	1.250
4	0.681	0.681	1.300	1.300
5	1.086	1.086	1.410	1.410
6	1.233	1.233	1.350	1.350
7	1.026	1.026	1.120	1.120
8	1.001	1.001	1.110	1.110
9	1.090	1.090	1.050	1.050
10	1.072	1.072	1.140	1.140
11	1.123	1.123	1.200	1.200
12	1.067	1.067	1.290	1.290
13	0.954	0.954	1.070	1.070
14	0.961	0.961	1.080	1.080
15	0.939	0.939	0.830	0.830
16	1.053	1.053	1.050	1.050
17	1.171	1.171	1.200	1.200
18	0.973	0.973	1.280	1.280
19	0.699	0.699	1.270	1.270
20	0.472	0.472	1.310	1.310
21	0.745	0.745	1.350	1.350
22	1.527	1.527	1.330	1.330
23	1.225	1.225	1.250	1.250
24	0.010	0.010	1.410	1.410
25	0.0	0.0	1.420	1.420
26	0.492	0.492	1.400	1.400
27	0.495	0.495	1.360	1.360
28	0.625	0.625	1.420	1.420
29	0.884	0.884	1.440	1.440
30	0.657	0.657	1.260	1.260
31	0.567	0.567	1.320	1.320
32	0.804	0.804	1.380	1.380
33	0.839	0.839	1.340	1.340
34	0.876	0.876	1.320	1.320
35	0.986	0.986	1.330	1.330
36	0.848	0.848	1.010	1.010
37	0.774	0.774	1.150	1.150
38	0.914	0.914	1.350	1.350
39	0.976	0.976	1.350	1.350
40	1.127	1.127	1.150	1.150
41	1.337	1.337	1.220	1.220
42	1.241	1.241	1.300	1.300
43	1.134	1.134	1.310	1.310
44	1.329	1.329	1.340	1.340
45	1.472	1.472	1.350	1.350
46	1.357	1.357	1.400	1.400

47	1.260	1.260	1.390	1.390
48	1.331	1.331	1.280	1.280
49	1.325	1.325	1.310	1.310
50	1.210	1.210	1.330	1.330
51	1.277	1.277	1.150	1.150
52	1.392	1.392	1.170	1.170
53	1.316	1.316	1.190	1.190
54	1.311	1.311	0.890	0.890
55	1.427	1.427	0.940	0.940
56	1.334	1.334	0.780	0.780
57	1.062	1.062	0.680	0.680
58	0.963	0.963	0.730	0.730
59	1.059	1.059	0.690	0.690
60	1.098	1.098	0.520	0.520
61	1.164	1.164	0.020	0.020
62	1.348	1.348	0.440	0.440
63	1.382	1.382	0.150	0.150
64	1.354	1.354	0.130	0.130
65	1.472	1.472	0.060	0.060
66	1.439	1.439	0.180	0.180
67	1.132	1.132	0.540	0.640
68	0.841	0.841	0.360	0.350
69	0.823	0.823	0.160	0.160
70	1.057	1.057	0.330	0.330
71	1.257	1.257	0.590	0.590
72	1.341	1.341	0.260	0.260
73	1.309	1.309	0.110	0.110
74	1.159	1.159	0.150	0.150
75	1.153	1.153	0.060	0.060
76	1.186	1.186	0.550	0.550
77	1.053	1.053	0.560	0.560
78	0.927	0.927	0.320	0.320
79	0.674	0.674	0.110	0.110
80	0.566	0.566	0.050	0.050
81	1.017	1.017	0.280	0.280
82	1.317	1.317	0.180	0.130
83	1.331	1.331	0.640	0.640
84	1.438	1.438	0.540	0.340
85	1.103	1.103	0.460	0.460
86	0.709	0.709	0.660	0.660
87	0.972	0.972	0.820	0.820
88	1.264	1.264	1.020	1.020
89	1.325	1.325	0.670	0.670
90	1.297	1.297	0.890	0.890
91	1.163	1.163	1.600	1.600
92	1.156	1.156	1.460	1.460
93	0.959	0.959	1.570	1.570
94	0.754	0.754	1.280	1.280
95	1.119	1.119	1.040	1.040
96	0.971	0.971	1.160	1.160
97	0.065	0.065	1.700	1.700
98	0.027	0.027	0.990	0.590
99	0.781	0.781	1.550	1.550
100	1.109	1.108	1.050	1.050
101	1.080	1.080	0.980	0.980
102	1.211	1.211	0.770	0.770
103	1.348	1.348	0.850	0.850
104	1.057	1.057	0.940	0.940
105	0.695	0.695	1.040	1.040
106	0.925	0.925	1.120	1.120
107	1.297	1.297	0.980	0.980
108	1.223	1.223	1.050	1.050
109	1.059	1.059	1.480	1.480
110	1.200	1.200	1.640	1.640
111	1.333	1.333	0.950	0.950
112	1.139	1.139	1.450	1.450

