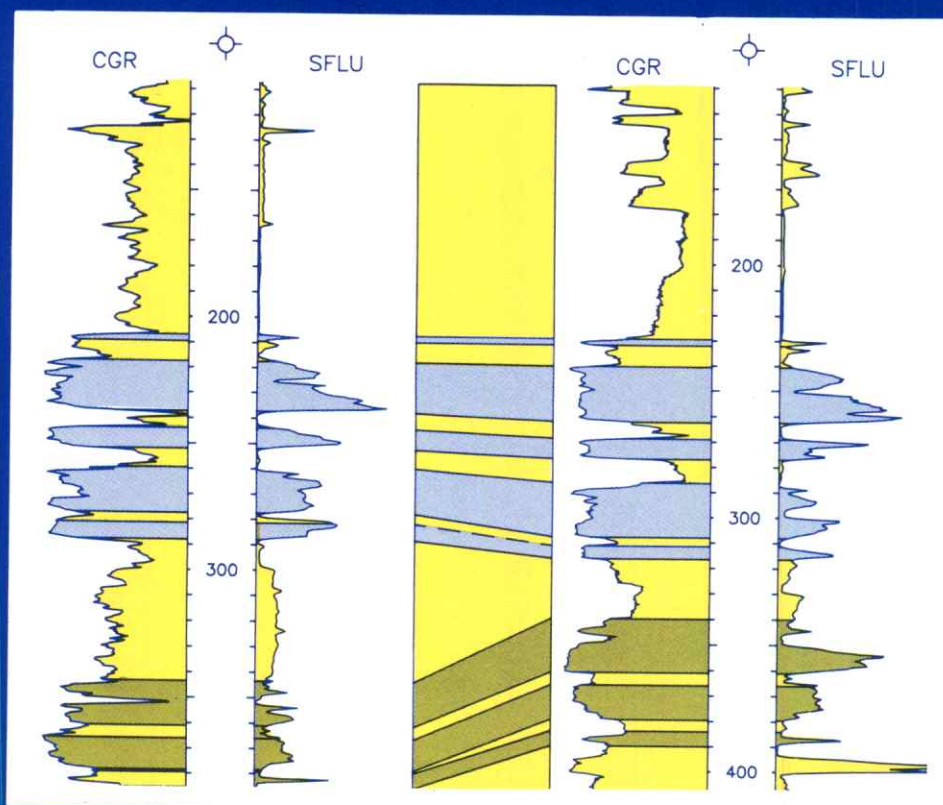


# CORRELATOR

An interactive computer system  
for lithostratigraphic  
correlation of wireline logs



Ricardo A. Olea

Petrophysical Series 4  
1988



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# CORRELATOR—an interactive computer system for lithostratigraphic correlation of wireline logs

by  
Ricardo A. Olea

Kansas Geological Survey  
Lawrence, Kansas  
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## Summary

An understanding of the geology thousands of feet below the earth's surface is essential for many scientific and commercial ventures. Wireline logs provide an alternative to unravel the geometry of bedded subsurface sedimentary rocks. This contribution presents a computer system able to introduce consistency and speed to the process of determining stratigraphic equivalence, which traditionally has been done by hand in a highly subjective way.

The computer procedure was designed to emulate the performance of experienced geologists in establishing wireline-log correlations. Standard practice in the manual procedure is to use two log traces per well and to correlate pairs of wells at a time, correlating as many wells as necessary to complete the cross section of interest. A shale log is used to discriminate in terms of a binary shaly and clean lithology. A second log is utilized to establish similarity based on the rate of change of a petrophysical property presenting regional continuity. Artificial intelligence is used to bring spatial consistency to the set of correlations by using an expert system to identify possibly spurious correlations which are resolved by interactive dialog between geologist and computer. The method has been tested successfully in both carbonate and clastic sequences, in rocks of Paleozoic, Mesozoic, and Tertiary age. Studies have been conducted in Alaska, Kansas, Louisiana, and Texas in the United States; in Chile in South America; and in the North Sea for cross sections up to 8,000 ft (2,400 m) thick along closed traverses involving up to eight wells, and for pairs of wells up to 18 mi (29 km) apart. Stratigraphic correlations equivalent or better than those produced manually by experienced geologists are found even in the presence of unconformities, faults, facies changes, and sudden lateral changes in thickness.

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# Introduction

*Lithostratigraphic correlation* can be defined as the correct determination of the spatial equivalence of rocks, based on their physical properties (Krumbein and Sloss, 1963, p. 332; American Geological Institute, 1974, p. 110; Gradstein et al., 1985, p. 387). The process of lithostratigraphic correlation is particularly meaningful in dealing with sedimentary rocks, as sedimentation produces deposits having moderate to excellent spatial continuity.

A sound stratigraphic framework is essential for many scientific and commercial ventures, and especially for exploration and exploitation of sedimentary basins having the potential for hydrocarbon production in economically attractive amounts. Until the 1920's, stratigraphy was established from direct observation of rocks along outcrops and in mine pits, or from cores and cuttings from boreholes. In 1927, brothers Conrad and Marcel Schlumberger, with aid of Henri Doll, successfully extended electrical surface measurements to boreholes. Surface measurements of electrical resistivity had been used since the turn of the century as an indirect method to provide physical and geometrical information about the subsurface. On September 5, 1927, a prototype resistivity sonde was unloaded into a well in northeast France. The sonde was lowered to the bottom of the hole and resistivity measurements were made at one-meter intervals and the values written down on a pad together with the depth reading. In Paris, the measurements were plotted by hand against depth on a strip of paper, resulting in the first of the graphs which today are called *wireline or borehole logs* (Allaud and Martin, 1977). Since then, continual improvements and diversity in logging tools, better understanding of the physics of the measurements, and reduction in operational costs have resulted in logs being favored over conventional cores as the primary source of information to establish correlations between wells.

In practice, the solution to the general problem of lithostratigraphic correlation is extremely dependent on the nature of the data. Here we limit our discussion to the special case where the primary sources of information about the subsurface are wireline logs, a common situation in petroleum prospecting and production. The problem can be reduced and expressed as: Given the top and bottom of rock unit A as indicated on a log from well X, where is the same unit A on logs taken from surrounding wells? The traverse in fig. 1 is a typical display of lithostratigraphic correlations based on wireline logs and illustrates the manner in which this question is answered. The correlations shown in fig. 1 could have been determined manually and the cross section drawn by hand, the method traditionally employed by petroleum geologists. However, what is novel about this illustration is that the cross section was produced entirely by a plotter displaying a digital file prepared by a computer.

A lithostratigraphic correlation, like the solution to a puzzle, is either right or wrong. There may be an infinite number of incorrect correlations, but the correct solution is unique. Unfortunately, there is usually no independent way to check the validity of correlations, so rather than a single, unambiguous lithostratigraphic correlation, many feasible correlations may exist that do not violate general stratigraphic constraints. Discarding severe tectonic disruption, the commonsense rule that the order of succession of units cannot be reversed from one well or outcrop to another is a typical constraint (Tipper, 1988).

Lithostratigraphic correlations are of paramount importance in the petroleum industry because they furnish the basic data needed to produce cross sections, isopach maps, structural maps, and fluid-flow models, which in turn are essential for subsurface interpretation. Thus, we have a crucial problem; lithostratigraphic correlations are vital but extremely difficult to establish with certainty. It is small wonder that those geologists who have mastered the skills needed to perform lithostratigraphic correlation—and whose interpretations withstand verification by drilling, seismic analysis, or restudy—are held in high regard. Once an explorationist masters wireline-log correlation, what is a difficult task for others becomes routine. Even then, the process of correlating wireline logs is demanding of time and keeps the expert away from other, more rewarding tasks.

The possibility that wireline-log correlation could be reduced to a routine and the routine expressed as an algorithm has tempted many investigators, the author included. This paper describes the development of CORRELATOR, a computer system developed over a period of five years at the Kansas Geological Survey for the determination of lithostratigraphic correlations under the practical circumstances found in the oil patch. CORRELATOR is not a prototype system. The method has been tested successfully in both carbonate and clastic sequences, in rocks of Paleozoic, Mesozoic, and Tertiary age. Studies have been conducted in Alaska, Kansas, Louisiana, and Texas in the United States; in Chile in South America; and in the North Sea in Europe for cross sections up to 8,000 ft (2,400 m) thick along closed traverses involving up to eight wells, and for pairs of wells up to 18 mi (29 km) apart. Stratigraphic correlations equivalent or better than those produced manually by experienced geologists have been found even in the presence of unconformities, faults, facies changes, and sudden lateral changes in thickness.

The early research on computer-aided correlation of wireline logs was conducted as a cooperative research effort between the Kansas Geological Survey and Texaco, Inc. Texaco provided partial financial support for the project and supplied wireline logs as well as geologic

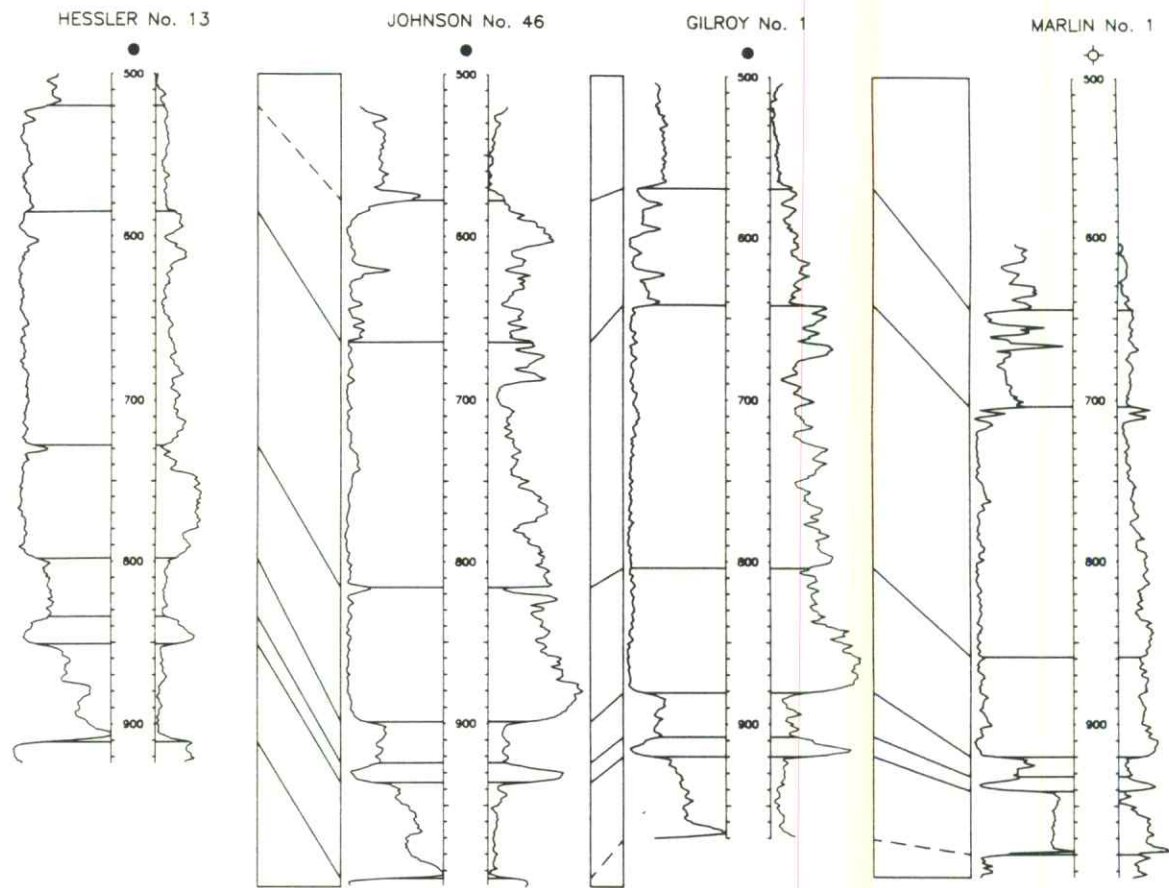


FIGURE 1—NORTH-SOUTH LITHOSTRATIGRAPHIC CROSS SECTION OF THE MISSISSIPPIAN SYSTEM IN GREENWOOD COUNTY, KANSAS. The sequence consists of alternating carbonates and shales. Vertical exaggeration is 100X.

information from the Lake des Allemands and Grand Bayou areas in Louisiana that have been used to illustrate the text. Wireline logs from an area in southern Chile were kindly released by Empresa Nacional del Petróleo (ENAP), Chile, while local examples were taken from our own wireline-log library. Marathon Oil Company and Union Oil Company of California contributed also with examples not included in the publication.

John C. Davis and Robert J. Sampson developed a prototype correlation program called DISLOG and con-

ducted the research program prior to 1985. Davis, John H. Doveton, Timothy C. Coburn, and Don Beaumont made valuable comments that greatly improved the content and readability of early versions of the manuscript. Richard L. Brownrigg's assistance as programmer was of great help during some of the most critical stages of system testing. He also prepared the macro to read wireline logs from digitized log files.

# Theoretical background

CORRELATOR is a blend of old and new concepts conveniently put together in a computer system designed to efficiently perform the historically elusive task of lithostratigraphic correlation with the aid of digital computers. This section explains the way CORRELATOR operates and links with the efforts of others.

## Previous studies

A *layer-cake model* is the simplest representation of subsurface stratigraphy. In this model, the stratigraphic framework consists of a finite number of rock units that extend at constant thickness throughout the area of investigation. This model does not consider the possibility that rock units may have variable thickness, that facies may change within the units, or that unconformities, folds, faults, and nonstratiform features such as reefs and algal mounds may occur.

Most methods for correlation by computer described in the literature are curve-matching procedures which work for short stratigraphic sequences where the geology conforms to the layer-cake model. If the stratigraphy is more complex or the intervals to be correlated are lengthy, these methods are computationally impractical and unacceptable correlations invariably appear (Mann, 1981). While some automated procedures seem promising, lithostratigraphic correlation is still exclusively a manual task (Hoyle, 1986; Tipper, 1988).

Perhaps the simplest form of comparison of two sets of measurements is *cross-association* analysis, which consists of comparing two sequences, each composed of a succession of discrete lithologic states, such as sandstone, shale, or limestone. Typically, these lithologic states are determined at equally spaced points, perhaps every foot, but the observations may consist simply of the lithologic succession without regard to the thickness of the stratigraphic units. Two sequences are correlated by computing the similarity between them at all possible positions of comparison. The matching coefficient,  $S$ , which is the ratio of the number of matches,  $m$ , to total number of comparisons,  $n$ , is a simple, appropriate measure of similarity (Sackin et al., 1965; Merriam and Sneath, 1967):

$$S = \frac{m}{n} \quad (1)$$

While cross-association analysis is of some value for comparing short sequences composed of a few classes, the matching coefficient is of no value if observations are measured on a continuous mode, as they are on a petrophysical log from a well. The dynamic programming

procedure called *slotting* is an improvement over cross-association analysis, as it can be applied to either discrete or continuous variables (Gordon, 1973; Gordon and Reymont, 1979; Gordon, 1980; Hawkins, 1984; Clark, 1985). Slotting also permits the introduction of external constraints into the correlation process, so correlations cannot cross any known lines of equivalency. However, the method sometimes produces *blocking* in the final slotting; that is, several readings from the same log sequence occur consecutively, with no intervening readings from the other sequence.

Maximizing the number of stratigraphic matches is equivalent to minimizing the mathematical distance or difference between the two sequences, a challenge conceptually equivalent to problems in other disciplines. Smith and Waterman (1980) were able to refine the slotting technique by borrowing from molecular biology, where evolutionary changes are studied by comparing gene sequences. Their technique can correlate across gaps in the stratigraphic sequences (Howell, 1983; Waterman and Raymond, 1987; Griffiths and Bakke, 1988). Lineman et al. (1987) adapted algorithms from speech processing to create a program that can accommodate both missing units and intervals of varying thickness. They use dynamic programming techniques to reduce processing time and to increase the flexibility of constraints. Comparisons are based on the absolute differences between log readings from the wells being correlated. Although multiple log traces can be used, the procedure may become confused if there are lateral changes in formation fluids and/or porosity.

Although matching coefficients are appropriate for use on stratigraphic sequences coded into discrete states, the statistical Pearsonian *cross-correlation coefficient* is a better measure for comparing series of real numbers  $x_k(z)$  defined over a common index set  $z$ . The process of computing the similarity at all possible positions of comparison between two series, 1 and 2, of real numbers is called cross correlation. If the series are sampled at regular intervals  $h$ , the cross-correlation coefficient,  $r_{1,2}(i, k, n)$ , is defined as

$$r_{1,2}(i, k, n) = \frac{\text{cov}_{1,2}(i, k, n)}{s_1(i, n) s_2(k, n)} \quad (2)$$

Covariance  $\text{cov}_{1,2}(i, k, n)$ , and standard deviations,  $s_1(i, n)$  and  $s_2(k, n)$ , are calculated over *length intervals* comprising  $(2n + 1)$  readings each. The *interval centers*  $x_1(z_j)$  and  $x_2(z_j)$  differ by an *offset* or *lag* of  $\lambda = (j - i)h = kh$  units in the common index set—depth in our case. The results are shown as a *correlogram*, a plot of  $r_{1,2}(i, k, n)$  versus  $\lambda$ . The cross-correlation coefficient varies from -1 to 1; perfect matches have a correlation coefficient equal

to 1, perfect inverse matches yield -1, and 0 indicates a lack of linear correlation which usually, but not necessarily, indicates a haphazard relationship between the sequences being compared. Cross correlation is invariant under addition of a constant or multiplication of either of the two series by a second constant, so the measure is sensitive to wave forms in the sequences rather than to the individual numerical values. The earliest applications of cross correlation to lithostratigraphy were made in the 1960's by Schwarzscher (1964), Anderson and Kirkland (1966), and Dean and Anderson (1967). At that time, as a method for processing geophysical seismic signals, the same technique was moving from the research laboratory to the field (Anstey, 1964; Lindseth, 1966). More recent approaches to correlation have tried to refine the cross-correlation method to cope with lateral variations in the thickness of lithostratigraphic units. Unfortunately, these largely trial-and-error approaches have not been especially successful, in part because of their excessive computing requirements (Neidell, 1969; Rudman and Lankston, 1973; Henderson, 1973; Kemp, 1982; Ghose, 1984).

Cross correlation has been extensively used with good success to automate the calculation of dips from microresistivity logs (Moran et al., 1962; Matuszak, 1972; Schoonover and Holt, 1973; Kemp, 1980). Three or four high-resolution microresistivity logs are recorded simultaneously in the same well by using electrodes spaced at uniform angles around the dipmeter tool. The objective of *dipmeter* computations is to determine any shifts in depth between features on the microresistivity traces. Dipmeter computation involves the same basic problem as lithostratigraphic correlation, but because of the extremely close distances between the electrodes, the lag is at most a few inches and the layer-cake model is fully valid. For this reason, methods for matching traces in dipmeter analysis are not particularly successful when applied to pairs of logs recorded hundreds or thousands of feet apart in different wells. It also should be noted that even under the relatively ideal conditions of dipmeter analysis, the cross-correlation technique is not free of problems (Mac-Robertson, 1972; Robinson, 1978).

Cross correlation, in the context of lithostratigraphic correlation, determines the degree of similarity between two series in the spatial domain. Fourier transformation provides an alternative way of making this comparison in the frequency domain, a different but mathematically equivalent process. The *Fourier transform* of the cross-correlation function is the cospectrum, a complex function whose real components are the coherence and phase spectra. The former is directly related to the correlation coefficient and varies between -1.0 and +1.0. Fourier transformation has been used to measure the similarity of sequences in attempts to preserve the strong points of the cross-correlation function while circumventing some of its problems. Limited success has been reported by several authors, although the procedures are computationally complicated (Preston and Henderson, 1964; Rudman et al.,

1975; Rudman and Blakely, 1976; Kwon et al., 1978; Mann and Dowell, 1978; Kwon and Rudman, 1979).

These methods cannot accommodate gaps in the stratigraphic sequences and work only with a fixed offset and stretch factor for (1987).

All techniques at a time. In contrast to a single well log, this method is based on the principle that the logs are relatively homogeneous in the vertical which are distinct from the lateral zonation for stratigraphic correlation. The techniques originate from sequences whose correlation is producing interval correlation without anything about the well, but the task is considered less difficult for log traces. The application of a procedure for the contribution of a procedure to the mathematical technique of Testerman (1962); Hawkins and Merritt (1973); Webster (1973, 1974); and ten Kroode et al. (1981); Lanning and Benveniste (1983); (1986, p. 238-242).

The *excluder-c* algorithm are two correlation discussions are based on the as geologic time, variations in sedimentation rates and differences in log readings between two locations are limited. In particular, it is presumed that there is a dependence between sediment type and sedimentation rate. Although perhaps conceptually correct, determining the analytical relationships and the parameters required by the algorithms has proved impossible.

Correlation by *pattern recognition* attempts to mimic the human ability to recognize and match similar features on curves that are usually nearly identical. Vincent et al. (1979) make use of templates or idealized representations of shapes of log curves and measure the correspondence between these elements and the real log. The method has been commercially available as the Schlumberger Geodip™ system, which detects shifts in microresistivity traces for dip determination when the signal-to-noise ratio is very high and the layer-cake model holds. Even so, incorrect correlations often obscure dipmeter interpretations (Kerzner, 1982). Cheng and Lu (1985) have developed an approach in which wave forms are represented by tree structures. Operations are defined on tree nodes and tree distances which are utilized by a matching algorithm and a backtracking procedure to find the best node-to-node

correlations. The potential of Cheng and Lu's methodology remains essentially untested at the present time.

The *activity function* is another procedure devised for correlating microresistivity logs for the determination of dips. The activity function is a transform of the square of the amplitude of the log trace and expresses the energy in a signal in a manner similar to the power spectrum of the Fourier transform. Kerzner (1982, 1983) used it as a guide to eliminate noise below a certain activity threshold, much like the power transforms suggested by Robinson (1975), and to discriminate among features in a less elaborate way than by the catalog of standard curve elements of Vincent et al. (1979). Once the activity is calculated for two logs, they are matched by comparing slopes of different features in the activity curves. However, the basic problems of lithostratigraphic correlation remain, as the transformation cannot correct for stratigraphic records that are incomplete or distorted. In a subsequent paper, Kerzner (1984) returned to simple cross correlation plus stretching for stratigraphic matching.

Finally, there are *hybrid methods*, which have been regarded as the only reasonable alternative to the problem (Mann, 1979). These methods are exemplified by the program written by Shaw and Cubitt (1979) which embodies zonation, stretching, and cross correlation. The difficulty of creating a computer algorithm which can perform a complex task that is routinely done by experienced, skilled people is not unique to wireline-log correlation. The branch of computer science called Artificial Intelligence is devoted to study of such problems. In particular, *expert, or knowledge-based systems* are computer procedures designed to emulate, and possibly exceed, the performance of human specialists in the solution of specific, complex, real-world problems. In a wide sense, expert systems can be viewed as high-level hybrid methods. Expert systems are characterized by the use of large sets of facts that need not necessarily be quantitative. These facts are learned from human experts, who have excelled in solving typical problems in their domain (Barr et al., 1982, vol. II, p. 79; Weiss and Kulikowski, 1984, p. 1; O'Shea and Eisenstadt, 1984). Expert systems have been developed for problems in a wide variety of areas. The works most relevant to wireline-log correlation include PROSPECTOR, in mineral exploration (Duda et al., 1979; Duda and Gaschnig, 1981); LITHO, in oil exploration (Bonnet and Dahan, 1983); Dipmeter Advisor, in dipmeter interpretation (Smith and Baker, 1983; Smith, 1984); ELAS, in formation evaluation (Weiss and Kulikowski, 1984, p. 127-136; Weiss et al., 1982); and MUDMAN, in drilling mud conditioning (DeCour, 1986; Kahn and McDermott, 1986). Other expert systems for tasks such as the identification of minerals in thin section are being designed (West, 1985). Since completion of the CORRELATOR program, we have noted a proliferation of artificial-intelligence applications to the wireline-log correlation problem. The literature now contains descriptions of several systems in

various stages of design and testing, although none is yet commercially available (Wu and Nyland, 1986, 1987; Startzman and Kuo, 1986, 1987; Kuo and Startzman, 1987; Lineman et al., 1987).

The ease with which expertise can be transferred from the real world to the expert system depends partly on the knowledge representation used in the expert-system model. Of many alternatives, the representation best suited to most complex problems is the so-called production system (Nilsson, 1980, p. 4; Duda and Gaschnig, 1981; Barr et al., 1982, v. I, p. 157; Weiss and Kulikowski, 1984, p. 74). A *production system* is a computational formalism containing three clearly separated major components: a set of production rules, a global data base, and a rule interpreter. A *production rule* is a statement cast in the form:

IF <this condition holds>  
THEN <this consequence follows>.

The conditions are handled in terms of facts called *antecedents*, while a *consequence* can be used to define a compound antecedent or to test an hypothesis. Largely, the positive testing of an hypothesis leads to some action or resolution. For example, the statement: ROCK UNITS LOW IN SHALE CAUSE THE SPONTANEOUS-POTENTIAL LOG TO SWING TO THE LEFT, might be recorded as the following production rule:

IF <there is a deflection to the left on the spontaneous-potential log>  
THEN <the rock unit is low in shale>.

The Artificial Intelligence approach to computer problem solving has been rather disappointing in accomplishments. Part of the blame might go to an initial over-reaction in the 1970's in terms of financial support and media coverage which has resulted in disenchantment from clients and funding agencies (Bobrow and Hayes, 1985).

## CORRELATOR methodology

The history of technology shows that first-generation attempts at automation tend to mimic human behavior rather than to incorporate shortcuts or revolutionary alternative solutions from the outset. In automating technical drawing, ink pens were mounted on mechanical arms long before electrostatic plotters were developed. Development of CORRELATOR is no exception to this rule, as it was developed by studying and imitating the skills that successful geologists use to perform the correlation task. If CORRELATOR's fate follows that of other innovations, this approach of imitating the manual methods may eventually prove inefficient. However, at

the present time, after many years of frustration in the attempt to automate wireline-log correlation under practical conditions, we feel that reproducing manual procedures is a sound starting point. The job will be done and practicing subsurface geologists should be more comfortable with this solution conforming to their own skills rather than confronting a solution based on a different conception. In a discipline characterized by resistance to accept quantitative method, user friendliness is equally if not more important than technical efficiency (Tipper, 1988).

Experienced subsurface geologists tend to follow a common set of procedures when correlating wireline logs and developing subsurface cross sections. First, even when seeking the correlations along a traverse composed of many wells, geologists progress by comparing wells two at a time.

Second, manual correlation is never based on the trace of a single logging tool. In spite of the number of different types of logs available, geologists tend to concentrate on two of the most common logs: a spontaneous-potential log to discriminate between shales and clean formations and a shallow-resistivity log on which the correlations themselves are based. CORRELATOR also uses only two log traces, but these may be any pair of logs that function in a way similar to the classical SP-resistivity pair. That is, one log must be sensitive to the amount of shale in the stratigraphic sequence, and the other must be able to measure, with high resolution, some petrophysical property that is persistent for extensive distances. Generically, we will label these wireline logs as *shale* and *correlation logs*, respectively. Other methods found in the literature use either a single log per well to establish correlations, or if more than one log is used, the additional logs simply are used in the same manner. In contrast, CORRELATOR uses a second log as the source for a completely different and independent criterion for correlation. However, if required, the process can proceed with a single log as well.

CORRELATOR uses the shale log to break the stratigraphic sequence into rock units according to a binary lithological classification. Prior to analysis, any two intervals in the pair of wells being correlated are likely to be geologically equivalent. Once the information contained in the shale logs has been utilized, the number of likely solutions is reduced significantly because the possible matches are now restricted to intervals having comparable lithologies. The correlation of clearly different lithotypes, such as a clean limestone and a black shale, is not encouraged. We defined a *normalized shale similarity coefficient*,  $\alpha_{1,2}(i, k, n)$ , in order to measure the degree of similarity in the amount of shale in the two sequences  $\xi_1(\cdot)$  and  $\xi_2(\cdot)$  being compared. Given that the two sequences vary between  $\xi_{\min 1} < \xi_{\max 1}$  and  $\xi_{\min 2} < \xi_{\max 2}$  respectively and that they have been sampled at regular intervals

$$\alpha_{1,2}(i, k, n) = 1 - \frac{1}{2n+1} \sum_{j=i-n}^{i+n} \left| \frac{\xi_1(j) - \xi_{\min 1}}{\xi_{\max 1} - \xi_{\min 1}} - \frac{\xi_2(j+k) - \xi_{\min 2}}{\xi_{\max 2} - \xi_{\min 2}} \right| \quad (3)$$

where  $(2n+1)$  is the length of the sub-sequences being compared whose centers are at  $i$  and  $(i+k)$ , respectively. The coefficient reaches a minimum value of 0 when all the values in one sequence are equal to the maximum value and all the values in the other are equal to the minimum value; the coefficient is equal to the maximum value of 1 when, for every possible value of  $j$ , the relative proportion  $(\xi_1(j) - \xi_{\min 1})/(\xi_{\max 1} - \xi_{\min 1})$  is equal to the relative proportion  $(\xi_2(j+k) - \xi_{\min 2})/(\xi_{\max 2} - \xi_{\min 2})$ .

On the display of wireline logs, for logs that are sensitive to shale content the convention is that the farther the reading is to the right, the greater the amount of shale in the unit. In fig. 2, a shale, arbitrarily labeled A, shows the greatest similarity with units P, R, T, and V, which also are shales. Conversely, unit A has minimal similarity to the clean units Q, S, and U. Because CORRELATOR seeks an equivalent interval in the right-hand well for a given interval in the left-hand well, in the graphical presentations and calculations we refer to the well on the left as the *reference well*, and the well on the right as the *matching well*.

The next step of lithostratigraphic correlation is more demanding; the interpreter must narrow the number of matches even further. Under normal circumstances there will be only one equivalent matching interval for each reference interval. Under extraordinary circumstances when a repeated section is present, there may be more than one equivalent matching interval for a reference interval. On less rare occasions there will be no equivalent interval at all, because of an unconformity, hiatus, or fault, for instance. The task of narrowing the possible set of equivalences is difficult because the variability in physical and chemical properties of the rocks and their contained fluids is limited and repetitious. The same matrix minerals and pore fluids occur repeatedly. Most changes in the rock are in the relative proportions of the constituents, and in the size, shape, and orientation of grains. The occurrence of key beds composed of unusual minerals is sporadic and so rare an occurrence that correlation procedures cannot be based on unique components (Gradstein et al., 1985, p. 393).

Under these circumstances, geologists have learned to rely on the rate of change in petrophysical properties, expressed as variation in the signature of the log traces, rather than on individual comparisons of isolated readings. Analyzing patterns of change in sequences has the additional advantage of helping to filter out undesirable components of the logs that result from changes in tool characteristics, borehole conditions, or regional geological variations in the petrophysical property being used to establish the correlations. Because a higher resolution log is more likely to capture small-scale variations that may be crucial in establishing equivalences, the reliability of wireline-log correlations is closely dependent on the vertical resolution of the log and on the sampling interval used.

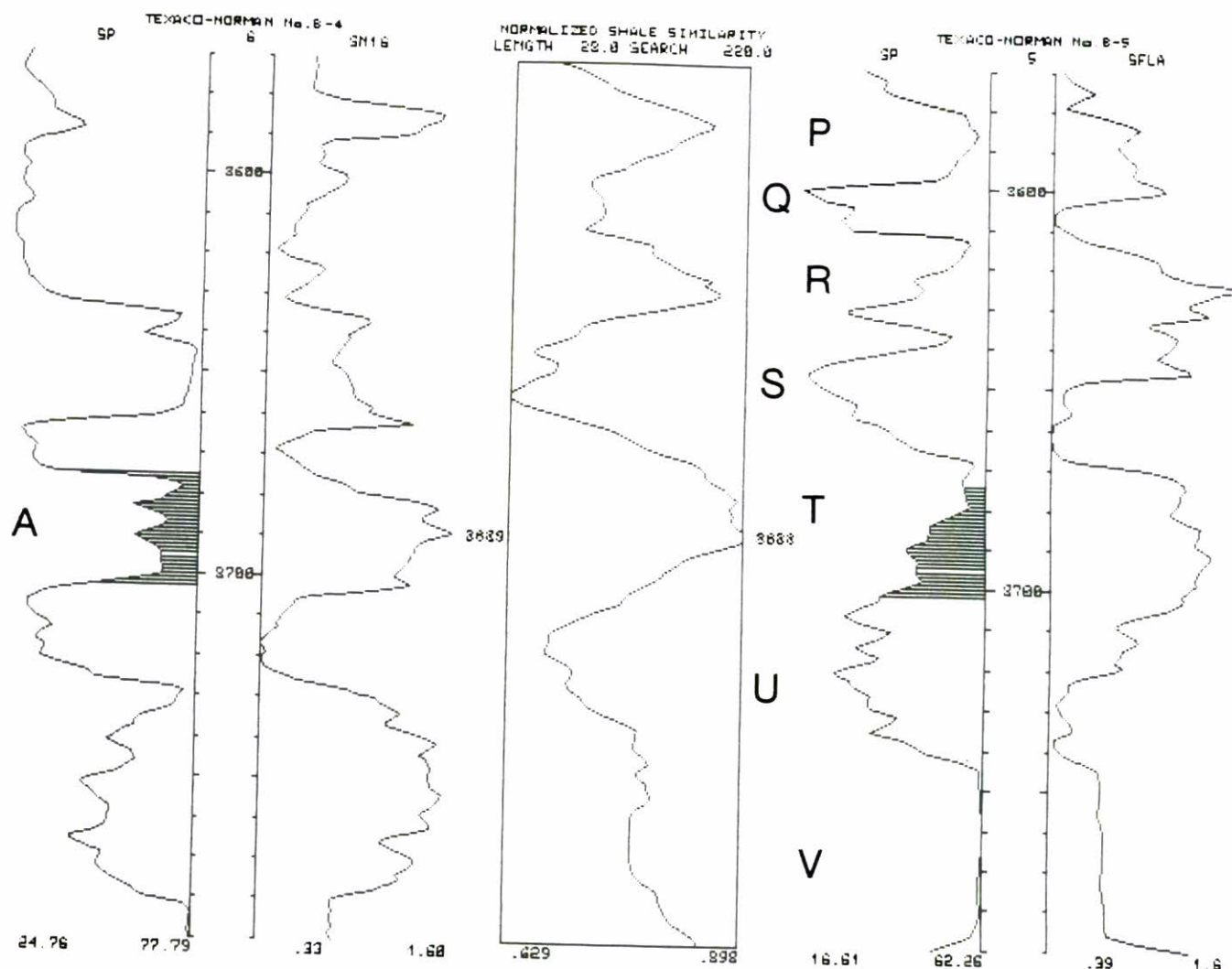


FIGURE 2—NORMALIZED SHALE SIMILARITY BETWEEN GAMMA-RAY LOGS OF TWO WELLS. Central track shows similarity in the amount of shale between unit A centered at 8,689 ft in well No. 6, and all possible intervals between 8,570 and 8,790 ft in well No. 5. All intervals compared are 28 ft in length. Best matches to unit A are with shale units P, R, T, and V.

Of the several mathematical techniques which can be used to measure rates of change, we have selected statistical correlation because of its simplicity and relative success in related applications. The method, when properly applied, is not adversely affected by the presence of gaps in the stratigraphic record, nor by lateral changes in thickness of equivalent intervals. By weighting the cross-correlation coefficient  $r_{1,2}(i, k, n)$  in equation (2) by the coefficient of similarity in shale content  $\alpha_{1,2}(i, k, n)$  in equation (3), we can have a compound coefficient that we will call *weighted correlation coefficient*

$$\omega_{1,2}(i, k, n) = \alpha_{1,2}(i, k, n)r_{1,2}(i, k, n) \quad (4)$$

Since  $r_{1,2}(i, k, n)$  varies between -1 and 1, and  $\alpha_{1,2}(i, k, n)$  can fluctuate between 0 and 1, the new coefficient will vary between -1 and 1 and will measure the joint quality in shale as well as in signature matching as provided by two independent set of measurements. The

weighted coefficient provides a joint discrimination both in terms of shale contact and signature. Continuing with the example started in fig. 2, we see that in fig. 3, of all possible correlative intervals shown in fig. 2, shale S best matches shale A. Provided that there is one and only one matching interval, selecting the matching depth providing the highest weighted correlation coefficient as the lithologically equivalent depth seems natural. A *threshold* or *cutoff* in the weighted correlation coefficient is introduced to take care of the case when there is actually no equivalence. Although there will always be a highest weighted correlation coefficient, in the absence of any real matching, the coefficient will only be the least worst value out of an unacceptable set. By conveniently setting a threshold, those low haphazard matchings will be weeded out. The only disadvantage of this fairly straightforward procedure is that along with the faked correlations will go weak but proper correlations. As far as the multiple equivalences

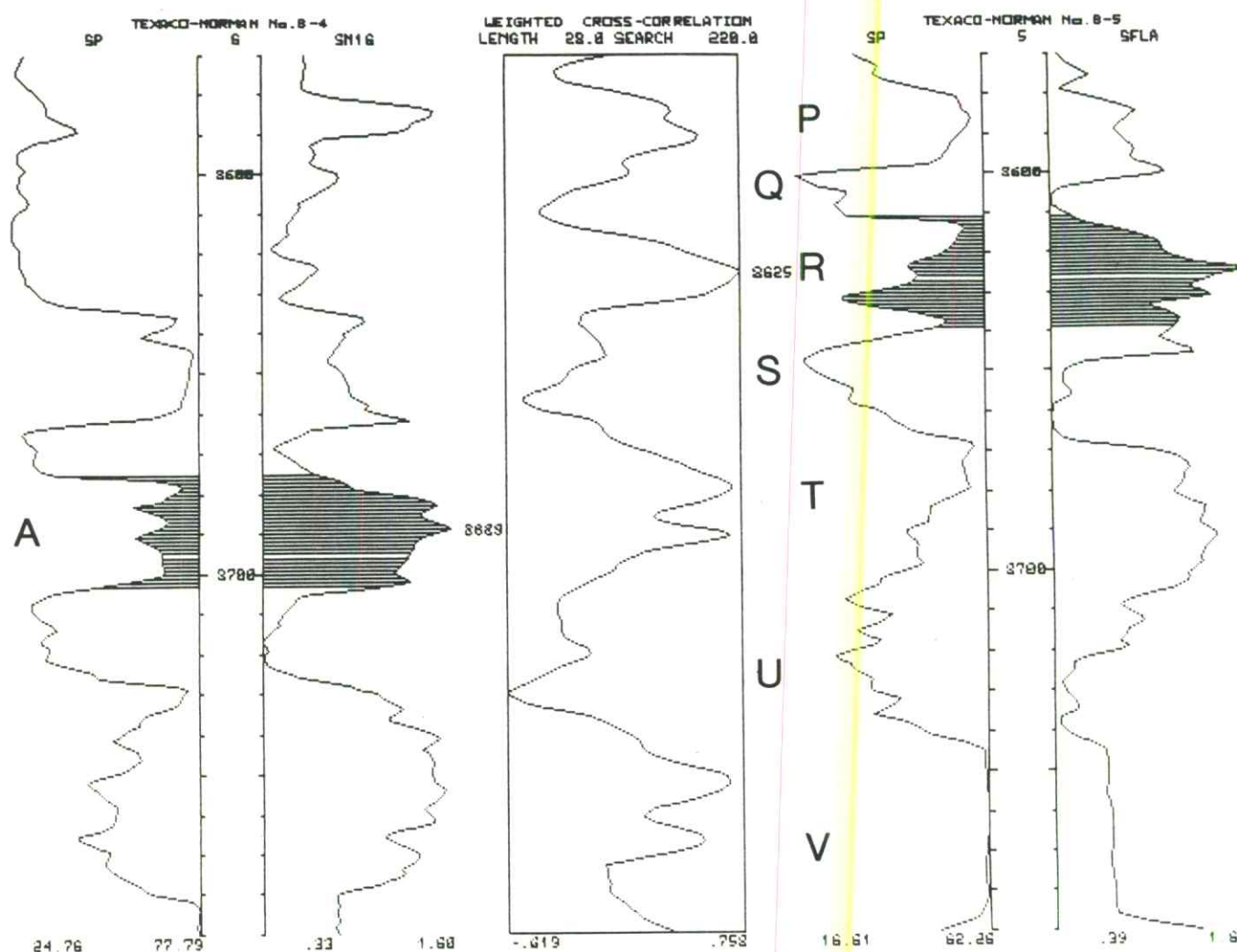


FIGURE 3—WEIGHTED CORRELATION COEFFICIENT BETWEEN LOGS OF TWO WELLS. Central track shows the product of normalized shale similarity and cross-correlation coefficient between rock unit A in well No. 6, and all possible intervals of the same size in well No. 5. The best match is between units A and R, which is the correct geological correlation.

are concerned, their occurrence is such an oddity that the procedure does not narrow much in its applicability by simple ignoring the situation.

