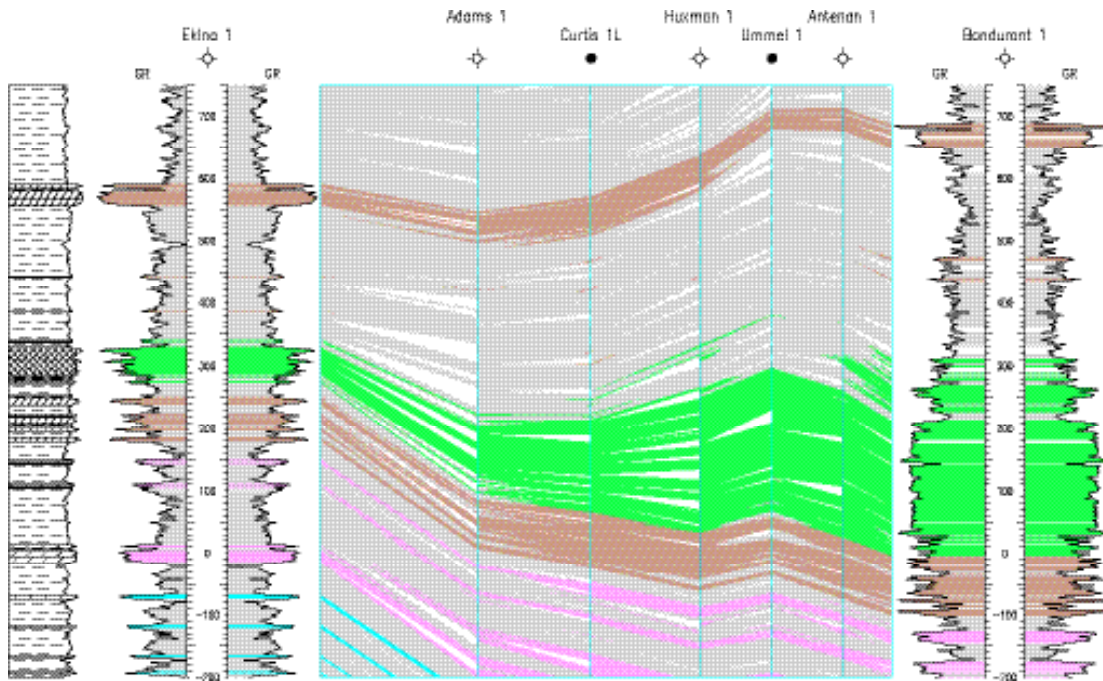


USER'S MANUAL FOR CORRELATOR, VERSION 5.2



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May 2003

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Preface

When computers first became widely available in oil companies and universities in the 1960's, everyone imagined that these miracle machines might relieve the tedium of the many repetitive tasks that occupy the time of professional geologists. One of the early dreams of stratigraphers and oil explorationists was that it might be possible to teach a computer to correlate well logs, by examining the wiggles in log traces from one well and finding a matching set of wiggles in logs from another well. In 1980, I gave a talk at the AAPG annual convention in Denver, describing all of the correlation procedures that had been attempted at the time. The talk was very pessimistic in tone, because I considered geological correlation to be an ill-defined, underdetermined, one-to-many problem, and such problems are not amenable to analytical solutions. In spite of my gloomy outlook, the next year Don Beaumont invited me to Texaco headquarters to discuss computer correlation of well logs. I repeated my AAPG presentation and again expressed my reservations about the possibility of automating such an unquantifiable procedure as geological correlation. At the conclusion of my talk, Don indicated his group was interested in supporting "blue-sky" research, including the possibility of automating well log correlation, and even though I thought the task was impossible would I suggest who was most qualified to try? "Well, we are," I replied, meaning my group in mathematical geology, and thus began the research that culminated in CORRELATOR.

It soon became obvious that the biggest problem was determining what geologists actually do when they slip logs and identify supposedly equivalent intervals in different wells. If this mental process of pattern recognition could be defined, it could be turned into computer code. So, the initial stage of our research consisted of working quite closely with experienced subsurface geologists and observing the steps they took to arrive at well log picks and correlations. We found that the comparison process was relatively simple, but that initial "guesses" were continually revised in light of tentative correlations of other intervals in the wells, and that geologists depended heavily on inferred geological relationships between successive correlated intervals in arriving at a final, plausible interpretation. At the suggestion of Don Beaumont, we turned to the field of artificial intelligence (subject of another "blue sky" investigation) to see if it could be used to automate the process of evaluation and revision of the set of initial correlations. At this time, Ricardo Olea rejoined the Kansas Geological Survey and was placed in charge of the project. Under his direction, the research and development accelerated and expanded until it eventually resulted in the software system we have today, which not only relieves the tedium of correlating logs, but also consistently outperforms human log interpreters in determining stratigraphic relationships. CORRELATOR can determine correct stratigraphic relationships in sedimentary sequences even when these are complicated by faulting, facies changes, and poor quality logs that defy manual interpretation.

This research has benefited from the support of many individuals and organizations, most notably Don Beaumont of Texaco, who provided the initial incentives for our work, and Tim Coburn of Marathon, who encouraged the development and refinement of the software, particularly its operational environment and AI capabilities.

CORRELATOR is the culmination of many years of research and development. In its present form, it is not only an easy-to-use tool for performing a routine but necessary task in subsurface stratigraphic interpretation, but also extends the capabilities of human analysts beyond their normal limits. Its development has provided insight into how geologists work, and how geological principles can be incorporated into computational procedures. All-in-all, significant accomplishments for something that I thought was impossible!

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Chapter 1: Introduction

Technological development of multiple sensors has allowed geologists to make observations where human sight is not possible, whether on distant planets or at the bottom of oceans. One form of such remote sensing is wireline logging, which captures variations in physical properties in the proximity of boreholes. The knowledge gained by well logging, as important and accurate as it may be, has the serious disadvantage of characterizing only a minute portion of the entire volume of interest.

Until the 1920s, stratigraphy was established based on direct observation of rocks along outcrops, quarries, and mine pits, or from cores and cuttings from boreholes. In 1927, brothers Conrad and Marcel Schlumberger, with aid of Conrad's son-in-law Henri Doll, successfully extended electric 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 device 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 readings. In Paris, the measurements were plotted by hand against depth on a strip of paper, resulting in the first graph that today we call wireline or borehole log (Allaud and Martin, 1977; Schlumberger, 1982). Since then, continuous improvements and diversity in logging tools, better understanding of the physics of the measurements, and reduction in operation costs have resulted in logs being favored over conventional coring as the primary source of information to establish what is in the immediate vicinity of boreholes.

The technique referred to as well-log correlation developed from the need to interpolate between well logs for the inference of rock properties between boreholes. Interpolations have been more meaningful and more successful in sedimentary rocks because sedimentation commonly produces deposits that have good to excellent lateral continuity.

Lithostratigraphic correlation

Lithostratigraphic correlation is the correct determination of spatial equivalence of rocks based on their physical properties (Krumbein and Sloss, 1963, p. 332; Gradstein et al., 1985, p. 387; Jackson, 1997, p. 372).

In practice, the solution of the general problem of lithostratigraphic correlation is extremely dependent on the nature of available data. Here we limit our discussion to the special case common to petroleum prospecting and production wherein the primary source of information about the subsurface is wireline logs measured in vertical boreholes. The problem can be reduced to: Given an interval A as indicated on a log from well X, where is the same interval

A on a log taken from a neighboring well Y? The cross section in Figure 1.1 is a typical display of lithostratigraphic correlations based on wireline logs and illustrates the manner in which the question is answered. The correlations shown in Figure 1.1 could have been determined manually and the cross section drawn by hand, the method traditionally employed by petroleum geologists, but instead it was generated by the program described in this manual.

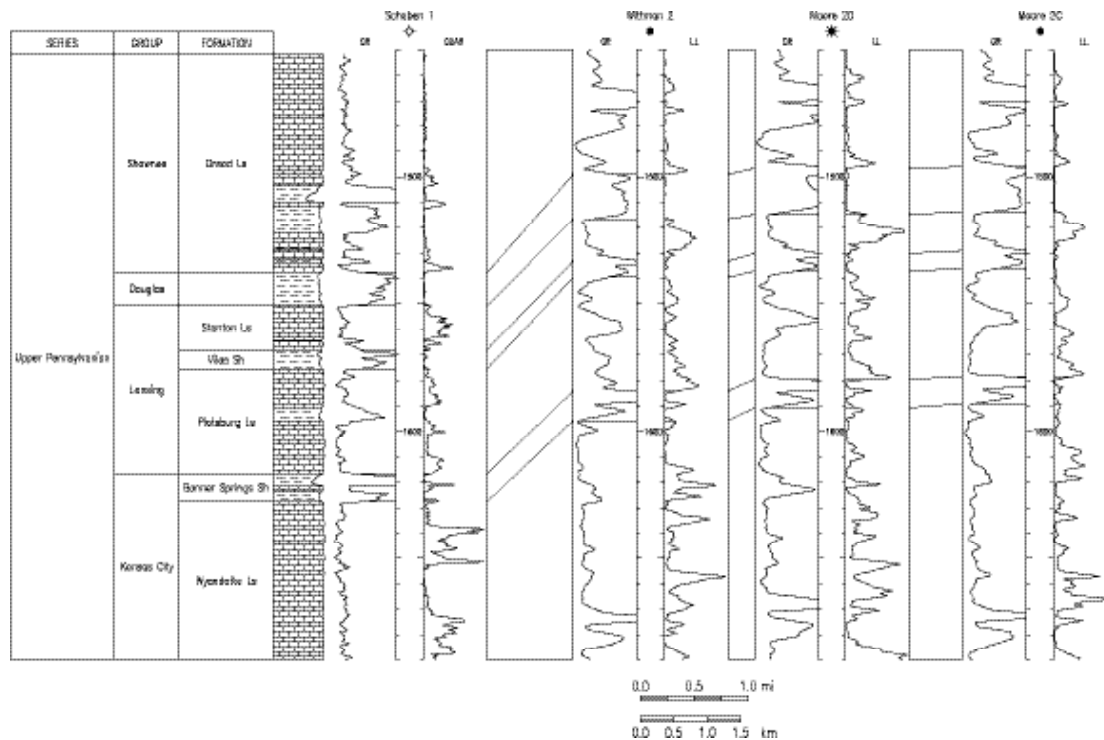


Figure 1.1. North-south lithostratigraphic cross section in Clark County, Kansas, showing carbonate and shale formations from the Upper Pennsylvanian. The vertical scale is in feet below sea level and the horizontal scale is given by the graphical scale, which involves a vertical exaggeration of 125 times.

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, given some data, there is 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 principles and constraints. It is a well know fact among geologists that every time a non-trivial correlation problem is submitted to the consideration of several colleagues, there are almost as many different answers as participants in the comparative interpretation. Disregarding severe tectonic disruption, for example, a golden rule is that the order of succession of units cannot be reversed from one well or outcrop to another (Tipper, 1988; Doyle et al., 2001, p. 11-18).

CORRELATOR

The possibility that wireline-log correlation could be reduced to a routine and the routine expressed as an algorithm has fascinated many researchers, the authors included. As a bare minimum, the challenge has the appeal to bring consistency and efficiency to the lithostratigraphic correlation problem.

This publication describes the capabilities of CORRELATOR, a computer system developed 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 program has been tested successfully in both carbonate and clastic sequences, in rocks of Paleozoic (Olea and Guy, 2000), Mesozoic (Olea, 1996; Olea and Bohling, 1996), Tertiary (Olea et al., 1985; Olea, 1989a and 1994b) and Quaternary age (Harff et al. 1999). Studies have been conducted using wireline logs from Alaska (Olea 1990), Illinois (Olea, 1991), Kansas (Olea et al., 1997; Watney et al. 1999; Olea, 2002a and 2002b; Olea et al., 2002), Louisiana (Olea et al. 1985; Olea and Davis, 1986; Olea, 1993 and 1994b), North Dakota (Gerhard et al. 1995), and Texas (Olea, 1989b) in the United States; from Chile (Olea, 1988b) in South America; and from the North Sea (Olea, 1988c) and the Baltic Sea (Harff et al., 2001) in Europe. Thickest section analyzed was 8,000 ft (2,400 m) thick (Olea et al., 1997), some cross sections have comprised 21 wells (Watney et al. 1999; Olea, 2002a and 2002b), and wells have been up to 18 miles (29 km) apart (Olea et al., 1997). 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 significant lateral variation in thickness.

CORRELATOR can prepare more sophisticated cross sections than the one in Figure 1.1. At its highest potential, the program can yield cross sections like the one in Figure 1.2 simultaneously displaying the architecture and lithology of the subsurface, a difficult and impractical task to attempt by hand.

Some remarks in connection with Figure 1.2 are:

- CORRELATOR has been designed to extract all possible information from the wireline logs and to perform all trivial computations without querying the user with questions that the program can resolve by itself. None of the lines or annotations in Figure 1.2 was drawn manually; all of them were calculated and displayed by the program.
- Weighted correlation is used to assess the quality of results.
- Vertical resolution is superior to comparable seismic interpretations.
- In contrast to many other programs, including recently released commercial software, CORRELATOR does not color an interval solidly. Figure 1.2 is the result of coloring individual tie lines one by one.
- Blank intervals, rather than being an inconvenience, are useful to assess onlaps, downlaps, and sudden lateral variation in the present physical properties of the sediments.
- The program offers multiple options to annotate the cross section for better understanding of the interpretations.