113	1.103	1.103	1.460	1.460
114	1.246	1.246	1.320	1.320
115	0.768	0.768	1.590	1.590
116	0.152	0.152	1.160	1.160
117	0.237	0.237	1.510	1.510
118	0.590	0.590	1.690	1.690
119	0.955	0.955	1.580	1.580
120	1.170	1.170	1.020	1.020
121	1.019	1.019	1.130	1.130
122	1.065	1.065	1.330	1.330
123	1.145	1.145	1.130	1.130
124	0.697	0.697	1.330	1.330
125	0.361	0.361	0.630	0.630
126	0.548	0.549	0.870	0.870
127	0.909	0.909	0.640	0.640
128	1.138	1.138	0.660	0.660
129	1.003	1.003	0.950	0.950
130	0.755	0.755	0.880	0.880
131			1.080	1.080
132			1.180	1.180
133			1.070	1.070
134			1.300	1.300
135			0.700	0.700
136			0.750	0.750
137			0.950	0.950
138			0.980	0.980
139			1.060	1.060
140			0.960	0.960
141			1.200	1.200
142			1.150	1.150
143			1.040	1.040
144			0.950	0.950
145			1.220	1.220
146			1.090	1.080
147			1.230	1.230
148			1.370	1.370
149			1.480	1.480
150			1.390	1.390
151			1.480	1.480
152			1.460	1.460
153			1.420	1.420
154			1.080	1.080
155			1.160	1.160
156			1.190	1.190
157			1.220	1.220
158			1.360	1.360
159			1.330	1.330
160			1.190	1.180
161			1.230	1.230
162			1.260	1.260
163			1.260	1.260
164			1.290	1.290
165			1.400	1.400
166			1.340	1.340
167			1.160	1.160
168			1.340	1.340
169			1.300	1.300
170			1.230	1.230
171			1.310	1.310
172			1.290	1.290
173			1.140	1.140
174			0.980	0.980
175			1.180	1.180
176			1.260	1.260
177			1.160	1.160
178			0.790	0.790

179	1.240	1.240
180	0.990	0.990
181	0.780	0.780
182	0.830	0.830
183	1.060	1.060
184	1.160	1.160
185	1.120	1.120
186	1.180	1.180
187	0.580	0.580
188	0.590	0.590
189	1.110	1.110
190	1.160	1.160
191	0.980	0.980
192	1.090	1.090
193	1.090	1.090
194	1.090	1.090
195	0.950	0.950
196	0.950	0.950
197	1.030	1.030
198	1.150	1.150
199	0.810	0.810
200	0.480	0.480
201	0.970	0.970
202	1.530	1.530
203	0.020	0.020
204	0.140	0.140
205	0.530	0.530
206	0.640	0.640
207	0.840	0.840
208	0.540	0.540
209	0.820	0.820
210	0.830	0.830
211	0.980	0.980
212	0.820	0.820
213	0.840	0.840
214	0.970	0.970
215	1.190	1.130
216	1.320	1.320
217	1.130	1.130
218	1.390	1.390
219	1.420	1.420
220	1.260	1.260
221	1.350	1.350
222	1.240	1.240
223	1.280	1.280
224	1.380	1.380
225	1.290	1.290
226	1.430	1.430
227	1.220	1.220
228	0.960	0.960
229	1.070	1.070
230	1.110	1.110
231	1.320	1.320
232	1.370	1.370
233	1.410	1.410
234	1.460	1.460
235	1.050	1.050
236	0.790	0.790
237	1.040	1.040
238	1.290	1.290
239	1.340	1.340
240	1.160	1.160
241	1.180	1.180
242	1.100	1.100
243	0.920	0.920
244	0.570	0.570

245	0.880	0.880
246	1.320	1.320
247	1.390	1.390
248	1.210	1.210
249	0.710	0.710
250	1.160	1.160
251	1.320	1.320
252	1.270	1.270
253	1.150	1.150
254	0.990	0.990
255	0.910	0.810
256	1.170	1.170
257	0.090	0.090
258	0.250	0.250
259	1.070	1.070
260	1.080	1.080
261	1.290	1.290
262	1.180	1.180
263	0.690	0.690
264	1.120	1.120
265	1.270	1.270
266	1.060	1.060
267	1.300	1.300
268	1.180	1.180
269	1.140	1.140
270	1.080	1.090
271	0.190	0.190
272	0.320	0.320
273	0.800	0.800
274	1.170	1.170
275	0.990	0.990
276	1.170	1.170
277	0.700	0.700
278	0.380	0.390
279	0.900	0.800
280	1.140	1.140
281	0.890	0.890
282	0.700	0.700
283	0.930	0.830
284	1.140	1.140
285	1.190	1.190
286	1.290	1.290
287	1.210	1.210
288	1.350	1.350
289	1.370	1.370
290	1.470	1.470
291	1.450	1.450
292	1.340	1.340
293	1.160	1.160
294	1.250	1.250
295	1.070	1.070
296	1.270	1.270
297	1.340	1.340
298	1.200	1.200
299	1.340	1.340
300	1.400	1.400
301	1.300	1.300
302	1.190	1.190
303	1.290	1.290
304	1.320	1.320
305	1.300	1.300
306	1.270	1.270
307	1.190	1.190
308	1.200	1.200
309	1.360	1.360
310	1.260	1.260