The procedure outlined above yields the best correlation between two wells, a single reference interval at a time. A complete set of correlations can be obtained by repeating the operation for all possible reference intervals in a pair of wells. The process can be extended to produce a geologic cross section that includes many wells by working successively with all pairs of wells along the traverse.

The petrophysical record of a stratigraphic succession is monotonous because the depositional processes that created the succession repeat over time. Sea level, for example, has risen and subsided countless times in many areas throughout the world. As marine conditions recurred, so did the type of sediments that were deposited and, consequently, the resulting facies we find today.

Within a given geological time interval there tended to be a persistent, gentle variation in the geographical distribution of sediments that, on the average, assured some horizontal continuity that makes the lithostratigraphic correlation problem solvable. However, as geological processes repeat, it is likely that at two locations X and Y, succession A at X may be more similar to succession B at Y than to the true succession A. We will refer to these improper equivalences as *miscorrelations*. This situation, illustrated in fig. 4, happens frequently, but not so often as to completely scramble the records formed by the rocks. In order to show simultaneously the correlation of many intervals, the central track contains lines connecting the centers of correlating intervals rather than a continuous presentation of the weighted correlation coefficient as in fig. 3. The search for correct geological equivalence is further complicated by expansions and compressions of rock units caused by spatial variation in sedimentation

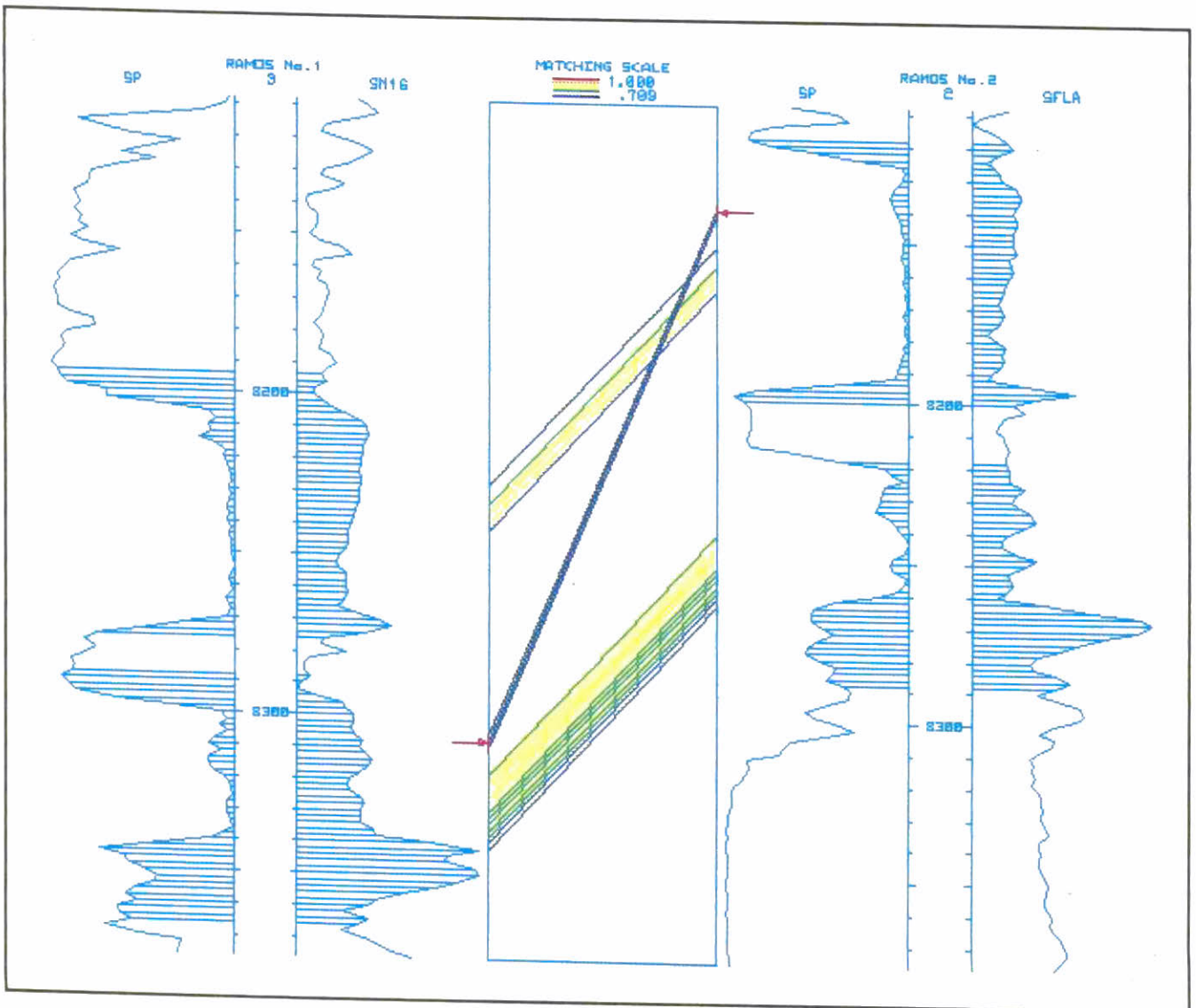


FIGURE 4—AN ANOMALOUS CORRELATION BETWEEN LOGS OF TWO WELLS, showing crossing lines of best correlation.



rates. In extreme cases there may have been no sedimentation at all, or partial erosion of rocks already deposited. There also may be discontinuous gaps in the vertical succession caused by differential movements along faults that cut the stratigraphic succession.

Because of these complexities, a best match in terms of shale content and log signature does not always establish the proper equivalence between two portions of the same rock unit. Notice, for instance, how close several mismatches are to the correct equivalences in fig. 3 alone. The confusion between geological equivalence and petrophysical similarity is real and is not an artifact of the correlation method. Because of this, lithostratigraphic correlation by visual inspection is a difficult undertaking, and there sometimes are as many opinions about the proper correlation as there are analysts. When correlations are made with the aid of computers, spurious correlations should be expected to occur, regardless of the mathematical technique used to compare traces.

What experienced geologists do in practice to resolve this ill-determined problem is to work not with the correlation of a single interval, but with correlations of several intervals at a time. An individual correlation is more apt to be in error than are a series of adjacent correlations. An expert system was implemented to mimic this geologist skill. The expert system that we designed for this specific purpose of editing correlations originally established independently from one another has five major components:

1. A data base containing all information about the correlations to be edited.
2. A *scheduler* to scan the data base.
3. A *knowledge base* containing geologic expertise.
4. An *inference system* to scan the knowledge base.
5. A communication module to interact with the user.

The scheduler automatically searches for all correlations and arranges them in order from top to bottom prior to their inspection.

```
**** CORRELATIONS FROM 8386.0 TO 8310.0 FEET SHOULD BE
    ELIMINATED. IS YOUR ANSWER YES (yes), N (no), or W (why)? : W
```

```
THE FOLLOWING RULE WAS SUCCESSFULLY TESTED:
```

```
Eliminate lower bundle of crossing correlations
```

```
BECAUSE :
```

```
There is a gap around the lower bundle
The correlation is the weakest for lower bundle
The dip is abnormal for the lower bundle
```

```
The bundle to eliminate goes from 8386.0 to 8310.0 feet.
```

```
PLEASE ANSWER Y (yes), OR N (no): DO
YOU WANT TO ELIMINATE THE CORRELATION NOW? : Y
```

FIGURE 5—EDITING OF THE CORRELATION FILE BY THE EXPERT SYSTEM. Anomalous correlations shown in fig. 4 are flagged with red arrows indicating bundles that deviate from the pattern of surrounding bundles. The user may request an explanation and then must decide whether to keep or to discard the anomalous bundle.

The expert system in CORRELATOR contains 23 antecedents and 11 hypotheses in 19 production rules comprising the knowledge base. The basic unit of comparison is not an individual correlation, but what we have called a *bundle* of consistent correlations. A bundle is defined as a set of one or more correlations such that:

- a. Correlated intervals are consecutive. There are no gaps in the sequence larger than the digitization interval.
- b. Centers for all correlation intervals in the set are within the same rock unit.
- c. Correlations are essentially parallel. Differences in dip are small and no larger than a preset threshold.
- d. Correlations do not cross. If interval A occurs above interval B in well X, correlated interval B cannot be above correlated interval A in well Y.

The data base consists of the wireline-log readings, along with the strengths of the weighted correlations and the elevations of the centers of each interval in a matching pair of intervals.

All of the production rules involve discarding anomalous correlations based on geometry, as well as the relative strength of the questionable bundle and the bundles directly above and directly below. At most, four bundles are involved in the analysis at any time. No measure of certainty is attached to the production rules. This reflects the widely held philosophy that, although the idea might be appealing, it is impossible to assess practically such degrees of uncertainty (Feigenbaum, 1979; Doyle, 1983; Zadeh, 1986).

The inference system is goal-driven and uses backward reasoning to scan through the rules. Backward-chaining is used as the search mechanism to assure that rules are tried in descending order of number of antecedents. In this way, the search progresses from the strongest to the weakest supported hypotheses.

## Processing philosophy

The correlation system is interactive. Special provisions were made not to overwhelm the user with questions. CORRELATOR, in general, and the expert system, in particular, have been instructed to extract all possible information from the wireline logs and to perform all trivial computations without asking the user questions that the system can resolve by itself with the amount of data already on file. Use of a Socratic-type expert system, in which the user is bombarded with questions that provide the bulk of the knowledge required to come to a conclusion, was specifically rejected. As shown in fig. 5, no direct intervention is required from the user in order for

the expert system to diagnose the anomalous correlation shown in fig. 4. Any information required by the inference system in CORRELATOR is obtained from the data base itself rather than by consultation with the user. In a sense, CORRELATOR is *autonomous*, like a federal system of government, in which all routine decisions are made locally. The user, representing the highest authority, is consulted only on matters which are too important to be decided by the program, which is the local authority in this

metaphor. The decision to keep or eliminate correlation bundles, for instance, is reserved for the user working interactively with the expert system in CORRELATOR. This philosophy assures the user a comfortable position away from the extreme approaches of black boxes or high-maintenance systems.

Central to the conversational mode is a menu presenting options available to the user at all times. Table 1 lists all of these options.

TABLE 1—CATALOG OF OPTIONS.

| Option | Action                                                         |
|--------|----------------------------------------------------------------|
| COIN   | Compute cross-correlation coefficients for an interval.        |
| COLE   | Find cross-correlation coefficient for a single level.         |
| COBS   | Correct base line on spontaneous-potential logs.               |
| DATA   | Select log-data file.                                          |
| DELE   | Delete correlation-file records.                               |
| DICO   | Display a correlation file on screen.                          |
| ELCO   | Eliminate crossing and abnormal correlations.                  |
| IALO   | Initialize or add to binary log-data files.                    |
| IAWE   | Initialize or add wells to a well-data file.                   |
| INCO   | Initialize correlation files.                                  |
| LIST   | List correlation file on screen.                               |
| PERS   | Plot and print persistent correlations in a cross section.     |
| PLOT   | Display logs on screen.                                        |
| PRNC   | Print a correlation file.                                      |
| PRNP   | Print persistent correlations.                                 |
| PRNT   | Print traced correlations.                                     |
| REDE   | Run regression on difference in elevation.                     |
| SECT   | Plot and print correlation files on a cross section.           |
| SHAL   | Provide difference in shale for a single level.                |
| SORT   | Sort correlation file.                                         |
| STAN   | Standardize logs.                                              |
| STOP   | Finish CORRELATOR execution.                                   |
| TRAC   | Trace correlation in a cross section.                          |
| TREN   | Remove trend from logs.                                        |
| WEIN   | Compute weighted correlation coefficients for an interval.     |
| WELE   | Calculate weighted correlation coefficient for a single level. |
| WELL   | Select wells.                                                  |

## Hardware and software requirements

The entire CORRELATOR program is written in FORTRAN 77, which was selected as the programming language for the expert system as well, because of its higher portability than symbol manipulation languages such as LISP or PROLOG (Myers, 1986), and support of recursion.

The CORRELATOR program was developed on a Data General MV-20000 computer. The program runs interactively through graphics terminals—either a Tektronix 4014 black-and-white monitor or a Tektronix 4113 color monitor. A plotter is highly recommended to take full advantage of the capabilities of the correlation system.

The correlation system interacts with several types of files where partial or final results are saved. Wireline logs for all wells to be correlated must reside in digitized form in a *wireline-log file*. General information about the logs and about the wells themselves must be in a *well-data file*. Correlations established by the system are saved in pre-initialized *correlation files*. Correlation files are used to determine trends in the differences in elevation between wells; the resulting trend information is saved in *regression-coefficient files*. The datum from which correlations can be displayed can be selected as desired, using elevations contained in *datum files*. Finally, the user can find selected lithostratigraphic equivalences by entering the elevations for the correlations of interest in a given well into a *tracing file*.

## Well- and file-selection capabilities

The correlation system presumes that certain operations are completed before any actual computation takes place. These operations are selected by choosing options from the catalog on table 1. The following options are used to build basic files required by CORRELATOR.

### IALO—Initialization and Additions to binary Log data files

The correlation system requires that digitized log readings for all wells to be analyzed must be in a single digitized *log-data file*. To conserve space, digitized logs are stored as direct-access unformatted binary files which can be prepared with option IALO. Information to be incorporated into the binary log files must be tabulated in a free-formatted form, such as that shown in fig. 6. Different logs from the same well can be located in one file in multiplexed format or in separate files. Within a *multiplex formatted file*, successive records represent uniform increments of depth, and columns represent different log responses. Although the log responses in fig. 6 are from the same well, it is also possible to include readings from different wells in the same formatted file. This, however, is not a desirable alternative if starting and ending logging depths differ from one well to the other.

Even if the logs for all wells are contained in one formatted log file, the use of IALO is still the obvious choice to make the conversion from formatted to unformatted binary file. If the input files are set up according to these guide lines, the same option can be used to prepare digitized logs for input to CORRELATOR regardless whether the log readings are taken directly from magnetic tapes or obtained by digitizing.

| DEPTH   | LOG A  | LOG B  |
|---------|--------|--------|
| 200.000 | 99.075 | 3.409  |
| 200.500 | 99.242 | 3.449  |
| 201.000 | 99.408 | 3.456  |
| 201.500 | 99.110 | 3.293  |
| 202.000 | 98.962 | 4.000  |
| 202.500 | 98.516 | 5.429  |
| 203.000 | 97.940 | 6.067  |
| 203.500 | 97.752 | 6.431  |
| 204.000 | 98.450 | 6.413  |
| 204.500 | 99.263 | 4.659  |
| 205.000 | 98.830 | 4.711  |
| 205.500 | 98.705 | 5.707  |
| 206.000 | 96.780 | 6.439  |
| 206.500 | 94.109 | 9.704  |
| 207.000 | 91.889 | 13.313 |
| 207.500 | 91.297 | 14.843 |
| 208.000 | 92.450 | 15.635 |
| 208.500 | 92.998 | 13.923 |
| 209.000 | 90.802 | 8.322  |
| 209.500 | 91.019 | 5.512  |
| 210.000 | 95.638 | 5.521  |
| 210.500 | 97.221 | 5.006  |
| 211.000 | 96.816 | 5.829  |
| 211.500 | 95.837 | 7.476  |
| 212.000 | 95.569 | 8.366  |
| 212.500 | 94.204 | 8.502  |
| 213.000 | 96.002 | 8.929  |
| 213.500 | 94.722 | 10.605 |
| 214.000 | 96.142 | 6.261  |
| 214.500 | 97.648 | 4.948  |
| 215.000 | 97.462 | 4.022  |

FIGURE 6—PART OF A FREE-FORMATTED FILE CONTAINING READINGS OF TWO LOG TRACES FROM A WELL.

```

) IALO

FROM WHAT FILE DO YOU WANT TO READ IN DIGITIZED WELL LOGS?: :SI21:AP.TEMP:FISHER.ASC

***FIRST FEW LINES FROM INPUT FILE***

1500.000    -999.000    -999.000    -999.000    -999.000    -999.000
-999.000    -999.000    -999.000    -999.000    -999.000    -999.000
-999.000    -999.000    -999.000    -999.000    -999.000    -999.000
-999.000    -999.000    -999.000    -999.000    -999.000    -999.000
-999.000    -999.000    -999.000    -999.000    -999.000    -999.000
-999.000    -999.000    -999.000    -999.000    -999.000    -999.000
1500.500    -999.000    -6.027    3.498    3.445    3.957
2.478    -.001    24.301    2.704    2166.281    786.141
2.787    9.157    89.454    9.001    105.462    .000
108.577    240.506    89.975    27.050    6.412    5.802
2648.000    13.567    1.597    2.446    93.786    10.238
11.719    247.250    106.125    4.780    3.156
1501.000    -999.000    -.527    3.520    3.422    3.957

***REMEMBER THE STARTING DEPTH FOR LATER USE***

HOW MANY DIGITIZED LOGS ARE THERE FOR THIS WELL?: 34
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 2
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 3
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 4
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 5
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 6
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 8
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 14
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 16
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 25
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 26
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 27
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 28
WHICH LOG DO YOU WANT TO EXTRACT (0 TO STOP)?: 0

NUMBER OF RECORDS READ: 1401

WHAT WILL BE THE STARTING DEPTH FOR ALL LOGS?: 1501
IN WHAT DIGITIZED LOG FILE DO YOU WANT TO STORE THE DATA?: LAN_KC
DO YOU WANT TO INITIALIZE THE BASE?:Y
WHAT IS THE DEPTH INCREMENT?: 0.5

```

FIGURE 7—AN EXAMPLE OF A SCREEN-DISPLAY DIALOGUE WITH OPTION IALO, used to construct CORRELATOR packed binary files from digital wireline logs or digitized log traces.

Fig. 7 is an example dialogue with the option IALO, showing the preparation of a digitized log file. Fig. 8 is a report produced by IALO following file preparation. In this example, the original log readings came from a magnetic tape. Note the convention, used in IALO and other options, of marking the end of a question and the beginning of a user response by a question mark and a colon (?:).

## Iawe—Initialization and Additions to Well data files

Some basic information must be entered into the well-data file for all wells to be correlated. Option Iawe is used to start a new well-data file or to add information to an existing data file.

|    |    |                          |
|----|----|--------------------------|
| 1  | 02 | :SI21:AP.TEMP:FISHER.ASC |
| 2  | 03 | :SI21:AP.TEMP:FISHER.ASC |
| 3  | 04 | :SI21:AP.TEMP:FISHER.ASC |
| 4  | 05 | :SI21:AP.TEMP:FISHER.ASC |
| 5  | 06 | :SI21:AP.TEMP:FISHER.ASC |
| 6  | 08 | :SI21:AP.TEMP:FISHER.ASC |
| 7  | 14 | :SI21:AP.TEMP:FISHER.ASC |
| 8  | 16 | :SI21:AP.TEMP:FISHER.ASC |
| 9  | 25 | :SI21:AP.TEMP:FISHER.ASC |
| 10 | 26 | :SI21:AP.TEMP:FISHER.ASC |
| 11 | 27 | :SI21:AP.TEMP:FISHER.ASC |
| 12 | 28 | :SI21:AP.TEMP:FISHER.ASC |
| 13 | 02 | :SI21:AP.TEMP:SCHL.ASC   |
| 14 | 03 | :SI21:AP.TEMP:SCHL.ASC   |
| 15 | 04 | :SI21:AP.TEMP:SCHL.ASC   |
| 16 | 05 | :SI21:AP.TEMP:SCHL.ASC   |
| 17 | 06 | :SI21:AP.TEMP:SCHL.ASC   |
| 18 | 08 | :SI21:AP.TEMP:SCHL.ASC   |
| 19 | 15 | :SI21:AP.TEMP:SCHL.ASC   |
| 20 | 17 | :SI21:AP.TEMP:SCHL.ASC   |
| 21 | 22 | :SI21:AP.TEMP:SCHL.ASC   |
| 22 | 30 | :SI21:AP.TEMP:SCHL.ASC   |
| 23 | 31 | :SI21:AP.TEMP:SCHL.ASC   |
| 24 | 32 | :SI21:AP.TEMP:SCHL.ASC   |
| 25 | 02 | :SI21:AP.TEMP:HOLM.ASC   |
| 26 | 03 | :SI21:AP.TEMP:HOLM.ASC   |
| 27 | 04 | :SI21:AP.TEMP:HOLM.ASC   |
| 28 | 05 | :SI21:AP.TEMP:HOLM.ASC   |
| 29 | 06 | :SI21:AP.TEMP:HOLM.ASC   |
| 30 | 07 | :SI21:AP.TEMP:HOLM.ASC   |
| 31 | 09 | :SI21:AP.TEMP:HOLM.ASC   |
| 32 | 16 | :SI21:AP.TEMP:HOLM.ASC   |
| 33 | 19 | :SI21:AP.TEMP:HOLM.ASC   |
| 34 | 26 | :SI21:AP.TEMP:HOLM.ASC   |
| 35 | 27 | :SI21:AP.TEMP:HOLM.ASC   |
| 36 | 28 | :SI21:AP.TEMP:HOLM.ASC   |

FIGURE 8—EXAMPLE OF THE SCREEN DISPLAY OF THE REPORT PRODUCED BY OPTION IALO, after generating the well-data file specified by the dialogue given in fig. 7. The first column shows the sequential number of logs in the compressed binary well-data file. The names of the formatted source files are given in the third column. The second column is the sequential number of the logs within the formatted source files.

The first question asked by IAWWE will offer the alternatives of adding to an existing well-data file or creating a new file. An incorrect choice may lead to serious problems: If an existing file that has not been properly protected is reinitialized, the original file will be lost. Also, if information is added to a nonexistent file, this will result in a well-data file without a heading and may cause a fatal error when CORRELATOR attempts to use the file.

IAWE will next request the file name for the well data. Conventions for naming files are the same as those used by the computer's operating system. Mnemonic names are recommended. The next five questions relate to the well-data file heading. These questions will be

skipped by the system if the option to add to an existing well-data file has been chosen. The answers to these questions will provide information for the entire file.

The first request is for the name of the log-data file that contains the logs for all wells to be included in the CORRELATOR well-data file. The next request is for the permanent datum or depth origin. The correlation system offers two ways to change the *field datum* or depth origin set by the logging company at the time the well was originally surveyed. An alternative *permanent datum* entered here will appear in all future listings and in all graphical displays except those mentioned in the section on presentation of final results in cross section. Sea level is a typical alternative permanent datum.

As the original field datum is always related to topographic elevation, a change to a permanent datum such as sea level is useful to make the description of subsurface geology independent of land form. Other alternatives apply to the construction of cross sections, which may require the use of many alternative display datums such as formation tops. Only one alternative permanent datum can be specified in a well-data file.

The third entry specifies the unit of measurement used to define depths: feet or meters. The selection is only for labeling purposes, as no transformation of units is done during processing. Convention dictates that some logs be shown with the scale for the log variable increasing either to the left or to the right. Entries four and five allow the user to adjust the scale convention.

Individual information per well must include the following:

1. Well identification name. This information is posted on the log headings.
2. Well posting symbol code selected from among the following:
  - 1: plus
  - 2: cross
  - 3: asterisk
  - 4: square

- 5: circle
- 6: triangle
- 7: fiducial mark
- 8: hexagon
- 11: oil well
- 12: gas well
- 13: oil and gas well
- 14: dry well

3. Elevation of the original depth origin of the wireline log relative to the alternative permanent datum.
4. Type of shale log.
5. Sequential number of the shale log in log-data file.
6. If shale log is a spontaneous-potential log, this entry is the degree of the polynomial required to correct the base line if that correction was not made during log digitization. If shale log is other than a spontaneous-potential log, this entry allows the shale-log reading to be set for a normal shale. Readings above the normal-shale reading will be truncated to the normal-shale reading. CORRELATOR will ignore a negative entry and will replace a normal-shale reading which is less than zero by the maximum shale-log reading.
7. Type of correlation log.
8. Sequential number for correlation log in log-data file.

WHAT IS YOUR OPTION?: IAWE

DO YOU WANT TO ADD TO AN EXISTING  
FILE (A) OR INITIALIZE A NEW FILE (I)? : I

HOW WOULD YOU LIKE TO NAME THIS NEW WELL DATA FILE?: MISSISS

IN WHAT FILE ARE THE DIGITIZED LOGS FOR ALL THE  
THE WELLS TO BE ENTERED INTO THIS WELL DATA FILE?: :UDD:OLEA:CORREL:LGLIB:KANSAS.1FT

WHAT IS THE NAME FOR THE REFERENCE LEVEL FOR THE ELEVATIONS?: SEA LEVEL

ARE THE ELEVATIONS GIVEN IN FEET(F), OR METERS(M)? : F

IN THE DISPLAYS, DO YOU WANT THE SHALE LOG AXIS  
TO INCREASE TO THE LEFT(L), OR TO THE RIGHT(R)? : R

IN THE DISPLAYS, DO YOU WANT THE CORRELATION LOG  
AXIS TO INCREASE TO THE LEFT(L), OR TO THE RIGHT(R)? : R

WHAT IS THE NAME FOR WELL No. 1?: WOODS No. 1

WHAT IS THE WELL SYMBOL CODE?: 14

WHAT IS THE ELEVATION FOR THE FIELD DATUM RELATIVE TO SEA LEVEL ? : 1106

WHAT IS THE 4 LETTER MNEMONIC USED  
TO IDENTIFY THIS TYPE OF SHALE LOG?: GR

WHAT IS THE GR LOG SEQUENTIAL NUMBER IN THE DIGITIZED LOG FILE?: 2

WHAT IS THE GR LOG READING FOR A NORMAL SHALE?: -1

WHAT IS THE 4 LETTER MNEMONIC USED  
TO IDENTIFY THIS TYPE OF CORRELATION LOG?: NEUT

WHAT IS THE NEUT LOG SEQUENTIAL NUMBER IN THE DIGITIZED LOG FILE?: 1

DO YOU WANT TO ADD MORE WELLS TO THE FILE?: Y

FIGURE 9—AN EXAMPLE OF THE SCREEN DIALOGUE WITH OPTION IAWE, used to initialize a new well-data file.

```

:UDD:OLEA:CORREL:LGLIB:KANSAS.1FT
SEA LEVEL
1 WOODS No. 1      14 1106.0 GR  2 -1 NEUT 1
2 MCGREW No. 1     14 1108.0 GR  4 -1 NEUT 3
3 BUTLER No. 1      14 1122.0 GR  6 -1 NEUT 5
4 HESSLER No. 13    11 1216.0 GR  8 -1 NEUT 7
5 JOHNSON No. 46    11 1080.0 GR 10 -1 NEUT 9
6 GILROY No. 1      11 1046.0 GR 12 -1 NEUT 11
7 MARLIN No. 1      14 1196.0 GR 14 -1 NEUT 13
8 FEE No. 2-3       14 1062.0 GR 16 -1 CNL 15
9 DANIEL No.1       14 1080.0 GR 18 -1 NEUT 17
10 BELL No.1        12  946.0 GR 20 -1 NEUT 19
11 GAYLORD No. 1    11  946.0 GR 22 -1 NEUT 21
12 OAK RIDGE No. 2  18  914.0 GR 24 -1 NEUT 23
13 SHELLEY No. 1    14  940.0 GR 26 -1 NEUT 25
14 BRIM No. 101     18 1004.0 GR 28 -1 NEUT 27
15 B-6 No. 2A SWD   18  772.0 GR 30 -1 NEUT 29
16 SERVENS No. 7    11  796.0 GR 32 -1 NEUT 31
17 TETER No. B-16   11 1414.0 GR 34 -1 NEUT 33
18 HOLLIS No. 1     14 1374.0 GR 36 -1 NEUT 35
19 CARSON No. 1     11 1148.0 GR 38 -1 NEUT 37
20 KIPER No. 1      14 1230.0 GR 40 -1 NEUT 39
21 BAHR No. 1       14 1088.0 GR 42 -1 NEUT 41
22 EVANS No. 1      14 1076.0 GR 44 -1 NEUT 43
23 STABLER No. 42   18 1036.0 GR 46 -1 NEUT 45
24 CARPENTER No. 1  14 1060.0 GR 48 -1 NEUT 47

```

FIGURE 10—SCREEN DISPLAY OF A WELL-DATA FILE CREATED BY OPTION IAWF. The example is a listing of file MISSISS. The beginning of the dialogue that resulted in file MISSISS is displayed in fig. 9.

When a well-data record has been completed, option IAWF will optionally repeat or exit. Fig. 9 shows the beginning of the dialogue that created the file shown in fig. 10.

## DATA—log DATA file selection

Option DATA poses a single question for the purpose of loading a log-data file into the system. The answer consists of the name of the desired well-data file. Option DATA is a prerequisite for the selection of all other options except IAWF and STOP.

## WELL—correlating WELLS

Having selected a well-data file, a decision must be made about the particular pair of wells in the file that are to be correlated. Selecting option WELL will allow the user to choose such wells. The well selections are made by entering the implicit sequential well-record number in the well-data file. As shown on the screen display in fig. 11, for instance, the user must enter the number 3 to select the third well in the data file.

The order in which a well is specified in a pair is important. The first well entered will be used as the reference well in computations involving well-to-well comparisons. Logs from the second or matching well of a pair will be compared to those from the reference well. If, for example, well No. 3 is the reference well and well No. 1 the matching well, elevations in well No. 1 that are equivalent to different levels in well No. 3 will be found. If well No. 1 is entered first as the reference well, CORRELATOR will search for equivalent intervals in well No. 3 that match intervals in well No. 1.

CORRELATOR will display the characteristics of the selected well immediately after the requested sequential numbers are provided. Fig. 11 shows a typical conversational dialogue on the display screen.

## INCO—Initialize Correlation files

As we will see later, correlations between wells can be saved in correlation files. These files must be initialized; this is the purpose of option INCO. When option INCO is selected, the system will pose four questions:

1. First is a request for the name of the file where correlations are to be saved. The name is arbitrary,

WHAT IS YOUR OPTION?: WELL

WHAT IS THE REFERENCE WELL SEQUENTIAL NUMBER IN THE WELL DATA FILE?: 3

GENERAL INFORMATION ABOUT THE REFERENCE WELL LOGS

=====

|                              |   |                   |
|------------------------------|---|-------------------|
| WELL NAME                    | : | CONOCO-HOLM No. 1 |
| SURFACE ELEVATION            | : | 1456.0            |
| PRODUCTION CODE              | : | 14                |
| SHALE LOG TYPE               | : | CGR               |
| SEQUENTIAL NUMBER            | : | 33                |
| CGR READING ON NORMAL SHALE: | : | 120               |
| CORRELATION LOG TYPE         | : | CNL               |
| SEQUENTIAL NUMBER            | : | 31                |

WHAT IS THE MATCHING WELL SEQUENTIAL NUMBER IN THE WELL DATA FILE?: 1

GENERAL INFORMATION ABOUT THE MATCHING WELL LOGS

=====

|                              |   |                     |
|------------------------------|---|---------------------|
| WELL NAME                    | : | CONOCO-FISHER No. 1 |
| SURFACE ELEVATION            | : | 1441.0              |
| PRODUCTION CODE              | : | 14                  |
| SHALE LOG TYPE               | : | CGR                 |
| SEQUENTIAL NUMBER            | : | 12                  |
| CGR READING ON NORMAL SHALE: | : | 140                 |
| CORRELATION LOG TYPE         | : | CNL                 |
| SEQUENTIAL NUMBER            | : | 6                   |

\*\*\*\*\* REFERENCE SHALE LOG TRUNCATED TO 120

\*\*\*\*\* MATCHING SHALE LOG TRUNCATED TO 140

FIGURE 11—EXAMPLE OF THE SCREEN DIALOGUE PRODUCED BY THE OPTION WELL.

- within the conventions of the computer's operating system. However, the use of mnemonic names is highly recommended as an aid in keeping track of the working files. If a file already exists having the same name as that proposed for the new correlation file, the old file will be overwritten unless it is protected.
- Next, the reference well must be identified. The user must provide the sequential number of the reference well in the well-data file. In response, CORRELATOR will display the information available for the selected well.

- The matching well is then identified by providing the sequential number for the second well in the pair of wells to be correlated. CORRELATOR will produce a screen display similar to that given for the reference well.
- The distance between wells is next specified, in the same units used to measure depth. This information on horizontal distance is used to compute apparent dips and to properly scale plotter displays of wells along traverses, as explained in the section on presentation of results in cross section.

Fig. 12 shows a screen display of an example conversation using the option INCO.

WHAT IS YOUR OPTION?: INCO

HOW WOULD YOU LIKE TO NAME THIS NEW CORRELATION FILE?: LKC31.INCO

WHAT IS THE REFERENCE WELL SEQUENTIAL NUMBER IN THE WELL DATA FILE?: 3

GENERAL INFORMATION ABOUT THE REFERENCE WELL LOGS

=====

|                              |   |                   |
|------------------------------|---|-------------------|
| WELL NAME                    | : | CONOCO-HOLM No. 1 |
| SURFACE ELEVATION            | : | 1456.0            |
| PRODUCTION CODE              | : | 14                |
| SHALE LOG TYPE               | : | CGR               |
| SEQUENTIAL NUMBER            | : | 33                |
| CGR READING ON NORMAL SHALE: | : | 120               |
| CORRELATION LOG TYPE         | : | CNL               |
| SEQUENTIAL NUMBER            | : | 31                |

WHAT IS THE MATCHING WELL SEQUENTIAL NUMBER IN THE WELL DATA FILE?: 1

GENERAL INFORMATION ABOUT THE MATCHING WELL LOGS

=====

|                              |   |                     |
|------------------------------|---|---------------------|
| WELL NAME                    | : | CONOCO-FISHER No. 1 |
| SURFACE ELEVATION            | : | 1441.0              |
| PRODUCTION CODE              | : | 14                  |
| SHALE LOG TYPE               | : | CGR                 |
| SEQUENTIAL NUMBER            | : | 12                  |
| CGR READING ON NORMAL SHALE: | : | 140                 |
| CORRELATION LOG TYPE         | : | CNL                 |
| SEQUENTIAL NUMBER            | : | 6                   |

WHAT IS THE DISTANCE BETWEEN THE WELLS, IN FEET?: 7086

FIGURE 12—AN EXAMPLE OF THE SCREEN DIALOGUE WITH OPTION INCO, used to initialize correlation files.

# Wireline-log display and transformation

Wireline-log correlation can be performed more efficiently after some prior familiarization with the wireline logs and after any necessary modification of the raw log readings. This chapter describes options that are available for these purposes.

## PLOT—PLOT the original logs

Option PLOT simultaneously displays two wireline logs at a time. It is useful to display the original logs in order to confirm digitization and to develop a general feeling for the sections being compared. As in most options, PLOT requires the prior use of the option WELL to select the desired well information. Wireline logs can be displayed in the original depth scale of the field logs, or by using the permanent datum provided in the well-data file. Figs. 13 and 14 show the same wells using the alternative reference levels. The well-identification

names, sequential well numbers in the well-data file, and the log types appear at the top of the display. Numbers along the bottom line show the minimum and maximum log readings for the traces displayed.

## STAN—wireline-log STANdardization

CORRELATOR allows the user to normalize wireline-log readings by subtracting the mean and scaling by the standard deviation of the wireline-log trace. Standardization improves processing accuracy, especially when dealing with logs that have numerically large readings. Fig. 15 shows a dialogue for standardizing two log traces. Fig. 16 shows the logs before and after standardization. Notice that the standardized log remains exactly the same following transformation, but the scale is changed.

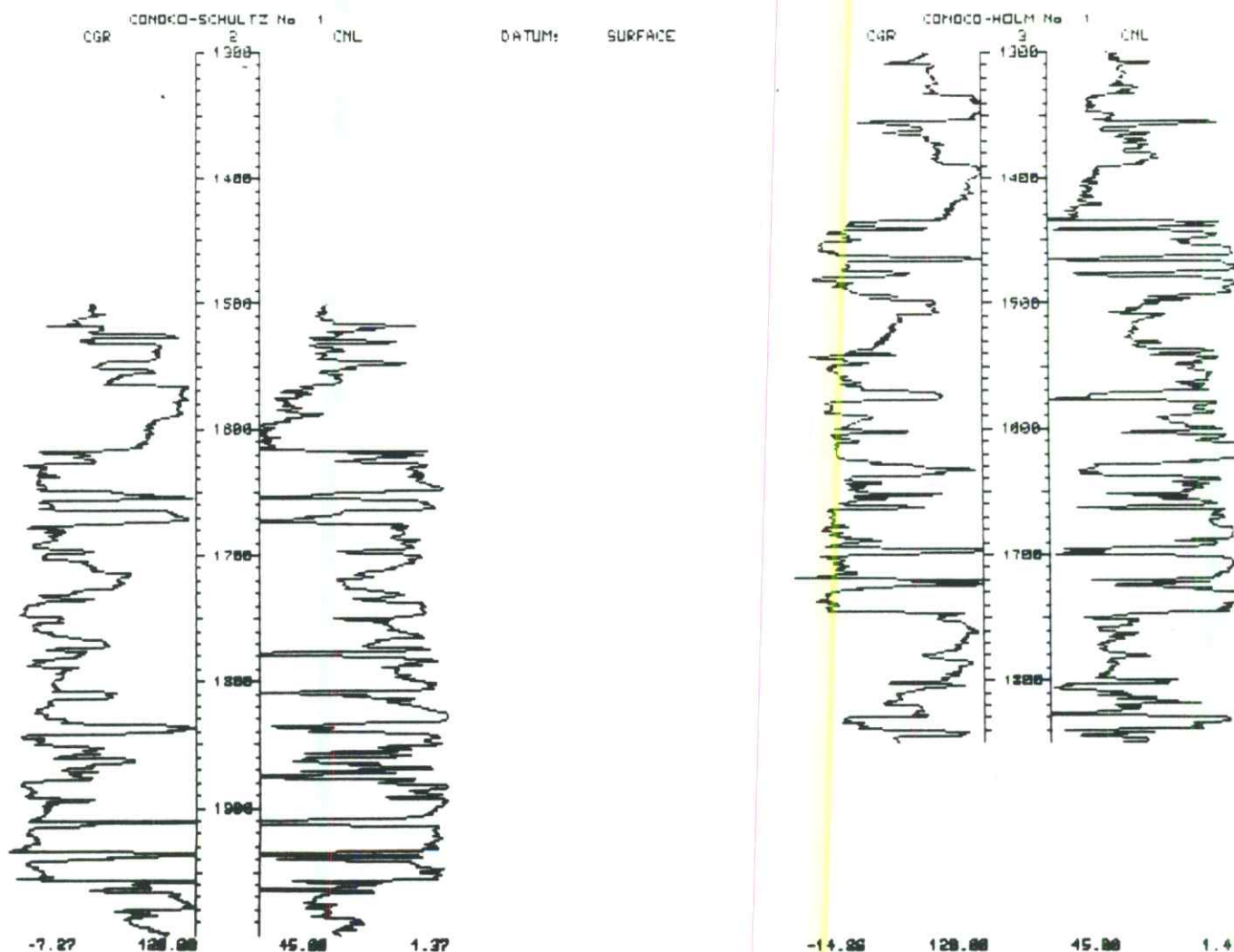


FIGURE 13—SCREEN DISPLAY SHOWING PLAYBACKS OF TWO SETS OF WIRELINE LOGS, using surface elevations as the reference datum for depth.