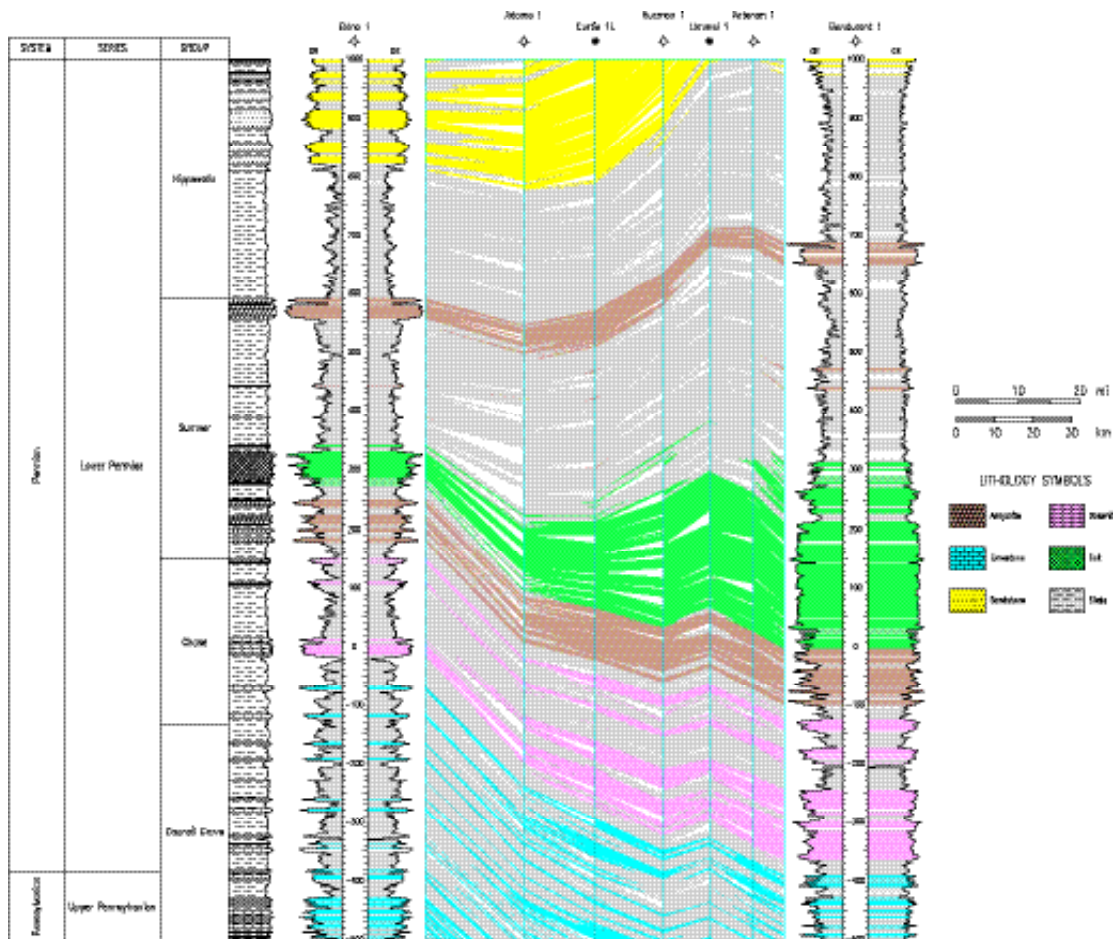


Figure 1.2. Cross section from Gove to Ness counties, Kansas, that focuses on the rendition of the Permian groups. The vertical scale is in feet relative to sea level with a vertical exaggeration of 500 times. This display is a partial rendition of a cross section extending for 201 mi (323 km) (Olea, 2002a).

An additional feature of CORRELATOR that does not follow from the inspection of Figure 1.2 is the systematic scrutiny of correlations. All correlations between pairs of wells can be analyzed with an expert system to check for inconsistencies within each collection of correlations from well to well. Besides, if the cross section is arranged in a closed loop, the program generates closing errors, which are extraordinary useful to check the global consistency of the correlations.

CORRELATOR was developed in a Unix environment. With the exception of one routine in C, the program comprises 424 routines coded following the ANSI standard of Fortran 77 as closely as possible. Development of the software has been going on sporadically since the mid-1980s, when some of the languages that are popular today had not made a heading yet. Fortran continues to be used widely, remaining the most common programming language in the earth sciences, providing an important reason to set low priority to efforts to translate

the code relative to requirements to process situations of practical interest and production of meaningful displays with accuracy and adequate formatting. The graphical routines in the interactive part of CORRELATOR restrict its application to an X Windows environment. Files for the display of final cross sections may be coded in PostScript, a highly portable code.

The program was extensively tested so that the same code runs both on Sun workstations and PCs with slightly different make files only. Main tests were run on a SunBlade 100 workstation under Solaris 2.x with a Fortran and a C Sun compiler 4.2. In the case of personal computers, the compilation, linkage, and execution took place on an Intel Pentium 200 computer under a Red Hat Linux release 9 operating system. The Fortran and C compilers for this test were part of a GNU GCC 3.2.2 compiler collection.

Even after years of effort and multiple versions of CORRELATOR leading to the present version 5.2, the program remains open for improvements, especially concerning the data input and dialog menus for the selection of options and parameters.

Acknowledgments

Don Beaumont and John Davis never thought in 1982 that the activity generated by their agreement to devote resources to computer correlation of wireline logs would last, on and off, for twenty years. At the time, Don Beaumont was with Texaco's research laboratories in Houston and John Davis was Chief of the Advanced Projects Section at the Kansas Geological Survey. Both regarded automation of stratigraphic correlation as a scientific and technological challenge worth pursuing. Don Beaumont took early retirement during the fifth year of the project, but John Davis remained the most fervent supporter of CORRELATOR until the completion of its development. From the beginning, development and implementation of the software was the responsibility of the authors, who alternated these tasks with other projects. Texaco provided partial financial support and supplied wireline logs as well as geologic information that were extensively used to illustrate CORRELATOR's first user's manual (Olea, 1988a). Data kindly received from Empresa Nacional del Petróleo, Chile, were used to complete another study in Patagonia.

Texaco's seminal support was undertaken for a short time by Union Oil Company and more extensively by Marathon Oil Company, which was behind the development of CORRELATOR through its version 3.9 of 1994. Tim Coburn and Janine Carlson contributed greatly to the project in terms of financing, data, and suggestions to add generality, flexibility and friendliness to the program.

Jan Harff, Chief Marine Geologists with the Institut für Ostseeforschung Warnemünde, Germany, has been studying the Baltic Sea since 1997 with an eye in sediments as records of recent climatic change. CORRELATOR has been instrumental in producing conclusive results based on the correlation of logs with a resolution of one centimeter obtained by taking measurement in

penetration cores. This particular application of CORRELATOR was partly funded by joint grants from the National Science Foundation and the Deutscher Akademischer Austauschdienst.

Robert Sampson left the Kansas Geological Survey in 1997 after designing the architecture of the databases, and contributing most of the input/output and graphical aspect of the software. A series of applications in the last five years using some of the 87,000 wells with at least one log at the Kansas Geological Survey Data Library proved inspirational to bring the program to the current version 5.2 described in this second version of the user's manual. In this late phase of development we are grateful for the discussions and support received from Dan Merriam, Lynn Watney, John Doveton, Geoff Bohling, Jim Deputy, Tyler Stransky, Bill Guy, and Saibal Bhattacharya.

Chapter 2: Quantitative methods for wireline-log correlation

CORRELATOR conveniently combines old and new concepts 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.

A layer-cake model is the simplest representation of subsurface stratigraphy. In this model, the subsurface 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 reef and algal mounds, may occur.

Most methods for correlation by computer described in the literature are curve-matching procedures that 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 look promising, lithostratigraphic correlation is still primarily a manual task.

Cross-association

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 lithological states, such as sandstone, shale, or limestone. Typically, these lithological states are determined at equally spaced points, say, every foot, but the observations may consist simply of the lithologic succession without regard to the thickness of the stratigraphic unit. 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):

$$S = \frac{m}{n}.$$

Dynamic sequence matching

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 in a petrophysical log. The dynamic programming procedure called slotting is an improvement over cross-association analysis, as it can be applied to either discrete and continuous variables (Gordon, 1973; Gordon and Reyment, 1979; Gordon, 1980; Hawkins, 1984; Clark,

1985). Slotting also allows 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 Euclidean distance or difference between 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 sequence (Howell, 1983; Waterman and Raymond, 1987; Griffiths and Bakke, 1988, 1990; Fang et al., 1992, Le Nir et al., 1998). Lineman et al. (1987) adapted algorithms from speech processing to create a program that can accommodate both missing units and intervals of varying thickness. Both these authors and Wu and Nyland (1987) use dynamic programming techniques to reduce processing time and to increase the flexibility of constraints. Comparisons are based on the absolute difference between log readings from the wells being correlated.

The evaluation of dynamic sequence matchings is heavily linked on the selection of cost function to penalize the discrepancies and the choice of the best function is not universal (Waterman and Raymond, 1987). A strong requirement is the knowledge of the correct correlation for the top and bottom of the sequence.

Pearsonian cross-correlation coefficient

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 of real numbers, $x_k(z)$, are sampled at regular intervals h , the cross correlation coefficient, $r_{1,2}(i, k, n)$, is defined as

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

The covariance $\text{cov}_{1,2}(i, k, n)$ and the standard deviations, $s_1(i, n)$ and $s_2(k, n)$, are calculated over interval lengths comprising $(2n + 1)$ readings each. The interval centers $x_1(z_i)$ and $x_2(z_j)$ differ by an offset of $h = (i - j)a = k a$. Rendition of results can be in the form of a correlogram, or plot of $r_{1,2}(i, k, n)$ versus h . 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 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. Hence the measure is sensitive to patterns of variations rather than to individual numerical values.

The earliest applications of cross-correlation to lithostratigraphy were made in the 1960s by Schwarzacher (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). Subsequent approaches 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 (Niedell, 1969; Rudman and Lankston, 1973; Henderson, 1973; Kemp, 1982; Ghose, 1984).

Cross-correlation has been employed extensively with 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 regular 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 magnitude of the lag is at most a few inches, and the layer-cake model is fully valid most of the time. For this reason, methods for matching traces in dipmeter analysis are not always 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 (MacRobertson, 1972; Robinson, 1978).

Fourier transform

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 problem. The Fourier Transform of the cross-correlation function is the cospectrum, a complex function whose real component are the coherence and phase spectra. The former is directly related to the correlation coefficient and varies also 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. Several authors have reported limited success, although the procedures are computationally elaborated (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 the analyzed sequences (Lineman et al., 1987)

Zonation and segmentation

All techniques previously mentioned involve two wells at a time. In contrast, zonation is performed on a sequence of measurements from a single well that is subdivided into zones. Zonation and segmentation are based on the premise that stratigraphic sequences are relatively homogeneous within intervals, called zones or segments, which are different from enclosing partitions. The use of zonation for stratigraphic correlation is an extension of techniques originally applied to subdivision of rock sequences whose top and bottom are known, such as the producing interval within a reservoir.

Zonation says nothing about the way zones from different wells correlate. A major problem of zonation is the inability to guarantee that the zonation of logs from different wells will result in sequences that are all equivalent. Without such assurance, the use of zonation in the development of a procedure aiming at the automation of correlation is of limited value. In addition, zonation is of limited potential if the interest goes beyond correlating top of zones into establishing correlations anywhere inside the zones.

Major contributions to zonation include a myriad of different mathematical techniques and are reported in the works of Testerman (1962), Kulinkovich et al. (1966), Gill (1970), Hawkins and Merriam (1973, 1974, 1975), Hawkins (1976), Webster (1973, 1978, 1980), Souder and Pickett (1974), Hawkins and ten Krooden (1979a, 1979b), Stephanou (1979), Levine et al. (1981), Lanning and Johnson (1983), Doveton (1986, p. 238-242; 1994, p. 68), Chen and Fang (1986), Mehta et al., (1990), Vermeer and Alkemade (1992), Gill et al. (1993), Bohling et al. (1998, p. 145).

Excluder-order algorithm and integrating algorithm

These algorithms are two analytical methods for stratigraphic correlation discussed by Dienes (1974). These algorithms are based on the assumption that over a fixed length of 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 sediment rate. Although sometimes conceptually correct, determining the analytical relationships and the parameters governing the relationship has proved impossible, thus preventing practical use of the methods.

Pattern recognition

Correlation by pattern recognition attempts to mimic the human ability to recognize and match similar features. Schlumberger's researchers (Vincent et al. 1979) made use of templates of idealized representations of shapes of logs curves and measures the correspondence between these elements and real logs. The method has been commercially available as the 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 under such limited conditions, incorrect correlations blemish dipmeter interpretation (Kerzner, 1982). Cheng and Lu (1985) have developed an approach in which wave forms are represented by three structures. Operations are defined on tree nodes and tree distances that are

utilized by a matching algorithm and a backtracking procedure to find the best node-to-node correlations.