311			1.210	1.210
312			1.360	1.360
313			1.260	1.260
314			1.380	1.380
315			1.180	1.180
316			0.970	0.970
317			1.070	1.070
318			1.210	1.210
319			1.290	1.290
320			1.450	1.450
321			1.460	1.460
322			1.430	1.430
323			1.380	1.380
324			1.310	1.310
325			1.450	1.450
326			1.110	1.110
327			1.180	1.180
328			1.320	1.320
329			1.230	1.230
330			1.200	1.200
331			1.260	1.260
332			1.370	1.370
333			1.340	1.340
334			1.220	1.220
335			1.050	1.050
336			0.960	0.850
337			1.100	1.100
338			1.160	1.160
339			1.020	1.020
340			0.980	0.980
341			1.020	1.020
342			1.030	1.030
343			1.180	1.130
344			1.020	1.020
345			1.120	1.120
346			1.170	1.170
347			1.120	1.120
348			1.130	1.130
349			1.160	1.160
350			0.870	0.870

DERIVATIVED DATA

	LOG A		LOG B	
1	-0.461	-0.461	0.030	0.030
2	-0.242	-0.242	-0.010	-0.010
3	0.200	0.200	0.050	0.050
4	0.405	0.405	0.110	0.110
5	0.147	0.147	-0.060	-0.060
6	-0.207	-0.207	-0.230	-0.230
7	-0.025	-0.025	-0.010	-0.010
8	0.089	0.089	-0.060	-0.060
9	-0.018	-0.018	0.090	0.090
10	0.051	0.051	0.060	0.060
11	-0.056	-0.056	0.090	0.090
12	-0.113	-0.113	-0.220	-0.220
13	0.007	0.007	0.010	0.010
14	-0.022	-0.022	-0.250	-0.250
15	0.114	0.114	0.220	0.220
16	0.118	0.118	0.150	0.150
17	-0.198	-0.198	0.080	0.080
18	-0.274	-0.274	-0.010	-0.010
19	-0.227	-0.227	0.040	0.040
20	0.273	0.273	0.040	0.040

21	0.782	0.782	-0.020	-0.020
22	-0.302	-0.302	-0.080	-0.080
23	-1.215	-1.215	0.160	0.160
24	-0.010	-0.010	0.010	0.010
25	0.492	0.492	-0.020	-0.020
26	0.003	0.003	-0.040	-0.040
27	0.130	0.130	0.060	0.060
28	0.259	0.259	0.020	0.020
29	-0.227	-0.227	-0.180	-0.180
30	-0.090	-0.090	0.060	0.060
31	0.237	0.237	0.060	0.060
32	0.035	0.035	-0.040	-0.040
33	0.037	0.037	-0.020	-0.020
34	0.110	0.110	0.010	0.010
35	-0.138	-0.138	-0.320	-0.320
36	-0.074	-0.074	0.140	0.140
37	0.140	0.140	0.200	0.200
38	0.062	0.062	0.0	0.0
39	0.151	0.151	-0.200	-0.200
40	0.210	0.210	0.070	0.070
41	-0.096	-0.096	0.080	0.080
42	-0.107	-0.107	0.010	0.010
43	0.195	0.195	0.030	0.030
44	0.143	0.143	0.010	0.010
45	-0.115	-0.115	0.050	0.050
46	-0.097	-0.097	-0.010	-0.010
47	0.071	0.071	-0.110	-0.110
48	-0.006	-0.006	0.030	0.030
49	-0.115	-0.115	0.020	0.020
50	0.067	0.067	-0.180	-0.180
51	0.115	0.115	0.020	0.020
52	-0.076	-0.076	0.020	0.020
53	-0.005	-0.005	-0.300	-0.300
54	0.116	0.116	0.050	0.050
55	-0.093	-0.093	-0.160	-0.160
56	-0.272	-0.272	-0.100	-0.100
57	-0.099	-0.099	0.050	0.050
58	0.096	0.096	-0.040	-0.040
59	0.039	0.039	-0.170	-0.170
60	0.066	0.066	-0.500	-0.500
61	0.184	0.184	0.420	0.420
62	0.034	0.034	-0.290	-0.290
63	-0.025	-0.025	-0.020	-0.020
64	0.119	0.118	-0.070	-0.070
65	-0.033	-0.033	0.120	0.120
66	-0.307	-0.307	0.460	0.460
67	-0.291	-0.291	-0.280	-0.280
68	-0.019	-0.019	-0.200	-0.200
69	0.234	0.234	0.170	0.170
70	0.200	0.200	0.660	0.660
71	0.084	0.084	-0.730	-0.730
72	-0.032	-0.032	-0.150	-0.150
73	-0.150	-0.150	0.040	0.040
74	-0.006	-0.006	-0.090	-0.090
75	0.033	0.033	0.490	0.490
76	-0.133	-0.133	0.010	0.010
77	-0.126	-0.126	-0.240	-0.240
78	-0.253	-0.253	-0.210	-0.210
79	-0.108	-0.108	-0.060	-0.060
80	0.451	0.451	0.230	0.230
81	0.300	0.300	-0.100	-0.100
82	0.014	0.014	0.460	0.460
83	0.107	0.107	-0.100	-0.100
84	-0.335	-0.335	-0.080	-0.080
85	-0.394	-0.394	0.200	0.200
86	0.263	0.263	0.160	0.160