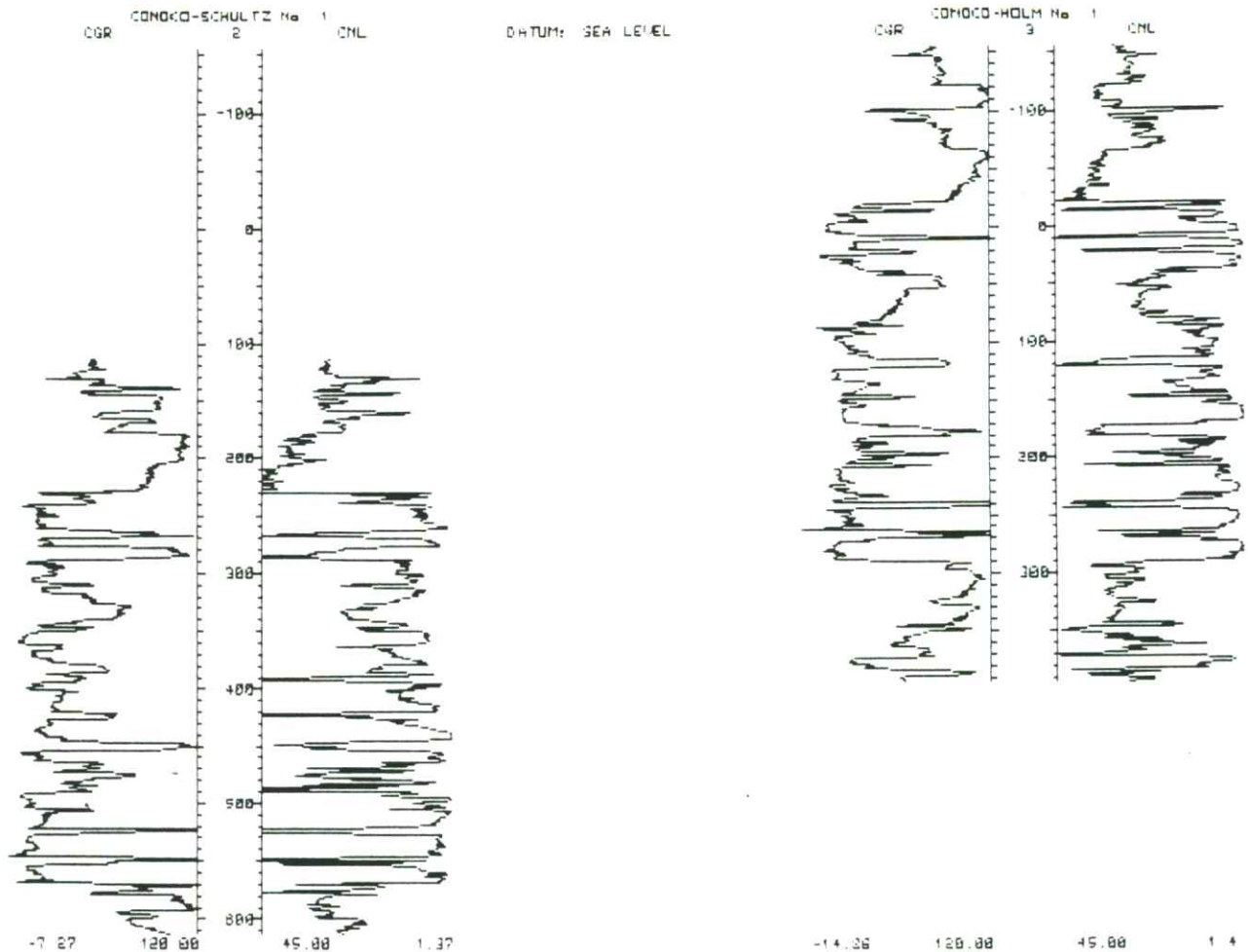


FIGURE 14—SCREEN DISPLAY ILLUSTRATING THE EFFECT OF CHANGING THE REFERENCE LEVEL. The same wireline logs as in fig. 13 are displayed using sea level as the new datum.

```

WHAT IS YOUR OPTION?: STAN

DO YOU WANT TO STANDARDIZE THE SHALE LOGS - YES OR NO?: N

DO YOU WANT TO STANDARDIZE THE CORRELATION LOGS - YES OR NO?: Y

DEPTH INTERVAL FOR THE REFERENCE LOG IS      544.00 TO      894.00

DO YOU WANT TO STANDARDIZE THE ENTIRE LOG - YES OR NO?: Y

MEAN FOR CORRELATION LOG AT THE REFERENCE WELL IS      1079.0786
STANDARD DEVIATION FOR CORRELATION LOG AT REFERENCE WELL IS      204.1149

DEPTH INTERVAL FOR THE MATCHING LOG IS      514.00 TO      874.00

DO YOU WANT TO STANDARDIZE THE ENTIRE LOG - YES OR NO?: Y

MEAN FOR CORRELATION LOG AT THE MATCHING WELL IS      745.7876
STANDARD DEVIATION FOR CORRELATION LOG AT MATCHING WELL IS      228.5069
  
```

FIGURE 15—AN EXAMPLE OF THE SCREEN DIALOGUE WITH OPTION STAN, used to standardize wireline logs.

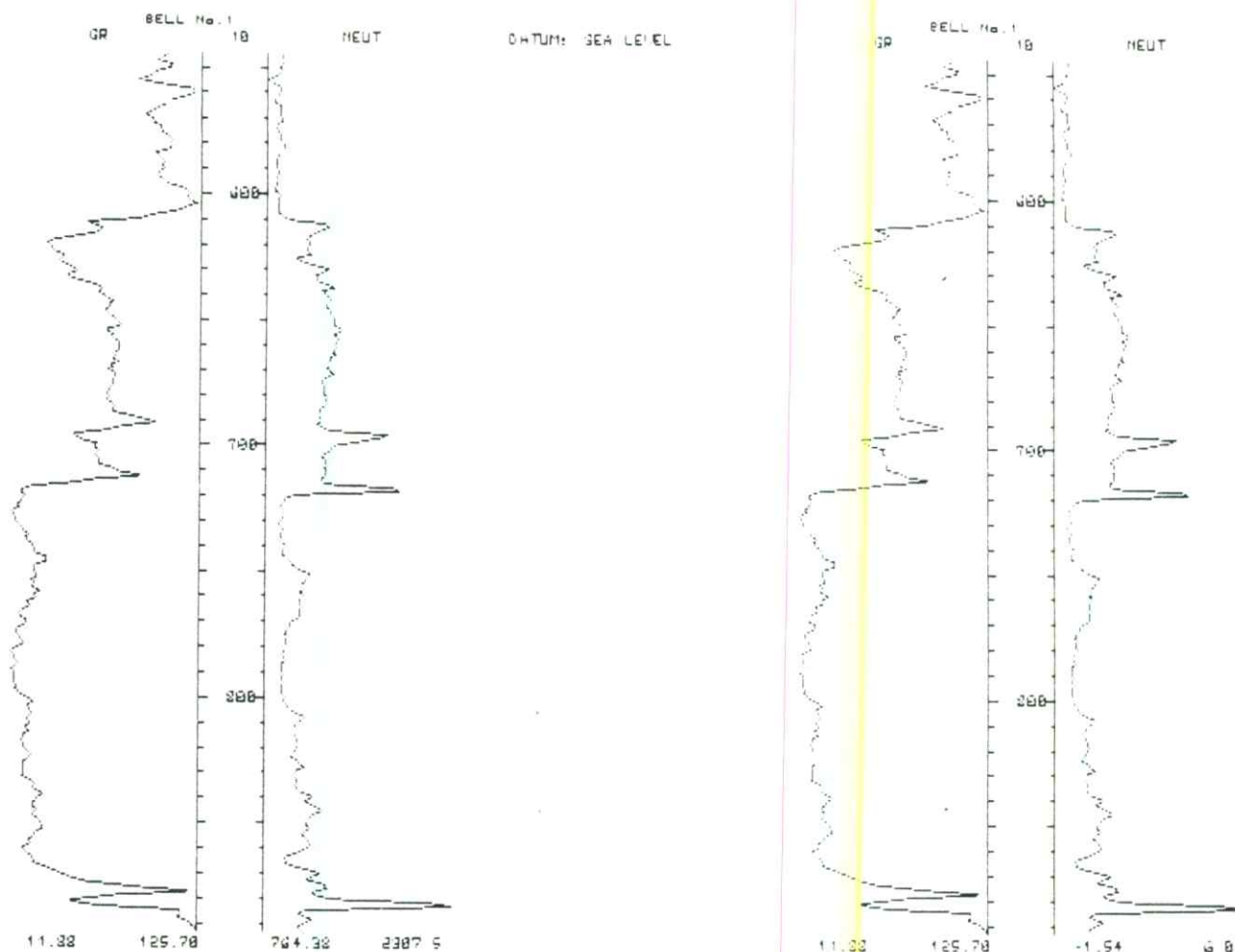


FIGURE 16—SCREEN DISPLAY SHOWING THE EFFECT OF WIRELINE-LOG STANDARDIZATION. Neutron readings are shown before and after removing the mean and dividing each reading by the standard deviation.

## COBS—Correction for Base line of Spontaneous-potential logs

Spontaneous-potential logs display the natural electric potential gradient throughout the stratigraphic column. The spontaneous-potential log is used because there is a high statistical correlation between spontaneous-potential voltage and percent shale in rock units. The best results are obtained if the effect of the normal continuous increase in formation-water salinity with depth is removed from the readings, because this has the effect of producing a systematic drift in the base line of the log trace. The base line can be regarded as a straight line or a low-order polynomial curve representing the right-hand side of an envelope around excursions of the spontaneous-potential log. The salinity effect can be eliminated by measuring spontaneous-potential readings from the base line rather than from zero on the SP scale. This is equivalent to transforming the data so that the base line is a constant. Base-line correction is performed by option COBS.

When selected, option COBS asks for the degree of the polynomial to be used to approximate the base line.

The option of saving the polynomial into the well-data file is offered. Fig. 17 illustrates a COBS dialogue. The user should try several polynomials before deciding which is the best model of the spontaneous-potential base line. Use option PLOT to display the results. Once an appropriate polynomial degree is found, it should be saved into the well-data files. CORRELATOR will automatically make the correct shift in the base line every time the log is used, without further prompting from the user. Fig. 18 shows a spontaneous-potential log before and after shifting of base line.

## TREN—TREND removal

Option TREND is similar to option COBS. However, COBS fits and removes an envelope that corresponds only to the base line of a shale log, whereas TREND removes a drift in value corresponding to a curve fitted by least-squares to all readings of a given log. Option COBS can be used to remove a trend from either a shale or a correla-

WHAT IS YOUR OPTION?: COBS

REFERENCE LOG  
\*\*\*\*\*

DEPTH INTERVAL FOR THE LOG IS 620.50 TO 1820.00

WHAT IS THE POLYNOMIAL DEGREE?: 0

COEFFICIENTS OF THE REGRESSION EQUATION

1 97.658

|                                   |   |            |
|-----------------------------------|---|------------|
| NUMBER OF SAMPLES                 | : | 46         |
| SUMS OF SQUARES DUE TO REGRESSION | : | .00000E+00 |
| TOTAL SUMS OF SQUARES             | : | 292.83     |
| CORRELATION COEFFICIENT           | : | .00000E+00 |

DO YOU WANT TO SAVE THIS NEW BASE LINE  
POLYNOMIAL DEGREE IN THE WELL DATA FILE?: N

MATCHING LOG  
\*\*\*\*\*

DEPTH INTERVAL FOR THE LOG IS 564.50 TO 1604.00

WHAT IS THE POLYNOMIAL DEGREE?: 1

COEFFICIENTS OF THE REGRESSION EQUATION

1 98.927 2 .34552E-01

|                                   |   |        |
|-----------------------------------|---|--------|
| NUMBER OF SAMPLES                 | : | 41     |
| SUMS OF SQUARES DUE TO REGRESSION | : | 4422.7 |
| TOTAL SUMS OF SQUARES             | : | 4634.5 |
| CORRELATION COEFFICIENT           | : | .97688 |

DO YOU WANT TO SAVE THIS NEW BASE LINE  
POLYNOMIAL DEGREE IN THE WELL DATA FILE?: Y

FIGURE 17—AN EXAMPLE OF THE SCREEN DIALOGUE WITH OPTION COBS, used to correct for drift in a wireline-log trace.

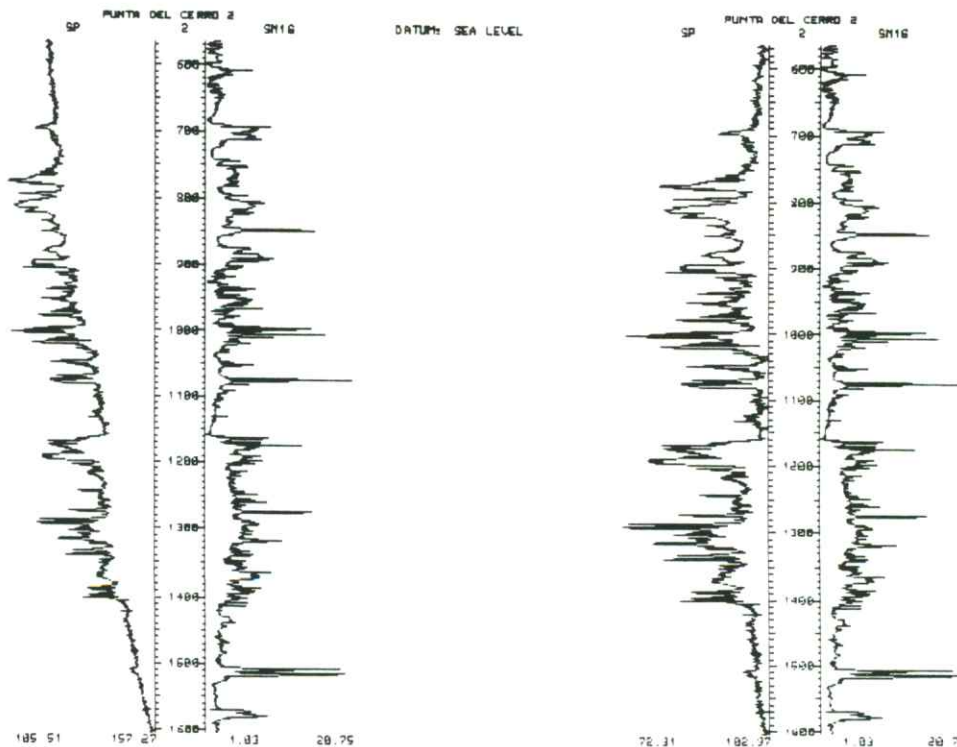


FIGURE 18—SCREEN DISPLAY SHOWING CORRECTION OF BASE-LINE DRIFT IN A SPONTANEOUS-POTENTIAL LOG. The original log is on the left and the log corrected using option COBS is on the right.

tion log. As shown in fig. 19, CORRELATOR will ask the user from which log trace is the trend to be removed,

and what polynomial degree is to be used to model the trend.

WHAT IS YOUR OPTION?: TREN

DO YOU WANT TO REMOVE THE TREND FROM THE SHALE LOGS - YES OR NO?: Y

REFERENCE LOG  
\*\*\*\*\*

DEPTH INTERVAL FOR THE LOG IS 7002.00 TO 11000.00

WHAT IS THE POLYNOMIAL DEGREE?: 0

COEFFICIENTS OF THE REGRESSION EQUATION

1  
1 -33.141

|                                   |   |            |
|-----------------------------------|---|------------|
| NUMBER OF SAMPLES                 | : | 2000       |
| SUMS OF SQUARES DUE TO REGRESSION | : | .00000E+00 |
| TOTAL SUMS OF SQUARES             | : | .32220E+07 |
| CORRELATION COEFFICIENT           | : | .00000E+00 |

MATCHING LOG  
\*\*\*\*\*

DEPTH INTERVAL FOR THE LOG IS 7002.00 TO 11000.00

WHAT IS THE POLYNOMIAL DEGREE?: 1

COEFFICIENTS OF THE REGRESSION EQUATION

1 2  
1 -118.62 .10054E-01

|                                   |   |            |
|-----------------------------------|---|------------|
| NUMBER OF SAMPLES                 | : | 2000       |
| SUMS OF SQUARES DUE TO REGRESSION | : | .26956E+06 |
| TOTAL SUMS OF SQUARES             | : | .21834E+07 |
| CORRELATION COEFFICIENT           | : | .35137     |

DO YOU WANT TO REMOVE THE TREND FROM THE CORRELATION LOGS - YES OR NO?: N

FIGURE 19—AN EXAMPLE OF THE SCREEN DIALOGUE WITH OPTION TREN, used to subtract a polynomial trend from a log trace.

# Simple matching

Options that produce reliable lithostratigraphic correlations will be discussed in the next section. Here, we present some simpler exploratory options that, from time to time, are helpful in understanding the results obtained from these more sophisticated procedures.

## SHAL—Normalized SHALE similarity coefficient

As shown in the section on theoretical background, CORRELATOR uses shale logs as rough indicators of lithostratigraphic similarity in terms of two constituents, shale and non-shale minerals. For a specified interval in the reference well, CORRELATOR will slide a window of the same length down the shale log of the matching well to produce a continuous measure of the average lithostratigraphic similarity. According to equation (3), the index of lithostratigraphic resemblance is zero should a pure shale interval in one well be compared to a clean rock interval containing no shale in the other well or vice versa. An index of one indicates the intervals being compared in the two wells have the same shale content.

When the user selects option SHAL, the system will ask a series of questions. These questions in the dialogue and illustrative responses are shown in fig. 20. First, the location and length of the center of the interval of interest in the reference well is ascertained. The next two questions determine which part of the log in the matching well is to be searched. Fig. 21 is the screen display of the response to specifications provided in fig. 20. The normalized similarity in shale content is displayed in the central track. Highest and lowest values of the log traces and the normalized shale similarity within the displayed intervals appear at the bottom of the screen. The value

10,130 posted to the left of the central track is the depth of the center of the reference interval in the left-hand well. The value 10,118 on the right of the central track is the elevation of the center of the interval in the right-hand well that best matches the reference interval. That is, of all 100-ft intervals whose centers range from 9,800 to 10,400 ft, the interval centered around 10,118 ft in well No. 7 has a shale content which is most similar to that in the 100-ft interval centered at 10,130 ft in well No. 5. Notice that the comparison is based entirely on the shale logs, with no consideration of the correlation logs.

## COLE—Cross Correlation of a single reference Level

Lithostratigraphic correlation based on wireline logs involves comparing the distinctive forms of log traces in short intervals. Only the form of the traces, and not the magnitudes of the log readings, are used, so the correlations are based on relative gradients within the compared intervals. As discussed in the section on theoretical background, there are two good reasons for this. First, the use of gradients helps to eliminate any differences caused by instrumentation. Ordinarily, logging is done by different contractors using similar tools that differ in terms of their resolution, background noise, and edge effects, to name only a few disrupting factors. Even within a single area, wells surveyed by the same contractor vary over the years because of advances in logging technology. Acoustic-velocity logs, for instance, are noticeably different in character depending upon their age.

There is also a statistical reason to use gradients. By and large, variables controlling the physical characteristics of rocks vary spatially in a manner that can be broken into two components: continuous, smooth variation over wide geographical areas, and abrupt local fluctuation. Differentiation tends to cancel out the regional component, enhancing variations which are minor in magnitude but highly important for the purpose of establishing lithostratigraphic correlations. Statistical cross-correlation is naturally suited for the lithostratigraphic-correlation process. The cross-correlation coefficient as a measure of linear dependence provides a quantitative comparison of the degree of similarity in wireline-log signatures.

Figs. 22 and 23 show the screen dialogue and the best resulting matching for the same intervals as in the previous example. The matching is based completely on the corelogram of the correlation logs and no use is made of the shale logs. There is a significant discrepancy of 78 ft (23 m) in the position of best match shown in figs. 21 and 23. The latter result is clearly unacceptable because an interval comprising exclusively shale has been correlated with

```

WHAT IS YOUR OPTION?: SHAL

DEPTH INTERVAL FOR REFERENCE WELL IS  7002.00 TO  11100.00

WHAT IS THE ELEVATION FOR THE CENTER OF INTERVAL?: 10130
WHAT IS THE INTERVAL LENGTH?: 100
WHAT IS THE TOP OF SEARCH INTERVAL?: 9800
WHAT IS THE BOTTOM OF SEARCH INTERVAL?: 10400
  
```

FIGURE 20—AN EXAMPLE OF THE SCREEN DIALOGUE WITH OPTION SHAL, used to find the best normalized shale similarity coefficient.

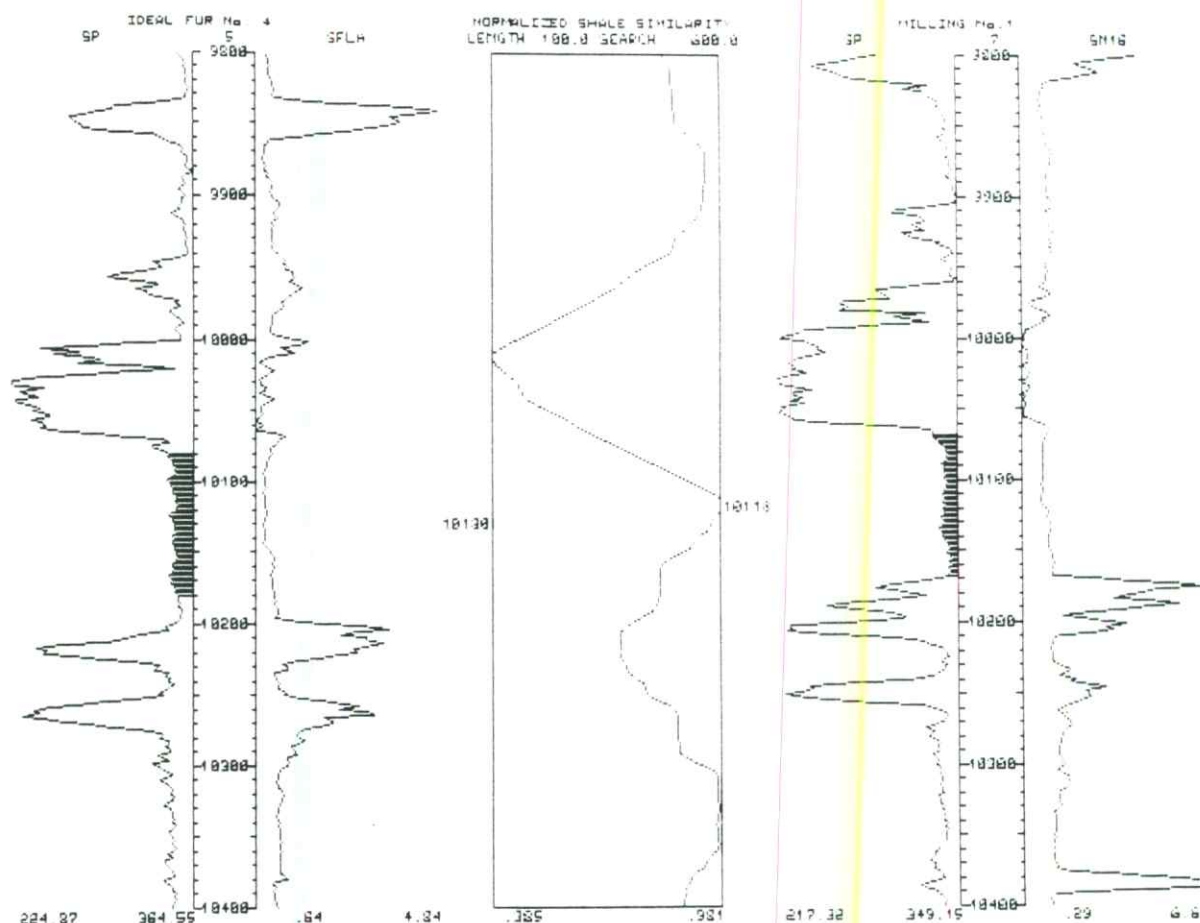


FIGURE 21—SCREEN DISPLAY SHOWING NORMALIZED SHALE SIMILARITY BETWEEN GAMMA-RAY LOGS OF TWO WELLS. Central track shows similarity in shale content between the 100-ft interval centered at 10,130 ft in well No. 5 and all 100-ft intervals between 9,800 and 10,400 ft in well No. 7. The best match is at 10,118 ft, with a shale similarity of 0.98. Shading indicates the locations of intervals most similar in shale content.

another interval whose upper part is a sandstone and only the lower part a shale. This illustrates that similarity in log signature is a necessary but not sufficient condition for establishing lithostratigraphic equivalence.

## COIN—Correlation for an Interval

Option COLE will correlate only a single reference interval at a time, but option COIN can be used to accelerate the processing by correlating multiple levels in a reference interval. However, only the best correlations can be displayed in the form of a series of straight lines connecting the centers of the best correlating intervals in the two wells. With option COIN, it is not possible to show the continuous variation in the strength of correlation or the degree to which the best match is superior to secondary maxima, as is done by option COLE. However, a cutoff can be used to assure that the displayed correlations

are at least above a threshold; this helps to eliminate weak correlations that otherwise would clutter and confuse the display. Figs. 24 and 25 illustrate the use of option COIN.

```

WHAT IS YOUR OPTION?: COLE

DEPTH INTERVAL FOR REFERENCE WELL IS  7002.00 TO  11000.00

WHAT IS THE ELEVATION FOR CENTER OF INTERVAL?: 10130
WHAT IS THE CORRELATION LENGTH?: 100
WHAT IS THE TOP OF SEARCH INTERVAL?: 9800
WHAT IS THE BOTTOM OF SEARCH INTERVAL?: 10400
  
```

FIGURE 22—AN EXAMPLE OF THE SCREEN DIALOG WITH OPTION COLE, used to find the best cross correlation for a given level in the reference well.

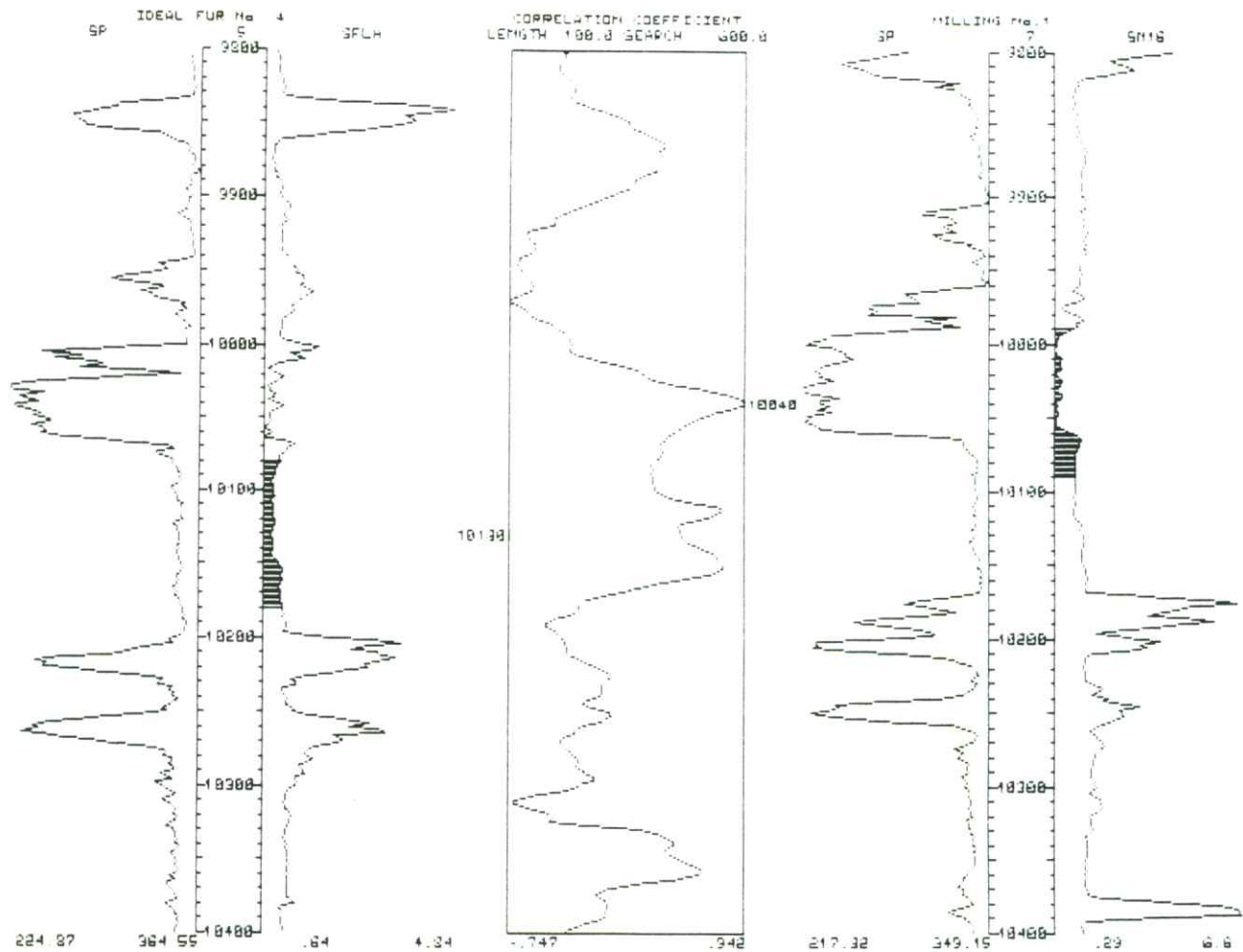


FIGURE 23—SCREEN DISPLAY SHOWING CORRELOGRAM BETWEEN CORRELATION LOGS OF TWO WELLS FOR A SINGLE REFERENCE INTERVAL. Central track shows the cross-correlation coefficient between the 100-ft interval centered at 10,130 ft in well No. 5 and 100-ft intervals between 9,800 and 10,400 ft in well No. 7. The best match is with the interval centered at 10,040 ft in well No. 7, having a correlation coefficient of 0.94. Shading indicates the intervals which match best.

WHAT IS YOUR OPTION?: COIN

DEPTH INTERVAL FOR REFERENCE WELL IS 7002.00 TO 10998.00

WHAT IS THE STARTING DEPTH FOR CORRELATION?: 9000

WHAT IS THE ENDING DEPTH FOR CORRELATION?: 9700

WHAT IS THE CORRELATION LENGTH?: 100

WHAT IS THE TOP OF THE SEARCH INTERVAL?: 8900

WHAT IS THE BOTTOM OF THE SEARCH INTERVAL?: 9800

WHAT IS THE CORRELATION DISPLAY CUTOFF?: 0.97

FIGURE 24—AN EXAMPLE OF A SCREEN DIALOGUE WITH OPTION COIN, used to find cross correlations within a given interval in the reference well.

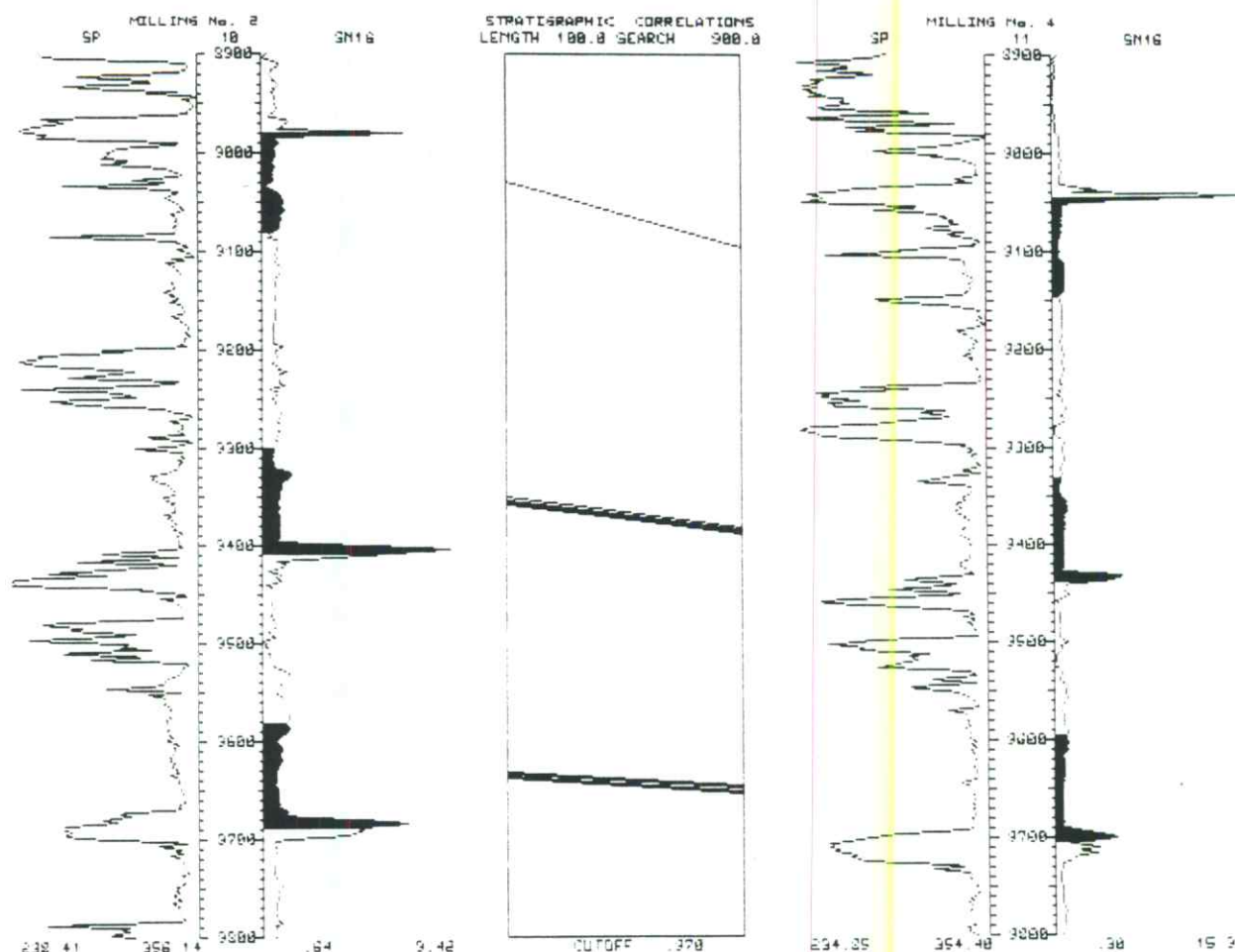


FIGURE 25—SCREEN DISPLAY OF MULTIPLE CROSS CORRELATIONS BETWEEN TWO WELLS. Straight lines in the central track go from center to center of each of the best matching 100-ft intervals within 9,000 to 9,700 ft in well No. 10, and which have a correlation strength of at least 0.97. Shading indicates the correlated intervals.

## Compound matching

We have seen in the previous section that by using a shale log and a correlation log, lithostratigraphic equivalence can be established based on two independent criteria. In this section we present options allowing the simultaneous use of shale and correlation logs.

### WELE—WEighted correlation for a single reference LEvel

Two complementary criteria, based on the shale similarity and the cross correlation, are used to establish equivalency between intervals in two wells. Lithostratigraphically equivalent units must simultaneously contain comparable amounts of shale and have similar signatures on their correlation logs. Because cross correlation is sensitive only to rate of change and not to the absolute values of the log traces, a cross correlation between two

shale logs would not measure the difference in average shale between the wells. In most instances, cross correlating two shale logs would merely duplicate a cross-correlation of the correlation logs. Since the cross-correlation function depends on rate of change in the correlation log, as shown in fig. 23, it is possible to correlate shales to non-shale units if the shale similarity is not also considered. Option WELE selects the best match between intervals in two wells based on the product of the normalized shale similarity and the cross-correlation coefficient. As shown in equation (4), this product is called the weighted correlation coefficient.

Queries presented after typing option WELE are those shown in fig. 26 and are similar to those asked by options SHAL and COIN. Fig. 27 is the display of the weighted correlation that will be produced by option WELE. CORRELATOR creates the weighted-correlation product internally and presents only the result; to also display the shale-similarity function and the cross correlation, it is

WHAT IS YOUR OPTION?: WELE

DEPTH INTERVAL FOR REFERENCE WELL IS 7002.00 TO 11000.00

DEPTH INTERVAL FOR CORRELATION WELL IS 7002.00 TO 10998.00

WHAT IS THE CENTER OF CORRELATION DEPTH INTERVAL?: 10130

WHAT IS THE CORRELATION LENGTH?: 100

WHAT IS THE TOP FOR THE SEARCH INTERVAL?: 9800

WHAT IS THE BOTTOM FOR THE SEARCH INTERVAL?: 10400

DO YOU WANT TO SAVE THIS CORRELATION INTO A  
PREVIOUSLY INITIALIZED CORRELATION FILE - YES OR NO?: Y

WHAT IS THE NAME OF SUCH PREVIOUSLY INITIALIZED CORRELATION FILE?: LD57.WELE

FIGURE 26—AN EXAMPLE OF A SCREEN DIALOGUE WITH OPTION WELE, used to generate the results shown in fig. 27.