Activity function

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, 1986) used the activity function 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 elaborated 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 another paper, Kerzner (1984) returned to simple cross-correlation plus stretching to find stratigraphic matchings.

Expert systems

The difficulty of creating a computer algorithm that can perform a complex task that is routinely and efficiently done by experienced, skilled individuals is not unique to wireline-log correlation. The branch of computer science called artificial intelligence is devoted to the study of such problems.

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. 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 domains (Weiss and Kulikowski, 1984, p. 1).

Expert systems have been developed in a wide variety of areas. The pioneering 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 (DelCour, 1986; Kahn and McDermott, 1986).

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. Out of many alternatives, the representation best suited to most complex problems is the so-called production system (Durkin, 1994, p. 167; Giarratano and Riley, p. 11; Nilsson, 1998, p. 27). 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 a hypothesis leads to some action or resolution.

Applications of experts systems to lithostratigraphic correlation include the work Wu and Nyland (1986, 1987), Startzman and Kuo (1986, 1987), Kuo and Startzman (1987), and Lineman et al. (1987), all good attempts that never passed the testing phase.

Artificial neural networks

Artificial neural networks are another result from unfulfilled attempts to create machines with the same or superior intelligence than human beings. Artificial neural networks are the by-product of partial progress on the more focused research aiming at the understanding of how human brain processes information and generates results.

The consensus is that the basic unit in the brain is the neuron, of which the human brain has billions. Each neuron has a nucleus that process information gathered by dendrites and delivers a response through a single prominence branching at the end to connect to the dendrites of other neurons. This mechanism has provided the inspiration to assemble processing networks that, far from having the speed and flexibility of the human brain, have been able to produce encouraging results in solving problem in areas in which previous techniques have produced unsatisfactory results. Figure 2.1 illustrates the most common type of artificial neural network that comprises layers of nodes of three types: input, hidden, and output. The activation potential v_i at any node i is a linear combination of the output from all preceding nodes x_j and the output value, y_i , is determined by an activation function, $f(\cdot)$ (Haykin, 1999, p. 11):

$$v_i = \sum_{j=1}^m w_{ij}x_j$$
$$y_i = f(v_i).$$

The key to have a useful artificial neural network is the setting of the weights w_{ij} for the connecting links and the nature of the activation function. The setting of all those values is what is called the training of the neural network. The most successful and common type of training is that in which the network is forced to match sets of output values using sets of associated input data by gradually minimizing the output error, in which case the selection of the rules to update the weights and the stopping criterion also become crucial.

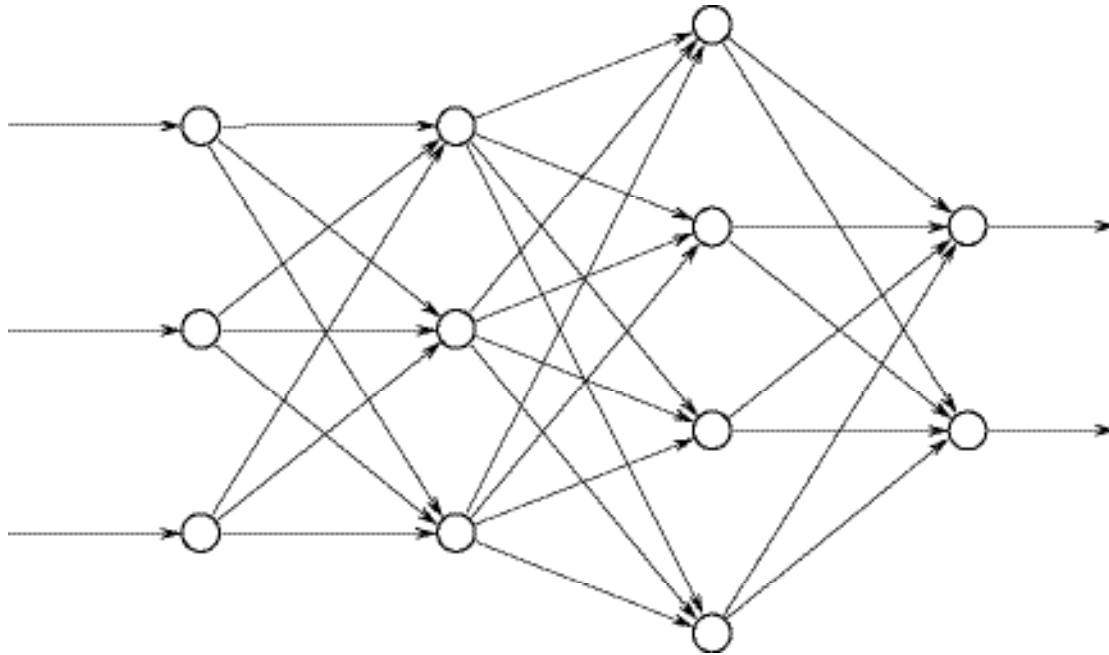


Figure 2.1. Illustrative example of topology of a neural network with two hidden layers. The arrows denote flow of calculation. Compensation of calibration errors works in the opposite direction.

One of the most successful examples reported in the geologic literature relates to the prediction of carbonate permeabilities. Wiener et al. (1991) used the input of 5 logs plus computed porosity, water saturation and bulk volume of water to predict permeabilities, namely, one final output variable. After trying multiple options, the best model had two hidden layers and took 6000 iterations to calibrate. The correlation coefficient between the neural network permeabilities and measured permeabilities was 0.96, significantly higher than the 0.76 obtained with the best linear regression scheme, which, by the way, is equivalent to a neural network without hidden layers. More significantly, they were able to predict permeabilities based on log measurements that had a correlation coefficients of 0.9 when applying the calibrated neural network to data not part of the calibration set. Another interesting result is that of Rogers et al. (1992), who used gamma ray, neutron, and density logs—3 input variables—to predict a four-mineral lithology: proportion of shale, sandstone, limestone, and dolomite, thus requiring a neural network with 4 output nodes. These authors used one hidden layer.

Neural networks with more than one hidden layer are nonlinear systems. The most challenging part of being able to successfully use neural networks for predictions is the calibration. Inappropriate choice of output functions make the convergence to an optimal network difficult or impossible. Selection of the number and value of weights make neural networks to fluctuate in their behavior between true generalization—the desirable situation—and a tendency to duplicate training sets—and undesirable case called memorization. For having a satisfactory

generalization, it is fundamental that the number of training sets be larger than the number of connecting links (Nilsson, 1998, p. 51).

Reports of application of neural networks to problems related to lithostratigraphic correlation are scant and tentative (Luthi et al., 1995; Luthi and Bryant, 1997; Luthi, 2001, p. 325-330). These publications report moderate success in the training and recognition of one marker at a time at different wells. Such results suggest that the technique is either at its infancy or that there are inherent problems that will never make neural networks the method of choice to correlate logs. Currently, it is too early to make a conclusive prediction.

Comments

Researchers interested in lithostratigraphy saw in digital computers the advent of a convenient tool to facilitate the determination of correlations. For three decades, from the early 1960s to the late 1980s, there was continuous output of work by various individuals creating and adapting mathematical techniques suitable of doing the correlation of logs by computer. Unfortunately many of this researchers had only a casual interest in well-log correlation. Upon reaping the benefit of acceptance of one or two papers in the subject, many of these authors moved to other topics, often leaving behind promising but unfinished work, if one defines finished work as a computer program that, as a bare minimum, is capable of processing situations of general interest and displaying results in a format comparable with renditions of results by manual correlation. From 1990 on, curiously and suddenly, researchers have abandoned the subject of automated well log correlation, denoting that the problem is either already solved or hopeless. We think the truth is somewhere in between.

Overall, review of the literature demonstrates that three techniques have allowed the most reliable results in diverse scenarios:

- Pearsonian correlation
- Dynamic programming
- Expert systems

While commercial packages by software vendors have concentrated on the display of top of formations and production units while handling a staggering amount of log and seismic data, the problem of computers being able to correlate any interval accurately and display results according to practice, remains open. This is the niche of CORRELATOR.

Chapter 3: CORRELATOR methodology

We have seen in the previous chapter that three techniques are behind the most successful results in the application of computers to lithostratigraphic correlations: Pearsonian correlation, expert systems, and dynamic programming. This chapter explains the blending of the first two to determine correlations.

Early approaches

The history of technology shows that first generation attempts to automation tend to mimic human behavior rather than to incorporate shortcuts or revolutionary solutions from the outset. Consider the example of the plotter. In automating technical drawing, ink pens were mounted on mechanical arms long before electrostatic plotters were developed. The relevance of this remark has to do with the selection of Pearsonian correlation over dynamic programming as the technique of choice to determine lithostratigraphic correlations; Pearsonian correlation is more analogous to the manual process of establishing correlations. In the long run, there is no reason not to expand the program to be able to handle both or other methods. If CORRELATOR's fate follows that of other innovations, eventually Pearsonian correlation may prove inefficient. However, at the present time, this first stage of imitation in automation is yielding acceptable results.

Another consideration in trying to correlate with computers is minimization of resistance to change. In a discipline like geology characterized by resistance to accept quantitative methods, user friendliness is equally if not more important than technical efficiency (Tipper, 1988). In case of discrepancy between the interpretation of a geologist and a computed-aided interpretation, it is always easier to sell to the geologist the computer-generated solution if one can assure that the computer was following exactly his or her logic. Otherwise, the discussion sidetracks to argue about the relative merits of correlation by eye and the way computers establish lithostratigraphic equivalence.

What is, then, the way experience geologists correlate logs? First, manual correlation is never based on the trace of a single logging tool. In the old days, 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 to make fine comparisons. With the increase in the types of logs available, other options are today common, especially the replacement of the spontaneous-potential log by the gamma-ray log to discriminate shales. Yet, partly because of problems of general availability, the most common practice is to use two consistent sets of logs to determine lithostratigraphic correlation. This is exactly the requirement of CORRELATOR, which accepts up to two logs, one that must be sensitive to the amount of shale in the stratigraphic sequence, and the other must be able to measure, with high vertical resolution, some petrophysical property that is laterally persistent for extensive distances.

Generically, we will denote these wireline logs as shale logs and correlation logs, respectively. If needed, however, the process can proceed with a single log.

Second, the geologists use shale logs to discriminate roughly into shales and clean intervals low in shale. The objective of this screening is to reduce the number of solutions and to establish likely correlations.

Finally, the choices are reduced in most cases to one, sometimes to none in the case of non-deposition or erosion, rarely to more than one in the presence of repeated sections. The task of narrowing the number of possible solutions is complicated by the fact that lateral continuity is never perfect, particularly in the case of lateral basinal contribution of sediments or variations in the nature of occluded fluids. Under those circumstances, geologists have learned to rely on the rate of change in petrophysical properties, rather than on individual comparisons of isolated readings. Sometimes analyzing the patterns that result from the variation in the sequence of measurements has the advantage of helping to filter out components of the readings that are the result of undesirable effects such as changes in tool calibration, tool model, or borehole conditions. In addition, lithology types commonly are fairly repetitious—a sandstone may be followed by a shale, and then another sandstone and a shale, and yet another sandstone. Without significant variations in thickness for units of similar lithology, the likelihood of mismatches may be even higher. The occurrence of key beds composed of unusual minerals are of great help in establishing correlations, but a correlation procedure cannot be based in the systematic existence of rare lithologies (Gradstein et al., 1985, p. 393).

Pearsonian correlation coefficient

CORRELATOR honors all the basic step of lithostratigraphic correlation observed by an experienced geologist. We have seen that experts use a high resolution log to match the signature resulting from the rate of change. Among the several mathematical techniques that can be employed for such purpose, we chose the coefficient of Pearsonian correlation for its simplicity and relative success in related applications. The method is sufficiently robust to be used even in the presence of gaps in the stratigraphic record and moderate changes in thickness of equivalent intervals. Calculation of the coefficient requires previous computation of the covariance between the intervals and their standard deviations. When the logs are digitized at the same regular interval, if k is the offset between intervals and z_i is the reading for log z_i at depth z_i , then the covariance between the interval of length $(2n+1)$ centered at depth z_i in log z_i and the interval of the same length centered at z_{i+k} in log z_{i+k} is equal to

$$\text{cov}_2(i, k; n) = \frac{1}{2n+1} \sum_{j=i-n}^{i+n} z_i(j) z_{i+k}(j+k) - \frac{1}{2n+1} \sum_{j=i-n}^{i+n} z_i(j) \sum_{j=i-n}^{i+n} z_{i+k}(j+k)$$

while the standard deviations are

$$s_2(i; n) = \sqrt{\frac{1}{2n+1} \sum_{j=i-n}^{i+n} z_i(j)^2 - \left(\frac{1}{2n+1} \sum_{j=i-n}^{i+n} z_i(j) \right)^2}$$

$$s_4(i, k; n) = \sqrt{\frac{1}{2n+1} \sum_{j=i+k-n}^{i+k+n} x_j^2 - \left(\frac{1}{2n+1} \sum_{j=i+k-n}^{i+k+n} x_j \right)^2}$$

The Pearsonian correlation coefficient for these two intervals is,

$$r_{2,4}(i, k; n) = \frac{\text{cov}_{2,4}(i, k; n)}{s_2(i, n) s_4(i, k; n)}$$

Figure 3.1 contains a graphical display of the variation in the correlation coefficient with depth for an example in which the correlation logs are resistivity logs. The interest is in finding the best match for the interval from 1776 to 1788 ft (541.3-545.0 m) inside shale A at the well to the left. The highest correlation is for a matching depth of 1834.5 ft (559.2 m). This implies that shale A correlates best with the interval 1828.5-1840.5 ft (557.3-561.0 m) in well Wittman 1, which is partly in shale V and limestone W. All these names are arbitrarily introduced only for the purpose to facilitate the exposition. The wells are only half a mile apart in an area with good lateral lithological continuity. Based both in this lithological inconsistency and other correlations, the matching is incorrect.