87	0.292	0.292	0.200	0.200
88	0.061	0.061	-0.350	-0.350
89	-0.028	-0.028	0.220	0.220
90	-0.134	-0.134	0.710	0.710
91	-0.007	-0.007	-0.140	-0.140
92	-0.197	-0.197	0.110	0.110
93	-0.205	-0.205	-0.290	-0.290
94	0.365	0.365	-0.240	-0.240
95	-0.148	-0.148	0.120	0.120
96	-0.906	-0.906	0.540	0.540
97	-0.038	-0.038	-0.710	-0.710
98	0.754	0.754	0.560	0.560
99	0.327	0.327	-0.500	-0.500
100	-0.028	-0.028	-0.070	-0.070
101	0.131	0.131	-0.210	-0.210
102	0.137	0.137	0.080	0.080
103	-0.291	-0.291	0.090	0.090
104	-0.362	-0.362	0.100	0.100
105	0.230	0.230	0.080	0.080
106	0.372	0.372	-0.140	-0.140
107	-0.071	-0.074	0.070	0.070
108	-0.164	-0.164	0.430	0.430
109	0.141	0.141	0.160	0.160
110	0.133	0.133	-0.690	-0.690
111	-0.194	-0.194	0.500	0.500
112	-0.036	-0.036	0.010	0.010
113	0.143	0.143	-0.140	-0.140
114	-0.478	-0.478	0.270	0.270
115	-0.616	-0.616	-0.430	-0.430
116	0.085	0.085	0.350	0.350
117	0.353	0.353	0.180	0.180
118	0.365	0.365	-0.110	-0.110
119	0.215	0.215	-0.360	-0.560
120	-0.151	-0.151	0.110	0.110
121	0.046	0.046	0.200	0.200
122	0.080	0.080	-0.200	-0.200
123	-0.448	-0.448	0.200	0.200
124	-0.336	-0.336	-0.700	-0.700
125	0.187	0.187	0.240	0.240
126	0.361	0.361	-0.230	-0.230
127	0.229	0.229	0.020	0.020
128	-0.135	-0.135	0.290	0.290
129	-0.248	-0.249	-0.070	-0.070
130			0.200	0.200
131			0.100	0.100
132			-0.110	-0.110
133			0.230	0.230
134			-0.600	-0.600
135			0.050	0.050
136			0.200	0.200
137			0.030	0.030
138			0.080	0.080
139			-0.100	-0.100
140			0.240	0.240
141			-0.050	-0.050
142			-0.110	-0.110
143			-0.090	-0.090
144			0.270	0.270
145			-0.140	-0.140
146			0.150	0.150
147			0.140	0.140
148			0.110	0.110
149			-0.090	-0.090
150			0.090	0.090
151			-0.020	-0.020
152			-0.040	-0.040

153	-0.340	-0.340
154	0.080	0.080
155	0.030	0.030
156	0.030	0.030
157	0.140	0.140
158	-0.030	-0.030
159	-0.150	-0.150
160	0.050	0.050
161	0.030	0.030
162	0.0	0.0
163	0.030	0.030
164	0.110	0.110
165	-0.060	-0.060
166	-0.180	-0.180
167	0.180	0.180
168	-0.040	-0.040
169	-0.070	-0.070
170	0.080	0.080
171	-0.020	-0.020
172	-0.150	-0.150
173	-0.160	-0.160
174	0.200	0.200
175	0.080	0.080
176	-0.100	-0.100
177	-0.370	-0.370
178	0.450	0.450
179	-0.250	-0.250
180	-0.210	-0.210
181	0.050	0.050
182	0.230	0.230
183	0.100	0.100
184	-0.040	-0.040
185	0.060	0.060
186	-0.600	-0.600
187	0.010	0.010
188	0.520	0.520
189	0.050	0.050
190	-0.180	-0.180
191	0.110	0.110
192	0.0	0.0
193	0.0	0.0
194	-0.140	-0.140
195	0.0	0.0
196	0.080	0.080
197	0.120	0.120
198	-0.340	-0.340
199	-0.330	-0.330
200	0.490	0.490
201	0.560	0.560
202	-1.510	-1.510
203	0.120	0.120
204	0.390	0.390
205	0.110	0.110
206	0.200	0.200
207	-0.300	-0.300
208	0.280	0.280
209	0.010	0.010
210	0.150	0.150
211	-0.160	-0.160
212	0.020	0.020
213	0.130	0.130
214	0.210	0.210
215	0.140	0.140
216	-0.190	-0.190
217	0.260	0.260
218	0.030	0.030

219	-0.160	-0.160
220	0.090	0.090
221	-0.110	-0.110
222	0.040	0.040
223	0.100	0.100
224	-0.090	-0.090
225	0.140	0.140
226	-0.210	-0.210
227	-0.260	-0.260
228	0.110	0.110
229	0.040	0.040
230	0.210	0.210
231	0.050	0.050
232	0.040	0.040
233	0.050	0.050
234	-0.410	-0.410
235	-0.260	-0.260
236	0.250	0.250
237	0.250	0.250
238	0.050	0.050
239	-0.180	-0.180
240	0.020	0.020
241	-0.080	-0.080
242	-0.180	-0.180
243	-0.350	-0.350
244	0.310	0.310
245	0.440	0.440
246	0.070	0.070
247	-0.180	-0.180
248	-0.500	-0.500
249	0.450	0.450
250	0.160	0.160
251	-0.050	-0.050
252	-0.120	-0.120
253	-0.160	-0.160
254	-0.180	-0.180
255	0.360	0.360
256	-1.080	-1.080
257	0.160	0.160
258	0.820	0.820
259	0.010	0.010
260	0.210	0.210
261	-0.110	-0.110
262	-0.490	-0.490
263	0.430	0.430
264	0.150	0.150
265	-0.210	-0.210
266	0.240	0.240
267	-0.120	-0.120
268	-0.040	-0.040
269	-0.060	-0.060
270	-0.890	-0.890
271	0.130	0.130
272	0.480	0.480
273	0.370	0.370
274	-0.180	-0.180
275	0.180	0.180
276	-0.470	-0.470
277	-0.320	-0.320
278	0.420	0.420
279	0.340	0.340
280	-0.250	-0.250
281	-0.190	-0.190
282	0.130	0.130
283	0.310	0.310
284	0.050	0.050