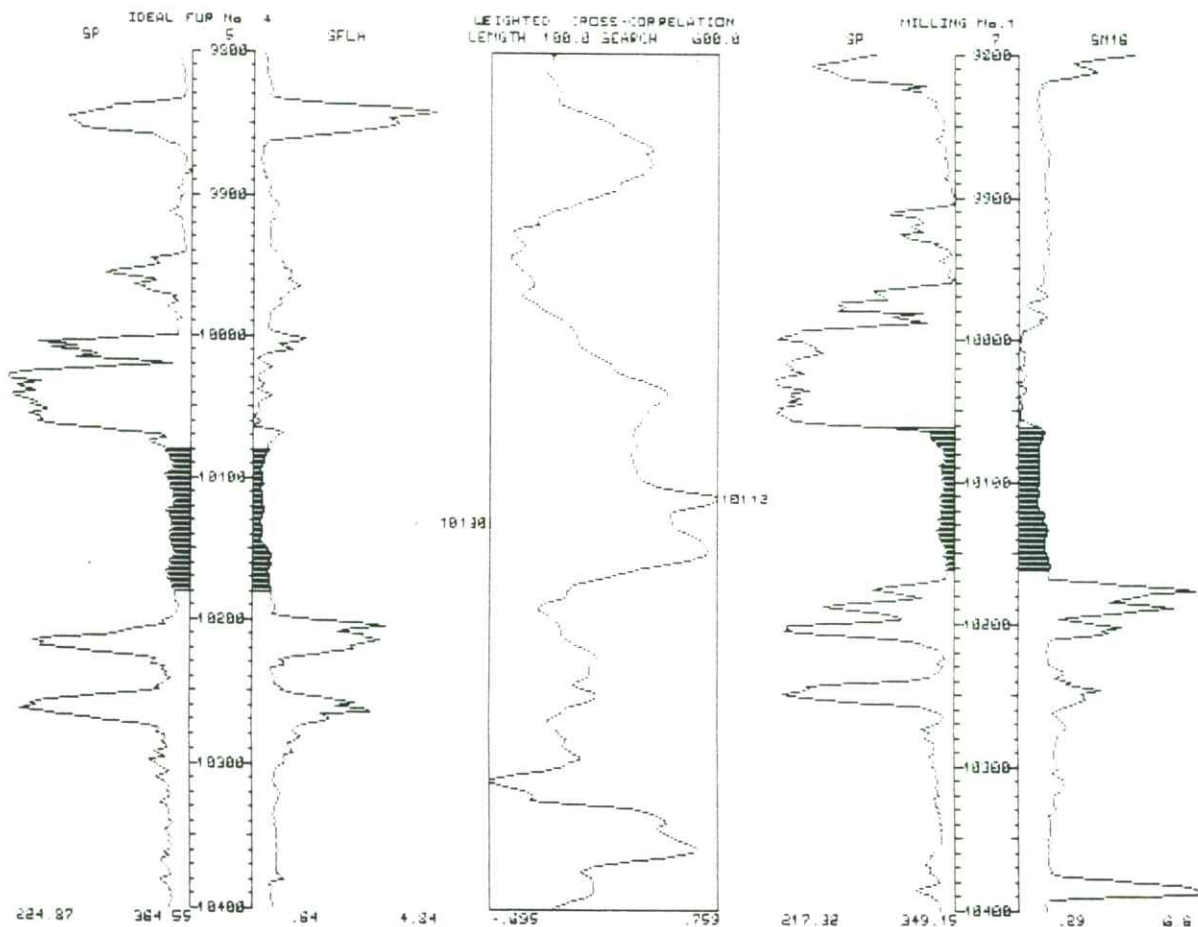


FIGURE 27—SCREEN DISPLAY OF THE WEIGHTED CROSS-CORRELATION COEFFICIENT FOR A SINGLE INTERVAL. The central track displays the product of shale similarity and cross-correlation coefficient. Shading indicates the best matching log segments.

necessary to select all three options. The sequence of selection is immaterial. Note that in the example shown, the weighted correlation provides the correct geological correlation of the interval, while cross correlation by itself cannot.

Option WELE asks additional questions after the graphical display is finished. If the correlation is satisfactory, the user may save the result in one of the correlation files previously initialized using option INCO.

## REDE—REgression on Differences in Elevation

By and large, a lag will occur at different depths in two wells, resulting in an *apparent dip* between the wells. If a series of intervals are correlated, most intervals will exhibit similar dips. If these dips, or differences in elevation, are plotted against depths of the intervals for a series of correlations between two wells, the resulting cross-plot will exhibit a pattern. The variation in dip can be regarded as having two components: a gently varying trend and secondary oscillations around the trend. The trend can be modeled by a low-order polynomial, but the secondary fluctuations are too complex to be modeled by analytical functions.

As shown in Appendix B, the search interval is a crucial parameter in the determination of weighted correlations. The notion of a *search interval* is useful when some additional information that is available suggests to the geologists that there is no need to look for the best matching along the entire digitized portion of the matching logs. The search interval is a sub-sequence of the matching well index presumably containing the matching level. Similarly to the correlation interval, the search interval can be characterized by its center and the length of search. At least in theory, a germane practice on defining search intervals will be to locate the search-interval centers along the dip trend and to select a search-interval length sufficiently wide to enclose all fluctuations around the trend. Since the dips in trend can be modeled by a low-order polynomial, regression techniques can be used to estimate the coefficients of the polynomial. All that is required is one more dip measurement than the degree of the polynomial chosen to model the gentle changes in dip.

The appropriate degree of polynomial is closely related to the complexity of the geology between the two

wells. Dip trends for an undisturbed, monotonous sequence can be modeled with a straight line. Highly disrupted areas will require models formed by higher degree polynomials. Changes in dip should be continuous, at least within segments, but it may be best to model the dip as several non-overlapping polynomials rather than having a single polynomial to model the whole interval. Although not considered here, yet another alternative would be to use splines to model dip in areas of complex geology.

The model of the trend in dips must be based on *unequivocal anchoring correlations*, since it will be used to guide other operations in CORRELATOR. We recommend extending the search length to cover the entire matching well. In this way, a circular question is avoided: Which search interval should be used to generate control points to be used to model the dip trend, which in turn will guide placement of the search intervals in subsequent analyses? The expression "entire well" means that portion of the well for which digitized traces are available. Usually, sound geological criteria have been used to decide which portion of the wireline log should be digitized. Fig. 28 shows one exhaustive search of well No. 13, made by option WELE. Elevation 10,814 ft in well No. 12 unequivocally correlates with elevation 10,506 ft in well No. 13. This correlation and four others were saved in a correlation file called LD1213.PAS1.

Option REDE performs linear regressions on data stored on correlation files. Fig. 29 shows the exchange of questions and the answers generated by option REDE and used to generate the graph shown in fig. 30 and the listing in fig. 31. The apparent dip is given both in depth units (feet or meters) and in sexagesimal degrees. A positive dip means that the correlated interval in the reference well is structurally higher than the equivalent interval in the matching well. The angular measurement is the true dip only if the two wells are located perpendicular to the local strike, and there are no structural complications between the wells. If there are faults or changes in structural attitude between the correlated wells, the line of equivalence is only an apparent slope that will not coincide with real dips in the subsurface. If a negative polynomial degree is specified, only the data will be plotted. No regression will be performed and no listing will be produced. The regression results can be preserved in regression-coefficient files.

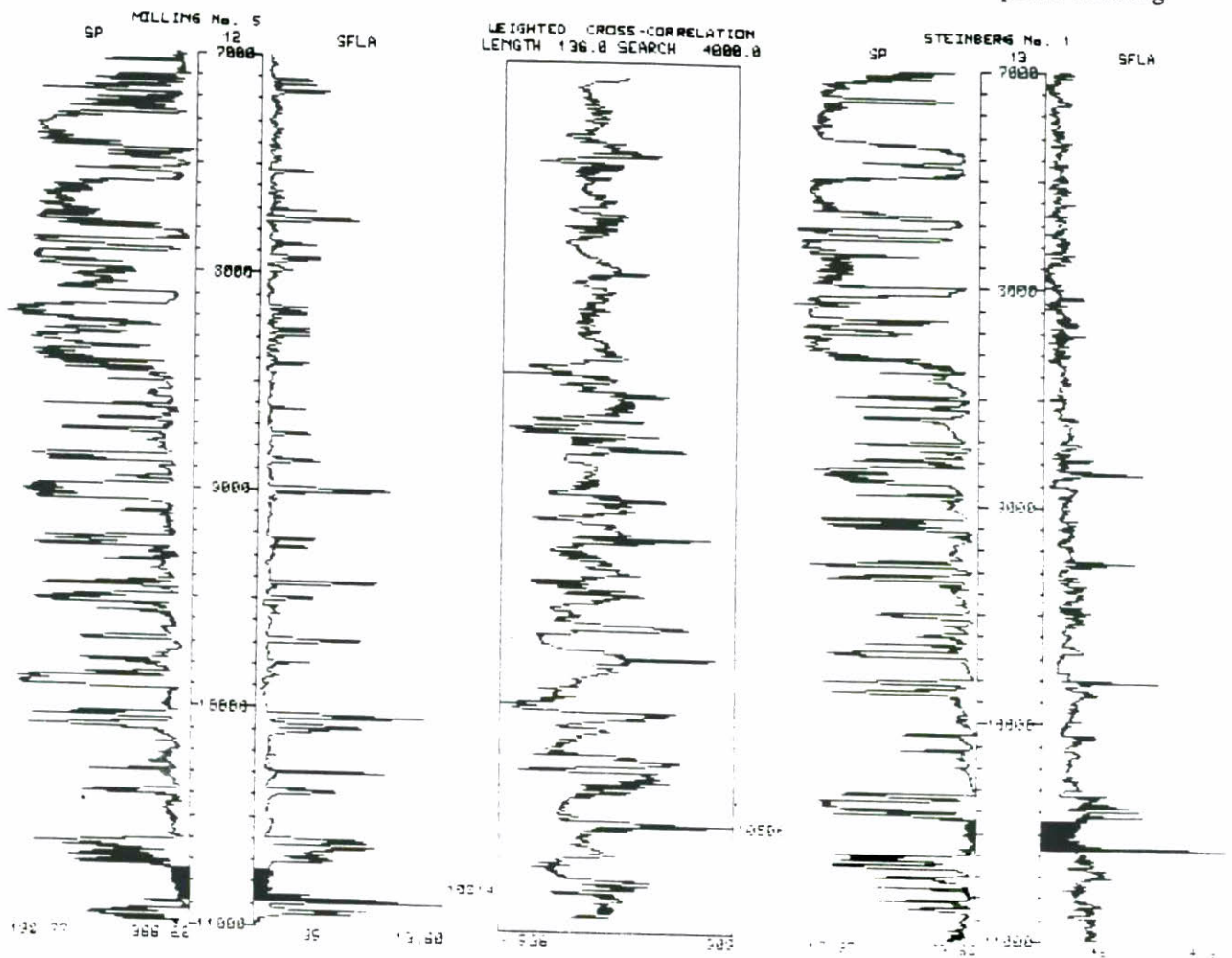


FIGURE 28—UNEQUIVOCAL CORRELATION USING AN UNRESTRICTED SEARCH. Shading indicates the best match between the 136-ft interval centered at depth 10,814 ft in well No. 12, and all possible intervals of the same length throughout the entire matching well. The central track displays the weighted cross correlation and shows that the strongest match, 0.909, occurs at 10,506 ft.

WHAT IS YOUR OPTION?: REDE

FROM WHAT FILE DO YOU WANT TO READ IN YOUR DATA?: LD1213.PAS1

WHAT IS THE STARTING DEPTH FOR REGRESSION?: 7000

WHAT IS THE ENDING DEPTH FOR REGRESSION?: 11000

WHAT IS THE MINIMUM WEIGHTED CROSS-CORRELATION  
COEFFICIENT FOR A LEVEL TO BE USED IN THE REGRESSION?: 0.7

WHAT IS THE POLYNOMIAL DEGREE?: 3

FIGURE 29—EXAMPLE OF A SCREEN DIALOGUE WITH OPTION REDE, used to model changes in elevation of best correlation with a polynomial regression.

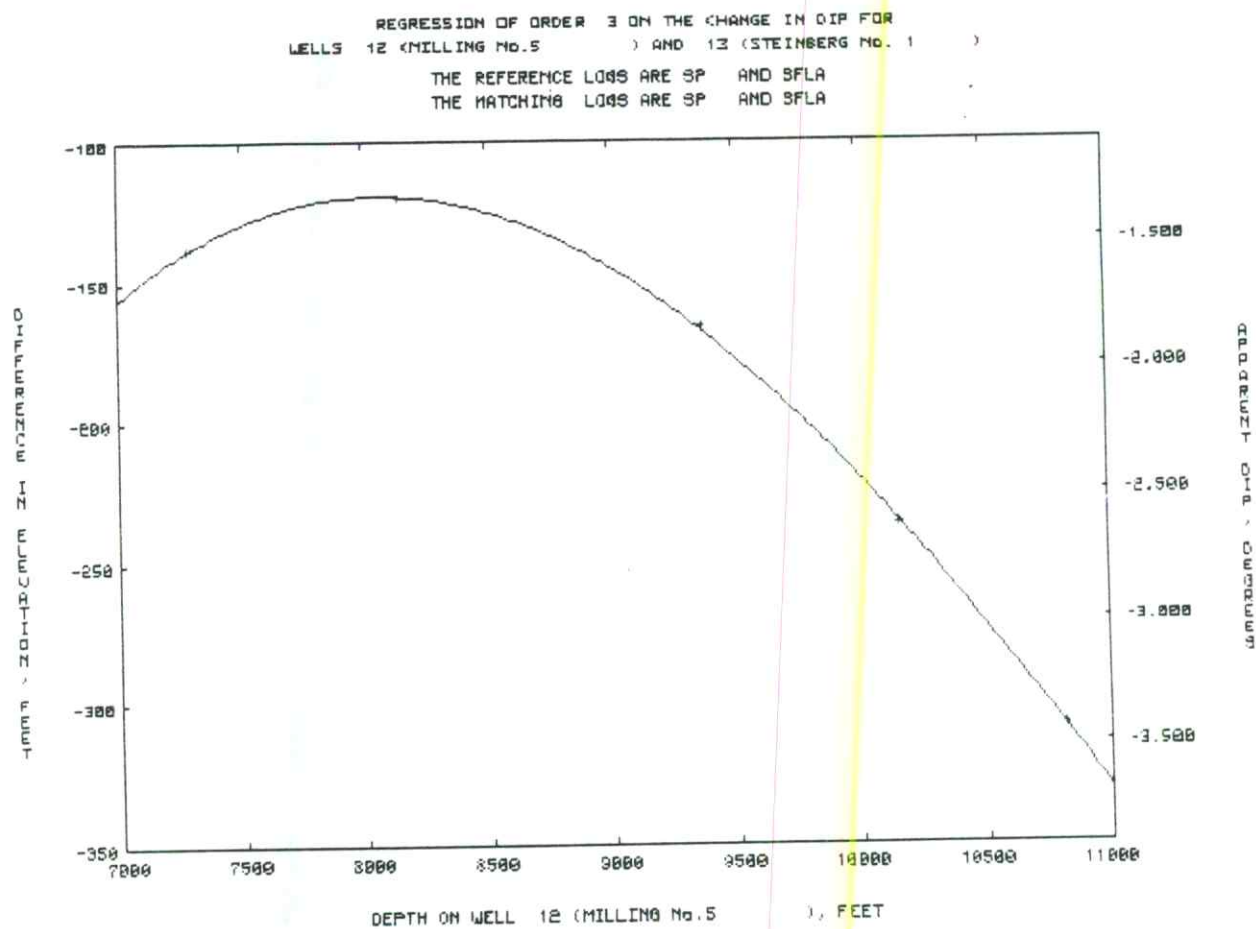


FIGURE 30—SCREEN DISPLAY SHOWING REGRESSION ON DIFFERENCES IN ELEVATION. A third-order polynomial fitted to differences in elevation between wells Nos. 12 and 13 is used to model the trend in offset between the pair of wells.

## WEIN—WEighted Correlation for an Interval

Option WEIN is the central option in CORRELATOR for establishing lithostratigraphic equivalences. This option is designed for rapid generation of lithostratigraphic correlations, using simultaneously the shale and correlation logs from each pair of wells. All other options can be considered peripheral to WEIN. Because of the power of option WEIN, the dialogue required for its control is more complex than that of other options.

Fig. 32 is a record of the conversation used to generate the correlations shown in fig. 33. The dialogue starts with four questions related to plotting and correlation boundaries. They are specified separately to allow the user to scale the display so sufficient margins can be provided above and below the highest and lowest correlations.

Good results depend in part upon thoughtful specification of the intervals to be used for comparative purposes, which are given by the correlation lengths. The lengths of correlation intervals can be either specified by the user or can be selected by the program. In automatic mode, CORRELATOR selects the best correlation length as a function of bed thickness. *Bed thickness* is defined as the vertical height of any one of the rock units into which the succession can be broken according to the binary lithology based on the shale log. The function is diagrammatically shown in fig. 34. Above an upper threshold, B, the optimum correlation length is a fixed proportion of bed thickness. Below a lower threshold, A, the correlation length is constant, which in terms of bed thickness is a hyperbolic function. In between the thresholds A and B, the factor is a decreasing linear function of bed thickness. The form of the functional relationship is dictated primarily by pragmatic considerations.

When first using the automatic mode for selection of correlation length, CORRELATOR requires that the coordinates ( $T_A, F_A$ ) and ( $T_B, F_B$ ) be specified for the two thresholds. A further discussion of how to choose these values, with examples based on practical situations, is presented in Appendix A. If the automatic mode is not selected, the user must provide an alternative for determining correlation lengths. The two choices are either a fixed length, such as 60 ft, or fixed rate, such as 0.7 times the bed thickness.

Once the parameters controlling length have been set, the next question concerns the trend in dips which is used by WEIN to offset the center of the search interval relative to the center of the reference interval to be correlated. The example uses the automatic mode and the polynomial model of the dip trend shown in fig. 30 that was properly saved in a regression-coefficient file.

The next question pertains to the search band around the polynomial model of the dip trend. The user must

### ORIGINAL DATA AND REGRESSED VALUES

|   | 1       | 2       | 3       | 4       | 5      |
|---|---------|---------|---------|---------|--------|
| 1 | 7288.0  | -138.00 | -138.24 | -.23532 | .82474 |
| 2 | 8142.0  | -120.00 | -119.25 | .75040  | .83463 |
| 3 | 9370.0  | -166.00 | -167.47 | -1.4663 | .85261 |
| 4 | 10150.0 | -236.00 | -234.58 | 1.4186  | .82491 |
| 5 | 10814.0 | -308.00 | -308.47 | -.46741 | .90929 |

where:

Column 1 is the elevation in the reference well, feet  
Column 2 is the actual dip, feet  
Column 3 is regressed dip, feet  
Column 4 is the difference between the regressed and the actual dips, feet  
Column 5 is the strength of the correlation.

### Coefficient matrix of unknown parameters in normal equations

|   | 1          | 2          | 3          | 4          |
|---|------------|------------|------------|------------|
| 1 | 5.0000     | 45764.     | .42717E+09 | .40598E+13 |
| 2 | 45764.     | .42717E+09 | .40598E+13 | .39213E+17 |
| 3 | .42717E+09 | .40598E+13 | .39213E+17 | .38418E+21 |
| 4 | .40598E+13 | .39213E+17 | .38418E+21 | .38106E+25 |

### Vector of crossproducts of X and Y

|   | 1       | 2           | 3           | 4           |
|---|---------|-------------|-------------|-------------|
| 1 | -968.00 | -.92643E+07 | -.90191E+11 | -.89103E+15 |

### The parameters of the regression equation

|   | 1       | 2      | 3           | 4          |
|---|---------|--------|-------------|------------|
| 1 | -3265.2 | .92257 | -.83606E-04 | .21802E-08 |

Order of equation : 3

Number of observations : 5

Total sums of squares : 24155.

Sums of squares due to regression : 24150.

Sums of squares due to deviation : 4.9992

Maximum underestimation : -1.46626

Maximum overestimation : 1.41858

Goodness of fit : .999793

Correlation coefficient : .999897

DO YOU WANT TO SAVE THESE CORRELATION COEFFICIENTS? Y

WHAT IS THE FILE NAME? LD1213.REDE

FIGURE 31—AN EXAMPLE OF A SCREEN DIALOGUE WITH OPTION REDE, showing results of the regression modeling.

```

WHAT IS YOUR OPTION?: WEIN

DEPTH FOR WELL 12 (MILLING No. 5      ) GOES FROM 7002.0 TO 11000.0
DEPTH FOR WELL 13 (STEINBERG No. 1    ) GOES FROM 7002.0 TO 10998.0

WHAT IS THE STARTING DEPTH FOR PLOTTING, IN FEET?: 8700
WHAT IS THE ENDING DEPTH FOR PLOTTING, IN FEET?: 9600
WHAT IS THE STARTING DEPTH FOR CORRELATION, IN FEET?: 9000
WHAT IS THE ENDING DEPTH FOR CORRELATION, IN FEET?: 9500
DO YOU WANT AUTOMATIC COMPUTATION OF CORRELATION LENGTHS - YES OR NO?: Y

THE LINEAR BOUNDS FOR THE OPTIMAL FRACTION OF THE
LITHOSTRATIGRAPHIC ROCK UNIT NEED TO BE SPECIFIED.

WHAT IS THE LOWER BOUND FOR THE ROCK UNIT LENGTH?: 48
WHAT IS THE OPTIMAL FRACTION AT THAT LOWER BOUND?: 1
WHAT IS THE UPPER BOUND FOR THE ROCK UNIT LENGTH?: 240
WHAT IS THE OPTIMAL FRACTION AT THAT UPPER BOUND?: 0.40
DO YOU WANT AUTOMATIC COMPUTATION OF CORRELATION OFFSETS - YES OR NO?: Y

WHAT IS THE NAME OF THE FILE WITH THE
COEFFICIENTS OF THE REGRESSION ON THE OFFSET?: LD1213.REG

REGRESSION ORIGINALLY COMPUTED FOR:

REFERENCE WELL      : WELL 12 (MILLING No.5      )
REFERENCE LOGS      : SP -SFLA
MATCHING WELL       : WELL 13 (STEINBERG No. 1    )
MATCHING LOGS       : SP -SFLA
REGRESSION STARTING AT : 7000. FEET
AND ENDING AT       : 11000. FEET
NUMBER OF OBSERVATIONS : 0
MINIMUM WEIGHTED CROSS-
CORRELATION COEFFICIENT: .700
POLYNOMIAL DEGREE    : 3
MAXIMUM ERROR ON THE
POLYNOMIAL REGRESSION : 1.5 FEET

WHAT IS THE SEARCH LENGTH, IN FEET?: 100
WHAT IS THE CORRELATION DISPLAY CUTOFF?: .75
DO YOU WANT TO CHANGE ANY OF THE PARAMETERS - YES OR NO?: N

```

FIGURE 32—AN EXAMPLE OF A SCREEN DIALOGUE WITH OPTION WEIN, showing the specification of automatic-correlation offsets.

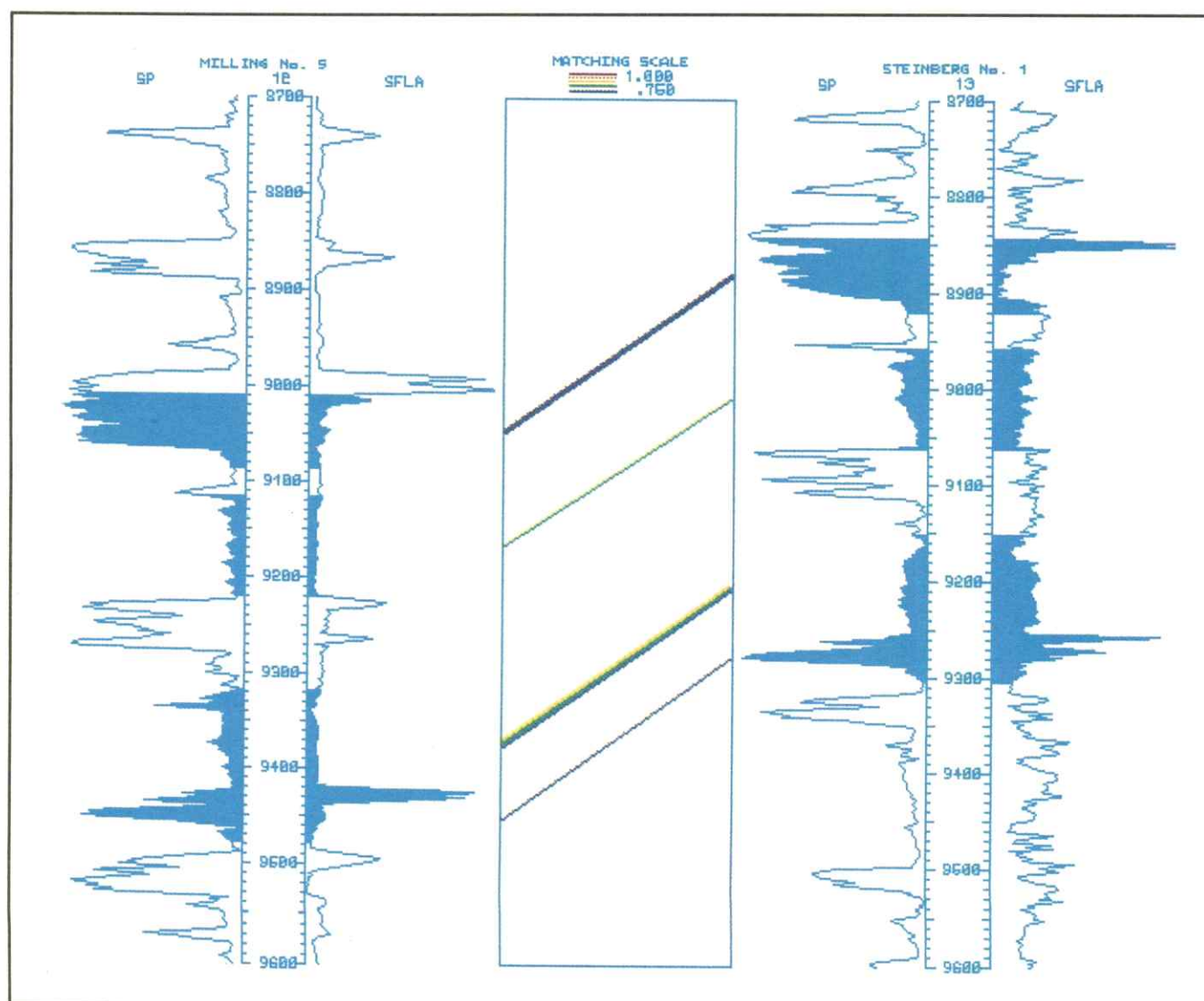


FIGURE 33—SCREEN DISPLAY SHOWING MULTIPLE WEIGHTED CROSS CORRELATIONS BETWEEN TWO WELLS. Straight lines in the central track go from center to center of matching intervals that have a strength of at least 0.75. Color coding represents quality of match, with red representing the highest correlation. Shading on logs indicates the location and length of matched intervals.



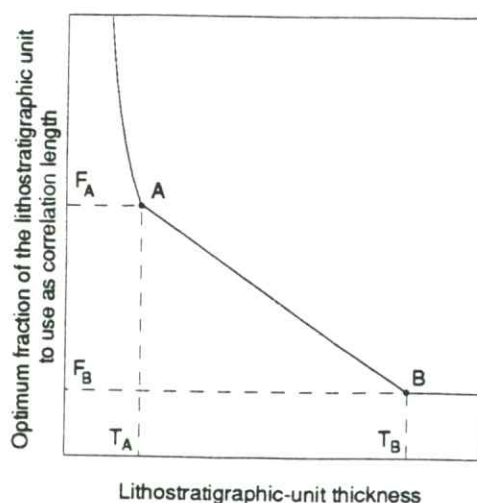


FIGURE 34—FUNCTIONAL RELATIONSHIP BETWEEN LITHOSTRATIGRAPHIC UNIT THICKNESS AND THE OPTIMAL FRACTION OF THICKNESS TO BE USED AS THE CORRELATION LENGTH.

enter the desired search length. Remember that the total search length is specified, with half the search length above and half below the trend. Appendix B gives additional details on this point. If the automatic mode is not selected, CORRELATOR will request a user-specified offset, which is equivalent to a constant trend in the differences in elevation between the two wells. The offset chosen may be zero, in which case the search is centered around an elevation in the matching well that is the same as the center of the correlated interval in the reference well.

Finally, a cutoff in the weighted correlation coefficient is provided so that correlations presenting low coefficients might be discarded. By the nature of the comparison, there is always a best match for every possible interval, no matter how poor that match might be. The highest match might even be an anti-correlation, in which peaks were matched with troughs and vice versa, in which case the correlation coefficient would be negative. To display only correlations which the human eye would consider to be reasonable, the cutoff should be set no lower than about 0.6 to 0.75. For experimental purposes, the user may want to see all matches found by CORRELATOR, regardless of how poor they might be. In this case, the cutoff should be made inactive by setting the threshold value to -1.0.

If an erroneous parameter is accidentally specified, the WEIN dialogue provides the possibility to go back and begin the dialogue again. Once this dialogue is completed, there will be no action on the screen for a few seconds while the system is processing. A graphical display similar to that shown in fig. 33 will appear when processing is complete. Lines joining correlated intervals are color coded to indicate the strength of the correlation when the Tektronix 4113 color-display terminal is used. The hotter the color, namely the closer to red, the stronger the

TABLE OF CORRELATIONS FOR WELLS  
12 (MILLING No. 5) AND 13 (STEINBERG No. 1)

DATUM: KELLY BUSHING  
WELL 12 .0 FEET  
WELL 13 .0 FEET  
REFERENCE LOGS SP - SFLA  
MATCHING LOGS SP - SFLA  
DIGITIZATION INTERVAL 2.0 FEET  
SEARCH LENGTH 100.0 FEET  
CORRELATION DISPLAY CUTOFF .750

| DATA                                         |                |              |            | RESULTS               |                         |
|----------------------------------------------|----------------|--------------|------------|-----------------------|-------------------------|
| WEIGHTED CROSS-CORRELATION<br>LENGTH<br>FEET | OFFSET<br>FEET | FROM<br>FEET | TO<br>FEET | DIF.<br>ELEV.<br>FEET | W. C.-C.<br>COEFFICIENT |
| 72.0                                         | -147.2         | 9046.0       | 8880.0     | -166.0                | .787                    |
| 72.0                                         | -147.3         | 9048.0       | 8882.0     | -166.0                | .787                    |
| 72.0                                         | -147.4         | 9050.0       | 8884.0     | -166.0                | .774                    |
| 104.0                                        | -154.3         | 9168.0       | 9010.0     | -158.0                | .816                    |
| 104.0                                        | -167.5         | 9370.0       | 9204.0     | -166.0                | .853                    |
| 104.0                                        | -167.6         | 9372.0       | 9206.0     | -166.0                | .831                    |
| 104.0                                        | -167.7         | 9374.0       | 9208.0     | -168.0                | .831                    |
| 104.0                                        | -167.9         | 9376.0       | 9208.0     | -168.0                | .814                    |
| 104.0                                        | -168.0         | 9378.0       | 9210.0     | -168.0                | .769                    |
| 48.0                                         | -173.5         | 9454.0       | 9280.0     | -174.0                | .768                    |

CORRELATION ON REFERENCE WELL : 340.0 FEET  
WEIGHTED CORRELATION ON REFERENCE WELL : 273.1 FEET  
AVERAGE WEIGHTED CORRELATION COEFFICIENT : .803

FIGURE 35—LINE-PRINTER LISTING GIVING PROCESSING PARAMETERS AND RESULTS FOR OPTION WEIN. This listing accompanies the screen display shown in fig. 33 and was produced as a result of the screen dialogue in fig. 32.

correlation. Pressing return on the keyboard will display an additional listing of the input parameters and the characteristics of each of the correlations, such as the one in fig. 35. The bar graph on the right of the display provides a quick visual comparison of the stronger correlations above a 0.8-weighted correlation coefficient. Three *efficiency parameters*—correlated footage, relative fraction correlation, and the average weighted correlation—are presented to provide some global characteristics of the reference interval intended to correlate well levels on the matching well.

CORRELATOR allows the user to repeat the display using different thresholds, provided they are higher than the original cutoff. Correlations found by option WEIN can be saved into a previously initialized correlation file using option INCO. The save is non-destructive; each save adds correlations to those already on file, allowing the file to be built gradually. However, attempting to save on a file which has not been initialized will cause a fatal error when the file is used because it will not have a heading.

## Editing a correlation file

The correlations determined by either option WELE or WEIN are established without taking any previously established correlations into account. Geologic processes are limited in number, as are the possible number of lithologies. Over geologic time, events, or even sequences of events, repeat many times in the same location. For example, successive marine regressions and transgressions have occurred frequently in many places around the world. As mentioned in the section on simple matching, lithostratigraphic correlation of wireline logs is based on the comparison of curve characteristics that result from a succession of geological events. Where events have been repeated, there is a potential for confusion. At two locations, the possibility cannot be ruled out that successions of events in rock units which are not equivalent have produced wireline-log signatures which are more alike than those of the equivalent rock units. In the absence of additional criteria, it is not possible to identify log matches that, although mathematically the best, are geologically regarded as miscorrelations. Miscorrelations are not related to the method used to compare wireline logs, but rather to the practice of establishing correlations one at a time, without regard for other correlations between the same pair of wells, not to mention correlations with other nearby wells. The concept of making each correlation a function of other correlations would help avoid miscorrelations, but would greatly increase the complexity of the analysis. In CORRELATOR, the task of resolving inconsistent or conflicting correlations is instead assigned to an expert system.

### ELCO—Editing Lithostratigraphic Correlation files

Option ELCO uses an expert system to inspect a correlation file for potential miscorrelations. The expert

system searches for anomalous correlations, displays those found on the screen, and requests that the user either delete or accept them. Although possible miscorrelations are found by the expert system, the distinction between a geologically anomalous but correct correlation and a false correlation must be made by the user. Once the user decides a correlation is unacceptable, it is deleted from the correlation file.

The expert system uses production rules to store and represent knowledge about spatial or geometric relationships in stratigraphy. Backwards reasoning is used to single out correlations which satisfy conditions that the expert system recognizes as potentially wrong—in particular, crossing correlations and sudden changes in dip. The expert system works with a bundle, a group of one or more successive and congruent correlations between two wells. Four consecutive bundles are considered at a time. The expert system displays potential miscorrelations, such as the one on fig. 36, and flags the conflicting bundle. The user may ask the expert system the reasons for selecting such a bundle as possibly erroneous. As shown in fig. 37, after considering the explanation, the user must accept or reject the expert system's suggestion. Unlike other expert systems that overwhelm the user with requests for information or opinions before being able to produce any results, option ELCO asks only a single question: the name of the correlation file to be assessed.

### DICO—screen Display of Cor- relation files

Option DICO can be used at any time, before or after editing with option ELCO, to inspect the correlations or to generate paper copies of the results through the Tektronix terminal. Figs. 38 and 39 are examples of the dialogue and graphic display.

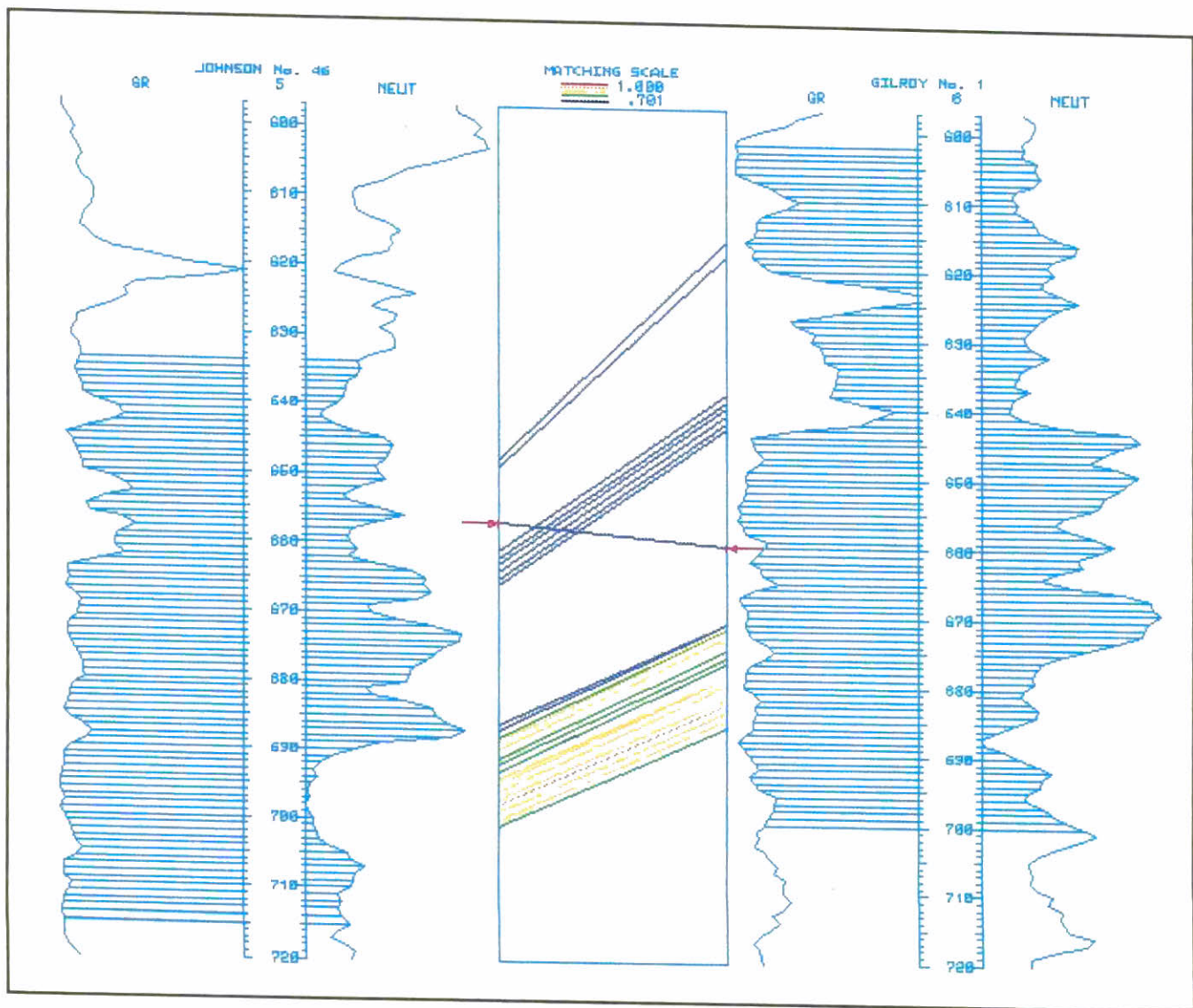


FIGURE 36—SCREEN DISPLAY SHOWING EDITING OF A CORRELATION FILE BY THE EXPERT SYSTEM. Option ELCO searches for geometrically anomalous correlations and flags suspect correlations with red arrows. In the example, the correlation between depth 657 in well No. 5 and depth 659 in well No. 6 deviates from the pattern presented by the surrounding correlations.



\*\*\*\* CORRELATION AT 657.0 FEET SHOULD BE  
ELIMINATED. IS YOUR ANSWER Y (yes), N (no), or W (why)? : W

THE FOLLOWING RULE WAS SUCCESSFULLY TESTED:

Eliminate upper bundle of crossing correlations

BECAUSE :

There is a gap around the upper bundle  
There are 2 inconsistent bundles in the rock unit  
The dip is abnormal for the upper bundle

The bundle to eliminate comprises a single correlation at 657.0 feet.

PLEASE ANSWER Y (yes), OR N(no): DO  
YOU WANT TO ELIMINATE THE CORRELATION NOW? : Y

FIGURE 37—SCREEN DISPLAY SHOWING REASONING PRESENTED BY EXPERT SYSTEM. The expert system will respond to a user request for reasons why a correlation was picked as spurious by presenting an explanation. The user must make the decision to discard or to keep a correlation.

WHAT IS YOUR OPTION? : DICO

FROM WHAT FILE DO YOU WANT TO READ IN YOUR CORRELATIONS? : LD712.ELCO

DEPTH FOR WELL 7 (MILLING No.1 ) GOES FROM 7002.0 TO 10998.0

DEPTH FOR WELL 12 (MILLING No.5 ) GOES FROM 7002.0 TO 11000.0

WHAT IS THE TOP TO DISPLAY? : 9600

WHAT IS THE BOTTTOM TO DISPLAY? : 10700

WHAT IS THE MINIMUM CORRELATION DEPTH? : 9750

WHAT IS THE MAXIMUM CORRELATION DEPTH? : 10700

FIGURE 38—SCREEN DISPLAY SHOWING AN EXAMPLE DIALOGUE WITH OPTION DICO, used to generate fig. 39.