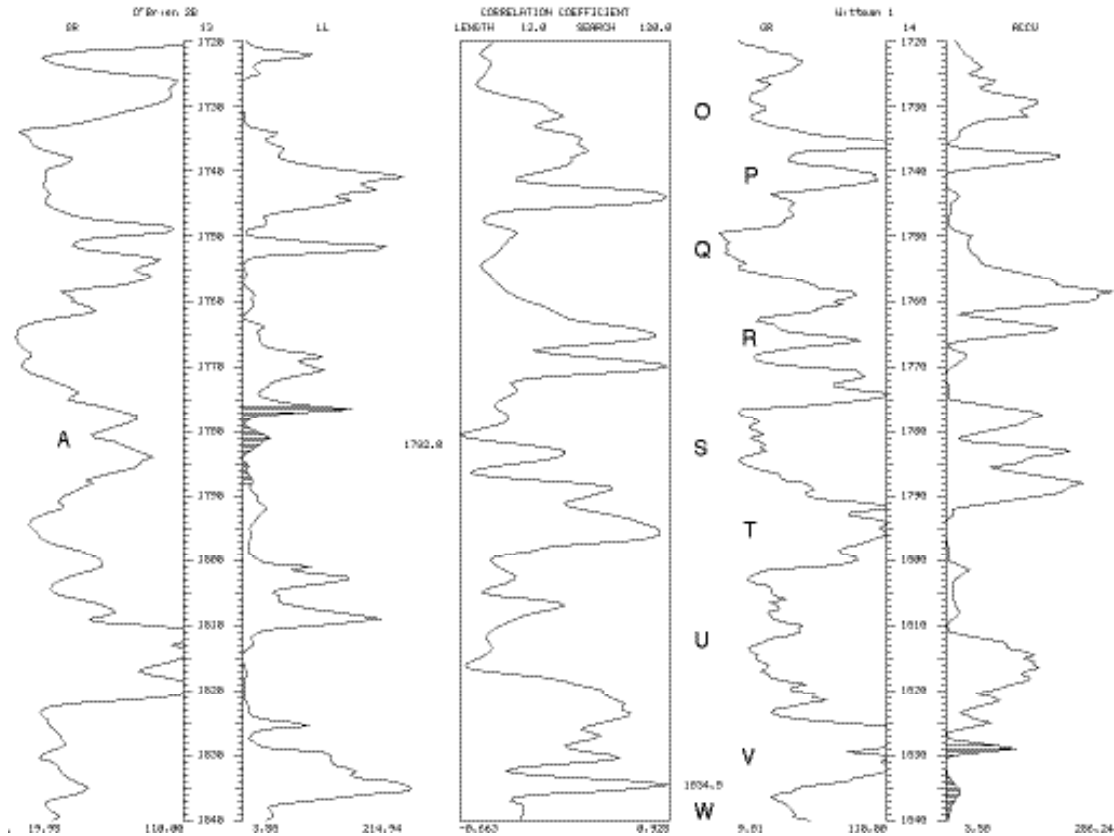


Figure 3.1. Correlogram for a pair of wells in Ness County, Kansas. The central track shows the correlation coefficient between unit A centered at 1782 ft (543.2 m) in well O'Brien 2B and all possible intervals 12 ft (3.7 m) in length with centers from 1720 to 1840 ft (524.3-560.8 m) in well Wittman 1. The maximum coefficient is between the intervals centered at 1782 and 1834.5 ft (543.2-559.2 m).

Because of systematic search by CORRELATOR of an equivalent interval in the right-hand well for a given interval in the left-hand well, is that we refer the wells as matching well and reference well.

Standardized shale similarity

Geologists also rely on a second log, a shale log, to prepare correlations. We have defined a standardized similarity coefficient to mathematically incorporate information from shale logs into the determination of correlations. Let l_1 and l_3 be their shale logs digitized at regular intervals. If z_i is the depth for the center of an interval in the reference well comprising $(2n+1)$ readings, then the standardized shale similarity coefficient, $s_{1,3}(i, k; n)$, is:

$$s_{1,3}(i, k; n) = 1 - \frac{1}{2n+1} \sum_{j=1-n}^{i+n} \left| \frac{l_1(j) - \text{shale1}}{\text{min1} - \text{shale1}} - \frac{l_3(j+k) - \text{shale3}}{\text{min3} - \text{shale3}} \right|,$$

where:

shale_l is the reading corresponding to a hypothetical end-member of pure shale.

min_l is the minimum value of log l .

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 interval are equal to the minimum value. The coefficient is equal to the maximum value of 1 when every first term in the difference under the summation sign is equal to the second term, under which conditions, point by point all proportions of shale are the same.

On the display of wireline logs, for logs that are sensitive to shale content, the convention is that the farther the reading to the right, the greater the amount of shale for that elevation. In Figure 3.2, an interval in shale A correctly shows a tendency to higher similarity with intervals of the same length inside units arbitrarily labeled P, R, T, and V, which are shales also. Conversely, the unit-A interval has minimal similarity to the clean-unit intervals O, Q, S, U, and W.

Weighted correlation coefficient

We denote by weighted correlation coefficient, $w_{1,2,3,4}(i, k; n)$, the product of the standardized shale similarity coefficient, $s_{1,3}(i, k; n)$, and the Pearsonian correlation coefficient $r_{2,4}(i, k; n)$:

$$w_{1,2,3,4}(i, k; n) = s_{1,3}(i, k; n) r_{2,4}(i, k; n).$$

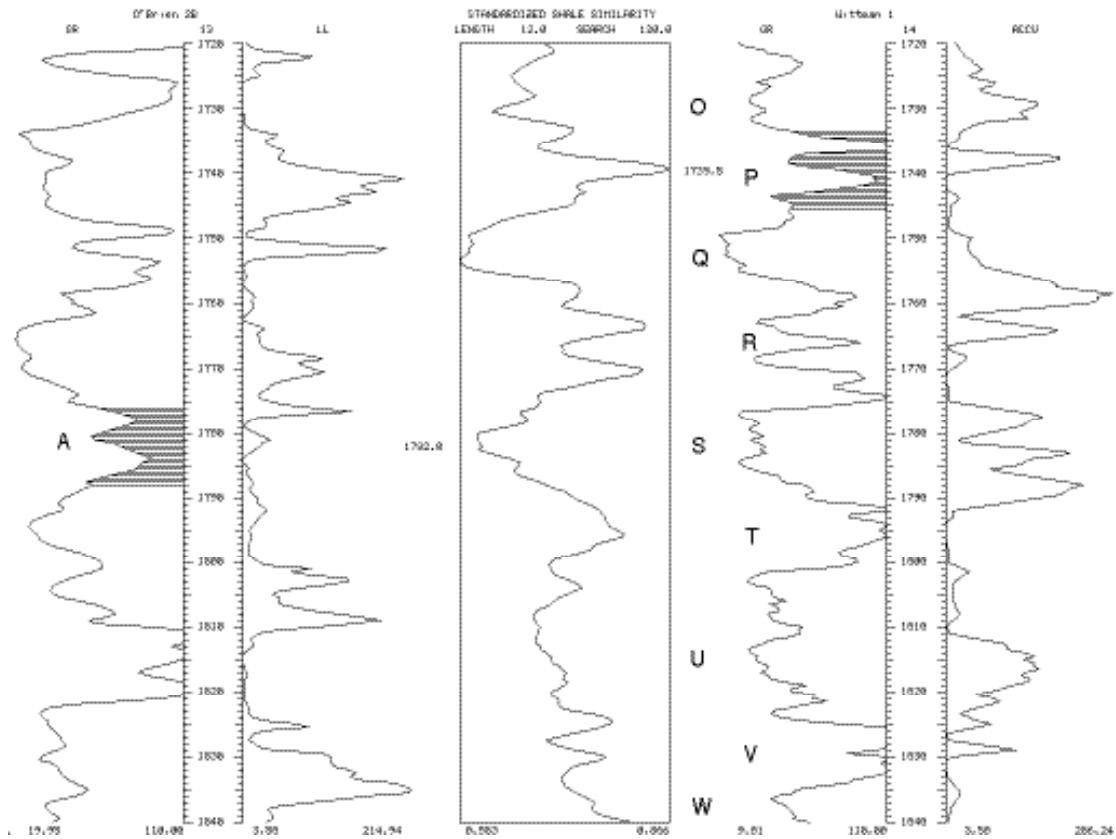


Figure 3.2. Standardized shale similarity for the same wells, intervals and units in Figure 3.1. The highest similarity is between the intervals centered at 1782 and 1739.5 ft (543.2-530.2 m).

By construction, the new coefficient is jointly sensitive to the amount of shale measured by the shale log and the similarity in signature between the correlation logs. The range of variation is (-1,+1). The higher the weighted correlation coefficient, the higher the similarity, hence the better the lithostratigraphic equivalence.

Continuing with the example started in Figure 3.1, we see in Figure 3.3 that, of all possible intervals, the interval inside shale A has the best weighted correlation coefficient with an interval inside shale R, which is yet a third answer for the same question. According to experts in the area and other correlations that one can determine, this is the correct correlation.

The lesson that follows from the preparation of Figures 3.1–3.3 is that joint usage of the correlation coefficient and the standardized shale similarity can provide better results than their separate consideration.

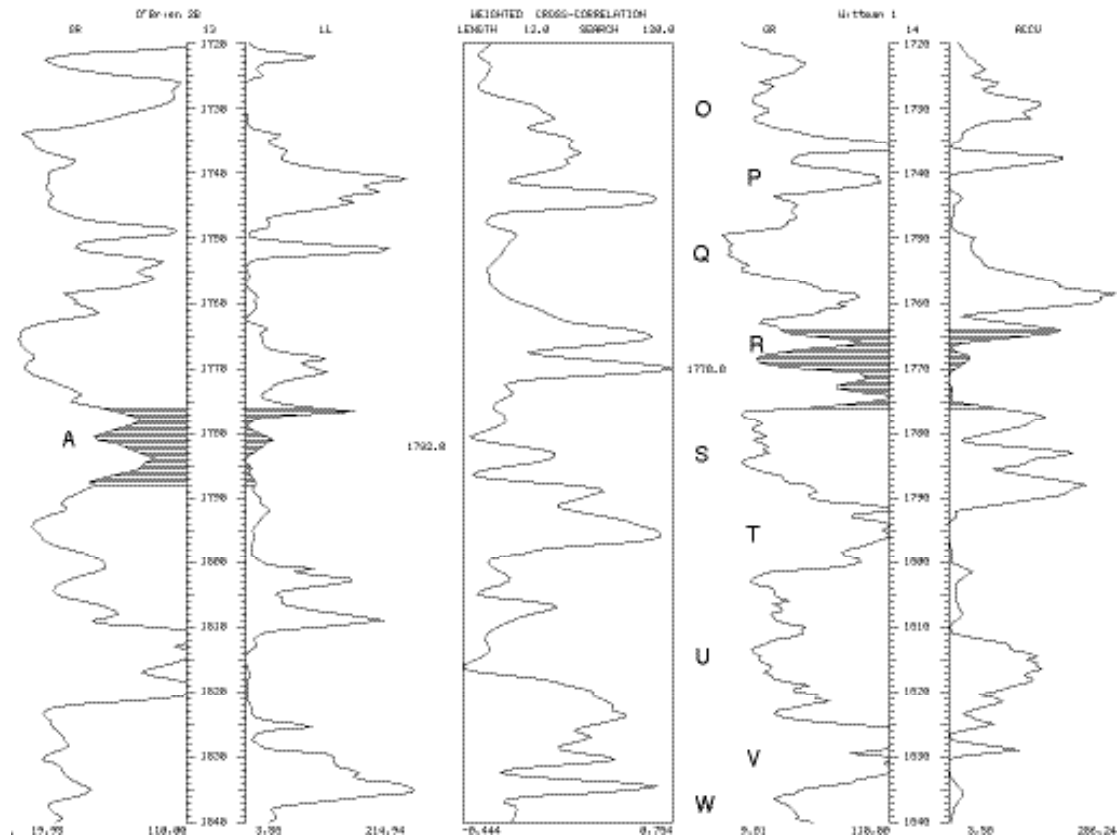


Figure 3.3. Weighted correlation coefficient for the same wells, intervals and units in Figure 3.1. The best match is between the intervals centered at 1782 and 1770.0 ft (543.2-539.5 m), which is the correct correlation.