285	0.100	0.100
286	-0.080	-0.080
287	0.140	0.140
288	0.020	0.020
289	0.100	0.100
290	-0.020	-0.020
291	-0.110	-0.110
292	-0.180	-0.180
293	0.090	0.090
294	-0.180	-0.180
295	0.200	0.200
296	0.070	0.070
297	-0.140	-0.140
298	0.140	0.140
299	0.060	0.060
300	-0.100	-0.100
301	-0.110	-0.110
302	0.100	0.100
303	0.030	0.030
304	-0.020	-0.020
305	-0.030	-0.030
306	-0.090	-0.090
307	0.010	0.010
308	0.160	0.160
309	-0.100	-0.100
310	-0.050	-0.050
311	0.150	0.150
312	-0.100	-0.100
313	0.120	0.120
314	-0.200	-0.200
315	-0.210	-0.210
316	0.100	0.100
317	0.140	0.140
318	0.080	0.080
319	0.160	0.160
320	0.010	0.010
321	-0.030	-0.030
322	-0.050	-0.050
323	-0.070	-0.070
324	0.140	0.140
325	-0.340	-0.340
326	0.070	0.070
327	0.140	0.140
328	-0.090	-0.090
329	-0.030	-0.030
330	0.060	0.060
331	0.110	0.110
332	-0.030	-0.030
333	-0.120	-0.120
334	-0.170	-0.170
335	-0.190	-0.190
336	0.240	0.240
337	0.060	0.060
338	-0.140	-0.140
339	-0.040	-0.040
340	0.040	0.040
341	0.010	0.010
342	0.150	0.150
343	-0.160	-0.160
344	0.100	0.100
345	0.050	0.050
346	-0.050	-0.050
347	0.010	0.010
348	0.030	0.030
349	-0.290	-0.290

POWER SPECTRUM

	LOG A	LOG B	LOG C	LOG D
1	0.000	0.000	0.001	0.001
2	0.001	0.001	0.005	0.005
3	0.002	0.002	0.003	0.003
4	0.002	0.002	0.004	0.004
5	0.002	0.002	0.028	0.028
6	0.003	0.003	0.020	0.020
7	0.002	0.002	0.005	0.005
8	0.001	0.001	0.002	0.002
9	0.001	0.001	0.001	0.001
10	0.003	0.003	0.018	0.018
11	0.005	0.005	0.003	0.003
12	0.003	0.003	0.005	0.005
13	0.000	0.000	0.002	0.002
14	0.005	0.005	0.046	0.046
15	0.012	0.012	0.018	0.018
16	0.009	0.009	0.039	0.039
17	0.004	0.004	0.011	0.011
18	0.013	0.013	0.031	0.031
19	0.016	0.016	0.001	0.001
20	0.006	0.006	0.014	0.014
21	0.002	0.002	0.010	0.010
22	0.006	0.006	0.005	0.005
23	0.004	0.004	0.001	0.001
24	0.002	0.002	0.008	0.008
25	0.003	0.003	0.018	0.018
26	0.003	0.003	0.006	0.006
27	0.004	0.004	0.027	0.027
28	0.002	0.002	0.002	0.002
29	0.001	0.001	0.024	0.024
30	0.017	0.017	0.018	0.018
31	0.028	0.028	0.028	0.028
32	0.009	0.009	0.007	0.007
33	0.009	0.009	0.009	0.009
34	0.042	0.042	0.010	0.010
35	0.059	0.059	0.021	0.021
36	0.085	0.085	0.000	0.000
37	0.115	0.115	0.006	0.006
38	0.087	0.087	0.012	0.012
39	0.047	0.047	0.009	0.009
40	0.030	0.030	0.008	0.008
41	0.003	0.003	0.035	0.035
42	0.014	0.014	0.070	0.070
43	0.037	0.037	0.020	0.020
44	0.007	0.007	0.029	0.029
45	0.013	0.013	0.047	0.047
46	0.040	0.040	0.091	0.091
47	0.008	0.008	0.052	0.052
48	0.012	0.012	0.075	0.075
49	0.041	0.041	0.157	0.157
50	0.010	0.010	0.043	0.043
51	0.013	0.013	0.064	0.064
52	0.058	0.068	0.203	0.203
53	0.075	0.075	0.058	0.058
54	0.042	0.042	0.058	0.058
55	0.026	0.026	0.017	0.017
56	0.074	0.074	0.004	0.004
57	0.161	0.161	0.030	0.030
58	0.173	0.173	0.041	0.041
59	0.089	0.089	0.014	0.014
60	0.007	0.007	0.047	0.047
61	0.037	0.037	0.029	0.029