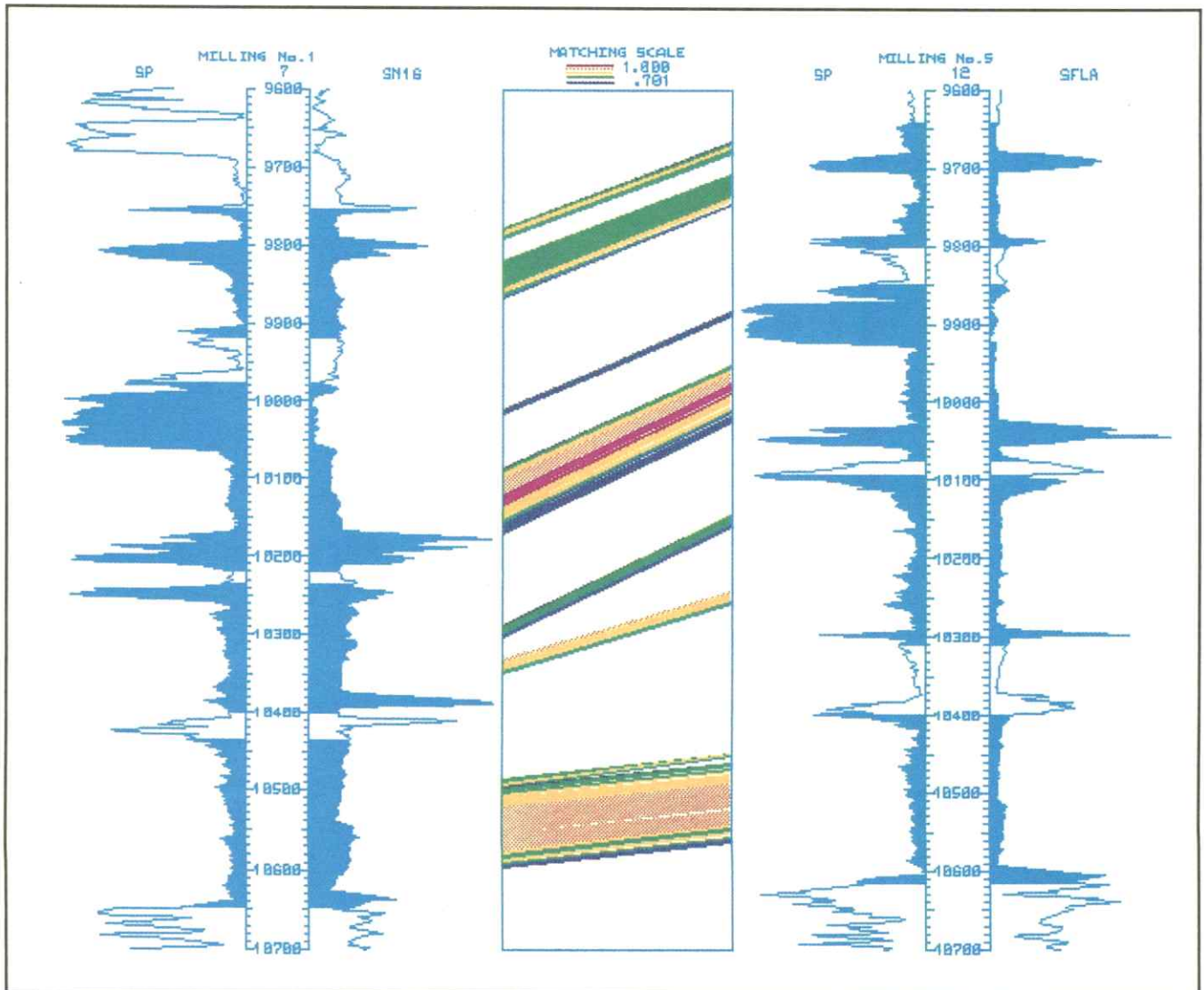


FIGURE 39—SCREEN DISPLAY OF CORRELATION FILE PRODUCED USING OPTION DICO. Location of matching intervals is indicated by shading. Color lines go from center to center of matching intervals. The strongest correlations are shown in hot colors.



# Presentation of final results in cross sections

Rarely will stratigraphic interest in an area be confined to the correlations between a pair of wells. Commonly, we will wish to analyze traverses consisting of many wells. Although a traverse can be constructed by linking the correlations between successive pairs of wells, patching together the individual sheets of output is not the most desirable way to produce a cross section. CORRELATOR offers a more convenient procedure if a plotter is available. A cross section produced on a plotter is superior to hard copies from a screen display in terms of size and resolution. At the present time, however, color is not available in the CORRELATOR cross section options.

## SECT—display of all correlations in a cross SECTION

The most obvious extension of the screen display using option DICO is to have CORRELATOR controlling all the mending and patching so correlations between multiple wells along a traverse appear on one piece of paper. This is the function of option SECT which, in addition, produces a listing on the computer's printer.

As shown in fig. 40, option SECT first requests the number of files and file names for all correlation files to be

displayed in a cross section. Next, the system requests a two-line title to be displayed at the top of the plot. Wells can be labeled either with their actual names or with their sequential number. Logs of all wells along a traverse can be displayed or, to present dips in their proper magnitudes on the diagrams, only the wireline logs at the ends of the traverse can be posted. Figs. 41 and 42 illustrate both capabilities.

As mentioned in the section on well- and file-selection capabilities, the user may specify alternative datums when preparing plotter displays. The datum used by option SECT can either be the datum already selected using option IAWF for the well-data file, or any other convenient datum. A common practice is to select a marker bed as the reference datum surface. As shown in fig. 43, the user must prepare a file containing elevations of the selected marker, with one elevation per correlation file, in the same sequence as the logs appear along the traverse. In this instance, the alternative marker chosen as the datum plane is the top of the Lansing Group, which is 207 ft (62 m) below sea level in the first well, Fisher No. 1; 229.5 ft (68.9 m) below sea level in well Schultz No. 1; 22.5 ft (7 m) above sea level in well Holm No. 2; and 206.5 ft (62 m) below sea level in the starting well, Fisher No. 1. As the loop is closed, this discrepancy of 0.5 ft. indicates there was a small error in the determination of the correlations. As expected, the dip of the top of the Lansing in the diagrams shown in figs. 41 and 42 is perfectly horizontal.

The interval to be plotted and the vertical scale can be selected by the user. The horizontal scale can be set independently from the vertical scale to allow for any desired vertical exaggeration. For good displays, tick marks in the depth scale must be set to a spacing according to the vertical scale. Logs can be trimmed to avoid plotting outlying readings.

In cross sections generated with option SECT, lines on the dip diagram have the same meaning as in options DICO and WEIN. Each line of correlation goes from center to center of equivalent intervals. If the threshold for the weighted correlation coefficient is chosen consistently for all pairs of wells, the cross section produced by option SECT will show all weighted correlations stronger than the given threshold. In this example, the threshold was set at 0.7.

Option SECT also produces a companion listing for each plot. A portion of the listing for fig. 41 is shown in fig. 44. Simple and weighted cumulative correlated intervals are displayed for each pair of wells to give the user an idea of the efficiency of the correlation process. In the example, 59.5% of the reference log was correlated, so 40.5% of the digitized interval has no detected lithostratigraphic equivalent. The average weighted correlation coefficient was 0.77.

```

WHAT IS YOUR OPTION?: SECT

WHAT IS THE NUMBER OF CORRELATION FILES TO PROCESS?: 3
WHICH IS THE NAME OF CORRELATION FILE NO. 1?: LKCS12.ELCO
WHICH IS THE NAME OF CORRELATION FILE NO. 2?: LKCS23.ELCO
WHICH IS THE NAME OF CORRELATION FILE NO. 3?: LKCS31.ELCO
WHAT IS THE FIRST LINE TITLE?: ALL LITHOSTRATIGRAPHIC CORRELATIONS
WHAT IS THE SECOND LINE TITLE?: LANSING AND KANSAS CITY GROUPS
DO YOU WANT TO LABEL THE WELLS BY SEQUENTIAL NUMBER(S) OR NAME(N)? : N
DO YOU WANT TO POST ALL(A) OR THE EXTREME WELLS(E) ONLY?: A
DO YOU WANT THE DATUM TO BE THE ORIGINAL SEA LEVEL DATUM?: N
WHAT IS THE FILE NAME WITH DEPTH TO THE NEW DATUM
BELOW THE ORIGINAL SEA LEVEL DATUM AT EACH WELL?: LKCS.DATUM
HOW MUCH ABOVE THE NEW DATUM DO YOU WANT TO START PLOTTING?: 150
HOW MUCH BELOW THE NEW DATUM DO YOU WANT TO FINISH PLOTTING?: 450
WHAT WILL BE THE VERTICAL PLOTTING SCALE, IN FT/IN?: 50
AND THE HORIZONTAL PLOTTING SCALE, IN FT/IN?: 5000
HOW CLOSE DO YOU WANT THE TICK MARKS ON THE DEPTH SCALE?: 10
WHAT WILL BE THE MAXIMUM VALUE FOR THE SHALE LOG SCALE?: 140
WHAT WILL BE THE MAXIMUM VALUE FOR THE CORRELATION LOG SCALE?: 100
  
```

FIGURE 40—SCREEN DISPLAY SHOWING AN EXAMPLE OF DIALOGUE WITH OPTION SECT, showing selection of an alternative datum.

# ALL LITHOSTRATIGRAPHIC CORRELATIONS LANSING AND KANSAS CITY GROUPS

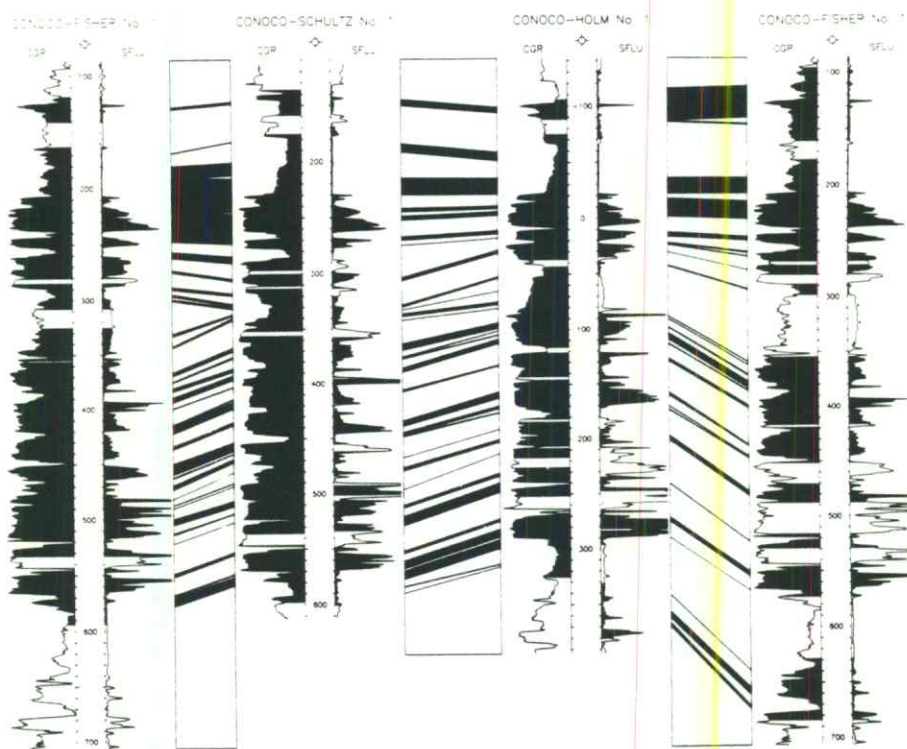


FIGURE 41—PLOTED CROSS SECTION PRODUCED BY OPTION SECT, displaying all correlations in three files and log traces for all wells along a cross section in Morris and Wabaunsee counties, Kansas. Lines in the diagram connect centers of correlated intervals. Vertical exaggeration is 100X. Reference level is top of the Lansing Group (Pennsylvanian).

## ALL LITHOSTRATIGRAPHIC CORRELATIONS LANSING AND KANSAS CITY GROUPS

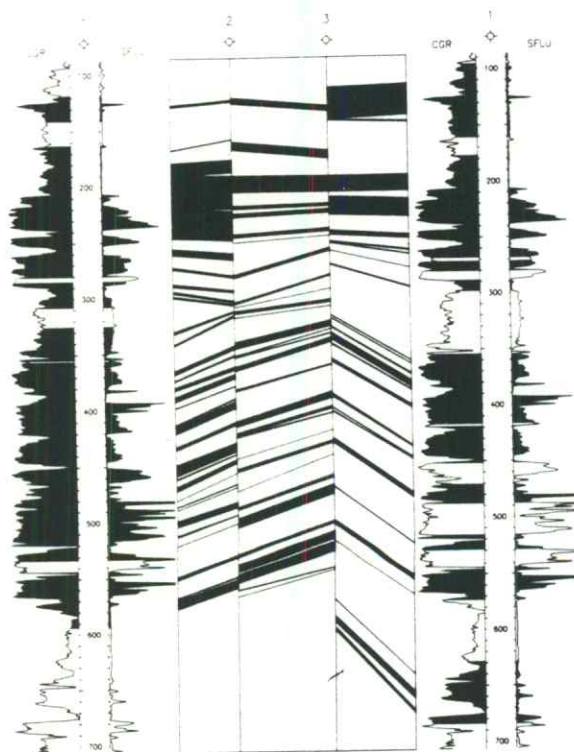


FIGURE 42 (left)—PLOTED CROSS SECTION PRODUCED BY OPTION SECT, displaying all correlations in three files but posting logs only from the extreme wells along a cross section in Morris and Wabaunsee counties, Kansas. Lines in the diagram connect centers of correlated intervals. Vertical exaggeration is 100X. Reference surface is top of the Lansing Group (Pennsylvanian).

207  
229.5  
-22.5  
206.5

FIGURE 43—LISTING OF DATUM FILE LKCS.DATUM, used to refer correlations to the top of the Lansing Group.

PAGE 6

PROCESSING PARAMETERS AND CORRELATION RESULTS FOR  
 \*\*\*\*\*  
 WELLS 2 (CONOCO-SCHULTZ No. 1) AND 3 (CONOCO-HOLM No. 1 )  
 \*\*\*\*\*

DATUM: SEA LEVEL ( 1387.0; 1456.0)  
 REFERENCE LOGS CGR - SFLU  
 MATCHING LOGS CGR - SFLU

| BASIC INFORMATION        |                          |                          |                   | FINAL RESULTS           |                        |                       |                                 |
|--------------------------|--------------------------|--------------------------|-------------------|-------------------------|------------------------|-----------------------|---------------------------------|
| CORREL<br>LENGTH<br>FEET | SEARCH<br>LENGTH<br>FEET | SEARCH<br>OFFSET<br>FEET | DISPLAY<br>CUTOFF | REFER.<br>DEPTH<br>FEET | MATCH<br>DEPTH<br>FEET | DIF.<br>DEPTH<br>FEET | WEIGHTED CORREL.<br>COEFFICIENT |
| 30.0                     | 30.0                     | -278.9                   | .700              | 578.0                   | 298.5                  | -279.5                | .799                            |
| 30.0                     | 30.0                     | -279.0                   | .700              | 578.5                   | 299.0                  | -279.5                | .798                            |
| 30.0                     | 30.0                     | -279.1                   | .700              | 579.0                   | 299.5                  | -279.5                | .798                            |
| 30.0                     | 30.0                     | -279.2                   | .700              | 579.5                   | 301.0                  | -278.5                | .797                            |
| 30.0                     | 30.0                     | -279.3                   | .700              | 580.0                   | 301.5                  | -278.5                | .804                            |
| 30.0                     | 30.0                     | -279.3                   | .700              | 580.5                   | 301.5 E                | -279.0                | .831 ***                        |
| 30.0                     | 30.0                     | -279.4                   | .700              | 581.0                   | 302.0                  | -279.0                | .850 *****                      |
| 30.0                     | 30.0                     | -279.5                   | .700              | 581.5                   | 302.5                  | -279.0                | .842 *****                      |
| 30.0                     | 30.0                     | -279.6                   | .700              | 582.0                   | 303.0                  | -279.0                | .846 *****                      |
| 30.0                     | 30.0                     | -279.7                   | .700              | 582.5                   | 303.0 E                | -279.5                | .855 *****                      |
| 30.0                     | 30.0                     | -279.7                   | .700              | 583.0                   | 303.5                  | -279.5                | .824 **                         |

CORRELATION ON REFERENCE WELL : 365.5 FEET OR 69.3 %  
 WEIGHTED CORRELATION ON REFERENCE WELL : 276.5 FEET OR 52.4 %  
 AVERAGE WEIGHTED CORRELATION COEFFICIENT : .757

FIGURE 44—PRINTED OUTPUT CREATED BY OPTION SECT, showing the final portion of the listing.

## PERS—display of PERSistent correlations

Some users might regard displays produced by option SECT as working documents. They show, on a single piece of paper, the piecemeal correlations made for each pair of wells. However, continuous changes in the processing parameters and lateral discontinuities in the correlations may make a cross section generated by option SECT difficult to interpret.

To simplify the display, option PERS allows only the persistent correlations to appear on the cross section. As shown in fig. 45, the dialogue for option PERS is similar to that of option SECT. Typical displays for two different datums are given in fig. 46, where the datum is sea level, and in fig. 47, where the datum is the top of the Lansing Group.

The meaning of correlation lines on the cross section is different in the PERS option than in the SECT option. As SECT cross sections tend to be overloaded with information, only one line per correlating interval is presented: the line is drawn from center to center of equivalent intervals. In the PERS option, all lines between

equivalent correlations are drawn provided that such an equivalence can be traced along the entire traverse. Option PERS allows the user to visualize solely those correlations of regional extent which, depending on the objective of the study, may or may not be of interest. Most often, option PERS provides guidelines for the selection of marker beds based on criteria which are independent of those based on paleontology. As expected, these most conspicuous lithostratigraphic markers may not be coincident with traditional paleontologic markers.

Option PERS provides an additional three-dimensional check on the correlations when a traverse is arranged in a closed loop. If the starting and ending wells are the same, the *closure error* or difference between the correlations at this well can be used as a measure of accuracy in the correlation process. Unfortunately, a perfectly closed loop of correlations is only a necessary but not a sufficient condition for error-free correlations. This additional check to the inspection provided by option ELCO is highly recommended. CORRELATOR does not take any action if closure errors occur. It is the responsibility of the user to take any corrective actions that may be needed, by tracing backwards through the successive interpretations whenever a closure discrepancy is found that is unacceptably high.

Option PRNP is related to option PERS and allows the user to print the persistent correlations without producing plots. In the dialogue CORRELATOR will

present only the initial questions and will ignore all queries related to the posting. Fig. 48 is an example of the listing provided by either options PERS or PRNP.

```

WHAT IS YOUR OPTION?: PERS

WHAT IS THE NUMBER OF CORRELATION FILES TO PROCESS?: 3
WHICH IS THE NAME OF CORRELATION FILE NO. 1?: LKCS12.ELCO
WHICH IS THE NAME OF CORRELATION FILE NO. 2?: LKCS23.ELCO
WHICH IS THE NAME OF CORRELATION FILE NO. 3?: LKCS31.ELCO
WHAT IS THE FIRST LINE TITLE?: PERSISTENT LITHOSTRATIGRAPHIC CORRELATIONS
WHAT IS THE SECOND LINE TITLE?: LANSING AND KANSAS CITY GROUPS
DO YOU WANT TO LABEL THE WELLS BY SEQUENTIAL NUMBER(S) OR NAME(N)? : N
DO YOU WANT TO POST ALL(A) OR THE EXTREME WELLS(E) ONLY?: A
DO YOU WANT THE DATUM TO BE THE ORIGINAL      SEA LEVEL      DATUM?: Y
WHAT WILL BE THE STARTING DEPTH FOR PLOTTING?: -120
WHAT WILL BE THE ENDING DEPTH FOR PLOTTING?: 600
WHAT WILL BE THE VERTICAL PLOTTING SCALE, IN FT/IN?: 50
AND THE HORIZONTAL PLOTTING SCALE, IN FT/IN?: 5000
HOW CLOSE DO YOU WANT THE TICK MARKS ON THE DEPTH SCALE?: 10
WHAT WILL BE THE MAXIMUM VALUE FOR THE SHALE LOG SCALE?: 140
WHAT WILL BE THE MAXIMUM VALUE FOR THE CORRELATION LOG SCALE?: 100
ENTER STARTING DEPTH FOR TRACING : 100
ENTER ENDING DEPTH FOR TRACING : 600

```

FIGURE 45—SCREEN DIALOGUE WITH OPTION PERS, showing selection of sea level as the reference surface.

## PERSISTENT LITHOSTRATIGRAPHIC CORRELATIONS

## LANSING AND KANSAS CITY GROUPS

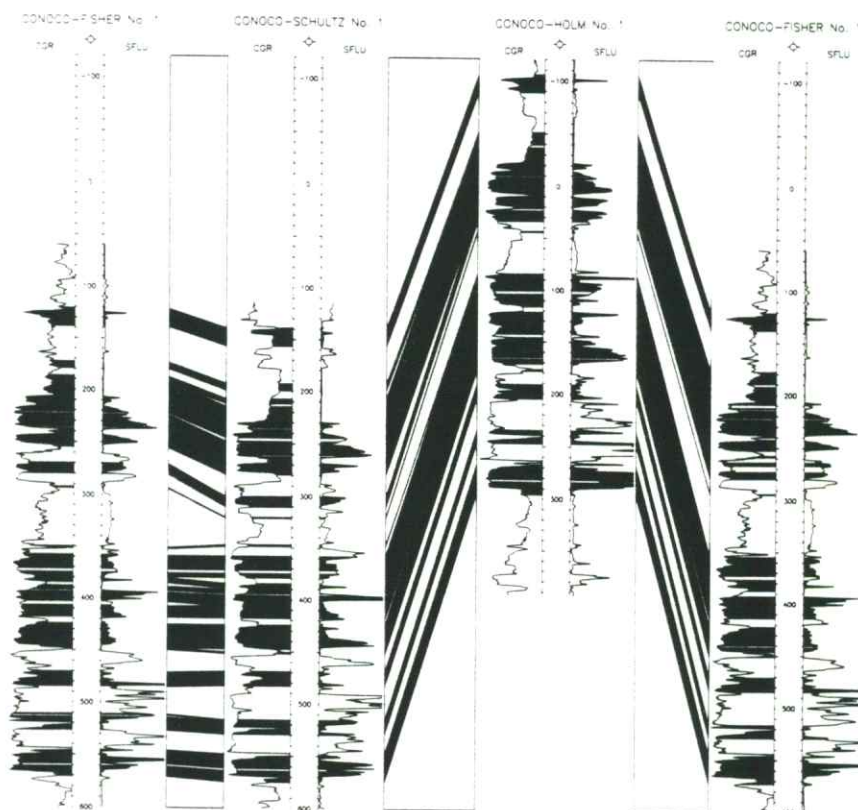


FIGURE 46—PLOTTED CROSS SECTION PRODUCED BY OPTION PERS, showing persistent correlations in three correlation files. Wells are located in Morris and Wabaunsee counties, Kansas. Lines in the diagram connect correlating elevations which persist from well to well across the entire section. Vertical exaggeration is 100X. Datum is sea level.

## PERSISTENT LITHOSTRATIGRAPHIC CORRELATIONS

## LANSING AND KANSAS CITY GROUPS

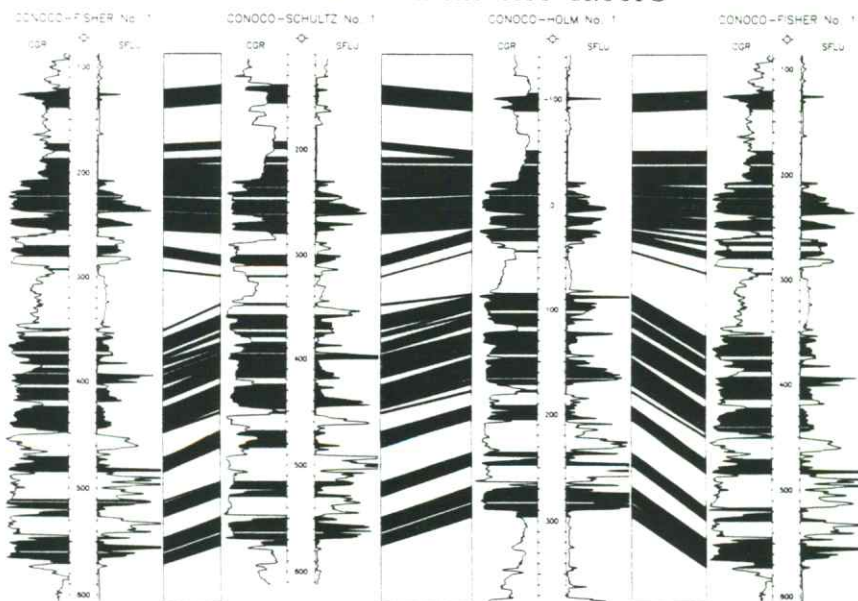


FIGURE 47—PLOTTED CROSS SECTION PRODUCED BY OPTION PERS, showing persistent correlations in three correlation files. Top of the Lansing Group is used as datum. Wells are located in Morris and Wabaunsee counties, Kansas. Lines in the diagram connect correlating elevations which persist from well to well across the entire section. Vertical exaggeration is 100X. Datum is top of the Lansing Group.

## TRAC—display of selected lithostratigraphic correlations

### TRACed across

Option TRAC allows the user to display correlations at individual selected elevations to generate cross sections resembling those produced manually. The questions that option TRAC asks are the same as those asked by option SECT, except that at the end there are additional questions concerning the levels to be traced. An example of the dialogue is displayed in fig. 49. The same correlation files that were used to produce figs. 40 and 45 are again used.

Fig. 50 is the cross section generated upon completion of the dialogue given in fig. 49. In this instance, elevations to be traced on the cross section were selected in the Schultz No. 1 well. These represent the contacts of rock units traditionally recognized in the area and were stored in file LKC.TW2, displayed in fig. 51. Elevation files must consist of one depth value per record, listed in increasing order of depth. Solid lines in fig. 50 are used to show equivalences based on correlations actually found by CORRELATOR; dashed lines represent interpolations

based on enclosing correlations. These interpolated correlations are marked with a capital letter I in the listings produced by option TRAC as shown in fig. 52. The names of rock units shown in fig. 52 have been added by hand. As in the case of option PERS, the listing given in fig. 48 can be used to check for closure errors.

Although the user may give a name to a lithostratigraphic unit, CORRELATOR does not assume responsibility for such names. CORRELATOR looks for equivalents to the elevations listed in the tracing file, but correctly tracing an actual geological marker is conditional on the assumption that the elevation given for the marker is correct at the starting well. Let us take the top of the Vilas Shale in fig. 52 to illustrate the point and assume that the tracing is, indeed, free of errors. However, if the real depth to the top of the Vilas Shale in starting well No. 2 is actually 275 ft (82.5 m) instead of 277 ft (83.1 m) as entered by the user, the correlation will be consistent but will not follow the real top of the Vilas Shale. The tracing will be made along a subparallel surface of equivalence roughly 2 ft (.6 m) below the real top of the Vilas Shale.

Option TRAC has a companion option PRNT, which is similar to option PERS. Option PRNT traces specified intervals without producing any graphic display or asking any questions concerning geometry in the dialogue.

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#### PERSISTENT CORRELATIONS

\*\*\*\*\*

THE DATUM IS SEA LEVEL  
ALL RESULTS ARE IN FEET

#### WELLS AND LOGS

| 1   |       | 2     |       | 3     |       | 1   |       | CLOSURE<br>ERROR |
|-----|-------|-------|-------|-------|-------|-----|-------|------------------|
| OGR | -SFLU | OGR   | -SFLU | OGR   | -SFLU | OGR | -SFLU |                  |
| 530 | 550.5 | 553.5 | 273.0 | 551.5 | -1.0  |     |       |                  |
| 531 | 551.0 | 553.5 | 273.0 | 551.5 | -1.0  |     |       |                  |
| 532 | 551.5 | 554.0 | 273.5 | 552.0 | -1.0  |     |       |                  |
| 533 | 552.0 | 554.5 | 274.0 | 552.5 | -1.0  |     |       |                  |
| 534 | 552.5 | 555.0 | 274.5 | 553.0 | -1.0  |     |       |                  |
| 535 | 553.0 | 555.5 | 275.0 | 554.0 | -1.0  |     |       |                  |
| 536 | 553.5 | 556.0 | 275.5 | 554.5 | -1.0  |     |       |                  |
| 537 | 554.0 | 556.5 | 276.0 | 555.0 | -1.0  |     |       |                  |
| 538 | 554.5 | 557.0 | 276.5 | 555.5 | -1.0  |     |       |                  |
| 539 | 555.0 | 557.5 | 277.0 | 556.0 | -1.0  |     |       |                  |
| 540 | 555.5 | 558.0 | 277.5 | 556.5 | -1.0  |     |       |                  |
| 541 | 556.0 | 558.5 | 278.0 | 557.0 | -1.0  |     |       |                  |
| 542 | 556.5 | 559.0 | 278.5 | 557.5 | -1.0  |     |       |                  |
| 543 | 557.0 | 559.5 | 279.0 | 558.0 | -1.0  |     |       |                  |
| 544 | 557.5 | 561.0 | 280.5 | 559.5 | -2.0  |     |       |                  |
| 545 | 558.0 | 561.5 | 281.0 | 560.0 | -2.0  |     |       |                  |
| 546 | 558.5 | 562.0 | 281.5 | 560.5 | -2.0  |     |       |                  |
| 547 | 561.0 | 564.5 | 284.0 | 561.0 |       |     |       |                  |
| 548 | 561.5 | 565.0 | 284.5 | 561.5 |       |     |       |                  |
| 549 | 562.0 | 565.5 | 285.0 | 562.0 |       |     |       |                  |
| 550 | 562.5 | 566.0 | 285.5 | 562.5 |       |     |       |                  |
| 551 | 563.0 | 566.5 | 286.0 | 563.0 |       |     |       |                  |
| 552 | 563.5 | 567.0 | 286.5 | 563.5 |       |     |       |                  |
| 553 | 564.0 | 567.5 | 287.0 | 564.0 |       |     |       |                  |
| 554 | 564.5 | 568.0 | 287.5 | 564.5 |       |     |       |                  |
| 555 | 565.0 | 568.5 | 288.0 | 565.0 |       |     |       |                  |
| 556 | 565.5 | 569.0 | 288.5 | 565.5 |       |     |       |                  |
| 557 | 566.0 | 569.5 | 289.0 | 566.0 |       |     |       |                  |
| 558 | 566.5 | 570.0 | 289.5 | 566.5 |       |     |       |                  |
| 559 | 567.0 | 570.5 | 290.0 | 567.0 |       |     |       |                  |
| 560 | 567.5 | 571.0 | 290.5 | 567.5 |       |     |       |                  |
| 561 | 568.0 | 571.5 | 291.0 | 568.0 |       |     |       |                  |
| 562 | 568.5 | 572.0 | 291.5 | 568.5 |       |     |       |                  |
| 563 | 569.0 | 573.0 | 292.5 | 569.5 | -1.5  |     |       |                  |
| 564 | 569.5 | 573.5 | 293.0 | 570.0 | -1.5  |     |       |                  |

MAXIMUM ABSOLUTE CLOSURE ERROR: 6.0 FEET

AVERAGE ABSOLUTE CLOSURE ERROR: 1.3 FEET

FIGURE 48—PRINTED OUTPUT CREATED BY OPTION PERS, showing the final portion of the listing.

WHAT IS YOUR OPTION?: TRAC

WHAT IS THE NUMBER OF CORRELATION FILES TO PROCESS?: 3

WHICH IS THE NAME OF CORRELATION FILE NO. 1?: LKCS12.ELCO

WHICH IS THE NAME OF CORRELATION FILE NO. 2?: LKCS23.ELCO

WHICH IS THE NAME OF CORRELATION FILE NO. 3?: LKCS31.ELCO

WHAT IS THE FIRST LINE TITLE?: LANSING AND KANSAS CITY GROUPS

WHAT IS THE SECOND LINE TITLE?: MORRIS AND WABAUNSEE COUNTIES, KANSAS

DO YOU WANT TO LABEL THE WELLS BY SEQUENTIAL NUMBER(S) OR NAME(N)? : N

DO YOU WANT TO POST ALL(A) OR THE EXTREME WELLS(E) ONLY?: A

DO YOU WANT THE DATUM TO BE THE ORIGINAL SEA LEVEL DATUM?: N

WHAT IS THE FILE NAME WITH DEPTH TO THE NEW DATUM  
BELOW THE ORIGINAL SEA LEVEL DATUM AT EACH WELL?: LKCS.DATUM

HOW MUCH ABOVE THE NEW DATUM DO YOU WANT TO START PLOTTING?: 100

HOW MUCH BELOW THE NEW DATUM DO YOU WANT TO FINISH PLOTTING?: 400

WHAT WILL BE THE VERTICAL PLOTTING SCALE, IN FT/IN?: 50

AND THE HORIZONTAL PLOTTING SCALE, IN FT/IN?: 5000

HOW CLOSE DO YOU WANT THE TICK MARKS ON THE DEPTH SCALE?: 10

WHAT WILL BE THE MAXIMUM VALUE FOR THE SHALE LOG SCALE?: 140

WHAT WILL BE THE MAXIMUM VALUE FOR THE CORRELATION LOG SCALE?: 100

WHICH IS THE SEQUENTIAL NUMBER FOR THE  
REFERENCE WELL WHERE TRACING ACROSS WILL BE STARTED?: 2

WHICH IS THE NAME OF THE FILE CONTAINING ELEVATIONS TO TRACE?: LKC.TW2

FIGURE 49—SCREEN DIALOGUE WITH OPTION TRAC, showing the selection of intervals to be traced across a cross section.

## LANSING AND KANSAS CITY GROUPS

## MORRIS AND WABAUNSEE COUNTIES, KANSAS

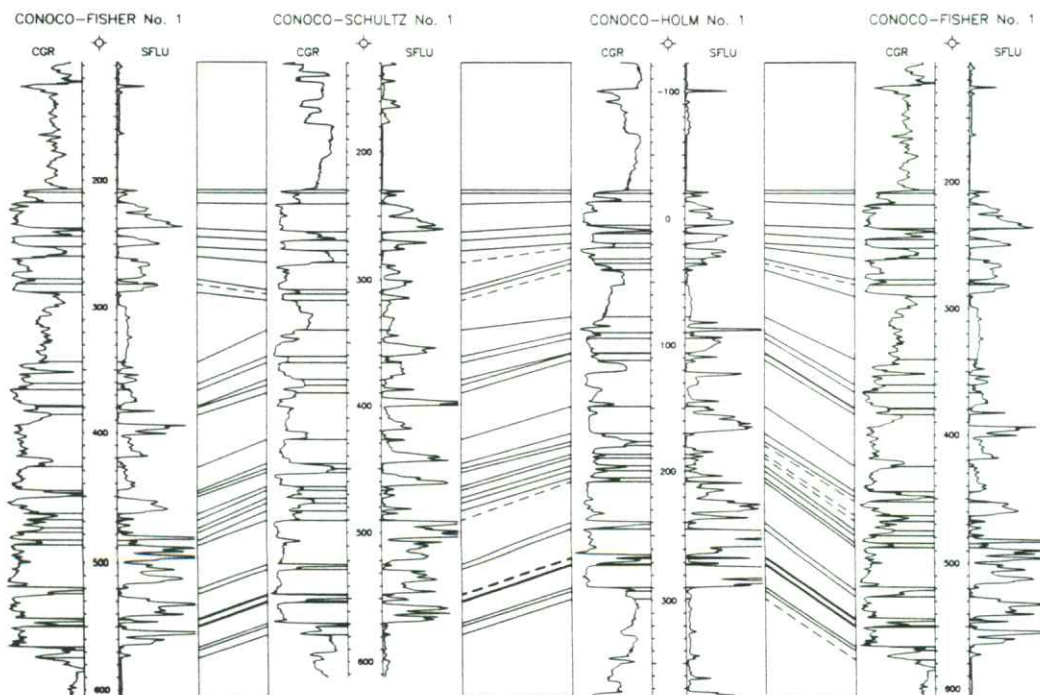


FIGURE 50—PLOTTED CROSS SECTION PRODUCED BY OPTION TRAC, showing selected lines of lithostratigraphic equivalence. Solid lines denote equivalences determined by correlations, dashed lines represent interpolations and extrapolations based on surrounding correlations. Reference datum is top of the Lansing Group. Depths are in positive feet below sea level. Vertical exaggeration is 100X.

FIGURE 51 (right)—LISTING OF FILE LKS.TW2, used to define rock units to be traced across a cross section. Numbers on the file are depths below sea level for the tops of all members in the Lansing and Kansas City groups, except for the final value which is the depth of the base for the lowest member.

229.5  
232  
240.5  
262.5  
269  
277  
286.5  
308  
311.5  
316.5  
340  
361  
366  
388.5  
395  
401  
427  
446  
450  
453  
463  
470  
473  
480.5  
483  
490.5  
523  
527  
547  
550.5  
551.5  
554  
569.5  
572  
578.5

CORRELATION TRACING  
\*\*\*\*\*

TRACING STARTED FROM WELL 2  
THE DATUM IS SEA LEVEL  
ALL RESULTS ARE IN FEET

| WELLS AND LOGS |           |           |           |       | CLOSURE<br>ERROR | MEMBER             |
|----------------|-----------|-----------|-----------|-------|------------------|--------------------|
| 1              | 2         | 3         | 1         |       |                  |                    |
| OGR -SFLU      | OGR -SFLU | OGR -SFLU | OGR -SFLU |       |                  |                    |
| 1              | 207.0     | 229.5     | -22.5     | 206.5 | .5               | South Bend ls.     |
| 2              | 209.5     | 232.0     | -20.0     | 209.0 | .5               | Rock Lake Sh.      |
| 3              | 217.5     | 240.5     | -13.5     | 218.0 | -.5              | Stoner ls.         |
| 4              | 237.5     | 262.5     | 5.0       | 236.5 | 1.0              | Eudora Sh.         |
| 5              | 244.0     | 269.0     | 11.5      | 245.0 | -1.0             | Captain Creek ls.  |
| 6              | 252.0     | 277.0     | 19.0      | 252.0 |                  | Vilas Sh.          |
| 7              | 259.5     | 286.5     | I         | 260.0 | -.5              | Spring Hill ls.    |
| 8              | 277.5     | 308.0     | 31.5      | 277.0 | .5               | Hickory Creek Sh.  |
| 9              | 281.5     | 311.5     | 35.0      | 281.0 | .5               | Merriam ls.        |
| 10             | 288.0     | 316.5     | I         | 290.5 | -2.5             | Bonner Springs Sh. |
| 11             | 343.5     | 340.0     | 77.5      | 344.0 | -.5              | Farley ls.         |
| 12             | 361.0     | 361.0     | 90.0      | 360.5 | .5               | Island Creek Sh.   |
| 13             | 366.0     | 366.0     | 94.5      | 366.5 | -.5              | Argentine ls.      |
| 14             | 378.5     | 379.5     | 106.0     | 379.0 | -.5              | Quindaro Sh.       |
| 15             | 379.5     | 384.0     | 106.5     | 379.5 |                  | Frisbie ls.        |
| 16             | 385.5     | 390.0     | 112.0     | 384.0 | 1.5              | Lane Shale         |
| 17             | 427.0     | 427.0     | 148.5     | 425.0 | 2.0              | Raytown ls.        |
| 18             | 445.5     | 446.0     | 170.0     | 444.5 | 1.0              | Muncie Creek Sh.   |
| 19             | 447.5     | 450.0     | 176.5     | 449.0 | -1.5             | Paola ls.          |
| 20             | 450.0     | 453.0     | 179.5     | 452.5 | -2.5             | Cement City ls.    |
| 21             | 463.5     | 464.0     | 186.5     | 463.5 |                  | Quivira Sh.        |
| 22             | 468.5     | 467.0     | 189.5     | 468.0 | .5               | Westerville ls.    |
| 23             | 475.0     | 473.0     | 195.5     | 475.0 |                  | Wea Sh.            |
| 24             | 478.5     | 477.0     | 199.5     | 479.0 | -.5              | Block ls.          |
| 25             | 484.5     | 483.0     | 205.0     | 484.5 |                  | Fontana Sh.        |
| 26             | 488.0     | 490.5     | I         | 487.5 | .5               | Winterset ls.      |
| 27             | 520.0     | 523.0     | 240.0     | 521.5 | -1.5             | Stark Sh.          |
| 28             | 524.0     | 527.0     | 245.0     | 526.5 | -2.5             | Bethany Falls ls.  |
| 29             | 543.5     | 546.5     | I         | 544.0 | -.5              | Hushpuckney Sh.    |
| 30             | 544.5     | 547.5     | I         | 545.0 | -.5              | Middle Creek ls.   |
| 31             | 549.0     | 552.0     | 271.0     | 549.5 | -.5              | Ladore Sh.         |
| 32             | 550.0     | 553.0     | 272.0     | 550.5 | -.5              | Sniabar ls.        |
| 33             | 566.0     | 569.5     | 289.5     | 566.5 | -.5              | Mound City Sh.     |
| 34             | 568.5     | 572.0     | 292.5     | 569.5 | -1.0             | Critzer ls.        |
| 35             | 574.5     | 578.5     | 298.5     | 577.0 | -2.5             |                    |

MAXIMUM ABSOLUTE CLOSURE ERROR: 2.5 FEET

AVERAGE ABSOLUTE CLOSURE ERROR: 0.843 FEET

FIGURE 52—LISTING PRODUCED BY OPTION TRAC. The letter I represents interpolations or extrapolations made when a reference level did not correspond to any correlated interval. In this example, equivalences were established for the tops of members named on the right.