Minimum correlation coefficient

In practice, there is never perfect lateral continuity for unlimited distances, which presents several problems for any correlation approach expecting perfect lateral continuity. Among the complications, one invariable effect is that there is never a perfect matching, which primarily may be due to variations in the conditions of deposition, diagenesis, or fluid migration. Depending on the geology and the well distance, the similarity may be really degraded, in which case the weighted-correlation coefficient between the truly equivalent intervals will be low.

Another result of lateral deterioration of lithological equivalence is the possibility of best matching with another sequence, either older or more recent, possibility that increases as the weighted-correlation coefficient decreases.

The practical solution to these problems is to set minimum standards. If the largest weighted-correlation coefficient is below a threshold, the mathematical solution is rejection; no correlating interval is reported for the reference interval.

Always there will be at least one matching interval with the highest weighted correlation coefficient, even in the presence of faulting, non-deposition or erosion, in which case there may be no geological solution to the problem of finding the lithostratigraphically equivalent interval for the reference interval. Hence, use of a threshold is conceptually satisfactory with the geological likelihood of absence of correlation.

CORRELATOR does not handle multiple equivalences due to the existence of a repeated section. The situation is so rare that consideration of this case has been delayed.

Abnormal correlations

Calculation of the best weighted-correlation coefficient for every possible interval in the reference well results in a table of correlations between the reference and the matching well. Except for duplication in readings resulting from the heavy overlapping among reference intervals, finding of one matching interval is independent from the finding of others.

The petrophysical record of a stratigraphic succession is monotonous because the depositional processes that created the succession repeated over time. Sea level, for example, has risen and fallen countless times throughout the world. For example, as marine conditions recurred, so did the type of sediments that were deposited in previous transgressions. 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 Figure 3.4, happens frequently, but not so often as to completely scramble the records that are the rocks. One way to better display simultaneously several correlations is to show in the central track lines connecting the centers of the correlating intervals rather than a continuous display of the weighted-correlation coefficient as in the previous figures. This practice of displaying tie lines will remain as the standard convention in following chapters.

The confusion between geological equivalence and petrophysical similarity is real and is not an artifact of quantitative correlation methods. Because of this, when correlations are established with the assistance of computers, spurious correlations should be expected to occur, regardless of the method employed to compare traces. What experienced geologists do in practice to resolve this ill-determined problem is to avoid working with the correlation of a single interval, but with the correlations of several intervals at a time. An individual correlation is more apt to be in error than a series of adjacent correlations.

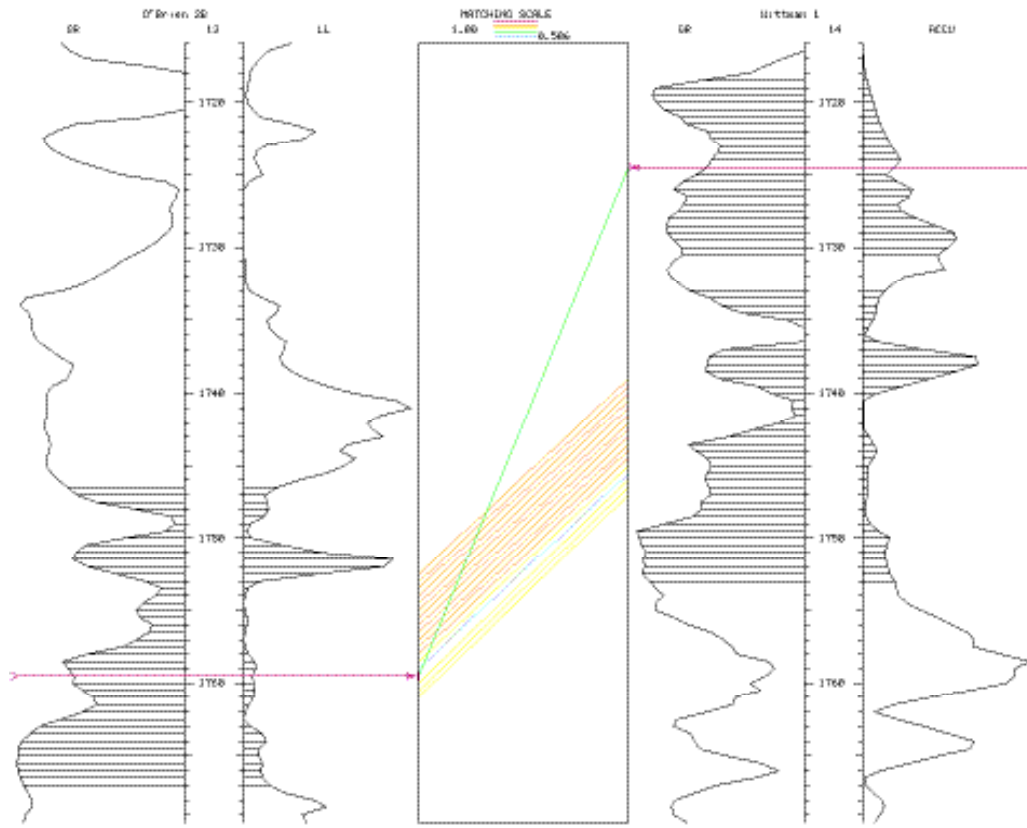


Figure 3.4. Example of miscorrelation showing a crossing tie line of best correlation.

CORRELATOR is a hybrid method in the sense that determination of the correct lithostratigraphic correlations depends on the utilization of more than one of the techniques listed in Chapter 2 for the computer-assisted lithostratigraphical correlation. CORRELATOR uses an expert system to systematically edit miscorrelations based on knowledge borrowed from skilled geologists. The expert system that we designed for this specific purpose has five major components:

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

The database 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.

The scheduler automatically searches for all correlations and sorts them from top to bottom prior to the inspection.

The expert system in CORRELATOR contains 23 antecedents and 11 hypothesis 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:

- Correlated intervals are consecutive. There are no gaps in the sequence larger than the digitization interval;
- Centers for all correlation intervals in the set are within the same binary type of rock based on the amount of shale above or below 50%;
- Correlations are essentially parallel. Within bundle differences in dip are small and no larger than a preset threshold;
- Correlations do not cross. If interval A occurs above interval B in well X, the interval correlating with interval B in well Y cannot be above the interval correlating with interval A.

All production rules involve discarding anomalous correlations based on geometry, as well as the relative strength of the questionable bundle and the relative strength of the bundles directly above and below. At most four bundles are involved in the analysis at any time. There are no measures of certainty 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 (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 the rules are tried in descending order of the number of antecedents. In this way, the search progresses from the strongest to the weakest supported hypotheses.

Figure 3.5 show an example of dialog. The expert system works interactively. Special provisions were made, however, not to overwhelm the user with questions. CORRELATOR in general and the expert system in particular have been designed to extract all possible information from the wireline logs and to perform all trivial computations without querying the user with questions that the system can resolve by itself with the amount of data already in file. We specifically rejected the use of a Socratic-type expert system, in which the user is bombarded with questions that provide the bulk of the required knowledge to come to any conclusion. As shown in Figure 3.5, no direct intervention is required from the user for the expert system to diagnose the miscorrelation in Figure 3.4. Any information required by the inference system in CORRELATOR is obtained from the database. The role of the user is restricted to make the final decision: take the expert system advice or overrule it. This design philosophy assures the user a comfortable intermediate position, away from the extreme approaches of black boxes and high maintenance systems.

Elimination of a bundle results in the discarding of all bundles involved in the analysis from further consideration in one pass of reviewing all correlations between a pair of wells. Hence, several passes may be necessary to discard all truly erroneous correlations. Once all pairs of correlating wells have been properly edited by the expert system, the tables of correlations are ready for further analysis and display.

***** CORRELATION AT 1759.5 FEET SHOULD BE
ELIMINATED. IS YOUR ANSWER Y (YES), N (NO), OR W (WHY)? : w

SOME CHARACTERISTICS OF THE BUNDLES INVOLVED IN THE ANALYSIS

REFERENCE DEPTH FEET	MATCHING DEPTH FEET	AV. DIFFER. IN ELEVATION FEET	AV. WEIGHTED CORR. COEF.	NUMBER OF CORRELATIONS
1752.5 TO 1757.5	1739.0 TO 1744.0	-13.5	0.815	11
1758.0 TO 1759.0	1744.5 TO 1745.5	-13.5	0.721	3
1759.5	1724.5	-35.0	0.621	1 *
1760.0 TO 1761.0	1746.0 TO 1747.0	-14.0	0.749	3

THE FOLLOWING RULE WAS SUCCESSFULLY TESTED:

ELIMINATE LOWER BUNDLE OF CROSSING CORRELATIONS

BECAUSE :

THE DIP IS ABNORMAL FOR THE LOWER BUNDLE
THERE ARE 2 INCONSISTENT BUNDLES IN THE ROCK UNIT
UPPER BUNDLE IS CONTIGUOUS TO ANOTHER BUNDLE

DO YOU WANT TO ELIMINATE THE BUNDLE NOW, Y(YES) OR N(NO)? : y

Figure 3.5. Expert-system dialog for the correction of the abnormal correlation in Figure 3.4.

Chapter 4: General remarks

Installation

CORRELATOR has been designed to run on a Unix-X Windows environment. The first step in the installation is to download the compressed source code lcor5.2.tar.Z into a writable directory in a computer with Fortran 77 and C compilers. Uncompress and untar the files keeping the structure of the resulting directory lcor5.2. The source code comes with no executable program.

The source code does come with make files to compile and link the code in computers with Solaris or Linux operating systems. Go to the lcor5.2 directory and generate the executable program by running the appropriate make file.

Upon generation of the executable program, go into the directory containing the well and log data of interest. Type `../lcor5.2/lcor` after the prompt sign in the Unix shell window to start execution of CORRELATOR. Some systems will require resizing of the resulting program window.

The program has been tested extensively to operate properly. However, it is distributed without any support or warranty.

Main menu

The program is structured into six major modules that appear on the screen menu of Figure 4.1 immediately after beginning the execution of the program.

The analysis and transformation module is mainly for preparation and verification of the data. The second module is primarily for the determination of correlations, which can be visualized in various ways employing the correlation display module. The geologic interpretation module is the most important one for extracting geological information from tables of correlations.

```

CORRELATOR MAIN MENU

AT -- ANALYSIS AND TRANSFORMATION      -->
CF -- CORRELATION FINDING              -->
CD -- CORRELATION DISPLAY              -->
GI -- GEOLOGIC INTERPRETATION          -->
FM -- FILE MANAGEMENT                  -->
SP -- SETTINGS AND PREFERENCES         -->
ST -- STOP

PLEASE ENTER YOUR SELECTION:
```

Figure 4.1. Main menu.

The last two modules deal with various files and parameters required for expediting the execution of the program, particularly concerning options related to the graphical display of results.

All the processing is interactive. Instructions in the menus should be clear enough not to require continuous reference to this manual once the user has gone a few times over most of the options in the program.

The manual is modular, so that it can be read either in its entirety or consulted only by topics as needed.

General features of CORRELATOR

Some characteristics of CORRELATOR useful to keep in mind at all times are:

- Display of information may occur in two different types of screens, either at the Unix shell window or at a CORRELATOR window generated by the program.
- We will use a SANS SERIF font to denote command acronyms, menu types, and file names.
- The Unix environment is case sensitive. During the invocation or creation of a file, if the user types any small letters, CORRELATOR will automatically change them to capital letters. In trying to read files, the program will not recognize file names including small letters. Mixing of capital or small fonts is permitted in titles.
- As much as possible, the program will warn the user on improper selection of parameters.
- Employing the name of an existing file in an attempt to create a new file will result in the destruction of the original file. For that reason, each time such situation occurs, CORRELATOR will print the warning in Figure 4.2 to minimize the potentially catastrophic possibility of employing the name of an existing file by mistake.
- CORRELATOR can use both elevation or depth in hardcopy displays, but all internal calculations and results are in depth below a reference level to be selected by the user, the most obvious choice being sea level.
- Type the command GO and press the return key each time you are ready for the execution of the activity displayed on a menu. For short, in following utilization of this command, the obvious reference to the return key will be frequently omitted.

```
***** THERE IS ALREADY A FILE WITH THE SAME NAME.
```

```
RE  --RETURN TO PREVIOUS MENU NOT TO DESTROY EXISTING FILE  
GO  --RECYCLE THE EXISTING FILE. EXISTING FILE WILL BE DESTROYED
```

```
PLEASE ENTER YOUR SELECTION:
```

Figure 4.2. Warning to avoid use of existing file.

- Type the command RE and press the return key each time you want to go back to the previous menu. For short, in following references to this command, the obvious mention to the return key commonly will be omitted.

Basic steps

Preparation from scratch of any of the types of cross sections in hardcopy form requires the following minimum steps, with chapters in parenthesis denoting place in the manual where to go for detailed explanations:

- Entering information for all wells in the cross section into a well/log database (Chapter 5).
- Adding the digitized wireline logs to the well/log database (Chapter 5).
- Initializing a correlation database (Chapter 5).
- Finding weighted correlations for all pairs of wells in the cross section and saving them as interpretations in the correlation database (Chapter 7).
- Editing all interpretations with an expert system to eliminate possible improper correlations (Chapter 7).
- Preparation of a source file indicating all interpretations going into the cross section (Chapter 8).
- Preparation of a file with general drawing specifications (Chapter 8).
- Optional preparation of stratigraphic columns (Chapter 10).
- Setting of a plotting file (Chapter 8).
- Execution of some of the commands to prepare an electronic file with graphic code for a hardcopy rendition of a cross section, which may be a correlation display (Chapter 8), display of persistent correlations or markers (Chapter 9), dip plots or spatial variation of the proportion of shale, porosity or lithology (Chapter 11).
- Processing of the resulting electronic file in a compatible printer or plotter.