62	0.155	0.155	0.078	0.078
63	0.166	0.166	0.010	0.010
64	0.074	0.074	0.065	0.065
65	0.050	0.050	0.095	0.095
66	0.040	0.040	0.010	0.010
67	0.004	0.004	0.133	0.133
68	0.028	0.028	0.044	0.044
69	0.038	0.038	0.053	0.053
70	0.005	0.005	0.028	0.028
71	0.023	0.023	0.194	0.194
72	0.055	0.055	0.162	0.162
73	0.043	0.043	0.014	0.014
74	0.011	0.011	0.146	0.146
75	0.015	0.015	0.029	0.029
76	0.068	0.068	0.155	0.155
77	0.059	0.059	0.154	0.154
78	0.004	0.004	0.175	0.175
79	0.040	0.040	0.248	0.248
80	0.068	0.068	0.095	0.095
81	0.029	0.029	0.015	0.015
82	0.043	0.043	0.013	0.013
83	0.044	0.044	0.314	0.314
84	0.000	0.000	0.173	0.173
85	0.061	0.061	0.250	0.250
86	0.119	0.119	0.057	0.057
87	0.049	0.049	0.023	0.023
88	0.022	0.022	0.099	0.099
89	0.098	0.098	0.003	0.003
90	0.126	0.126	0.069	0.069
91	0.072	0.072	0.020	0.020
92	0.022	0.022	0.037	0.037
93	0.031	0.031	0.099	0.099
94	0.105	0.105	0.040	0.040
95	0.173	0.173	0.004	0.004
96	0.143	0.143	0.058	0.058
97	0.042	0.042	0.049	0.049
98	0.003	0.003	0.140	0.140
99	0.040	0.040	0.053	0.053
100	0.042	0.042	0.077	0.077
101	0.005	0.005	0.057	0.057
102	0.010	0.010	0.003	0.003
103	0.043	0.043	0.134	0.134
104	0.045	0.045	0.066	0.066
105	0.033	0.033	0.026	0.026
106	0.034	0.034	0.055	0.055
107	0.033	0.033	0.135	0.135
108	0.018	0.018	0.032	0.032
109	0.008	0.008	0.125	0.125
110	0.019	0.019	0.154	0.154
111	0.025	0.025	0.001	0.001
112	0.013	0.013	0.124	0.124
113	0.016	0.016	0.105	0.105
114	0.048	0.048	0.024	0.024
115	0.054	0.054	0.066	0.066
116	0.016	0.016	0.027	0.027
117	0.003	0.003	0.284	0.284
118	0.033	0.033	0.034	0.034
119	0.048	0.048	0.167	0.167
120	0.025	0.025	0.093	0.093
121	0.004	0.004	0.126	0.126
122	0.001	0.001	0.079	0.079
123	0.001	0.001	0.056	0.056
124	0.010	0.010	0.066	0.066
125	0.027	0.027	0.007	0.007
126	0.022	0.022	0.155	0.155
127	0.007	0.007	0.065	0.065

128	0.014	0.014	0.180	0.180
129	0.020	0.020	0.310	0.310
130	0.007	0.007	0.058	0.058
131	0.001	0.001	0.137	0.137
132	0.003	0.003	0.087	0.087
133	0.001	0.001	0.111	0.111
134	0.001	0.001	0.003	0.003
135	0.001	0.001	0.048	0.048
136	0.000	0.000	0.129	0.129
137	0.000	0.000	0.028	0.028
138	0.000	0.000	0.002	0.002
139	0.000	0.000	0.111	0.111
140	0.000	0.000	0.143	0.143
141	0.000	0.000	0.007	0.007
142	0.000	0.000	0.008	0.008
143	0.000	0.000	0.025	0.025
144	0.000	0.000	0.137	0.137
145	0.001	0.001	0.082	0.082
146	0.000	0.000	0.103	0.103
147	0.000	0.000	0.092	0.092
148	0.001	0.001	0.008	0.008
149	0.000	0.000	0.029	0.029
150	0.000	0.000	0.041	0.041
151	0.000	0.000	0.064	0.064
152	0.000	0.000	0.215	0.215
153	0.000	0.000	0.192	0.182
154	0.000	0.000	0.003	0.003
155	0.000	0.000	0.082	0.082
156	0.000	0.000	0.081	0.081
157	0.000	0.000	0.016	0.016
158	0.000	0.000	0.094	0.094
159	0.000	0.000	0.072	0.072
160	0.000	0.000	0.084	0.084
161	0.001	0.001	0.015	0.015
162	0.000	0.000	0.083	0.083
163	0.000	0.000	0.042	0.042
164	0.000	0.000	0.030	0.030
165	0.000	0.000	0.035	0.035
166	0.000	0.000	0.020	0.020
167	0.000	0.000	0.022	0.022
168	0.000	0.000	0.022	0.022
169	0.000	0.000	0.135	0.135
170	0.000	0.000	0.064	0.064
171	0.000	0.000	0.001	0.001
172	0.000	0.000	0.070	0.070
173	0.000	0.000	0.103	0.103
174	0.000	0.000	0.029	0.029