# Correlation-file utility functions

This section presents an assortment of options which perform some action on correlation files.

## PRNC—PRiNting of Correlation files

The user can, through option PRNC, make a formatted printout from a correlation file at any time. Fig. 53 shows a sample dialogue with option PRNC, and fig. 54 shows the resulting listing. The listing is identical to that in fig. 44, except that there is no display of efficiency parameters.

```
WHAT IS YOUR OPTION?: PRNC
WHAT IS THE NAME OF THE FILE TO BE PRINTED?: K556.ELCD
WHAT IS THE STARTING REFERENCE DEPTH FOR PRINTING?: 500
WHAT IS THE ENDING REFERENCE DEPTH FOR PRINTING?: 1000

***** THERE IS A LISTING IN FILE PRINTER.OUT *****
```

FIGURE 53—SCREEN DIALOGUE WITH OPTION PRNC, showing specification of a file listing.

## LIST—correlation file LISTing

Option LIST is similar to option PRNC, except that the display appears on screen rather than on paper. Both options are especially helpful because the correlation files are stored in binary form, which normally cannot be displayed by standard operating-system options for file display.

Fig. 55 shows the dialogue necessary to display the file shown in fig. 56, which is a hard copy of the screen display produced after completion of the dialogue.

## DELE—correlation file DELE-tion

Alternative interpretations of unacceptable correlations may require the user to manually delete some correlations already in a particular file. As shown in fig. 57, option DELE allows the user to selectively eliminate one or more correlations within specified limits of elevation.

| PROCESSING PARAMETERS AND CORRELATION RESULTS FOR   |                          |                          |                   |                         |                        |                       |                                 |       |  |
|-----------------------------------------------------|--------------------------|--------------------------|-------------------|-------------------------|------------------------|-----------------------|---------------------------------|-------|--|
| ***** (JOHNSON No. 46 ) AND 6 (GILROY No. 1 ) ***** |                          |                          |                   |                         |                        |                       |                                 |       |  |
| DATUM: SEA LEVEL ( 1080.0; 1046.0)                  |                          |                          |                   |                         |                        |                       |                                 |       |  |
| REFERENCE LOGS                                      |                          |                          |                   |                         | GR - NEUT              |                       |                                 |       |  |
| MATCHING LOGS                                       |                          |                          |                   |                         | GR - NEUT              |                       |                                 |       |  |
| BASIC INFORMATION                                   |                          |                          |                   |                         | FINAL RESULTS          |                       |                                 |       |  |
| CORREL<br>LENGTH<br>FEET                            | SEARCH<br>LENGTH<br>FEET | SEARCH<br>OFFSET<br>FEET | DISPLAY<br>CUTOFF | REFER.<br>DEPTH<br>FEET | MATCH<br>DEPTH<br>FEET | DIF.<br>DEPTH<br>FEET | WEIGHTED CORREL.<br>COEFFICIENT |       |  |
| 28.0                                                | 40.0                     | -23.9                    | .700              | 920.0                   | 904.0                  | -16.0                 | .905                            | ***** |  |
| 28.0                                                | 40.0                     | -24.0                    | .700              | 921.0                   | 905.0                  | -16.0                 | .906                            | ***** |  |
| 28.0                                                | 40.0                     | -24.0                    | .700              | 922.0                   | 906.0                  | -16.0                 | .906                            | ***** |  |
| 28.0                                                | 40.0                     | -24.0                    | .700              | 923.0                   | 907.0                  | -16.0                 | .905                            | ***** |  |
| 28.0                                                | 40.0                     | -24.1                    | .700              | 924.0                   | 908.0                  | -16.0                 | .909                            | ***** |  |
| 28.0                                                | 40.0                     | -24.1                    | .700              | 925.0                   | 909.0                  | -16.0                 | .914                            | ***** |  |
| 28.0                                                | 40.0                     | -24.2                    | .700              | 926.0                   | 910.0                  | -16.0                 | .913                            | ***** |  |
| 28.0                                                | 40.0                     | -24.2                    | .700              | 927.0                   | 911.0                  | -16.0                 | .912                            | ***** |  |
| 28.0                                                | 40.0                     | -24.3                    | .700              | 928.0                   | 912.0                  | -16.0                 | .911                            | ***** |  |
| 28.0                                                | 40.0                     | -24.3                    | .700              | 929.0                   | 913.0                  | -16.0                 | .909                            | ***** |  |
| 28.0                                                | 40.0                     | -24.3                    | .700              | 930.0                   | 914.0                  | -16.0                 | .908                            | ***** |  |
| 28.0                                                | 40.0                     | -24.4                    | .700              | 931.0                   | 915.0                  | -16.0                 | .910                            | ***** |  |
| 28.0                                                | 40.0                     | -24.4                    | .700              | 932.0                   | 916.0                  | -16.0                 | .913                            | ***** |  |
| 28.0                                                | 40.0                     | -24.5                    | .700              | 933.0                   | 917.0                  | -16.0                 | .917                            | ***** |  |
| 28.0                                                | 40.0                     | -24.5                    | .700              | 934.0                   | 918.0                  | -16.0                 | .923                            | ***** |  |
| 28.0                                                | 40.0                     | -24.5                    | .700              | 935.0                   | 919.0                  | -16.0                 | .925                            | ***** |  |
| 28.0                                                | 40.0                     | -24.6                    | .700              | 936.0                   | 920.0                  | -16.0                 | .925                            | ***** |  |
| 28.0                                                | 40.0                     | -24.6                    | .700              | 937.0                   | 921.0                  | -16.0                 | .922                            | ***** |  |
| 28.0                                                | 40.0                     | -24.7                    | .700              | 938.0                   | 922.0                  | -16.0                 | .919                            | ***** |  |
| ...                                                 |                          |                          |                   |                         |                        |                       |                                 |       |  |
| 24.0                                                | 40.0                     | -24.7                    | .700              | 939.0                   | 923.0                  | -16.0                 | .927                            | ***** |  |
| 24.0                                                | 40.0                     | -24.7                    | .700              | 940.0                   | 924.0                  | -16.0                 | .923                            | ***** |  |
| 24.0                                                | 40.0                     | -24.8                    | .700              | 941.0                   | 925.0                  | -16.0                 | .919                            | ***** |  |
| 24.0                                                | 40.0                     | -24.8                    | .700              | 942.0                   | 926.0                  | -16.0                 | .918                            | ***** |  |
| 24.0                                                | 40.0                     | -24.9                    | .700              | 943.0                   | 927.0                  | -16.0                 | .915                            | ***** |  |
| 24.0                                                | 40.0                     | -24.9                    | .700              | 944.0                   | 928.0                  | -16.0                 | .909                            | ***** |  |
| 24.0                                                | 40.0                     | -24.9                    | .700              | 945.0                   | 929.0                  | -16.0                 | .902                            | ***** |  |
| 24.0                                                | 40.0                     | -25.0                    | .700              | 946.0                   | 930.0                  | -16.0                 | .890                            | ***** |  |
| 24.0                                                | 40.0                     | -25.0                    | .700              | 947.0                   | 931.0                  | -16.0                 | .853                            | ***** |  |
| 24.0                                                | 40.0                     | -25.1                    | .700              | 948.0                   | 932.0                  | -16.0                 | .748                            | ***** |  |
| ...                                                 |                          |                          |                   |                         |                        |                       |                                 |       |  |
| 14.0                                                | 40.0                     | -25.6                    | .700              | 962.0                   | 935.0                  | -27.0                 | .733                            |       |  |
| 14.0                                                | 40.0                     | -25.7                    | .700              | 963.0                   | 936.0                  | -27.0                 | .729                            |       |  |
| 14.0                                                | 40.0                     | -25.7                    | .700              | 964.0                   | 937.0                  | -27.0                 | .710                            |       |  |
| 14.0                                                | 40.0                     | -25.8                    | .700              | 965.0                   | 938.0                  | -27.0                 | .714                            |       |  |
| 14.0                                                | 40.0                     | -25.8                    | .700              | 966.0                   | 936.0                  | -30.0                 | .720                            |       |  |
| 14.0                                                | 40.0                     | -25.9                    | .700              | 967.0                   | 936.0                  | -31.0                 | .728                            |       |  |
| 14.0                                                | 40.0                     | -25.9                    | .700              | 968.0                   | 937.0                  | -31.0                 | .722                            |       |  |
| 14.0                                                | 40.0                     | -25.9                    | .700              | 969.0                   | 939.0                  | -30.0                 | .726                            |       |  |

FIGURE 54—LISTING PRODUCED BY OPTION PRNC. The E's stand for more than one level in the reference well correlating with the same level in the matching well. The X's denote crossing miscorrelations.

```

WHAT IS YOUR OPTION?: LIST
WHAT IS THE NAME OF THE FILE?: KS56.ELCO
WHAT IS THE TOP FOR THE INTERVAL TO PRINT?: 935
WHAT IS THE BOTTOM FOR INTERVAL TO PRINT?: 1000

```

FIGURE 55—SCREEN DIALOGUE WITH OPTION LIST, requiring portion of file KS56.ELCO to be listed.

```

KANSAS
SEA LEVEL
JOHNSON No. 46      5 11 1080.0 GR  10  0 NEUT  9
GILROY No. 1       6 11 1046.0 GR  12  0 NEUT 11
20064.000      1.000
935.0  919.0      28.0  40.0 -24.5 .70000 .92476*****
936.0  920.0      28.0  40.0 -24.6 .70000 .92478*****
937.0  921.0      28.0  40.0 -24.6 .70000 .92230*****
938.0  922.0      28.0  40.0 -24.7 .70000 .91905*****
941.0  925.0      24.0  40.0 -24.8 .70000 .91888*****
942.0  926.0      24.0  40.0 -24.8 .70000 .91805*****
943.0  927.0      24.0  40.0 -24.9 .70000 .91473*****
944.0  928.0      24.0  40.0 -24.9 .70000 .90875*****
945.0  929.0      24.0  40.0 -24.9 .70000 .90177*****
946.0  930.0      24.0  40.0 -25.0 .70000 .88958*****
947.0  931.0      24.0  40.0 -25.0 .70000 .85340*****
948.0  932.0      24.0  40.0 -25.1 .70000 .74793
962.0  935.0      14.0  40.0 -25.6 .70000 .73344
963.0  936.0      14.0  40.0 -25.7 .70000 .72852
964.0  937.0      14.0  40.0 -25.7 .70000 .71041
965.0  938.0      14.0  40.0 -25.8 .70000 .71377
974.0  950.0      14.0  40.0 -26.1 .70000 .71065

```

FIGURE 56—SCREEN DISPLAY OF LISTING PRODUCED BY OPTION LIST.

## SORT—correlation file SORTing

```

WHAT IS YOUR OPTION?: DELE
WHAT IS THE NAME OF THE FILE?: LD1112.WEIN
WHAT IS THE TOP FOR DELETION INTERVAL?: 8140
WHAT IS THE BOTTOM FOR DELETION INTERVAL?: 8190

```

FIGURE 57—SCREEN DIALOGUE WITH OPTION DELE, showing selection of an interval to be deleted from a file.

Most options require that correlations be arranged strictly by increasing elevation in the reference well. Failure to meet this requirement will cause execution of CORRELATOR to be interrupted.

Option SORT allows the user to sort any correlation file by increasing order of reference elevation. The only question that CORRELATOR will ask under this option is the name of the correlation file.

# Grand Bayou case study

Wireline logs from nine wells are used in this section to illustrate the use of CORRELATOR in the analysis of a typical stratigraphic problem. Results from the final lithostratigraphic correlation are displayed both in the form of cross sections and as maps produced by SURFACE III, a contour-mapping package (Sampson, 1988). Fig. 58

shows the location of the nine wells in the Grand Bayou field, Assumption Parish, Louisiana, approximately 50 mi (80 km) west of New Orleans. The interval of interest consists of alternating sandstones and shales deposited in a Miocene deltaic complex (Landes, 1970, p. 188–218; Tipsword et al., 1971).

TABLE 2—NAMES AND LOCATIONS OF WELLS USED IN THIS STUDY. WELLS ARE LOCATED IN ASSUMPTION PARISH, LOUISIANA.

| ID | Company | Well Name             | Surface Location |     |     |
|----|---------|-----------------------|------------------|-----|-----|
|    |         |                       | Sec              | Twp | Rge |
| 1  | Texaco  | P.F.V. La Barre No. 1 | 49               | 12S | 13E |
| 2  | Texaco  | Ramos Inv. Co. No. 1  | 51               | 12S | 13E |
| 3  | Texaco  | Ramos Inv. Co. No. 1  | 51               | 12S | 13E |
| 4  | Texaco  | P.R. Norman No. C-1   | 5                | 13S | 13E |
| 5  | Texaco  | P.R. Norman No. B-5   | 49               | 12S | 13E |
| 6  | Texaco  | P.R. Norman No. B-4   | 50               | 12S | 13E |
| 7  | Texaco  | P.R. Norman No. B-6   | 50               | 12S | 13E |
| 8  | Texaco  | P.R. Norman No. B-3   | 50               | 12S | 13E |
| 9  | Sun     | P.F.V. La Barre No. 1 | 5                | 13S | 13E |

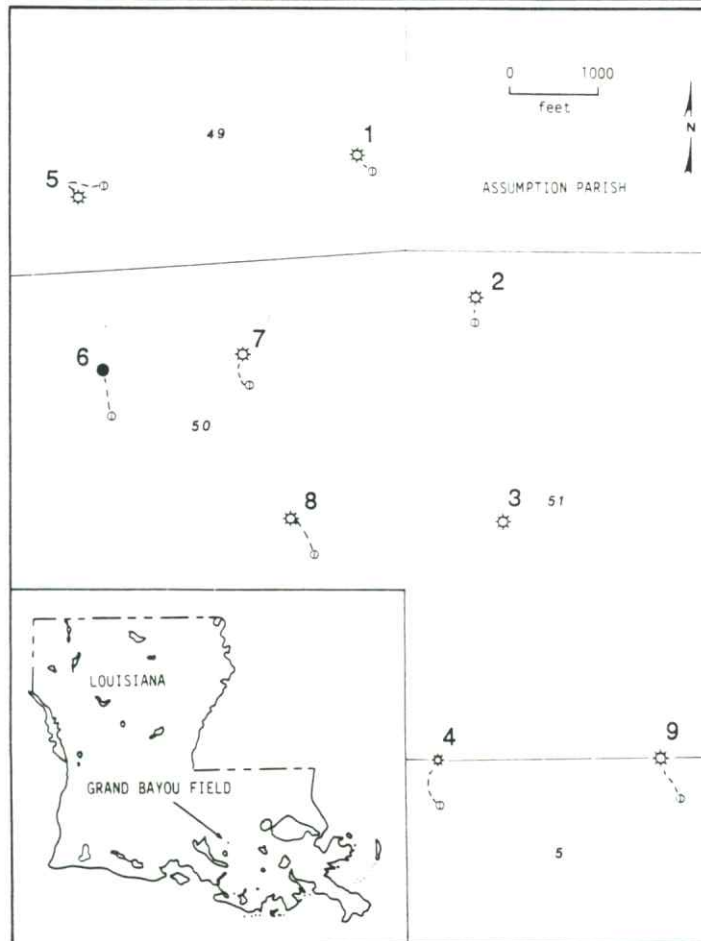


FIGURE 58—LOCATION OF WELLS IN THE GRAND BAYOU FIELD, LOUISIANA, WHOSE WIRELINE LOGS WERE USED IN THIS STUDY. Wells are identified by name in table 2.

To shorten the notation, individual wells will usually be referred to by their sequential number. Table 2 gives the actual well names and their locations. Most of the wells are slightly slanted. Information used in the study comes from 18 wireline-log traces digitized at 2-ft (.6-m) intervals from a depth of 8,000 ft (2,400 m) below sea level to the bottom of the holes. Each well is represented by a spontaneous-potential and a resistivity log. Variations in the nature of the resistivity logs are given in table 3.

TABLE 3—TYPE, DATE, AND SOURCE OF RESISTIVITY LOGS FROM WELLS USED IN THIS STUDY.

| ID | Date | Logging Company | Resistivity Log     |
|----|------|-----------------|---------------------|
| 1  | 1969 | Schlumberger    | 16" Short Normal    |
| 2  | 1977 | Schlumberger    | Focused Resistivity |
| 3  | 1968 | Schlumberger    | 16" Short Normal    |
| 4  | 1972 | Schlumberger    | Focused Resistivity |
| 5  | 1972 | Schlumberger    | Focused Resistivity |
| 6  | 1971 | Schlumberger    | 16" Short Normal    |
| 7  | 1976 | Schlumberger    | Focused Resistivity |
| 8  | 1970 | Schlumberger    | 16" Short Normal    |
| 9  | 1971 | Welex           | 18" Normal          |

## Wireline-log correlation procedure

CORRELATOR has sufficient flexibility to accommodate most geological circumstances and user's preference for the analysis. Because an interpretation using many options might be confusing, the following example may serve as a guide for the reasonable use of CORRELATOR to someone trying the system for the first time.

- Step 1.** Digitize all wireline logs or obtain them in digital form and store them in a log-data file using option IALO. In this case study, the file is called GRANDBAY.2FT.
- Step 2.** Select a reference level and using option IAWE, enter all well information into a well-data file. Fig. 59 is a display of the well-data file for Grand Bayou. Selecting a new permanent datum is unnecessary in this case because all depth measurements were based on sea level.
- Step 3.** Select a traverse to analyze. Fig. 60 shows a possible traverse as a line through wells 5, 6, 7, 2, 1, and back to 5. The traverse was chosen as a closed loop so the correlations could be verified using closure errors.

```

:UDD:OLEA:CORREL:LGLIB:GRANDBAY.2FT
KELLY BUSHING
TEXACO-LABARRE No. 1 12 .0 SP 2 0 SN16 1
TEXACO-RAMOS No. 2 12 .0 SP 4 0 SFLA 3
TEXACO-RAMOS No. 1 12 .0 SP 6 1 SN16 5
TEXACO-NORMAN No.C-1 12 .0 SP 8 0 SFLA 7
TEXACO-NORMAN No.B-5 12 .0 SP 10 3 SFLA 9
TEXACO-NORMAN No.B-4 11 .0 SP 12 2 SN16 11
TEXACO-NORMAN No.B-6 12 .0 SP 14 0 SFLA 13
TEXACO-NORMAN No.B-3 12 .0 SP 16 0 SN16 15
SUN-LABARRE No. 1 12 .0 SP 18 0 SN18 17

```

FIGURE 59—SCREEN LISTING OF THE WELL-DATA FILE FOR THE GRAND BAYOU CASE STUDY.

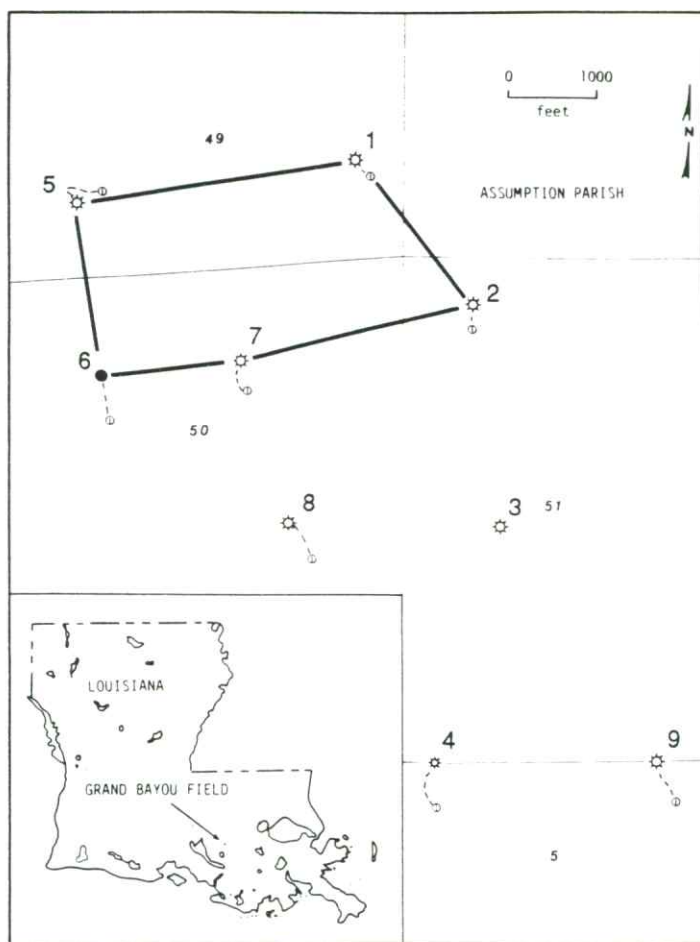


FIGURE 60—WELLS ALONG TRAVERSE AROUND GRAND BAYOU FIELD, LOUISIANA.

**Step 4.** Use option PLOT to check the base lines of all spontaneous-potential logs on the traverse. Correct any systematic trends in base lines, as on well No. 5 in fig. 61. Save the polynomial degree of the best base-line correction on the well-data file.

**Step 5.** Select any pair of wells along the traverse.

**Step 6.** Use option WELE to find the strongest, most reliable correlations which will form the anchor for subsequent interpretations. Use every possible piece of prior information to guide this initial stage. If the search for correlations cannot be guided, select intervals in the reference well and look for the best correlations from the top to the bottom of the matching well. Shale intervals or the intervals of transition to non-shale lithologies ordinarily produce reliable correlations, as the low-energy environments in which shales are deposited are more persistent than others

(Weaver, 1958; Krumbein and Sloss, 1963, p. 341). Fig. 62 shows an example of what we have called anchoring or unequivocal correlation. Two conditions are necessary to establish such an unequivocal correlation:

1. The correlation must be strong, 0.8 or higher, and established as the strongest correlation within a long search interval.
2. A strong correlation alone is not sufficient to establish a clear correlation. The second and following correlations must be perceptibly smaller than the strongest correlation. In fig. 63, for instance, the best correlation is stronger than the best correlation shown in fig. 62, but the correlation is not conclusive because the absolute maximum correlation is very close to at least seven other possible correlations.

Try to find a series of unquestionable correlations which are spaced as closely as possible to regular

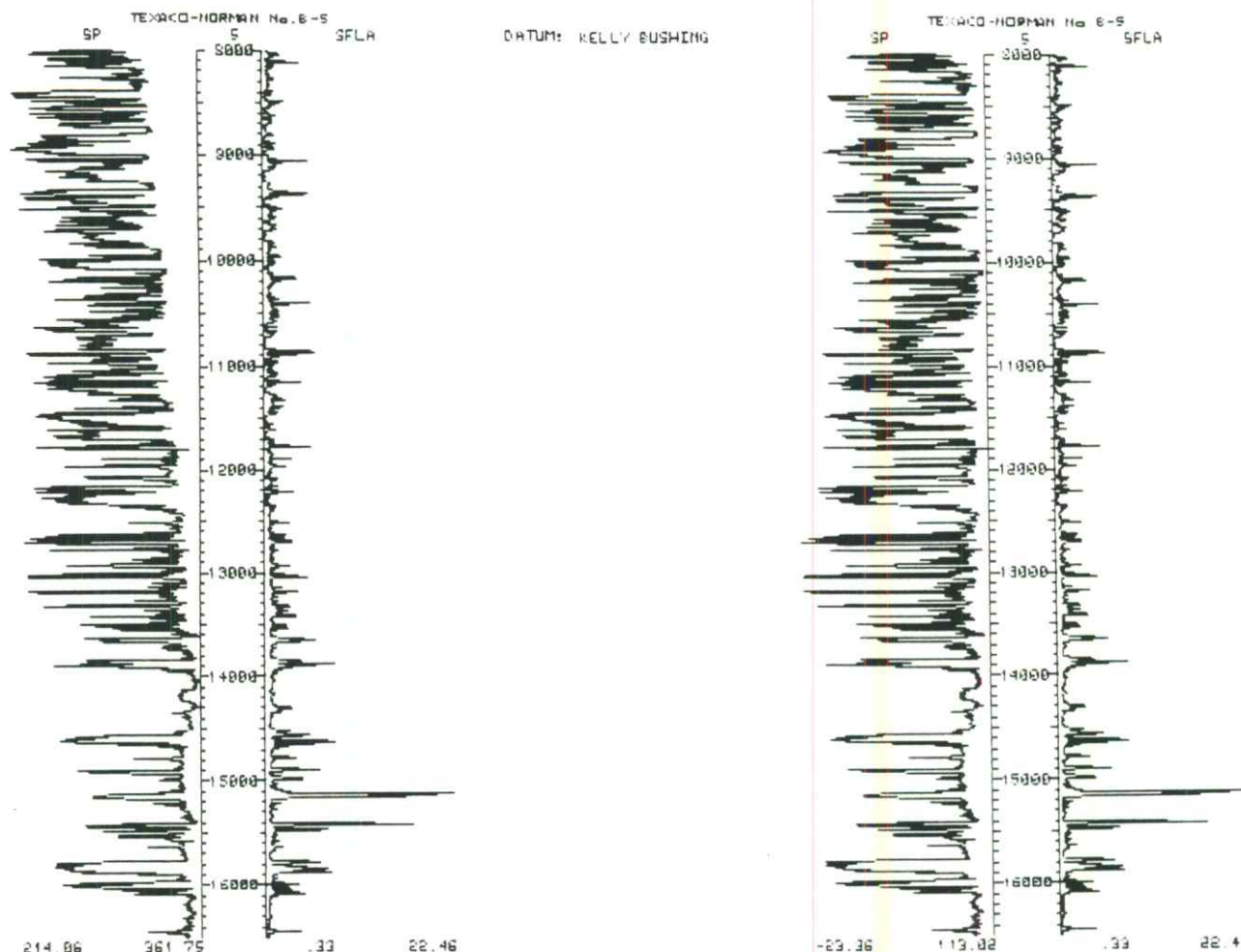


FIGURE 61—EXAMPLE OF DRIFTING BASE LINE ON THE SPONTANEOUS-POTENTIAL LOG FROM A WELL IN THE GRAND BAYOU FIELD. Original log is on the left and log corrected using option COBS is on the right.

intervals, and immediately before and after each sudden change in dip. The total number of anchoring correlations must be related to the complexity of the geology.

**Step 7.** Find a model for the trend in dips. Use option REDE to evaluate different polynomial models. If the number of control points provided in STEP 6 is insufficient, go back to Step 6 and establish additional anchoring correlations. Be parsimonious and work with the lowest degree of polynomial that can fit the control points without unstable fluctuations between control points or at the tails. The polynomial should approximate straight lines between and beyond the control points. Fig. 64 shows a single polynomial of degree 7 used to model the trend in dips. In figs. 65 and 66, the same trend has been broken into two much simpler polynomials with a discontinuity between them. This solution should be favored in situations where the trend in dip presents sudden abrupt changes. However, breaking the trend in dip into more than one

polynomial requires that the user keep track of the intervals over which one particular polynomial model is valid. Save the best solution in as many regression-coefficient files as segments in the model.

**Step 8.** Generate lithostratigraphic correlations by selecting option WEIN. If necessary, break the total sequence to be correlated into smaller segments so as not to exceed the maximum of 500 correlations per batch allowed by CORRELATOR, or to produce a screen display covering such a long range that resolution is poor. In the absence of special reasons, progress down the reference well from top to bottom without overlapping. Important considerations in the selection of parameters include:

1. Correlation length. The system allows the dynamic selection of correlation length as a function of shale and non-shale unit thickness. Unless a particular circumstance precludes use of the automatic mode, it

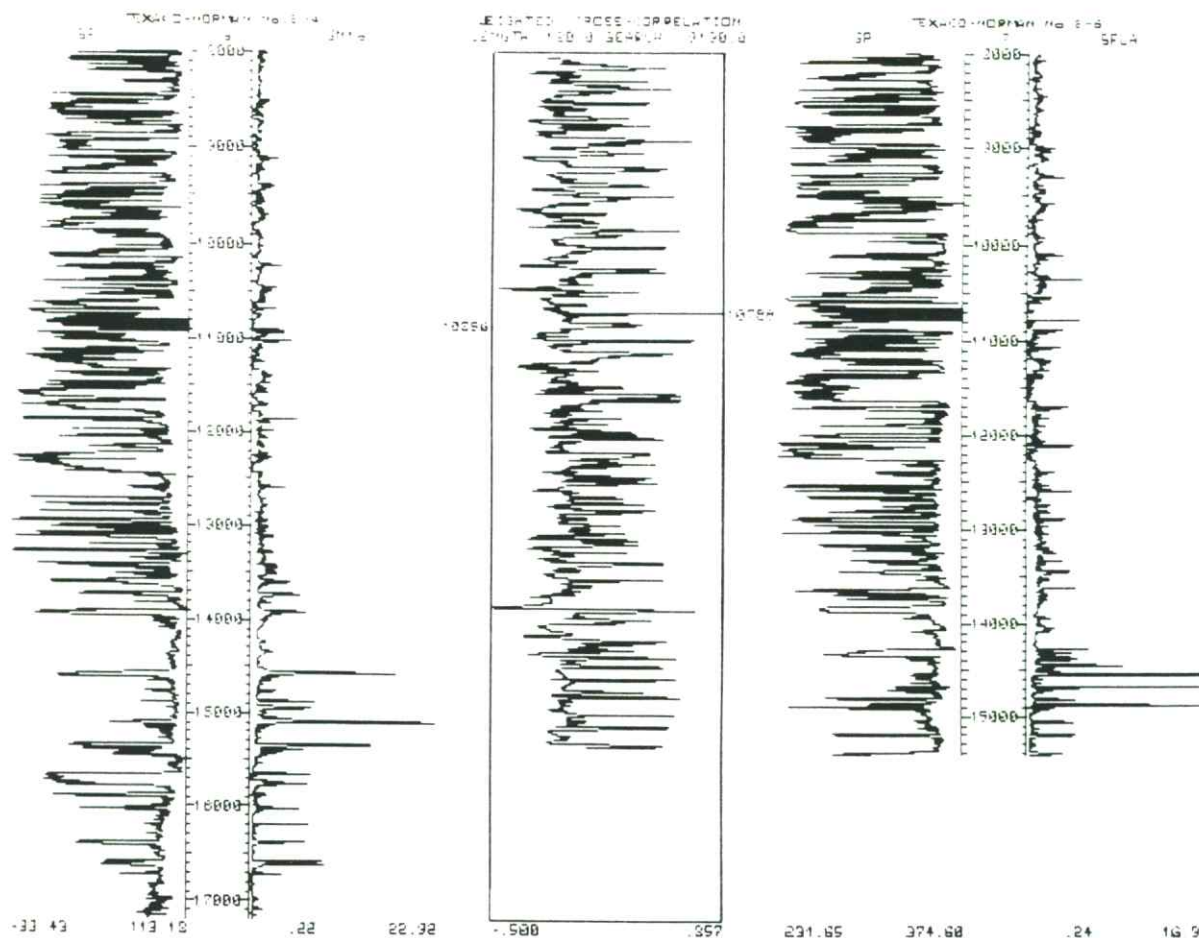


FIGURE 62—BEST WEIGHTED CORRELATION BETWEEN TWO GRAND BAYOU FIELD WELLS. The correlation indicated is significantly better than any other correlation between the wells. Length of correlated interval is 120 ft.

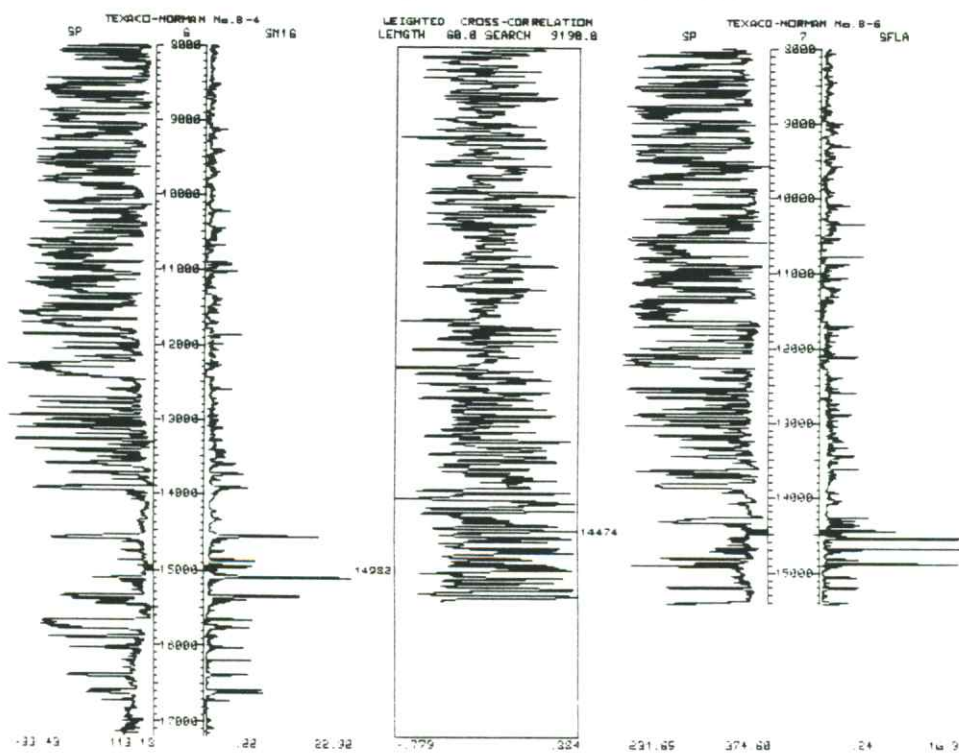


FIGURE 63—BEST WEIGHTED CORRELATION BETWEEN TWO GRAND BAYOU FIELD WELLS. The best correlation is not significantly better than several other correlations. Length of correlated interval is 60 ft.

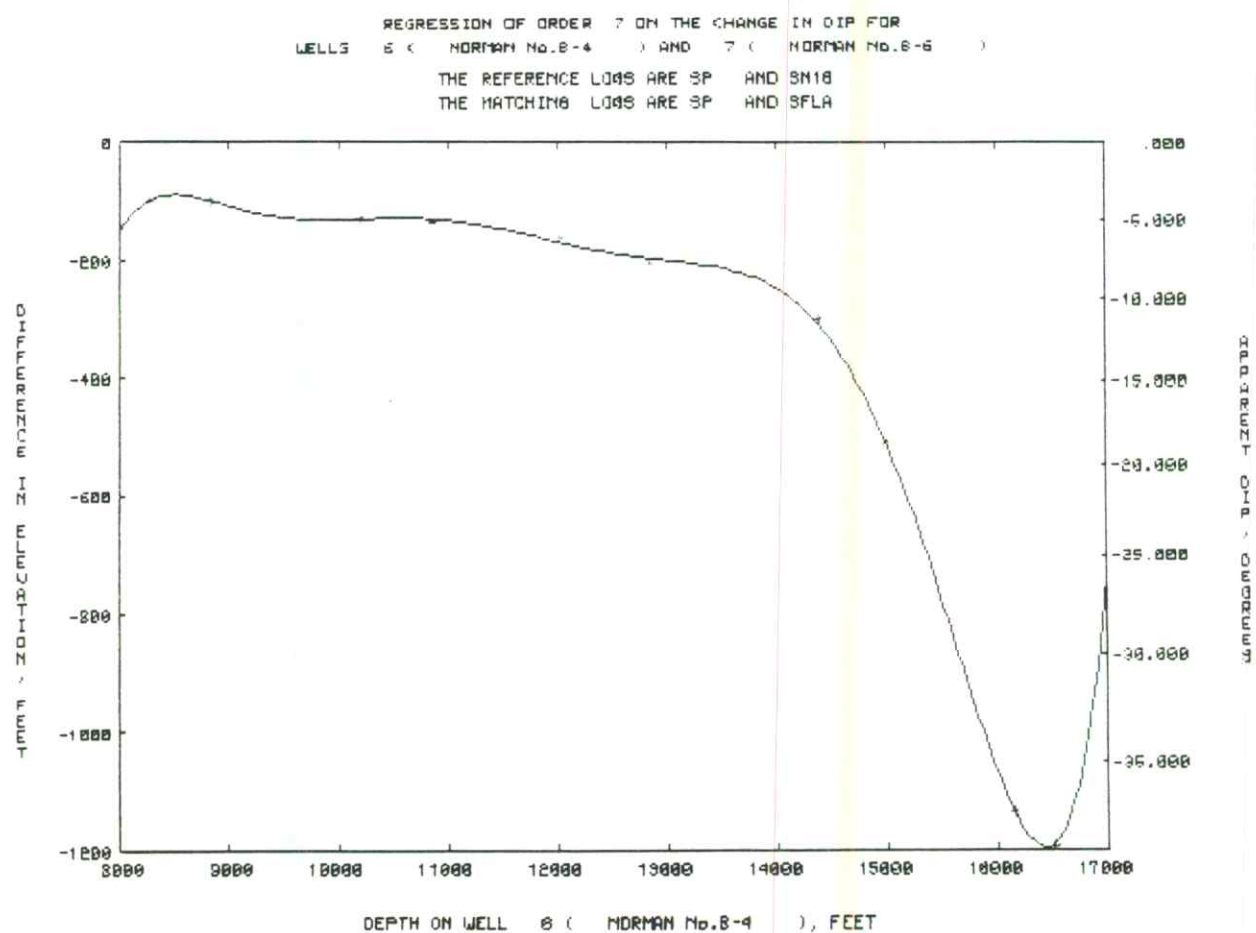


FIGURE 64—SCREEN DISPLAY SHOWING THE TREND IN DIFFERENCES IN ELEVATION BETWEEN TWO WELLS, modeled as a polynomial regression.