Figure 1.1 is an example of successful completion of all these steps for the particular case of the command for marker display.

Illustrative examples

All Kansas wireline logs used to illustrate this manual are available through the Internet. Two remarks about these files:

- Digitized files are downloadable from the Kansas Geological Survey web site < <http://www.kgs.ku.edu/Magellan/Logs/index.html>>. Files are saved in a compressed form.
- Well location is commonly available either as latitude and longitude or various forms of surveying systems that do not use Cartesian coordinates. Non-Cartesian coordinates require conversion using some utility program, such as LEO (Collins, 2000), which allows conversion to UTM coordinates.

Chapter 5: Data input and editing capabilities

Loading basic information about wells and logs is essential for obtaining any practical results employing CORRELATOR.

Initialization well log database

To begin entering data into the program, select menu File Management from the Main menu. This choice will result in the display of the menu in Figure 5.1.

Typing of option PW results in another menu requesting a name for the well/log database. Enter any convenient name, such as wl.database, by typing

FN WL.DATABASE

and then press the return key. This action will generate the menu in Figure 5.2 with some default values.

FILE MANAGEMENT MENU

WB -- SELECT LOGS AND THE WELL/LOG DATABASE FILE -->
PW -- PREPARE A WELL/LOG DATABASE FILE -->
RE -- RETURN TO MAIN MENU

ALSO IN THIS MENU ARE:

CB -- SELECT CORRELATION DATABASE FILE
WS -- SELECT WELL PAIR
EW -- EDIT WELL INFORMATION
AL -- ADD LOGS TO WELL/LOG DATABASE FILE
EL -- EDIT LOG INFORMATION
IC -- INITIALIZE CORRELATION DATABASE FILE
MC -- MANUAL PREPARATION OF A CORRELATION INTERPRETATION
SO -- SORT A CORRELATION INTERPRETATION
DL -- DELETE CORRELATIONS IN AN INTERPRETATION
PC -- PREPARE A CROSS SECTION SPECIFICATION FILE
PS -- PREPARE A SOURCE FILE
PF -- PREPARE A FAULT FILE
PD -- PREPARE A DATUM FILE
PM -- PREPARE A MARKER FILE
PA -- PREPARE A FILE WITH STRATIGRAPHIC COLUMN SUBDIVISIONS
PL -- PREPARE FILE FOR ANNOTATING LITHOLOGY IN STRAT. COLUMN
LC -- PREPARE FILE FOR DISPLAY OF LITHOLOGY IN CROSS SECTION

ALL THESE OPTIONS REQUIRE PRIOR EXECUTION OF OPTION WB.
DL, MC, PS, AND SO REQUIRE PRIOR EXECUTION OF OPTION CB.
MC, SO, AND DL REQUIRE PRIOR EXECUTION OF OPTION WS.

PLEASE ENTER YOUR SELECTION:

Figure 5.1. File Management menu.

Some of these parameters may require explanations and new values. CORRELATOR requires that the logs be digitized at fixed increments, preferably starting at an elevation that is a multiple of this increment. The default value 0.5 is the most common increment for logs with depth scales in feet. Except for rare occasions, the standard reference for depths and for elevations is sea level. Finally, it is of common occurrence that well coordinates are in one type of units and the log depths are in another system of units. The last parameter in this menu allows solving this inconsistency. For example, if the Cartesian coordinates of location are in meters and the depth scale of the logs is in feet, the conversion factor must be modified by typing:

CF 3.281

and pressing return. When all parameters have been properly set, type GO. A summary with the options, such as Figure 5.3, will appear in the shell window.

PREPARATION OF A WELL/LOG DATABASE FILE

FN -- NAME OF THE WELL/LOG DATABASE FILE	WL.DATABASE
SA -- START A NEW FILE (S) OR ADD TO AN EXISTING FILE (A)	START
DI -- DEPTH INCREMENT FOR LOGS	0.50
RL -- NAME OF THE REFERENCE LEVEL FOR THE ELEVATIONS	SEA LEVEL
FM -- UNIT OF LENGTH, FOOT (F) OR METER (M)	F
CF -- CONVERSION FACTOR FROM X-Y UNITS TO ELEVATION UNITS	1.000
RE -- RETURN TO PREVIOUS MENU	
GO -- UPDATE THE WELL/LOG DATABASE	

PLEASE ENTER YOUR OPTION:

Figure 5.2. Menu for preparation of a well/log database file.

WELL/LOG DATA FILE

WELL/LOG DATA FILE NAME	WL.DATABASE
DEPTH INCREMENT FOR LOGS	0.500
REFERENCE LEVEL FOR THE ELEVATIONS	SEA LEVEL
X-Y UNITS TO ELEVATION SCALE FACTOR	3.281
NUMBER OF LOGS IN THE DATABASE	0
NUMBER OF WELLS WITH REQUIRED LOGS	0

Figure 5.3. Report on well/log database.

Input of well data

In the menu displayed in Figure 5.2, change the value of START to ADD. Figure 5.4 shows the content of the new menu that will appear in the program window after completing the preparation of the information for the first well of an example that we will employ to illustrate this and following chapters. WN relates to the full well name up to 20 characters, while PI is an abbreviated form up to only 8 characters. Well symbols are restricted to icons customarily employed to denote hydrocarbon production. The options appear in Figure 5.5. The elevation above the reference surface refers to the elevation for the origin for the measurement of logs, which is the kelly bushing elevation in the case of oil wells. Finally the user must enter a pair of Cartesian coordinates indicating the relative location of the well. As mentioned in Chapter 4, ordinarily these X and Y coordinates are data the user must calculate with some utility program as systems for reporting well location commonly are not Cartesian.

Having prepared a well/log database does not mean that this is the active well/log database. There may be more than one well/log database in the same directory. Hence, the active well/log database must be implicitly loaded after its initialization or each time it needs to be loaded.

PREPARATION OF A WELL/LOG DATABASE

FN -- NAME OF THE WELL/LOG DATABASE FILE	WL.DATABASE
SA -- START A NEW FILE (S) OR ADD TO AN EXISTING FILE (A)	ADD
WN -- NAME OF WELL NO. 1	Schaben 1
PI -- WELL POSTING ID	Sch1
SC -- FIELD PRODUCTION SYMBOL CODE	14
EF -- FIELD DATUM ELEVATION ABOVE SEA LEVEL , FEET	2248.00
XL -- X LOCATION OF WELL	439844.00
YL -- X LOCATION OF WELL	4249234.00
RE -- RETURN TO PREVIOUS MENU	
GO -- UPDATE THE WELL/LOG DATABASE	

PLEASE ENTER YOUR SELECTIONS:

Figure 5.4. Menu for the input of well information for Twin Western Resources' well Schaben 1, Ness County, NE NW 19 19S 21W.



Figure 5.5. Well symbols.

Loading of an existing well/log database and setting of log options

Loading a well/log database is a fundamental task that can be done from any of the options in the Main menu. Let us continue within the File Management menu. Select option WB. Enter the name of the well/log database. If we continue with the example above, type

FN WL.DATABASE

and then press the return key. The menu will expand to the display in Figure 5.6.

Note that this menu contains options to specify the log types. CORRELATOR groups into categories the different models of tools available to measure basically the same petrophysical property. FAMILY.NAM is in this instance a file containing all those categories and mnemonics (Figure 5.7). If the user has not created a log mnemonic file, CORRELATOR will automatically create one. Only mnemonics in this file will be valid by the time the user actually tries to load the logs into the database. Categories and mnemonics can be added as needed.

Proper selection of parameters SX and CX allows the user to prepare different interpretations using different pairs of log categories employing the same database. Setting SX equal to CX allows to proceed with one log only. The program will require the input of only one log per well, although more logs can be loaded but will remain inactive. CORRELATOR automatically uses and displays this single log both as shale log and reference log, as in the example of Figure 1.2.

SELECTION WELL/LOG DATABASE FILE

FN -- NAME OF THE WELL/LOG DATABASE FILE	WL.DATABASE
LW -- LIST WELLS ON SCREEN—YES OR NO	YES
LF -- NAME OF THE LOG FAMILY FILE	FAMILY.NAM
SL -- SHALE LOG FAMILY NAME	SHALE
SX -- DIRECTION OF INCREASE FOR AXES OF SHALE LOGS IN THE GRAPHICAL DISPLAY, LEFT (L) OR RIGHT (R)	RIGHT
CL -- CORRELATION LOG FAMILY NAME	RESISTIVITY
CX -- DIRECTION OF INCREASE FOR AXES OF CORRELATION LOGS IN THE GRAPHICAL DISPLAY, LEFT (L) OR RIGHT (R)	RIGHT
RE -- RETURN TO FILE MANAGEMENT MENU	
GO -- UPDATE THE WELL/LOG DATABASE	

PLEASE ENTER YOUR SELECTIONS:

Figure 5.6. Menu for selection of log parameters.

When satisfied with all parameters in this window, type GO and press the return key. All the default values are correct in this instance. The loaded version of the well/log database becomes the active well/log database.

All parameters in this window can be modified at any future time in the present of further executions of CORRELATOR.

Input of digitized wireline-logs

Go to the File Management menu and select there option AL. In the new menu, enter the sequential number of the well for which you want to enter its logs. Continuing with the same example, Figure 5.8 shows the resulting menu after typing

WN 1 GO

If the name of the file with the logs from well Schaben 1 is SCHABEN1.LAS , the menu expands to the window in Figure 5.9 upon entering the file name using command LG. As mentioned in Chapter 4, remember that the name cannot include small letters. The value for the first and last reading can be entered either after or before the file name. The interval to be read can be any interval not going outside the digitized interval. As mentioned previously, the readings must be at the regular intervals specified in the menu displayed in Figure 5.3. No missing values are allowed.

FAMILY
 *SHALE
 SP
 SSP
 GR
 GRE
 *RESISTIVITY
 ASN
 ILD
 RLL8
 RN16
 SN16
 RFOC
 FR
 RSFL
 LLS
 LL
 SFL
 SN
 GUAR
 ACCU
 RES
 *DENSITY
 DNPFI
 RHOB
 FNL
 *NEUTRON
 CNL
 SNL
 *SONIC
 DTE
 DT
 AC

Figure 5.7. Example of file with tool categories and log mnemonics.

LOADING OF DIGITIZED LOGS

WN – WELL SEQUENTIAL NUMBER (Schaben 1)	1
DM – MINIMUM DEPTH READING FOR LOG VALUES	0.00
DX – MAXIMUM DEPTH READING FOR LOG VALUES	100.00
LG – LOG FILE NAME	?****?

PLEASE ENTER YOUR SELECTIONS:

Figure 5.8. Second pass of menu to load logs.

LOADING OF DIGITIZED LOGS

```
WN – WELL SEQUENTIAL NUMBER (Schaben 1)                1
DM – MINIMUM DEPTH READING FOR LOG VALUES              3700.00
DX – MAXIMUM DEPTH READING FOR LOG VALUES              4439.00
LG – LOG FILE NAME                                       SCHABEN1.LAS
NL -- NUMBER OF CHANNELS INCLUDING DEPTH                 0
L1 -- LOG1 -- CHANNEL, TYPE, SRFNS                       0 ??? 0
L2 -- LOG2 -- CHANNEL, TYPE, SRFNS                       0 ??? 0
L3 -- LOG3 -- CHANNEL, TYPE, SRFNS                       0 ??? 0
L4 -- LOG4 -- CHANNEL, TYPE, SRFNS                       0 ??? 0
L5 -- LOG5 -- CHANNEL, TYPE, SRFNS                       0 ??? 0
L6 -- LOG6 -- CHANNEL, TYPE, SRFNS                       0 ??? 0
```

PLEASE ENTER YOUR SELECTIONS:

Figure 5.9. Complete menu to load logs.

CORRELATOR has been designed to accept wireline logs in the LAS format, the most widely accepted format in North America for the coding of log information (Canadian Well Logging Society, 2000). CORRELATOR uses only the digitized values. Yet the header remains the most convenient place to keep all necessary information about each well. All the information in the header is ignored, which allows for a relaxation in the rules concerning the preparation of the header. The only relevant provision is that the line before the first record with digitized values must start with the characters ~A. Two restrictions apply to the formatting: the first value in a record must be depth, which is the convention anyway, and all following values in a record must be space delimited. Figure 5.10 shows an example of valid log file containing only essential information for the purpose of well log correlation using CORRELATOR.