INTERPOLATED POWER SPECTRUM (START FROM 10TH OF ORIGINAL)

	LOG A	LOG B	LOG C	LOG D
1	0.003	0.003	0.018	0.018
2	0.004	0.004	0.015	0.015
3	0.004	0.004	0.012	0.012
4	0.004	0.004	0.008	0.008
5	0.005	0.005	0.004	0.004
6	0.005	0.005	0.003	0.003
7	0.004	0.004	0.003	0.003
8	0.004	0.004	0.004	0.004
9	0.003	0.003	0.004	0.004
10	0.002	0.002	0.002	0.002
11	0.001	0.001	-0.000	-0.000
12	0.001	0.001	0.001	0.001
13	0.001	0.001	0.011	0.011
14	0.003	0.003	0.026	0.026

15	0.004	0.004	0.040	0.040
16	0.006	0.006	0.043	0.043
17	0.009	0.009	0.034	0.034
18	0.011	0.011	0.023	0.023
19	0.012	0.012	0.020	0.020
20	0.011	0.011	0.029	0.029
21	0.009	0.009	0.037	0.037
22	0.007	0.007	0.033	0.033
23	0.006	0.006	0.021	0.021
24	0.004	0.004	0.011	0.011
25	0.007	0.007	0.019	0.019
26	0.011	0.011	0.028	0.028
27	0.014	0.014	0.026	0.026
28	0.015	0.015	0.012	0.012
29	0.016	0.016	0.001	0.001
30	0.011	0.011	0.006	0.006
31	0.005	0.006	0.013	0.013
32	0.004	0.004	0.013	0.013
33	0.003	0.003	0.010	0.010
34	0.003	0.003	0.008	0.008
35	0.005	0.005	0.005	0.005
36	0.005	0.005	0.002	0.002
37	0.004	0.004	0.001	0.001
38	0.003	0.003	0.003	0.003
39	0.002	0.002	0.009	0.008
40	0.003	0.003	0.015	0.015
41	0.003	0.003	0.017	0.017
42	0.003	0.003	0.008	0.003
43	0.003	0.003	0.013	0.013
44	0.004	0.004	0.026	0.026
45	0.003	0.003	0.013	0.013
46	0.002	0.002	0.005	0.005
47	0.001	0.001	0.021	0.021
48	0.009	0.009	0.021	0.021
49	0.020	0.020	0.020	0.020
50	0.028	0.028	0.027	0.027
51	0.017	0.017	0.015	0.015
52	0.003	0.008	0.006	0.006
53	0.013	0.013	0.009	0.009
54	0.038	0.038	0.010	0.010
55	0.055	0.055	0.019	0.019
56	0.073	0.073	0.011	0.011
57	0.096	0.096	0.000	0.000
58	0.112	0.112	0.007	0.007
59	0.086	0.086	0.012	0.012
60	0.050	0.050	0.009	0.009
61	0.032	0.032	0.007	0.007
62	0.009	0.009	0.027	0.027
63	0.010	0.010	0.064	0.064
64	0.030	0.030	0.038	0.038
65	0.019	0.019	0.023	0.023
66	0.009	0.009	0.039	0.039
67	0.033	0.033	0.082	0.082
68	0.016	0.016	0.060	0.060
69	0.011	0.011	0.068	0.068
70	0.041	0.041	0.157	0.157
71	0.009	0.009	0.039	0.039
72	0.028	0.028	0.110	0.110
73	0.075	0.075	0.141	0.141
74	0.052	0.052	0.054	0.054
75	0.027	0.027	0.019	0.019
76	0.096	0.096	0.009	0.009
77	0.173	0.173	0.040	0.040
78	0.098	0.098	0.016	0.016
79	0.010	0.010	0.042	0.042
80	0.118	0.118	0.066	0.066

81	0.159	0.159	0.013	0.013
82	0.055	0.055	0.091	0.091
83	0.037	0.037	0.017	0.017
84	0.017	0.017	0.084	0.084
85	0.033	0.033	0.044	0.044
86	0.018	0.018	0.163	0.163
87	0.052	0.052	0.086	0.086
88	0.010	0.010	0.134	0.134
89	0.062	0.062	0.136	0.136
90	0.024	0.024	0.162	0.162
91	0.054	0.054	0.192	0.192
92	0.030	0.030	-0.004	-0.004
93	0.037	0.037	0.302	0.302
94	0.069	0.069	0.233	0.233
95	0.045	0.045	0.030	0.030
96	0.104	0.104	0.008	0.008
97	0.061	0.061	0.019	0.019
98	0.055	0.055	0.086	0.086
99	0.162	0.162	0.029	0.029
100	0.009	0.009	0.121	0.121
101	0.042	0.042	0.077	0.077
102	0.021	0.021	0.045	0.045
103	0.037	0.037	0.032	0.032
104	0.031	0.031	0.122	0.122
105	0.014	0.014	0.159	0.159
106	0.013	0.013	0.129	0.129
107	0.054	0.054	0.058	0.058
108	0.017	0.017	0.168	0.168
109	0.020	0.020	0.098	0.098
110	0.001	0.001	0.056	0.056
111	0.023	0.023	0.142	0.142
112	0.019	0.019	0.304	0.304
113	0.002	0.002	0.096	0.096
114	0.001	0.001	0.040	0.040
115	0.000	0.000	0.005	0.005
116	0.000	0.000	-0.001	-0.001
117	0.000	0.000	0.112	0.112
118	0.001	0.001	0.014	0.014
119	0.000	0.000	0.120	0.120
120	0.000	0.000	0.071	0.071
121	0.000	0.000	0.088	0.088
122	0.000	0.000	0.080	0.080
123	0.000	0.000	0.020	0.020
124	0.000	0.000	0.081	0.081