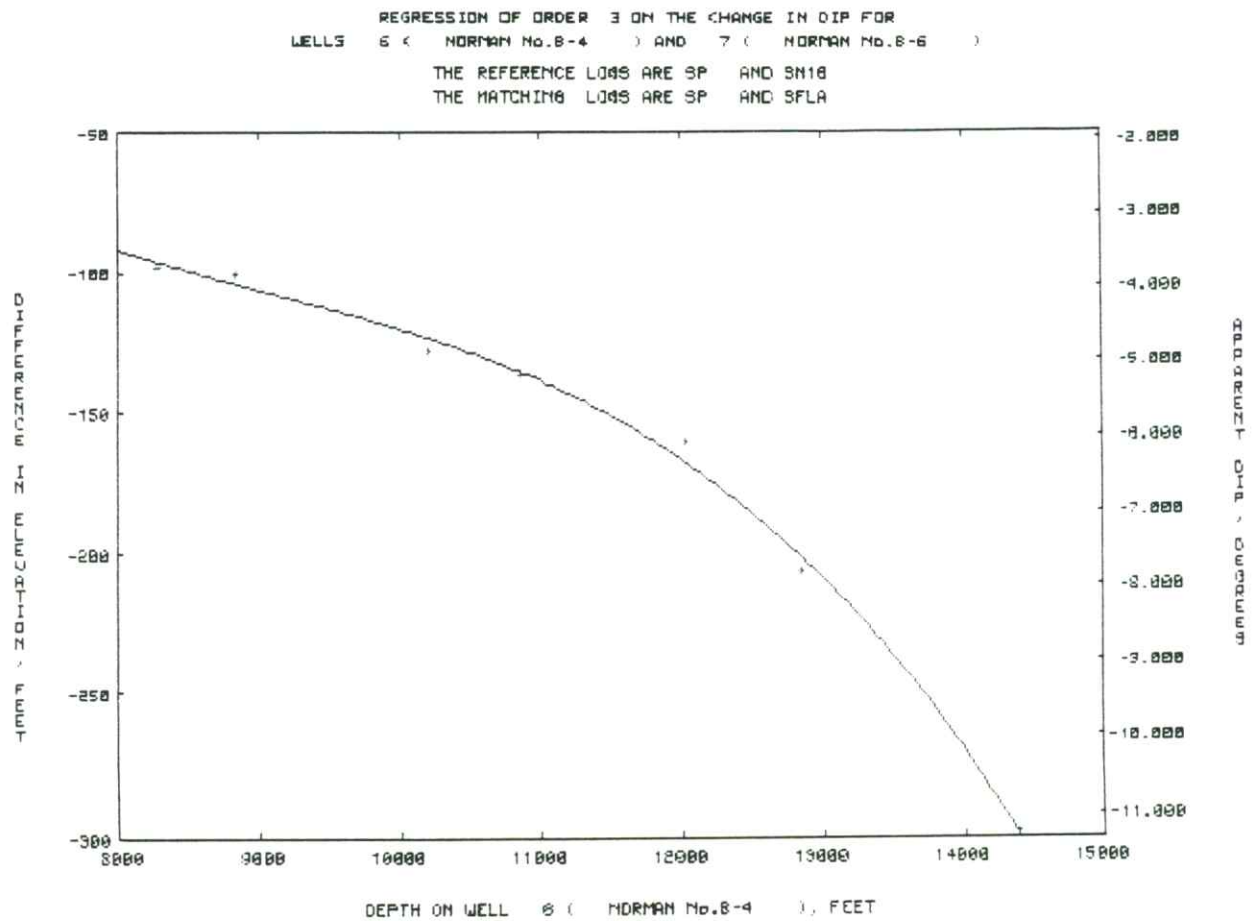


FIGURE 65—SCREEN DISPLAY SHOWING ONLY THE UPPERMOST OF TWO POLYNOMIALS TO MODEL THE TREND IN DIFFERENCES IN ELEVATION BETWEEN TWO WELLS. The lower portion of the model is shown in fig. 66. Control points are the same as in fig. 64.

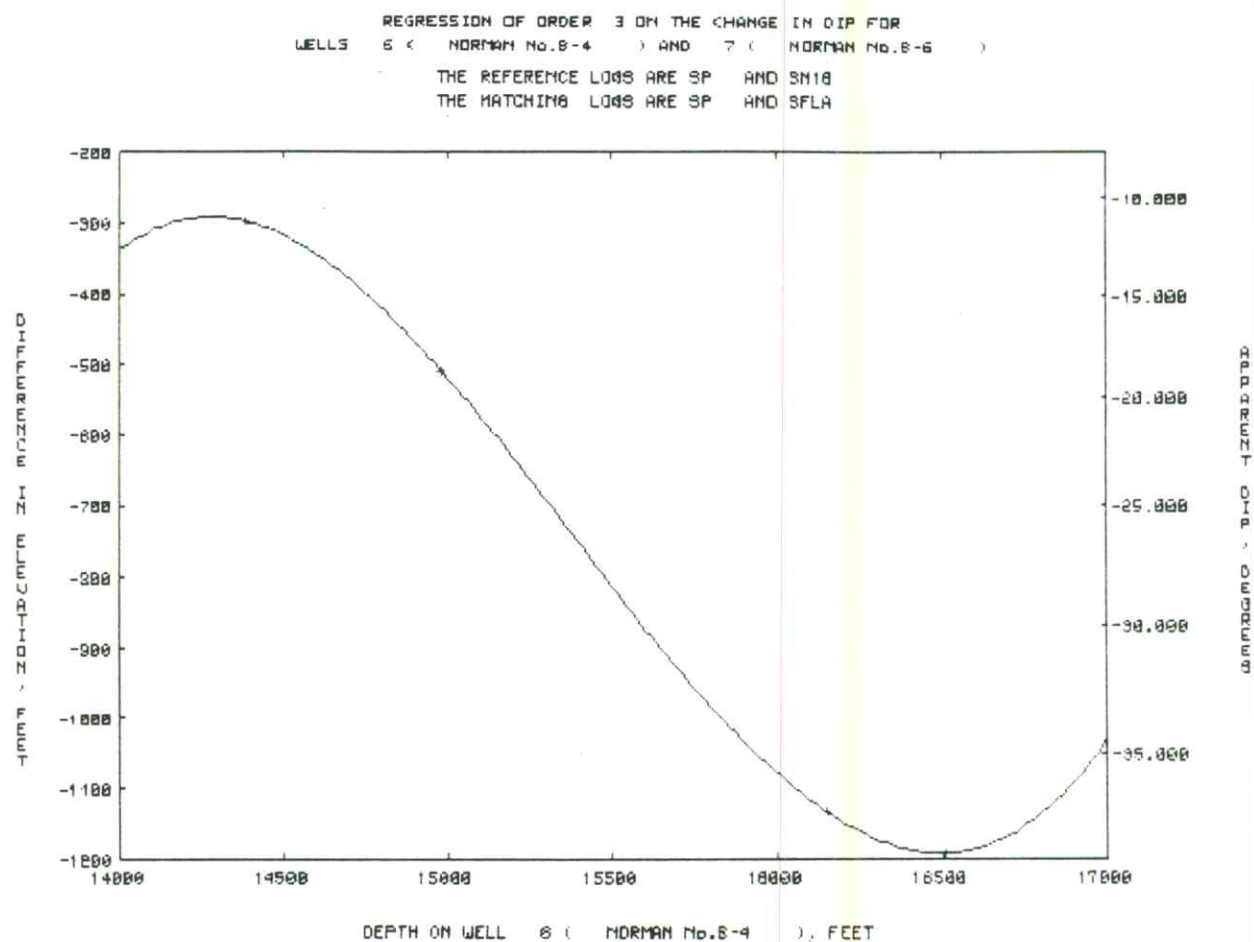


FIGURE 66—SCREEN DISPLAY OF THE LOWERMOST OF TWO POLYNOMIALS TO MODEL THE TREND IN DIFFERENCES IN ELEVATION BETWEEN TWO WELLS. The upper portion of the model is shown in fig. 65. Control points are the same as in fig. 64.

should be favored because it is faster and usually produces more and better quality correlations than the manual mode. The manual mode tends to be more effective in either very thin or very thick bedded rock units. See Appendix A for additional information.

2. Computation of offsets. There is no reason why automatic mode should not be used all the time. An exception may be in very monotonous, short sequences within which the dip remains constant. Be sure to check model boundaries to be sure that segmented polynomial models of the trend in dip are used within valid ranges.
3. Magnitude of search length. This parameter is related to the goodness-of-fit of the polynomial used to model trends in dips for the entire population of correlations. The goodness-of-fit measure of the polynomial regression is always optimistic, because of the small number of sample points used in the regression. The user must provide a wider search length than that suggested by the fit of the model, taking into account the perceived geology of the area. If there is no prior geological information to guide the selection of search length, a sensitivity analysis will be required to select the appropriate value. To save computer time, the analysis should proceed by increasing the search length. The best search length is the smallest that encloses all correlations over the specified threshold. In general, the search length should not exceed twice the largest departure from the trend in dip. Too short a search interval may fail to encompass the true lithostratigraphic solution, thus assuring that the correct answer will not be found. Instead, no equivalent correlation will be detected, or worse, a miscorrelation could arise instead of the correct correlation. Too long a search length will increase the processing time and will increase the proportion of miscorrelations. In the absence of any geologically guided constraints, the larger the search length, the higher the probability of finding a weighted correlation higher than that given at the true position of match, resulting in a miscorrelation. In summary, the search length should be no greater than absolutely necessary. Additional details are provided in Appendix B.

4. The threshold, or minimum acceptable weighted-correlation strength. This parameter helps to standardize the interpretation by weeding out correlations of dubious quality. The eye tends to establish a lithostratigraphic correlation when the resemblance between log traces is such that the correlation coefficient is above 0.6. Log traces below that threshold do not appear to be equivalent in form. If it is important that output from CORRELATOR accords well with manual interpretations, the correlation cutoff should be set at 0.6 to 0.75. Genuine correlations tend to have high weighted-correlation coefficients. However, setting the correlation cutoff too high has the disadvantage of dropping correct correlations that are too weak to make it over a stringent threshold. On the other hand, a correlation cutoff that is too low retains correlations which range from arguable to definitely wrong.

Save the correlations generated at this step in an initialized correlation file.

- Step 9. Edit the correlation file. Fig. 67 is a typical display of a correlation file as it appears prior to editing. Most correlations seem to be correct, but a few seem unacceptable. By using the expert system in option ELCO to inspect a correlation file, anomalous correlations will be identified and brought to the user's attention. The user must make the final decision as to whether the abnormal correlations have some geologic significance or are merely artifacts. The expert system may need to process the correlation file more than once to eliminate all miscorrelations. Allow at least two passes of option ELCO; repeat the procedure until no new anomalous correlations are brought to your attention. Very unusual cases may necessitate manual editing through option DELE. Fig. 68 is the edited section of fig. 67 after processing by the expert system.
- Step 10. If there are pairs of wells in the traverse that are not yet correlated, select one of the remaining pairs and go back to Step 6.
- Step 11. Use any or all of the graphical options SECT, PERS, and TRAC to produce a final presentation of the results. Fig. 69 shows some selected lithostratigraphic correlations that follow markers of geological interest.



**Step 12.** If the traverse is closed, check closure errors. Take correlative action to keep errors within acceptable boundaries, if necessary.

In spite of how correct the correlations between pairs of wells may look, a large closure error means there must be an error in correlation along a traverse. CORRELATOR cannot directly help the user locate such a miscorrelation. However, by this point in an analysis, miscorrelations seldom occur and are not difficult to locate by inspection of the surrounding correlations. Once

a problematic correlation has been located, it may be deleted using option DELE; or, generating additional correlations above or below the troublesome interval should cure the problem.

Because the cross section shown in fig. 69 is a closed traverse, the listing in fig. 70 can be used for a second round of editing. In this instance, all closure errors are within the inherent precision that can be expected from the use of wireline logs to establish correlations.

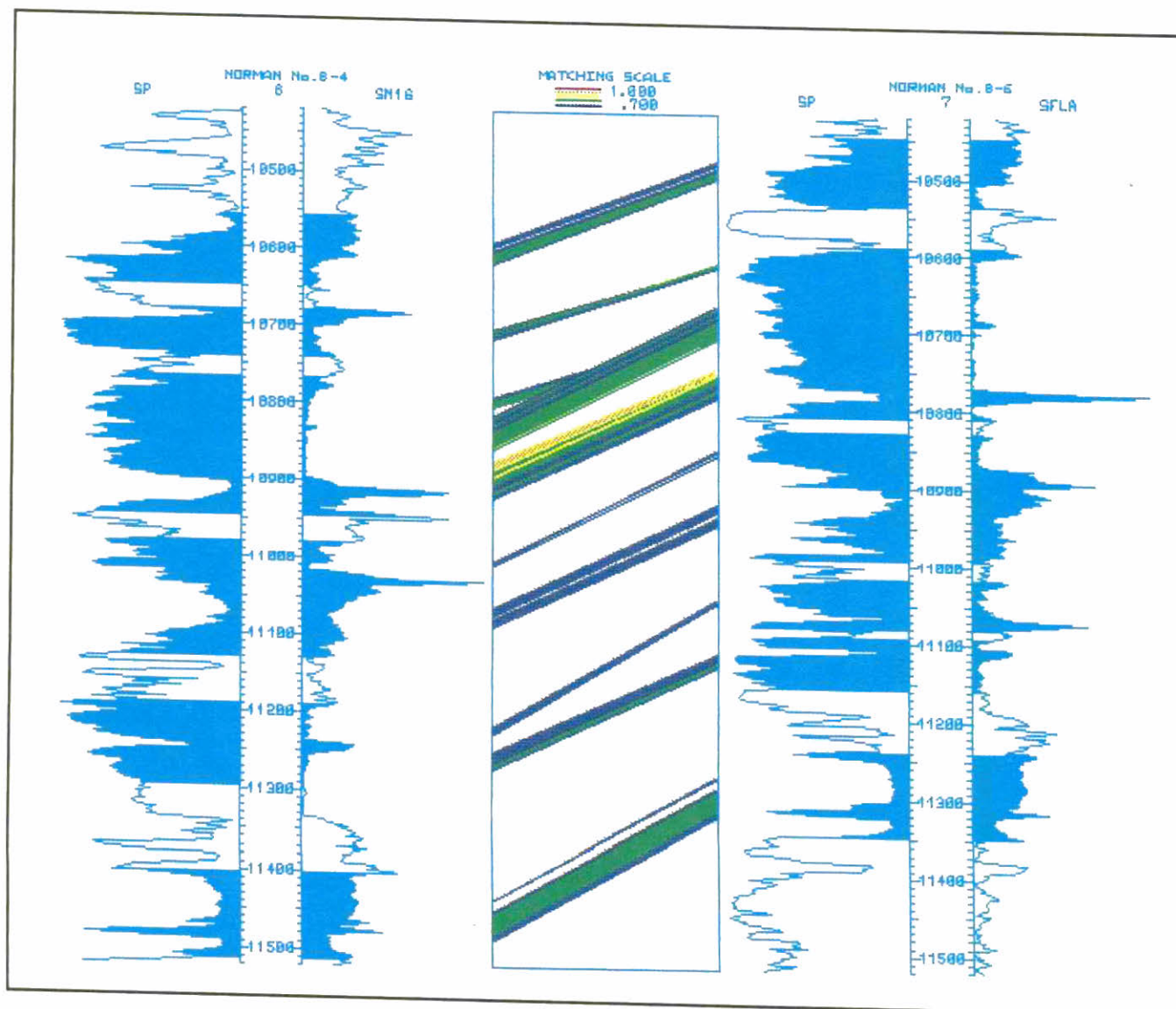


FIGURE 67—SCREEN DISPLAY SHOWING A CORRELATION FILE BEFORE EDITING BY THE EXPERT SYSTEM.



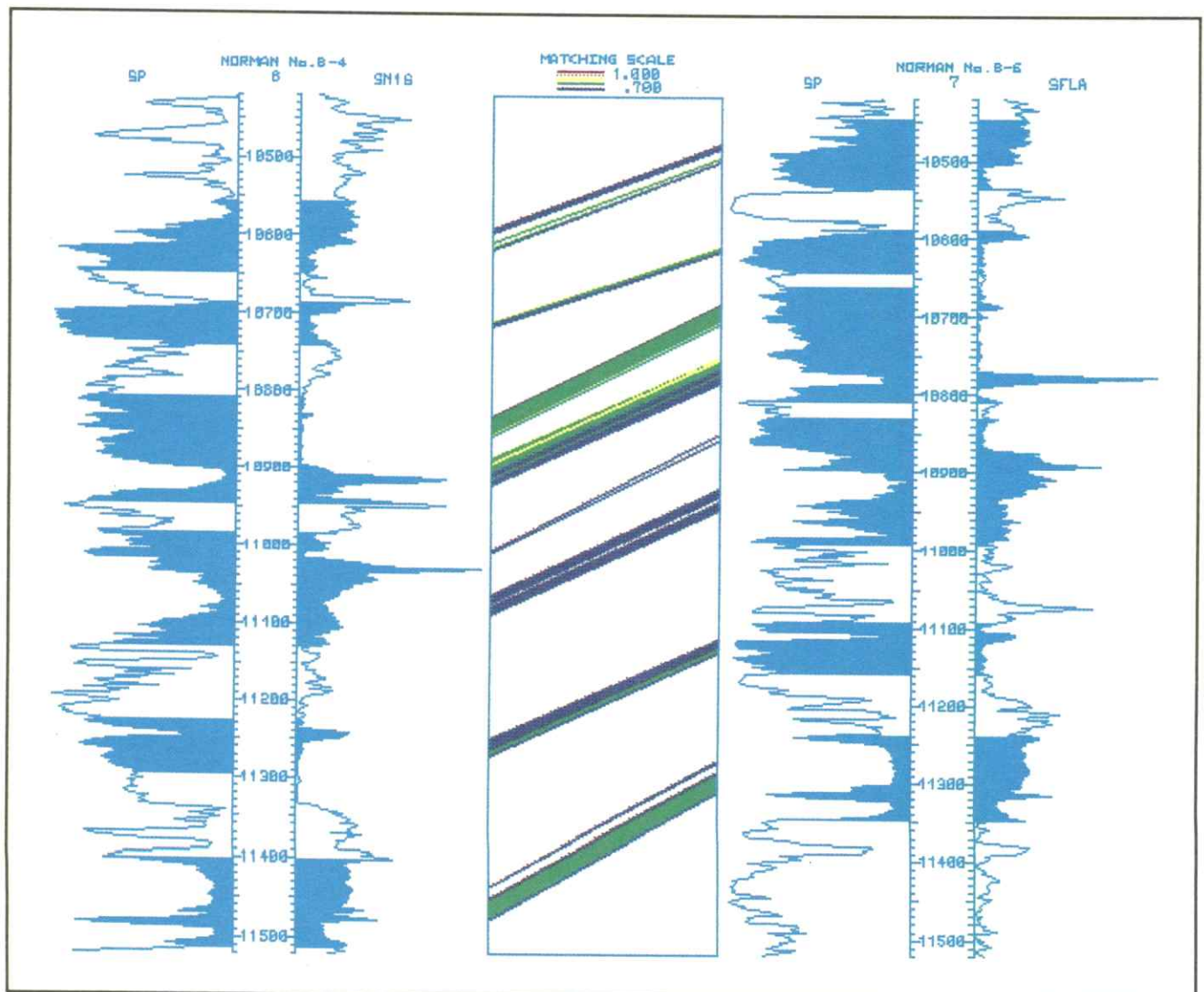


FIGURE 68—THE SAME FILE SHOWN IN FIG. 67 AFTER EDITING BY THE EXPERT SYSTEM.



SELECTED LITHOSTRATIGRAPHIC CORRELATIONS  
GRAND BAYOU, LOUISIANA

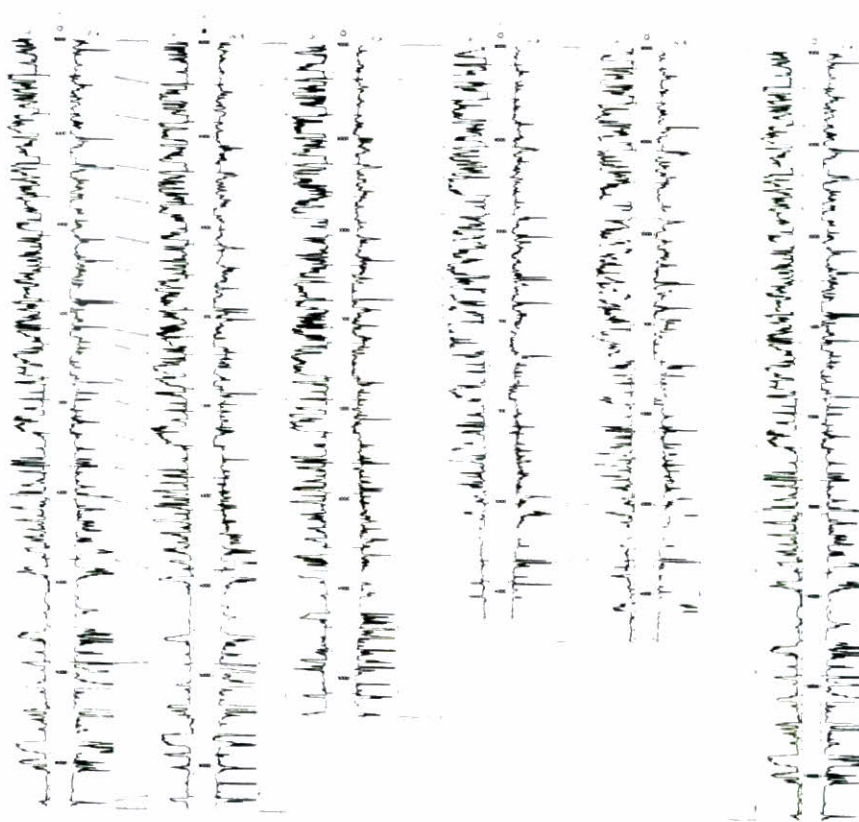


FIGURE 69—LITHOSTRATIGRAPHIC CROSS SECTION OF THE MIOCENE IN THE GRAND BAYOU FIELD, ASSUMPTION PARISH, LOUISIANA. Solid lines on the cross section are within correlated intervals. Dashed lines are interpolations. Vertical exaggeration is 5X.

CORRELATION TRACING  
\*\*\*\*\*

TRACING STARTED FROM WELL 6  
THE DATUM IS KELLY BUSHING  
ALL RESULTS ARE IN FEET

WELLS AND LOGS

|    | 5         | 6         | 7         | 2         | 1         | 5       |         |
|----|-----------|-----------|-----------|-----------|-----------|---------|---------|
|    | SP        | -SFLA SP  | -SN16 SP  | -SFLA SP  | -SN16 SP  | -SFLA   | CLOSURE |
|    |           |           |           |           |           |         | ERROR   |
| 1  | 8390.0    | 8446.0    | 8368.0    | 8200.0    | 8224.0    | 8392.0  | -2.0    |
| 2  | 8798.0    | 8846.0    | 8746.0    | 8564.0    | 8590.0    | 8798.0  |         |
| 3  | 9336.0    | 9386.0    | 9274.0    | 9078.0    | 9094.0    | 9334.0  | 2.0     |
| 4  | 9692.0    | 9750.0 I  | 9628.0 I  | 9410.0 I  | 9442.0 I  | 9692.0  |         |
| 5  | 10128.0   | 10190.0   | 10062.0   | 9812.0    | 9826.0    | 10130.0 | -2.0    |
| 6  | 10484.0 I | 10540.0 I | 10396.0   | 10152.0 I | 10172.0 I | 10490.0 | -6.0    |
| 7  | 10868.0   | 10930.0   | 10794.0   | 10526.0 I | 10540.0 I | 10874.0 | -6.0    |
| 8  | 11174.0   | 11232.0   | 11098.0   | 10820.0   | 10846.0   | 11176.0 | -2.0    |
| 9  | 11350.0   | 11430.0   | 11268.0   | 10964.0   | 11012.0   | 11346.0 | 4.0     |
| 10 | 11730.0   | 11814.0   | 11662.0   | 11340.0   | 11418.0   | 11730.0 |         |
| 11 | 11972.0   | 12066.0   | 11906.0 I | 11572.0   | 11664.0   | 11970.0 | 2.0     |
| 12 | 12352.0   | 12450.0   | 12272.0   | 11872.0   | 11896.0   | 12348.0 | 4.0     |
| 13 | 12708.0   | 12800.0   | 12600.0   | 12174.0   | 12196.0   | 12710.0 | -2.0    |
| 14 | 13076.0   | 13160.0   | 12940.0   | 12470.0   | 12488.0   | 13080.0 | -4.0    |
| 15 | 13738.0   | 13820.0   | 13540.0   | 13026.0   | 13014.0   | 13738.0 |         |
| 16 | 14886.0   | 14870.0   | 14438.0   | 13662.0   | 13628.0   | 14878.0 | 8.0     |
| 17 | 16416.0   | 16350.0   | 15170.0   | 13890.0   | 13952.0   | 16414.0 | 2.0     |

MAXIMUM ABSOLUTE CLOSURE ERROR: 8.0 FEET

AVERAGE ABSOLUTE CLOSURE ERROR: 2.706 FEET

FIGURE 70—TABLE OF CORRELATIONS FOR THE CROSS SECTION SHOWN IN FIG. 69. The letter I represents interpolations or extrapolations for reference levels that do not correspond to any correlated interval. These inferred correlations are indicated by dashed lines on fig. 69.

## Mapping results

Traverses such as the one shown in fig. 69 may not be the best way to present results. Other displays can be produced by passing correlation matrices, such as the one in fig. 70, to a contour-mapping package such as SURFACE III (Sampson, 1988). Additional correlations to four wells outside the traverse shown on fig. 60 were found by repeating the correlation process just described. The complete set of correlations for two marker units have been selected for illustrative purposes and are shown in table 4.

Figs. 71 and 72 are structural-contour maps for marker units A and B. Fig. 73 is an isopach map for the interval between marker A and marker B, and fig. 74 is a percent-sandstone map for the same interval. The map is based on sandstone percentages calculated directly from the spontaneous-potential logs. The product of the last two maps gives a map of the net feet of sandstone shown in fig. 75. An alternative presentation as a fishnet diagram is shown in fig. 76. Although not useful for quantitative purposes, block diagrams are helpful for presenting surfaces to persons not familiar with contour maps.

TABLE 4—DEPTH (IN FT) TO TWO MARKERS IN THE GRAND BAYOU FIELD, LOUISIANA.

|        | Well   |        |        |        |        |        |        |        |        |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Marker | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      |
| A      | 11,012 | 10,964 | 11,152 | 11,432 | 11,346 | 11,430 | 11,268 | 13,372 | 11,274 |
| B      | 11,418 | 11,340 | 11,547 | 11,828 | 11,730 | 11,814 | 11,662 | 13,764 | 11,678 |

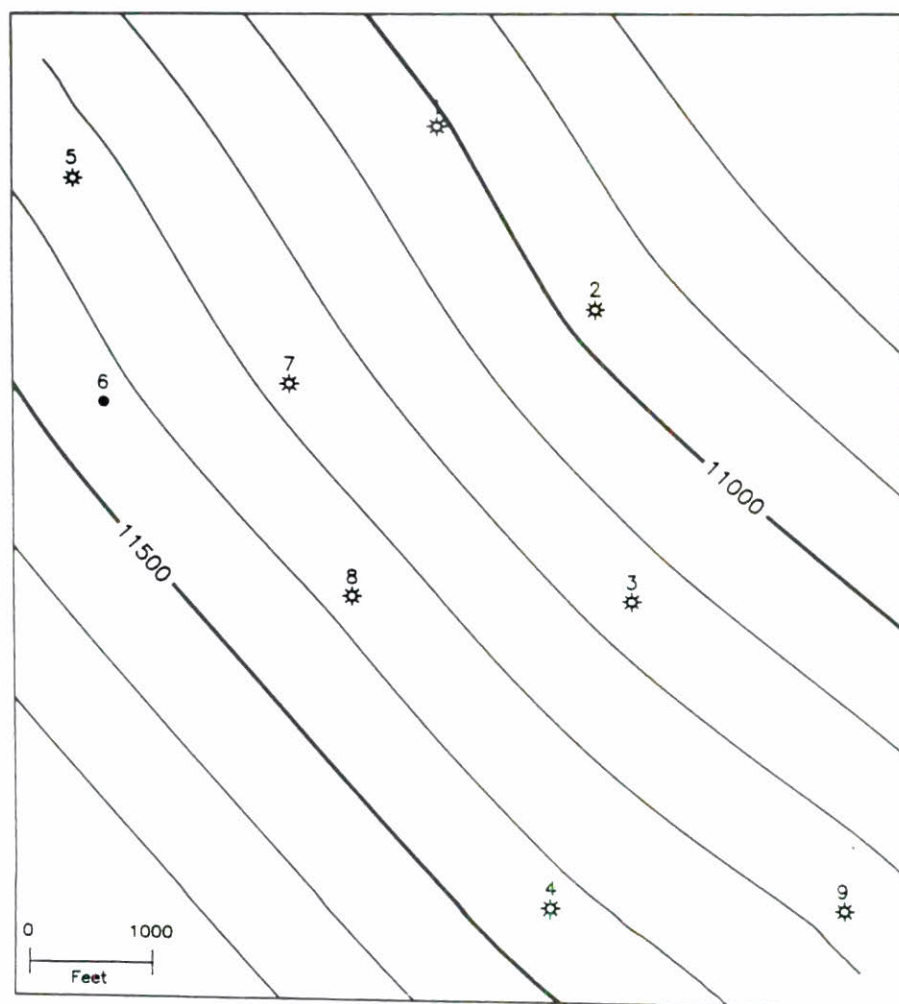


FIGURE 71—STRUCTURAL CONTOUR MAP OF MARKER A IN GRAND BAYOU FIELD, LOUISIANA. Contour interval is 100 ft.

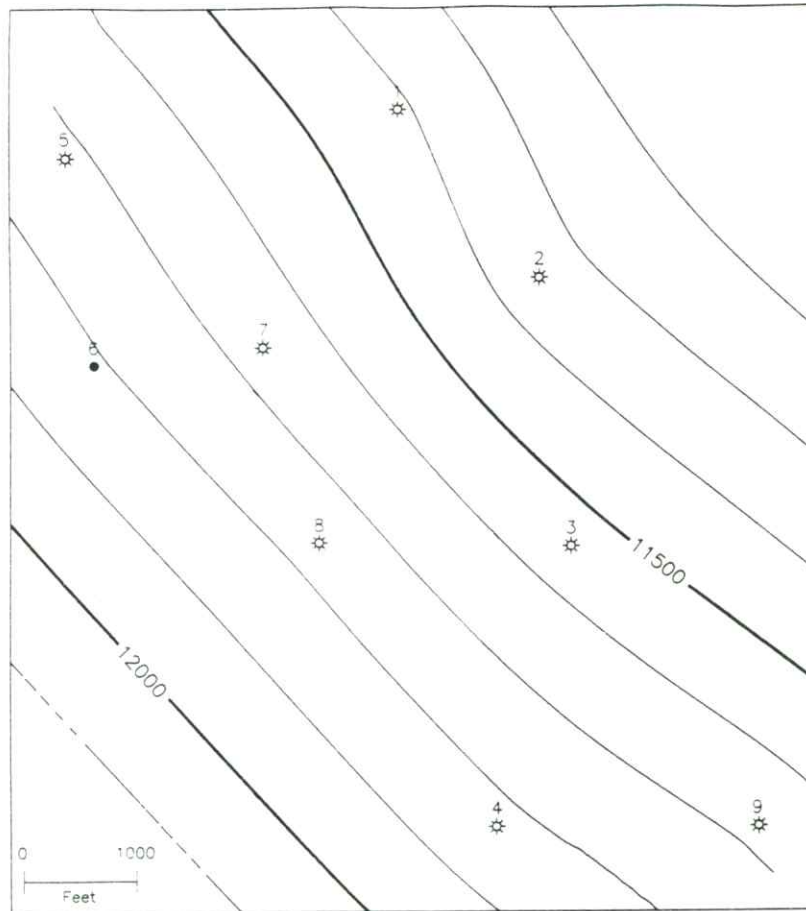


FIGURE 72—STRUCTURAL CONTOUR MAP OF MARKER B IN GRAND BAYOU FIELD, LOUISIANA. Contour interval is 100 ft.

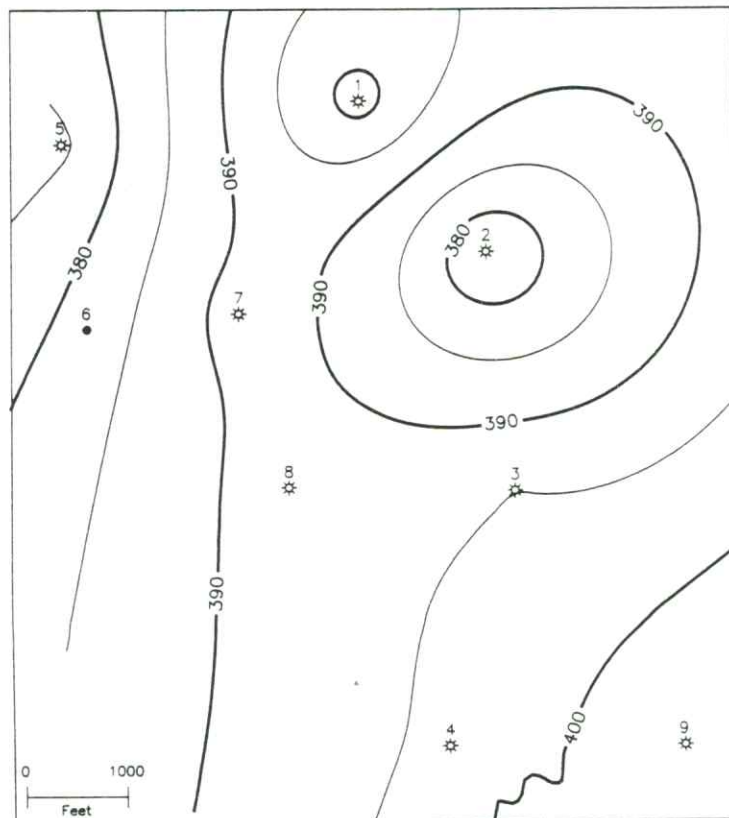


FIGURE 73—ISOPACH MAP FOR THE INTERVAL BETWEEN MARKERS A AND B IN THE GRAND BAYOU FIELD, LOUISIANA. Contour interval is 5 ft.

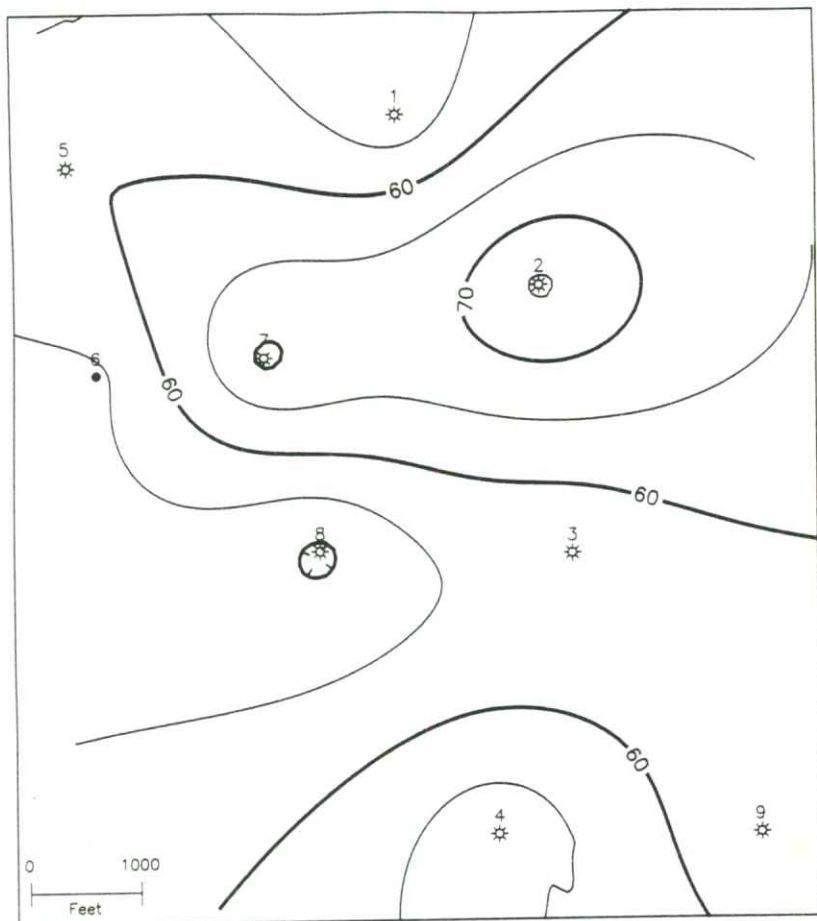


FIGURE 74—PERCENT SANDSTONE IN THE INTERVAL BETWEEN MARKERS A AND B IN THE GRAND BAYOU FIELD, LOUISIANA. Contour interval is 5% sandstone.

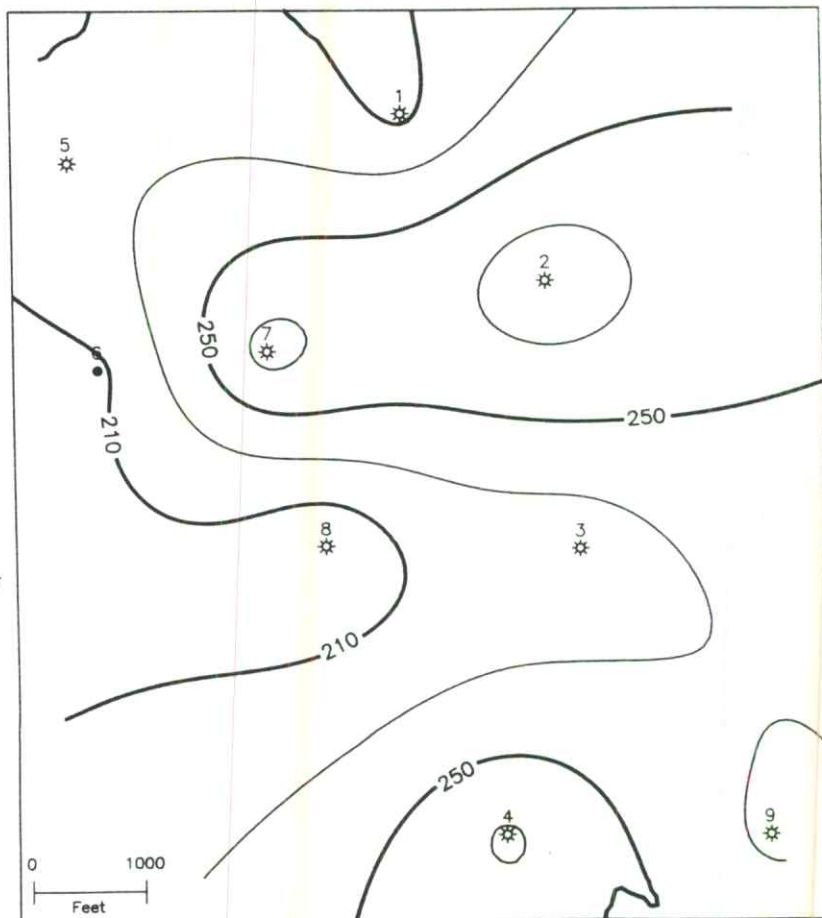


FIGURE 75—NET SANDSTONE MAP FOR THE INTERVAL BETWEEN MARKERS A AND B IN THE GRAND BAYOU FIELD, LOUISIANA. Contour interval is 20 ft.