The number of channels in the case of well Schaben 1 is 4 and the logs of interest are the second one and the last one. Each log requires the specification of up to three parameters:

- The first parameter refers to the channel (column) in the LAS file, starting from the left where depth should be channel 1.
- The middle parameter is also required and relates to the mnemonic for the log. To be valid, the mnemonic must be an entry in the file displayed in Figure 5.7.
- Shale logs require a third parameter. If the log is some type of gamma-ray log, the value to enter is the reading for a typical shale. If the log is a spontaneous potential log, the parameter must be the degree of a polynomial for the elimination of the systematic increasing in the readings because of increase in salinity with depth. If the trend is complex, it is recommended to externally detrend the log, either prior to digitization or with a special purpose program. If the log is not a shale log, enter any number as third parameter.

```

WELL                #1 SCHABEN
LOCATION              C,NE,NW, 19-19S-21W
UTM COORDINATES    RELATIVE TO ZONE 14
  X                  439844 M
  Y                  4249234 M
KELLY BUSHING      2248 FT
PRODUCTION          DRY
PURE SHALE READING 110 API UNITS
~A DEPT.F         GR  .GAPI  NEUT.API  RES  .OHMM
3700.0000         39.6388 1314.0970  3.2047
3700.5000         39.5972 1373.8944  3.3015
3701.0000         40.4529 1320.7872  2.6128
3701.5000         43.2099 1301.3737  2.5424
3702.0000         49.6296 1325.0211  2.4982
3702.5000         49.8473 1330.3381  2.2636
3703.0000         45.4860 1323.4812  1.7671
3703.5000         40.0000 1296.7761  1.6296
.
.
.
4425.5000         121.7248 1181.5823  3.3804
4426.0000         121.2079 1175.5453  3.1637
4426.5000         121.0904 1167.9724  3.2015
4427.0000         120.9729 1191.7252  3.3015
4427.5000         120.8555 1204.7256  3.2557
4428.0000         120.7380 1195.5872  3.1829
4428.5000         120.6205 1195.9991  3.1565
4429.0000         120.5030 1194.5699  3.1665

```

Figure 5.10. Example of file with well and log information.

In the case of well Schaben 1, the parameters to enter are:

```

L1 2 GR 110 GO
L2 4 GUAR 0 GO

```

In case of potential interest in using the density logs, the user may also enter the information about the density log by typing

```

L3 3 RHOB 0 GO

```

You may repeat the execution of option AL as many times as there are wells. Upon entering all log information, reload the well/log database by selecting option WB. The program will display all the information about the well/log database on the shell window. If you have properly executed every previous step, everything should be there ready for log processing. Figure 5.11 shows the well/log database content after loading all well and log information for wells Schaben 1 and Wittman 2, Ness County, Kansas.

WELL/LOG DATA FILE

WELL/LOG DATA FILE NAME	WL.DATABASE
DEPTH INCREMENT FOR LOGS	0.500
REFERENCE LEVEL FOR THE ELEVATIONS	SEA LEVEL
X-Y UNITS TO ELEVATION SCALE FACTOR	3.281

WELLS IN THIS DATABASE
=====

	WELL NAME	SYMBOL CODE	SURFACE ELEVATION FEET	SHALE LOG TYPE	NORMAL SHALE	CORR. LOG TYPE
1	Schaben 1	14	2248.00	GR	110	GUAR
2	Wittman 2	11	2261.00	GR	120	LL

NUMBER OF LOGS IN THE DATABASE	2
NUMBER OF WELLS WITH REQUIRED LOGS	2
SHALE LOGS INCREASING TO THE	RIGHT
CORRELATION LOGS INCREASING TO THE	RIGHT

Figure 5.11. Example of well/log database report on shell window.

To conserve space, digitized logs are stored in a direct-access, unformatted, binary form.

Modification of well data in the well/log database

Go to the File Management menu. If the well/log database it is not yet loaded, do it employing option WB previously explained in this chapter. To edit well information, select option EW in the same menu. The action should result in the window in Figure 5.12, whose display will expand after entering a well sequential number in the database, such as 2. Figure 5.13 has that window right before making the necessary correction in the northing coordinate.

Except for the font in titles, the effect of using capital or small fonts in the dialogs is immaterial.

To update the active copy of the well/log database, execute option WB again.

EDIT WELL INFORMATION

WN – WELL NUMBER 0

RE – RETURN TO PREVIOUS MENU

PLEASE ENTER YOUR SELECTIONS: wn 2

Figure 5.12. Menu for the editing of well information.

EDIT WELL INFORMATION

WN – WELL NUMBER	2
NW -- NAME OF WELL	Wittman 2
Pi -- WELL POSTING ID	Wi2
SC -- WELL PRODUCTION SYMBOL CODE	11
EF -- FIELD DATUM ELEVATION ABOVE SEA LEVEL, FEET	2261.00
XL -- X LOCATION OF WELL	439443.00
YL -- Y LOCATION OF WELL	4240014.00

RE – RETURN TO PREVIOUS MENU
GO -- EDIT THE WELL INFORMATION

PLEASE ENTER YOUR SELECTIONS: yl 4248014 go

Figure 5.13. Expanded menu for the editing of well information.

Initialization of a correlation data file

CORRELATOR deals with a second database, the correlation database, for the storage of all the correlation results. This database, like the well/log database, needs initialization. Creation of the correlation database is relevant at this point because it is required in the editing of log information in the well/log database. To start a new correlation database, select option IC in the File Management menu. Figure 5.14 shows the menu after entering a convenient name for the database and a descriptive title and be ready to create the file by pressing the return key. Pressing the key will generate a report in the shell window similar to the one in Figure 5.11 for the well/log database.

INITIALIZATION OF A NEW CORRELATION DATABASE

```
FN -- NAME OF THE CORRELATION DATABASE FILE          C.DATABASE
CN -- CORRELATION DATABASE DESCRIPTION              Schaben field, Kansas

RE -- RETURN TO PREVIOUS MENU
GO -- INITIALIZE THE NEW DATABASE

PLEASE ENTER YOUR SELECTIONS: go
```

Figure 5.14. Menu to initialize a correlation database.

```
CORRELATION DATABASE FILE INITIALIZATION
*****

FILE NAME:          C.DATABASE
DESCRIPTION:        Schaben field, Kansas
```

Figure 5.15. Shell window report on initialization of correlation database.

Loading of a correlation data file

Loading of a correlation database is straightforward, similar to the loading of a well/log database, and can be done from most of the options in the Main menu. Selection CB at the appropriate menu will generate the window in Figure 5.16. The same figure shows also the typing necessary to load database C.DATABASE. In this instance, the program will warn the user that the database is empty, which is true and fine. Press return.

```
LOAD A CORRELATION DATABASE

FN -- NAME OF THE CORRELATION DATABASE FILE          ?****?
RE -- RETURN TO PREVIOUS MENU
GO -- LOAD CORRELATION DATABASE

PLEASE ENTER YOUR SELECTION: fn c.database go
```

Figure 5.16. Menu to load a correlation database.

Modification of log header information

In version 5.2 of the program, log editing capabilities are restricted to the log header information. Change of digitized log values is not possible. To make changes in log header parameters, go to the File Management menu and select option EL. After selecting the correlation database and the well sequential number, CORRELATOR will display a window such as Figure 5.17 if the selection is the recently initialized correlation database and the second well in the well/log database. The window also shows, as an example, how to change the value of the gamma-ray reading for a typical shale, from 120 API units to 110 API units. To commit the modification, type GO.

Changes are only possible prior to saving correlations for any pair of wells.

```

                                EDIT LOG HEADER INFORMATION

CB -- SELECT CORRELATION DATABASE FILE                               ->
WN -- WELL SEQUENTIAL NUMBER (Wittman 2)                            2
DM -- MINIMUM DEPTH READING FOR LOG VALUES                        3700.00
DX -- MAXIMUM DEPTH READING FOR LOG VALUES                       4402.50

L1 -- LOG 1 -- TYPE, SRFNS                                         GR 120
L2 -- LOG 2 -- TYPE, SRFNS                                         LL  0

RE -- RETURN TO FILE MANAGEMENT MENU
GO -- EDIT LOG INFORMATION

PLEASE ENTER YOUR SELECTIONS: L1      L1 GR 110
```

Figure 5.17. Menu for the modification of log header information.

DATA ANALYSIS AND TRANSFORMATION MENU

```
WB -- SELECT WELL/LOG DATABASE FILE      ->
WS -- SELECT WELLS                       ->
CB -- SELECT CORRELATION DATABASE FILE   ->
RE -- RETURN TO MAIN MENU
```

OTHER OPTIONS INCLUDE

```
PL -- DISPLAY LOGS IN SCREEN
SE -- SEMIVARIOGRAMS
LS -- LOCAL SEMIVARIOGRAMS
TL -- TRUNCATE LOG PEAKS
SL -- STANDARDIZE LOGS
RT -- REMOVE TRENDS FROM LOGS
BL -- CORRECT BASE LINE ON SP LOGS
```

THESE OPTIONS REQUIRE PRIOR EXECUTION OF OPTION WS.

PLEASE ENTER YOUR SELECTION:

Figure 6.2. Expanded Data Analysis and Transformation menu after selecting the well/log database.

Selection of pair of wells

Having loaded the well/log database, we can choose a pair of wells. Execution of option WS results in the window in Figure 6.3. The selection can be done by typing the well sequential numbers or by clicking the posted wells at a graphical interface. To select well 1 in Figure 5.11 as reference well and well 2 as the matching well, simply type

```
RW 1 MW 2 GO
```

which will result in the report in the UNIX shell window displayed in Figure 6.4.

SELECT WELLS

```
RW -- REFERENCE WELL SEQUENTIAL NUMBER; -1 FOR      0
      SELECTION FROM GRAPHICAL INTERFACE
MW-- MATCHING WELL SEQUENCE NUMBER                 0

RE -- RETURN TO PREVIOUS MENU
GO -- SELECT THE WELLS
```

PLEASE ENTER YOUR SELECTIONS:

Figure 6.3. Menu for the selection of a pair of wells.

INFORMATION ABOUT THE REFERENCE WELL

WELL NUMBER : 1
WELL NAME : Schaben 1
WELL POSTING ID : Sch1
X LOCATION : 439844.00
Y LOCATION : 4249234.00
SURFACE ELEVATION : 2248.00
PRODUCTION CODE : 14
SHALE LOG TYPE : GR
GR READING ON NORMAL SHALE : 110
CORRELATION LOG TYPE : GUAR

INFORMATION ABOUT THE MATCHING WELL

WELL NUMBER : 2
WELL NAME : Wittman 2
WELL POSTING ID : Wi2
X LOCATION : 439443.00
Y LOCATION : 4248014.00
SURFACE ELEVATION : 2261.00
PRODUCTION CODE : 11
SHALE LOG TYPE : GR
GR READING ON NORMAL SHALE : 110
CORRELATION LOG TYPE : LL

DISTANCE BETWEEN WELLS 1 AND 2 IS 4213.500

Figure 6.4. Shell window report on well selection.

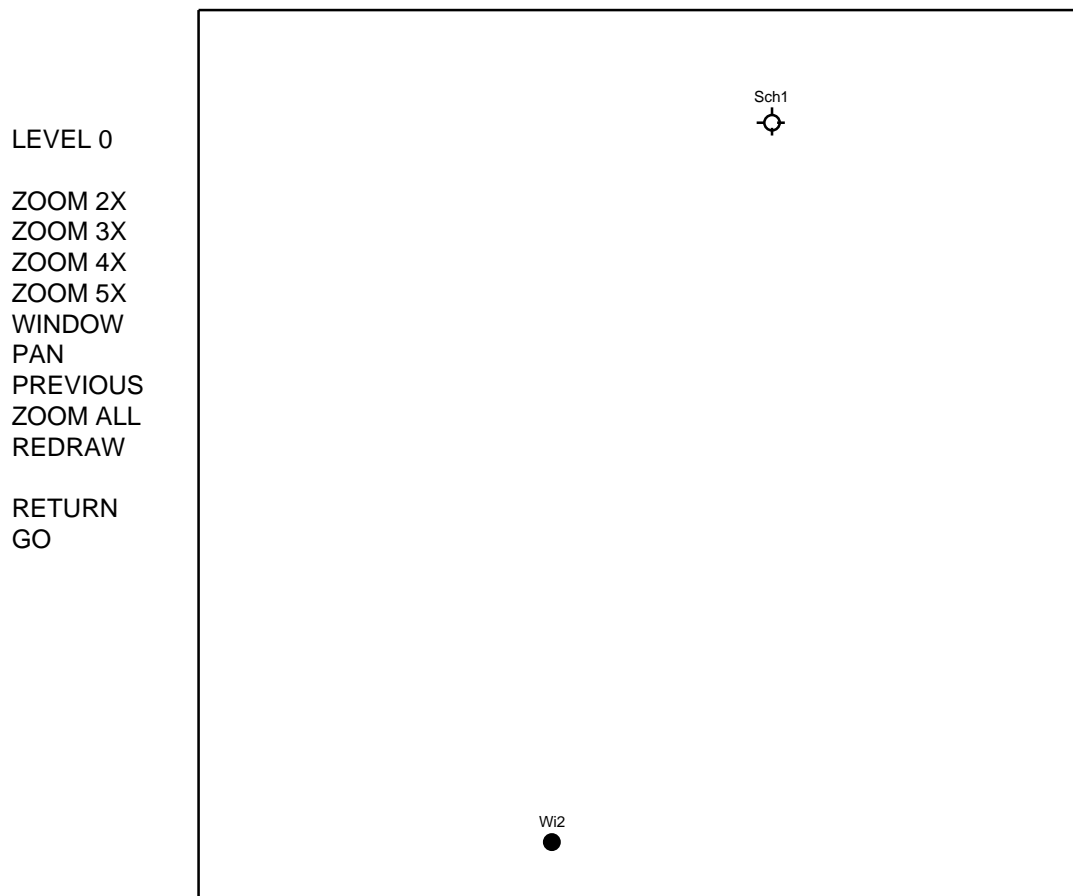
For selection from a well posting on the CORRELATOR window, type

RW -1 GO

At the window shown in Figure 6.5, click first on the well you want to be the reference well, then on the matching well, and finally click on GO at the left-hand menu to commit the selection.