NORMALIZED CORRELATION COEFFICIENTS

(ASSUME LONG LOG IS STRETCHED)

LAG NUMBER	VALUE OF COEFFICIENT
0	0.081
-1	0.137
-2	0.048
-3	0.216
-4	0.150
-5	0.266
-6	0.244
-7	0.187
-8	0.292
-9	0.165
-10	0.181
-11	0.100
-12	0.001
-13	0.090
-14	0.056

(ASSUME SHORT LOG IS STRETCHED

LAG NUMBER	VALUE OF COEFFICIENT
0	0.081
1	0.056
2	0.106
3	0.083
4	0.163
5	0.240
6	0.266
7	0.245
8	0.306
9	0.454
10	0.445
11	0.383
12	0.558
13	0.770
14	0.470

-15	-0.054	15	0.360
-16	-0.121	16	0.455
-17	-0.030	17	0.394
-18	-0.098	18	0.265
-19	-0.098	19	0.104
-20	-0.186	20	0.203
-21	-0.137	21	0.201
-22	-0.145	22	0.098
-23	-0.149	23	0.269
-24	-0.143	24	0.210
-25	-0.125	25	0.208
-26	-0.057	26	0.190
-27	-0.094	27	0.289
-28	-0.164	28	0.378
-29	-0.093	29	0.294
-30	-0.176	30	0.420

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STRETCH FACTOR FOUND FROM CORRELATION OF POWER SPECTRA

FIRST CHOICE  - SHORT LOG IS STRETCHED  1.35  TIMES

SECOND CHOICE - SHORT LOG IS STRETCHED  1.45  TIMES


FINAL RESULT SUGGESTS THAT SHORT LOG IS STRETCHED 1.35  TIMES

 MAXIMUM CORRELATION IS 0.851 AT A LAG OF  185
INITIALIZATION...
&INPUT
ROWS=        61.COLS=        129.ALT=  45.0000000    .AZ=  45.0000000    .VIEW=          0.TYPE=         4.WIDTH=  10.0000000    .
SMOOTH=          0.REPET=         0.LNINT=          0.HEIGHT=  3.00000000    .SQRTT=          0.IFBASE=          0.SAMH=
       0.ENDLNF=          0.AMIN=  .0               .AMAX=  .0               .SYMAP=         8.VD=  .0               .STEP=
  .0               .LEG=          1.FLP=            0.NOZERO=          0.PLTDOT=          4.FDATA=          1.NLEG=          0.SEPSM=
  .0               .NSCAL=          1.NAMIN=          0.NAMAX=          0.IFCPM=          0
&END

        0          4
       21        129         14
       31          1         14
       52        129         14
       52          1         14
  7.80  0.05  0.10  0.0   0.0       1
```

-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.6
-0.5	-0.5	-0.5	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	0.6	-0.6	-0.7
-0.5	-0.6	-0.6	-0.6	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.8
-0.6	-0.6	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.8	-0.8	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.8
-0.7	-0.7	-0.7	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.9
-0.7	-0.7	-0.8	-0.8	-0.8	-0.8	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.8	-0.8	-0.8	-0.8	-0.8	-0.9
-0.8	-0.8	-0.8	-0.8	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-1.0
-0.8	-0.9	-0.9	-0.9	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1
-0.9	-1.0	-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1
-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1
-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.2
-1.0	-1.1	-1.1	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	1.2	-1.2	-1.2	-1.2	-1.2
-1.1	-1.1	-1.2	-1.2	-1.2	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3
-1.1	-1.2	-1.2	-1.3	-1.3	-1.3	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.3
-1.1	-1.2	-1.3	-1.3	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
-1.1	-1.2	-1.3	-1.3	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
-1.1	-1.2	-1.2	-1.3	-1.3	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	1.4	-1.4	1.4	-1.4	-1.4	1.4	-1.4	-1.4
-1.1	-1.1	-1.2	-1.2	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3

```
 -1.0  -1.1  -1.1  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2
 -1.0  -1.0  -1.1  -1.1  -1.1  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.2  -1.1
END OF PLOT
RETURN FROM BASE
```

APPENDIX IV

List of the FORTRAN IV Computer Program to Convert the Data Supplied by the Digitizing Company to the Form Used by the Program BASEL

```
C       NAME OF THE WELL
        DIMENSION DU(20)
        N=0
        WRITE(6,50)
   10   READ(5,20,END=999) (DU(I), I=1,20)
   20   FORMAT (20F4.0)
        DO 30 I=1,20
        OHM=(DU(I)-291.)*.3497
        DEPTH=3500.+2.*((2 .*N)+I-1)
        WRITE(6,40) OHM,DEPTH
   40   FORMAT(F10.5,10X,F10.0)
   30   CONTINUE
   50   FORMAT(1X,'OHM',12X,'DEPTH')
        N=N+1
        GO TO 10
  999   STOP
        END
```