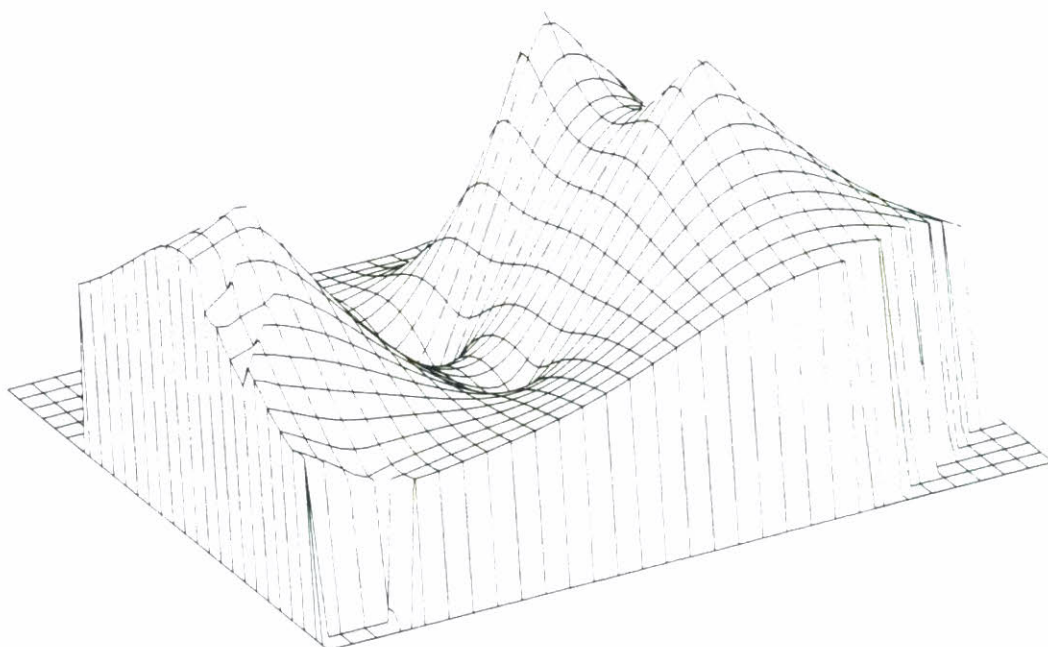


FIGURE 76—BLOCK DIAGRAM OF NET FEET OF SANDSTONE IN THE INTERVAL BETWEEN MARKERS A AND B IN THE GRAND BAYOU FIELD, LOUISIANA.

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# Appendix A

## Correlation-interval length and bed thickness

The strength of the matches calculated by weighted correlation depends heavily upon the length of the segments into which the wireline logs can be broken. This can be illustrated with a numerical experiment which leads to a model describing the dependence between rock unit thickness and the best correlation length to establish correlations.

### Numerical experiment

Logs from the Ramos No. 1 and No. 2 wells in the Grand Bayou field, Louisiana, were selected for this experiment. A correlation-interval center was arbitrarily chosen at the reference depth of 12,356 ft (3,707 m) in the Ramos No. 1 well. Weighted correlations were calculated for all possible match positions in the Ramos No. 2 well over an interval of 4,000 ft (1,200 m) in length. The correlation length was progressively increased from 4 ft to 1,000 ft (1.2–300 m). To calculate the weighted correlation coefficient, the center of the interval defined by the correlation length must coincide with a digitized point. Since the sampling interval in these wells is 2 ft (0.6 m), correlation lengths in this experiment must be multiples of 4 ft (1.2 m).

Fig. A.1 shows the depth to the center of the interval in the Ramos No. 2 well that has the highest correlation with the reference interval in the Ramos No. 1 well for successive correlation lengths. Independent geological information and correlations for reference depths other than 12,356 ft (3,707 m) suggest that the correct match to 12,356 ft (3,707 m) in the Ramos No. 1 well occurs at a depth of 12,088 ft (3,626 m) in the Ramos No. 2 well. Matching depths for different correlation lengths range from 11,470 to 14,182 ft (3,441–4,255 m), a difference of 2712 ft (814 m). The correct correlation was obtained only for correlation lengths ranging from 24 to 60 ft (7.2–18 m), as shown in fig. A.2.

Fig. A.1 also shows the value of the maximum weighted correlation coefficient. Notice that there is a continuous deterioration in the correlation strength as the correlation length increases. At short correlation lengths, it is easy to find several good matches, because only a few sample points are being compared on the two logs. The resulting coefficient is high, but the match is unreliable because the reference-correlation length is not sufficiently long to carry all the characteristic fluctuations in the wireline logs that fully characterize the rock unit being correlated. This is illustrated in fig. A.3, using a correla-

tion length of only 20 ft (6 m), which leads to an erroneous correlation.

When the correlation length is too long, as in fig. A.4, too much information is being considered. Since the interval is so long, the highly complex log signature cannot match any interval in the second well with accuracy, so all correlations will tend to be low. However, as there is always a best match, invariably there will be a least worse answer. The random nature of such matchings is reflected in low weighted correlation coefficients. Notice that in this instance, the correlation interval is composed of three rock units, two sandstones and one shale bed.

### Best correlation-length model

It is widely held that high-energy conditions of marine deposition occur over much smaller areas than do low-energy conditions. Thus, fine-grained sediments such as shales are more widespread and easier to correlate regionally than are sandstones (Weaver, 1958; Krumbein and Sloss, 1963, p. 341). Figs. A.5 and A.6 show, in normalized form, the fractions of thickness of shale units that produce the best matches for wells in two different fields. Note that for thicker shale units, a smaller fraction of the thickness should be used as the correlation length which produces the best weighted correlation coefficients. Because the results shown in the figures also were obtained for other pairs of wells, the following model is postulated:

$$c = \begin{cases} 48 & , L \leq 48 \\ L(1.15 - 0.003125L) & , 48 < L < 240 \\ 0.4L & , 240 \leq L \end{cases} \quad (A.1)$$

where

$L$  = thickness of lithostratigraphic unit

$c$  = correlation length that maximizes the weighted correlation coefficient.

The model is shown as a solid line in figs. A.5 and A.6. The line is deliberately biased toward the larger fractions, because the consequences of using too short a correlation length are more severe than using a length that is too long. The model more closely approximates one

side of an envelope around the observations rather than being a least-squares fit to the points.

This model has been successfully used to correlate sandstones and shales in the wells analyzed, as well as to

correlate sandstones and shales in other pairs of wells in the same fields but not considered in establishing the model. This is an encouraging result backing the possibility of automating the selection of the correlation length.

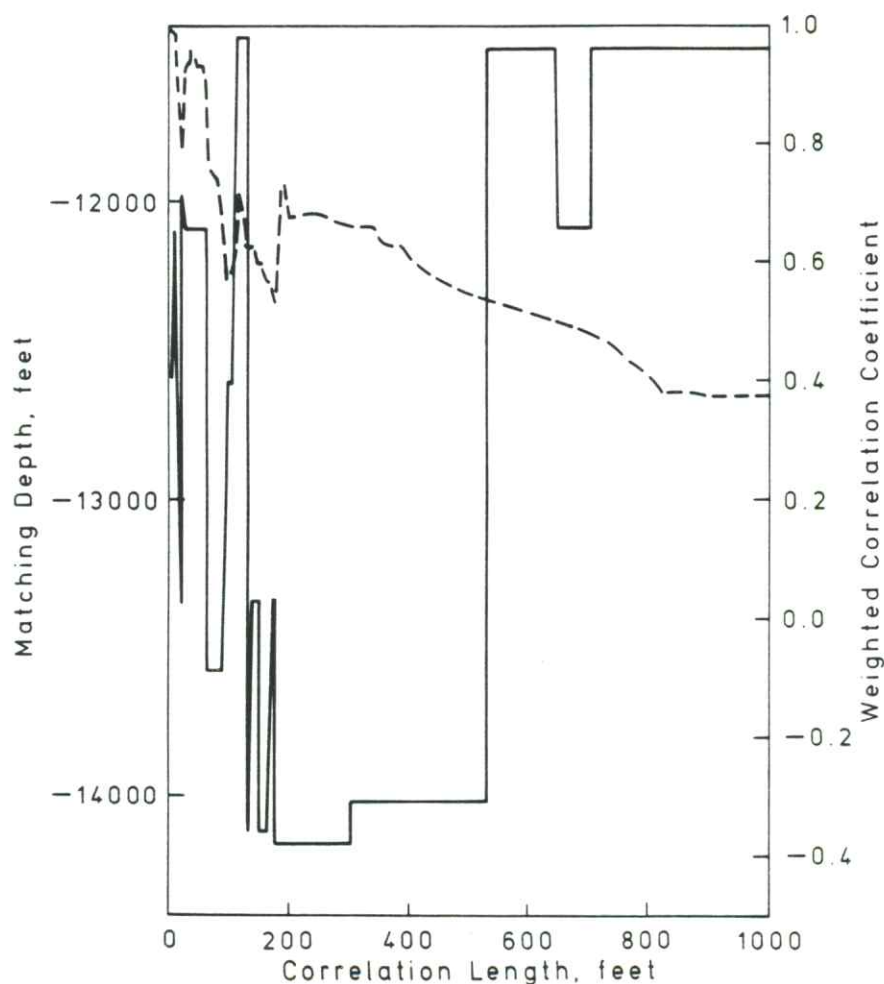


FIGURE A.1—SENSITIVITY ANALYSIS OF CORRELATION LENGTH FOR A SEARCH LENGTH OF 4,000 FT. The study was performed by matching resistivity logs weighted by spontaneous-potential logs from the Ramos No. 1 and Ramos No. 2 wells. A reference depth of 12,356 ft was set in Ramos No. 1. The solid line indicates depth of the interval in Ramos No. 2 that most closely matches the reference interval in Ramos No. 1. The dashed line indicates magnitude of the weighted correlation coefficient between matched intervals. Correct depth of match is 12,088 ft in the Ramos No. 2 well.

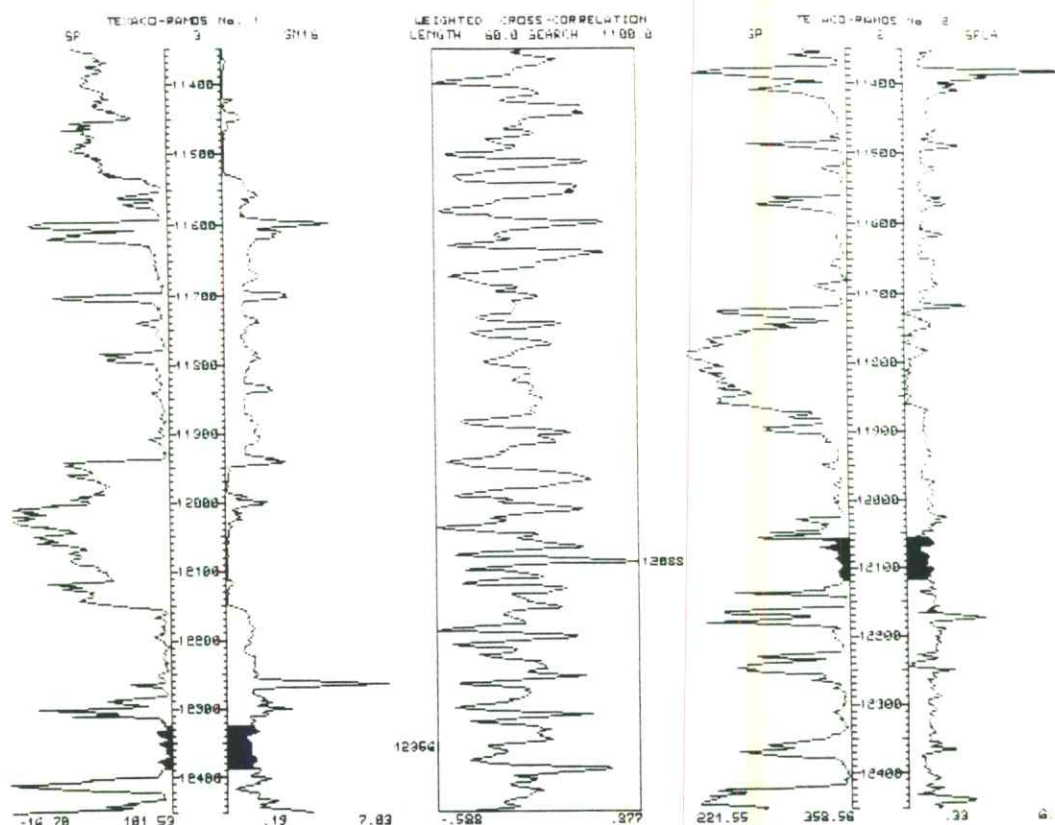


FIGURE A.2—BEST LITHOSTRATIGRAPHIC CORRELATION FOR INTERVAL AT DEPTH 12,356 FT IN WELL RAMOS No. 1, WHEN CORRELATION LENGTH IS 60 FT. Search length was restricted to 1,100 ft for this illustration, but the same best match is obtained using a 4,000-ft search length centered at 12,088 ft.

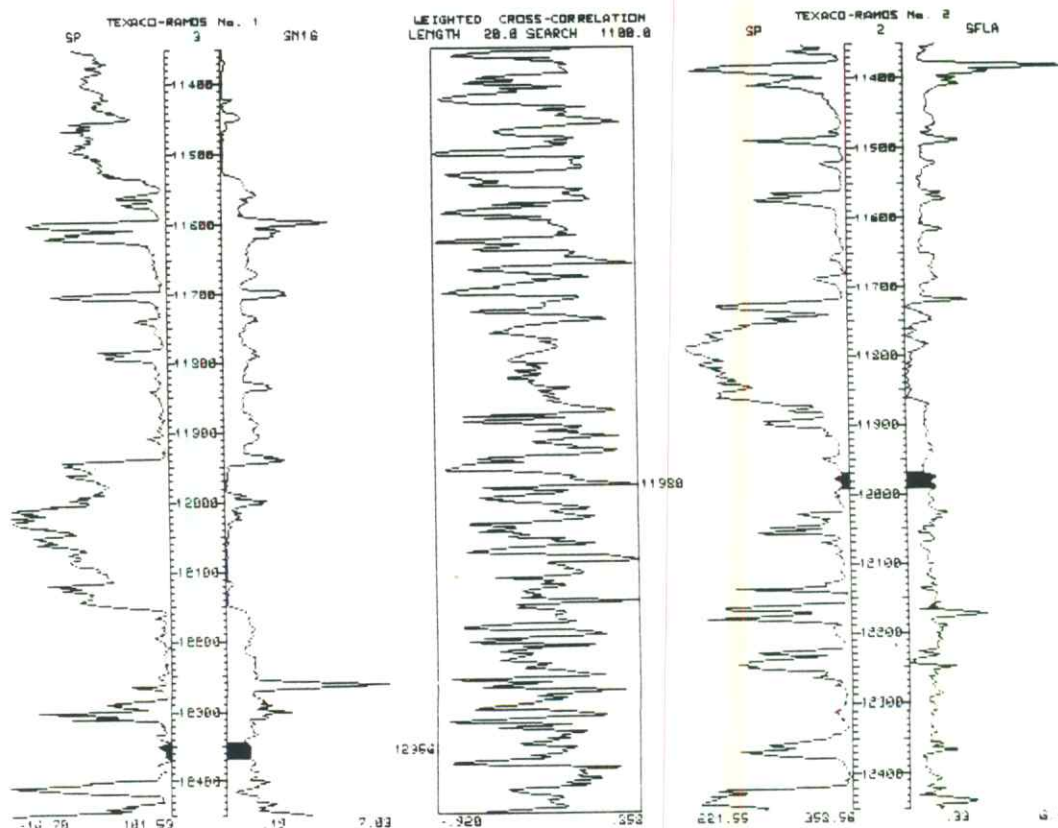


FIGURE A.3—BEST LITHOSTRATIGRAPHIC CORRELATION FOR THE INTERVAL AT DEPTH 12,356 FT IN WELL RAMOS No. 1, WHEN THE CORRELATION LENGTH IS 20 FT. The search length was restricted to 1,100 ft for this illustration, but the same best match is obtained using a 4,000-ft search length centered at 12,088 ft.

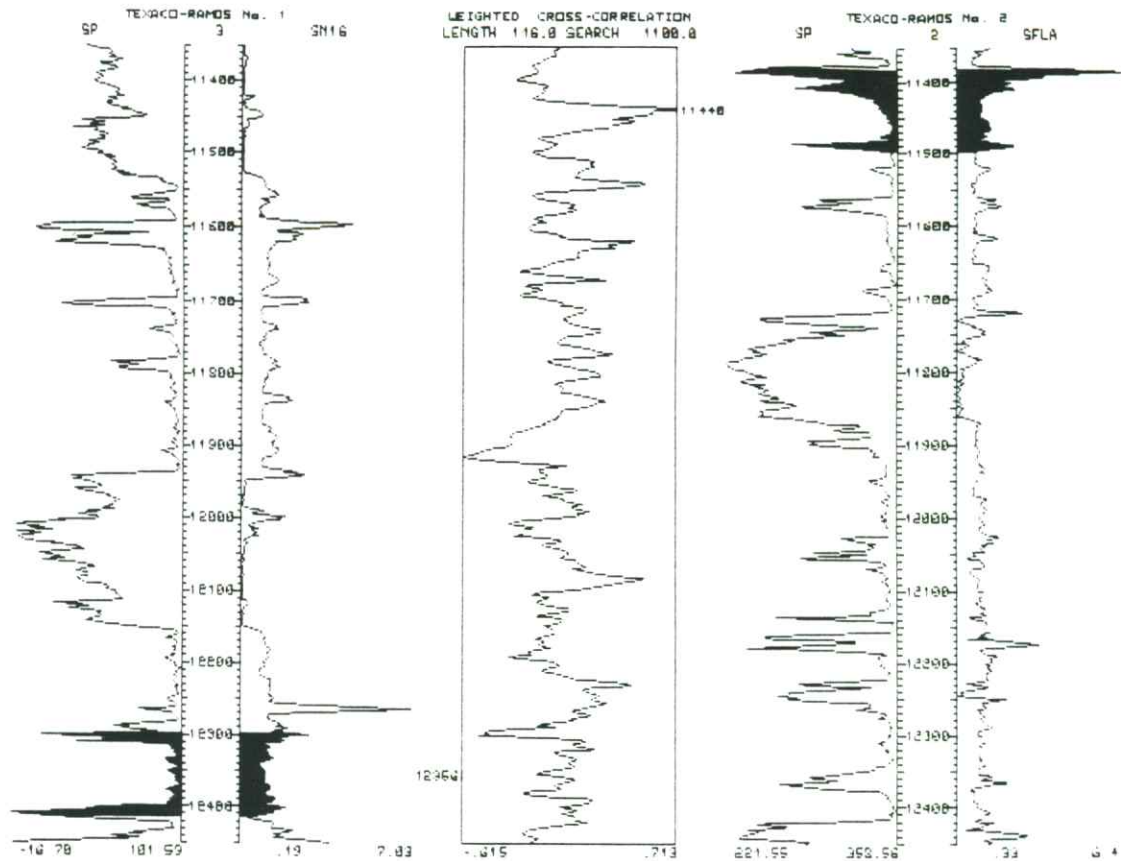


FIGURE A.4—BEST LITHOSTRATIGRAPHIC CORRELATION FOR THE INTERVAL AT DEPTH 12,356 FT IN WELL RAMOS NO. 1, WHEN THE CORRELATION LENGTH IS 116 FT. THE SEARCH LENGTH WAS RESTRICTED 1,100 FT FOR THIS ILLUSTRATION, BUT THE SAME BEST MATCH IS OBTAINED USING A 4,000-FT SEARCH LENGTH CENTERED AT 12,088 FT.

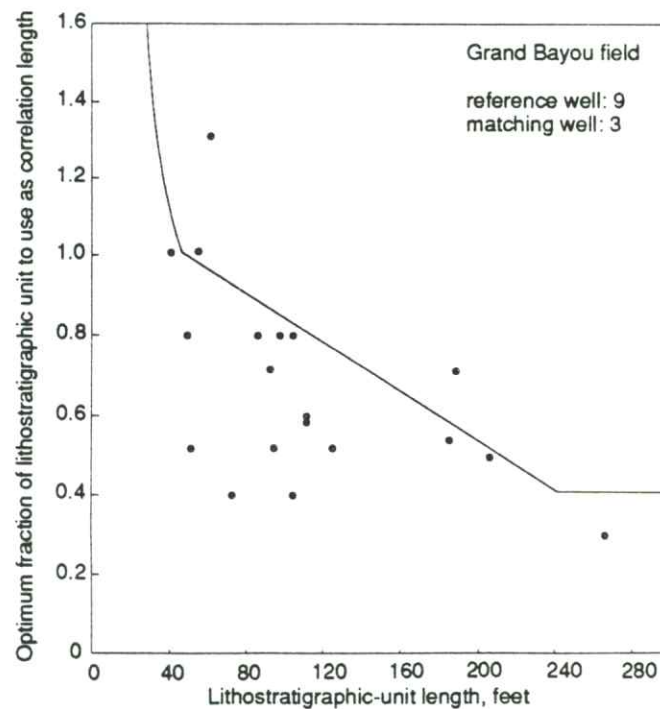


FIGURE A.5—FRACTION OF SHALE THICKNESS PRODUCING THE HIGHEST WEIGHTED CORRELATION COEFFICIENTS FOR A PAIR OF WELLS IN GRAND BAYOU FIELD, LOUISIANA. THE SEARCH LENGTH WAS RESTRICTED TO 200 FT.

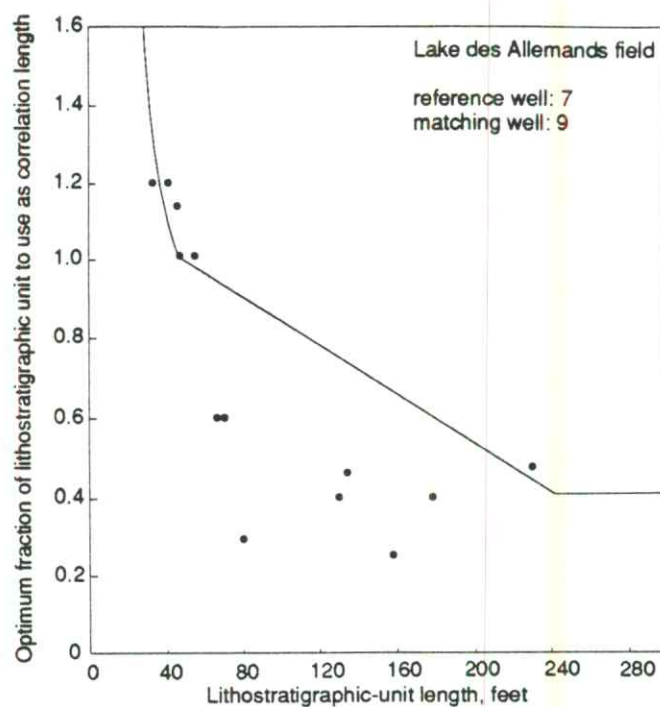


FIGURE A.6—FRACTION OF SHALE THICKNESS PRODUCING THE HIGHEST WEIGHTED CORRELATION COEFFICIENT FOR A PAIR OF WELLS IN THE LAKE DES ALLEMANDS FIELD, LOUISIANA. The search length was restricted to 200 ft. Line goes through additional control point at length 640 ft.

## Appendix B

### Search-interval length and weighted correlation coefficient

Search intervals are completely determined by the location of the center of search and the length of the interval around the center. In the section on compound matching, we introduced the idea of using trends in apparent dip differences as the center of search intervals. The problem still remains of the proper determination of the search-interval length. Although the problem cannot be analytically resolved, this appendix illustrates an approach to model the relationship by trial and error.

#### Method

This experiment basically repeats the test described in Appendix A but uses two other search lengths while keeping the center of the reference correlation interval at 12,356 ft (3,707 m) in the Ramos No. 1 well. For each specified search length, weighted correlations were computed for all possible match positions within the search interval in the Ramos No. 2 well. The correlation length was progressively increased from 4 ft up to 1,000 ft (1.2–300 m), selected so the centers of both the reference interval and the matching intervals coincide within digitized points. Search lengths were chosen arbitrarily to be 0, 400, and 4,000 ft.

#### Results

Fig. A.1 showed results obtained by comparing the reference interval to a section in the second well using the longest search length. In this example, the largest errors occur for correlation lengths between 176 ft to 312 ft (53–94 m). The miscorrelation occurs at an elevation of 14,156 ft (4,247 m), which represents a discrepancy of 2,068 ft (620 m) from the correct match. Geologically correct correlations occur using correlation lengths between 24 and 60 ft (7–18 m), and represent only 3% of all cases analyzed.

To produce the results shown in fig. B.1, the search length was limited to 400 ft (120 m) and centered around the elevation of correct match, 12,088 ft (3,626 m) in the Ramos No. 2 well. Since the search intervals bound the domain in which the correct match occurs, the largest miscorrelation is substantially reduced to 176 ft (53 m) for correlation lengths between 180 ft and 456 ft (54–137 m). Matches cannot be made outside the search interval, so matching is forced to occur within the range of 11,888 ft to 12,288 ft (3,566–3,686 m). Only correlation lengths of 8

ft (2.4 m), 16–60 ft (4.8–18 m), and 648–700 ft (194–210 m) remain unchanged. Restricting the search length to 400 ft (120 m) increases the number of correct correlations to 8.4%, and an additional 54% of the matches occur within 10 ft (3 m) of the correct geologic correlation.

In fig. B.2, the search interval is reduced to the trivial extreme of zero length, meaning that no actual search occurs. The only permitted match is between depth 12,356 ft (3,707 m) in the Ramos No. 1 well and 12,088 ft (3,626 m) in the Ramos No. 2 well. As the forced match is the geologically correct correlation, the correlation length and the strength of the weighted correlation do not affect the correctness of the match.

The three weighted correlation curves from figs. A.1, B.1, and B.2 are combined in fig. B.3 for comparative purposes. Note that the curves touch but do not cross. Somewhat remarkably, the worst measure of similarity occurs using a zero-length search. Because the match is confined to a single choice, finding a better fit is not possible. As the search interval increases, so do the chances of finding a higher, but incorrect, match. When the search interval is expanded to 400 ft (120 m), the greatest increase in weighted correlation coefficient occurs for correlation lengths between 200 and 250 ft (60–75 m). Increasing the search interval from 400 ft to 4,000 ft (120–1,200 m) increases primarily the weighted correlation coefficient for correlation lengths between 100 and 500 ft (30–150 m). However, increasing the search length has a more dramatic effect on the position of best match than on increases in the degree of similarity.

Figs. A.1 and B.2 illustrate the point that obtaining a correct geological correlation and improving the degree of similarity may be conflicting rather than compatible objectives. Except for correlation lengths between 24 to 60 ft (7–18 m), the weighted correlation coefficient for a zero-length search is at the most equal, and usually lower than, coefficients obtained using a 4,000-ft (1,200-m) search length, although 96.4% of these correlations are geologically incorrect. Extrapolating, we might suppose that a search from the Earth's surface down to its center would yield perfect matches having weighted correlation coefficients of 1.00, but all geologically incorrect!

These results suggest that selection of a proper search length must involve a constrained optimization process. The reason for using a search interval in the matching process is to take into account the uncertainty concerning the location of the correct match. The upper and lower limits of the search should be selected in such a way that there is complete assurance that the correct match is enclosed within the search interval. If the true correlation

interval is outside the search, it will be impossible to find the correct stratigraphic correlation. On the other hand, the search length should be as short as possible to reduce the computer time required, and to increase the probability that the match with the highest weighted correlation coefficient does, indeed, correspond to the correct geological correlation.

The selection of a reasonable search length cannot be regarded as a mathematical exercise. Determining a good

search interval is equivalent to an a priori estimate of the scatter around the dip trend. Fig. B.4 is an after-the-fact picture of such a scattering of apparent dips that the user should visualize in advance. In the absence of a method to produce an a priori estimate of the search interval solely from the logs themselves, an estimate based on external information on the regional geology from the area is the best solution to this ill-determined problem.

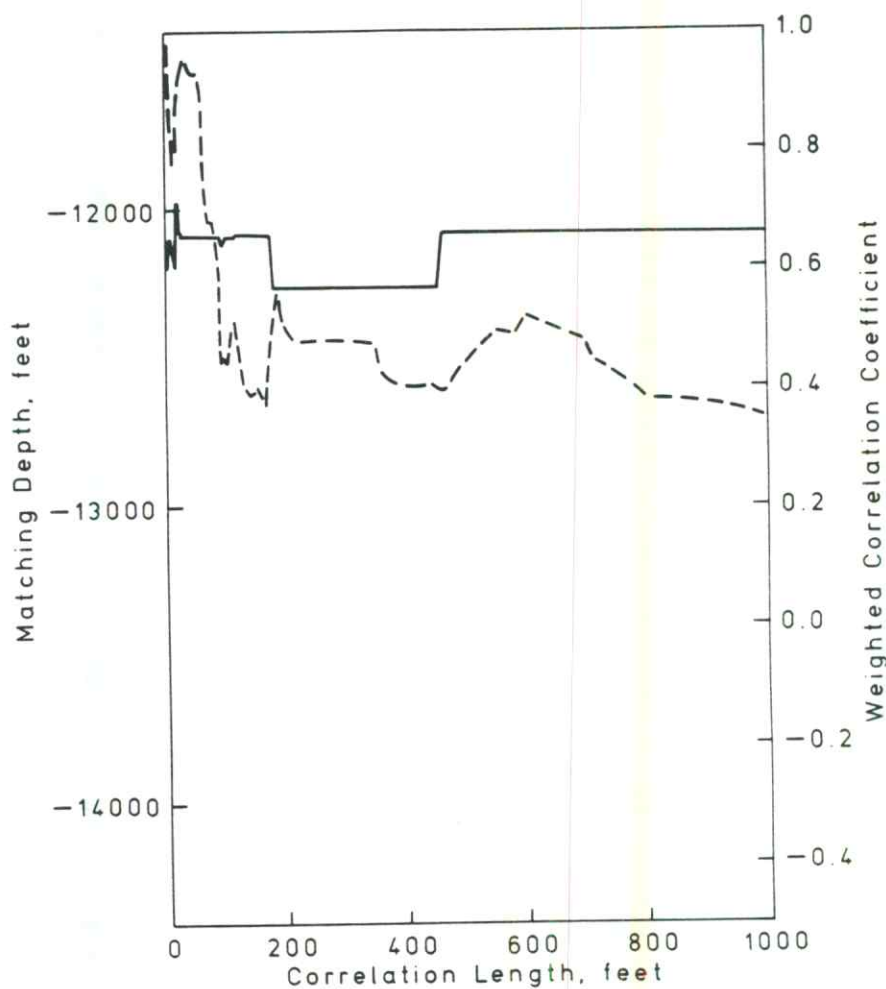


FIGURE B.1—SENSITIVITY ANALYSIS OF CORRELATION LENGTH FOR A SEARCH LENGTH OF 400 FT, based on resistivity logs weighted by spontaneous-potential logs from the Ramos No. 1 and Ramos No. 2 wells. A reference depth of 12,356 ft was set in Ramos No. 1. The solid line indicates depth of the interval in Ramos No. 2 that most closely matches the reference interval in Ramos No. 1. The dashed line indicates magnitude of the weighted correlation coefficient between matched intervals. Correct depth of match is 12,088 ft in the Ramos No. 2 well.

FIGURE B.2—SENSITIVITY ANALYSIS OF CORRELATION LENGTH WITHOUT SEARCHING, between intervals at depths of 12,356 ft in the Ramos No. 1 well and 12,088 ft in the Ramos No. 2 well. The study was performed by matching resistivity logs weighted by spontaneous-potential logs. The solid line indicates constant depth of the interval in Ramos No. 2 that was matched to reference interval in Ramos No. 1. The dashed line indicates magnitude of the weighted correlation coefficient between matched intervals.

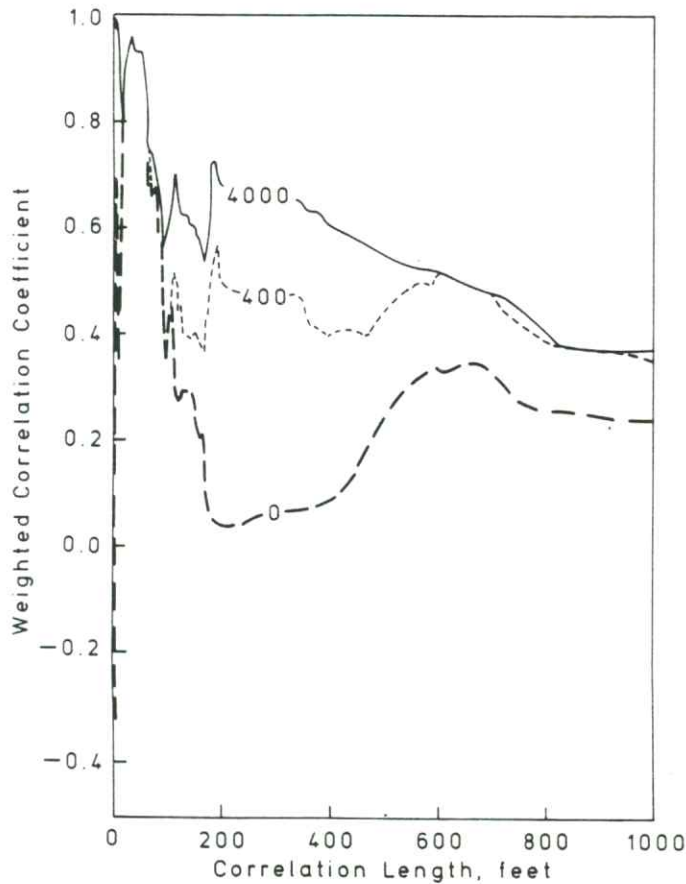
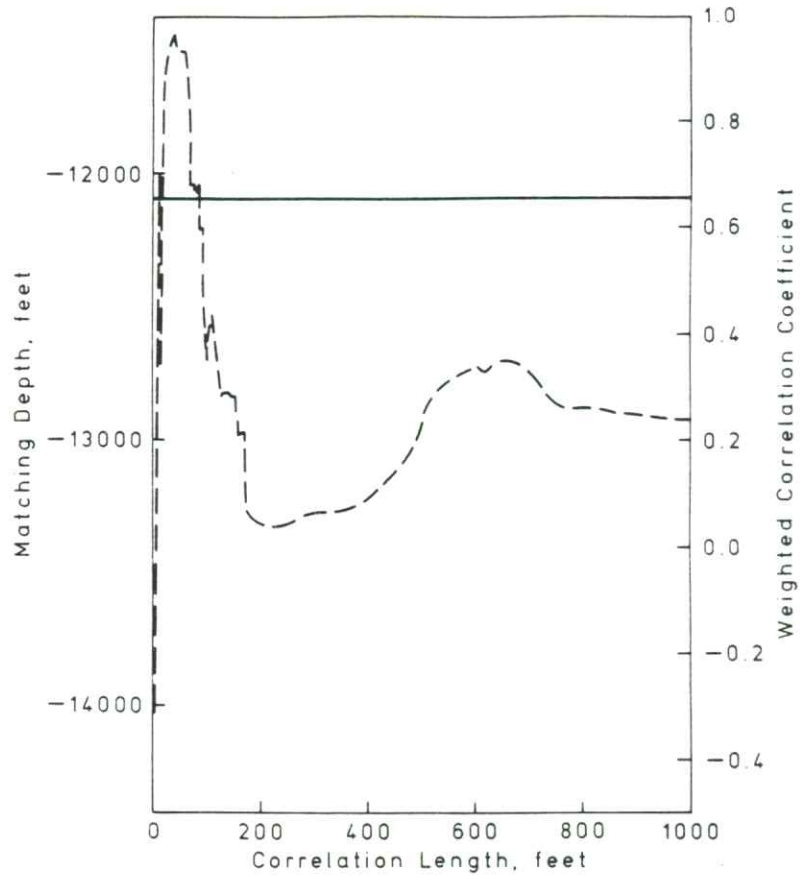


FIGURE B.3—DEGREE OF SIMILARITY RESULTING FROM THE SENSITIVITY ANALYSIS OF CORRELATION LENGTH FOR THREE SEARCH LENGTHS. The weighted correlations are taken from figs. A.1, B.1, and B.2. Solid line represents a 4,000-ft search length, short-dashed line represents a 400-ft search length, and long-dashed line represents zero search length.

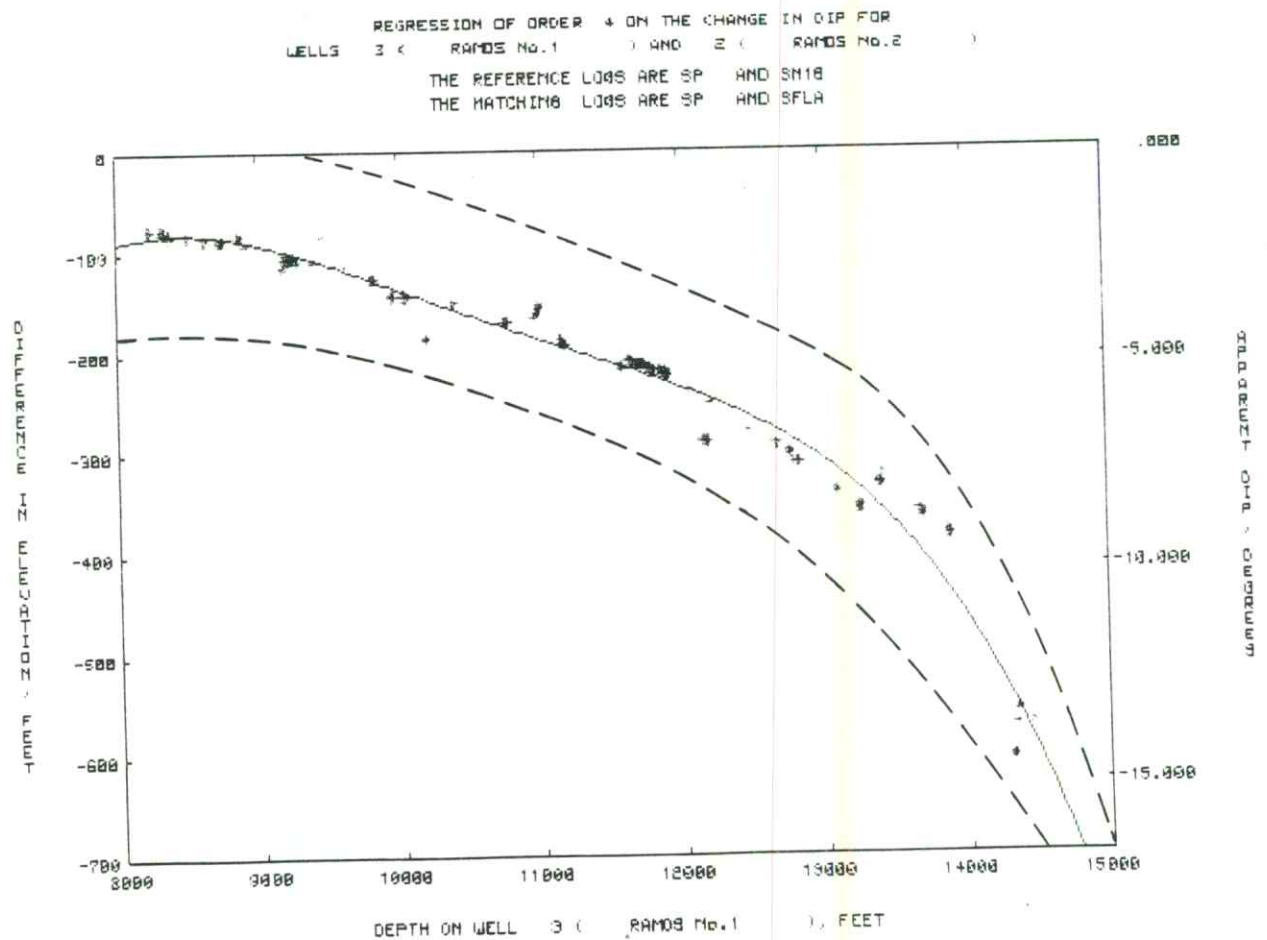


FIGURE B.4—DIFFERENCES IN ELEVATION BETWEEN TWO WELLS PREDICTED BY THE REGRESSION MODEL (SHOWN BY LINE) AND THOSE OBSERVED IN ALL CORRELATED INTERVALS (SHOWN BY CROSSES). Correlations were established using a 100-ft search above and below a trend originally fitted using only seven correlated intervals, providing differences in elevation spaced approximately every 1,000 ft. The search zone is enclosed by the dashed lines.

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