Well selection mode

By default, the option first offered to the user by the program is well selection through sequential numbers. The user can reverse such default by using option SW in the Settings and Preferences menu (Figure 6.6). Figure 6.7 is a display of the straightforward SW's menu.



SELECT REFERENCE WELL WITH LEFT MOUSE BUTTON

Figure 6.5. Graphic selection of wells.

SETTINGS AND PREFERENCES MENU

PR -- INITIALIZE A PRINTER FILE ->

PL -- INITIALIZE A PLOTTER FILE ->

SW -- PREFERENCE FOR SELECTING WELLS ->

RE -- RETURN TO MAIN MENU

PLEASE ENTER YOUR SELECTION:

Figure 6.6. Settings and Preferences menu.

SET WELL SELECTION OPTION

WS -- SEQUENCE NUMBER (S) OR GRAPHICAL MENU (G) SEQUENCE NUMBER

RE -- RETURN TO MAIN MENU

GO -- MAKE THE SELECTION

PLEASE ENTER YOUR SELECTIONS:

Figure 6.7. Menu to change default mode to select a pair of wells.

LOG PLOT MENU

DEPTH INTERVAL IN REFERENCE WELL IS 3700.00 TO 4429.00 FEET

DEPTH INTERVAL IN CORRELATION WELL IS 3700.00 TO 4402.50 FEET

DT -- DATUM -- (SU) SURFACE OR (SE) SEA LEVEL SURFACE

MN -- MINIMUM DEPTH TO DISPLAY, FEET 3700.00

MX -- MAXIMUM DEPTH TO DISPLAY, FEET 4429.00

RE -- RETURN TO PREVIOUS MENU

GO -- PLOT LOGS

PLEASE ENTER YOUR SELECTIONS:

Figure 6.8. Menu for the display of a pair of wells in the program window.

Selection of the reference well and the matching well is an option available at several other menus.

Window display of a pair of wells

At the Analysis and Transformation menu, select option PL. Presuming that the well/log database has been loaded and the well selection is the one in the previous section, the new window will be the one in Figure 6.8, which will generate the display in Figure 6.9 when executed without modifying the default values.

The display can be either in the same depth scale as in the paper logs, which is most convenient to check the digitization, or as depth below the reference surface—normally sea level—which is the scale used for the processing of the logs.

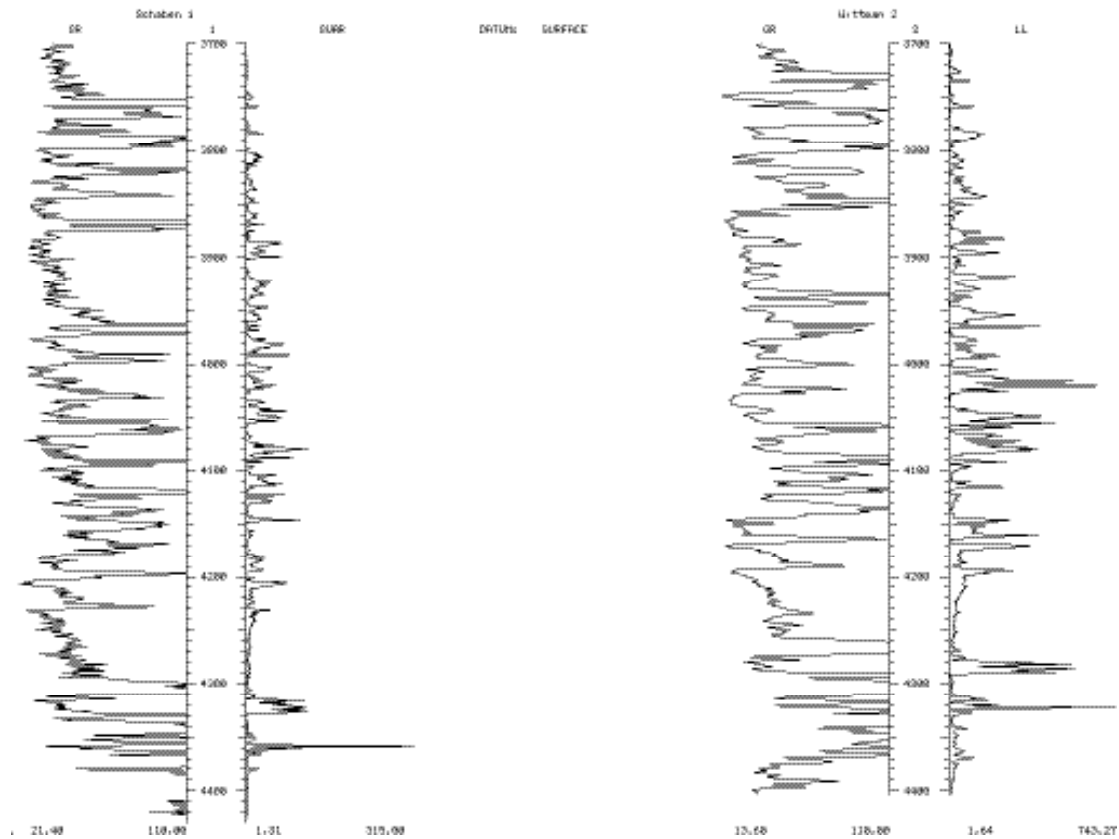


Figure 6.9. Program window display of wells Schaben 1 and Wittman 2.

Whatever the scale used to display the logs, there are two reasons that make display of all logs added to the database highly recommendable prior to any processing:

- Screen display is the most economical and fastest way to visually verify that all log readings are correct. Errors in the digitized logs are the most frequent source of problems in the data entry. Today all logs are directly recorded in digital form at the well site or are digitized by service companies with extensive experience, so blunders are rare. Yet, in our experience, two types of errors tend to appear in digitized logs. The first one relates to false readings at either end of the logs. Commonly, they are calibration values, or perturbed values before the tool was in proper operation or after the logging was supposed to be over. The other type of false readings happens commonly at the overlapping of logs surveyed in several stages or when poor quality of the paper copy make the digitizer to read erratic values. Generally these false readings must be corrected externally and the logs for the problematic well must be reloaded once perfectly edited. Option TL (Figure 6.1), discussed at the end of this chapter, offers limited remedial action through truncation.
- Display of the shale logs is the best way to verify that the shale line has been properly determined. If the setting is unsatisfactory, change it

using the capability to modify the log header values described in the previous chapter or command BL in this same chapter.

Semivariogram

As seen in Chapter 3, CORRELATOR uses a log segment as a basis for correlation. Segments of radically different lengths may produce radically different results, which brings the need to properly decide the correlation length.

As seen in Chapter 3, the program uses the cross-correlation coefficient for the determination of correlating intervals. The coefficient decreases with discrepancies in signature and is maximum when the signatures are identical. Identical signatures precludes erratic variation within the interval under consideration, which requires perfect lateral continuity. It turns out that the range of the semivariogram is a statistical measure of the distance within which measurements are statistically correlated (Olea, 1999, Chapter 5).

For better resolution in the display, Figure 6.10 shows the semivariogram for only 200 ft (61 m) of log generated with option SE. The semivariogram always appears as a solid line in the central track. In all displays, the semivariogram is always calculated using the correlation log for the reference log, the Guard log of Schaben 1 in this example. For a long sequence such as the one in Figure 6.10, the range of a semivariogram is the minimum distance for which the semivariogram is equal to the variance, which CORRELATOR denotes with a segmented line. In this example, the range is about 6 ft (1.8 m), which implies that on average, at any given level, a reading is correlated to readings 6 ft (1.8 m) above and below. If the reader decides to process these logs, she or he will not notice much change in range trying the entire log or other portions of it.

Disregarding lateral variation in bed thickness, twice the range should be the maximum correlation interval that, on average, will consistently provide high signature similarities based on correlation coefficients.

Local semivariogram slope at the origin

The semivariogram, $\hat{\gamma}_1(h)$, in Figure 6.10 was calculated using

$$\hat{\gamma}_1(h) = \frac{1}{2n(k)} \sum_{j=1}^{n(k)} [z_{i+k} - z_i]^2$$

taking advantage of the fact that the readings are at a regular interval a . Hence the resolution of the curve is the same as the 0.5 ft (0.15 m) of the digitization interval. The argument h is equal to ka , which in Figure 6.10 varies from 0 to 200 ft (0–61 m); z_i is the reading for the correlation log in the reference well at depth z_i ; and $n(k)$ is the number of pairs of readings that are h ft apart. Calculation of the semivariogram in Figure 6.10 uses all readings in the interval—401 of them in this instance—hence, the display is an average characterization of the interval.

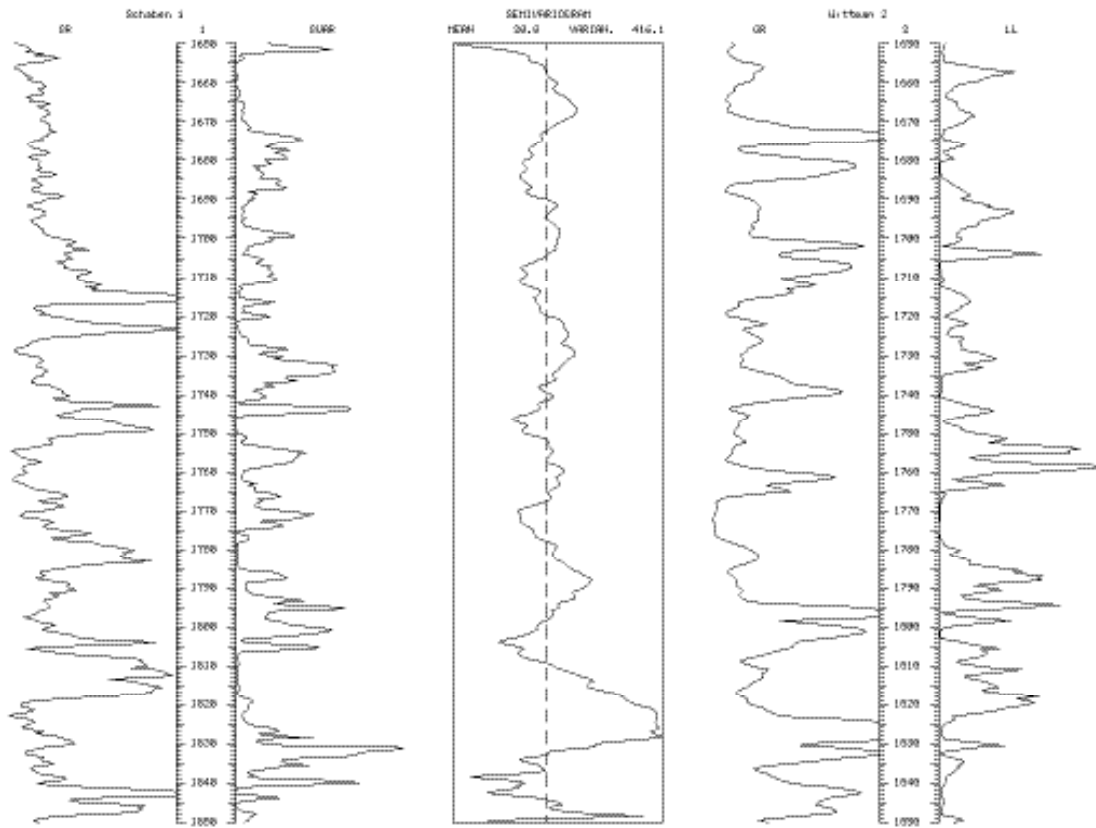


Figure 6.10. Semivariogram for the Guard log of well Schaben 1.

The incremental increase of the semivariogram at the origin per digitization interval is $\gamma_1(a)$, which in the case of Schaben 1 is $\gamma_1(0.5)$. An important difference of $\gamma_1(a)$ with the value of the semivariogram in Figure 6.10 is that only a maximum argument of 10 ft was used in the calculations employing option LS, so the qualification of local semivariogram. Figure 6.11 is a graph of the variation of $\gamma_1(0.5)$ for all the 10-ft windows centered at every depth from 1650 to 1850 ft (502.9–563.9 m) below sea level.

The local value of $\gamma_1(0.5)$ is sensitive to the smoothness of the log. The more sudden and frequent the fluctuations in the log, the higher is the local value of the slope, which commonly is associated with uniqueness in the signature. This property will be used in future chapters for the determination of the most obvious correlations. According to Figure 6.11, the most singular part of the Guard log is that from 1825–1840 ft (556.3–560.8 m).

Correction for base line of spontaneous potential logs

The spontaneous potential log was the only type of shale log available in the early days of wireline logging. It was gradually phased out by the higher resolution of gamma-ray logs. One additional problem of the spontaneous

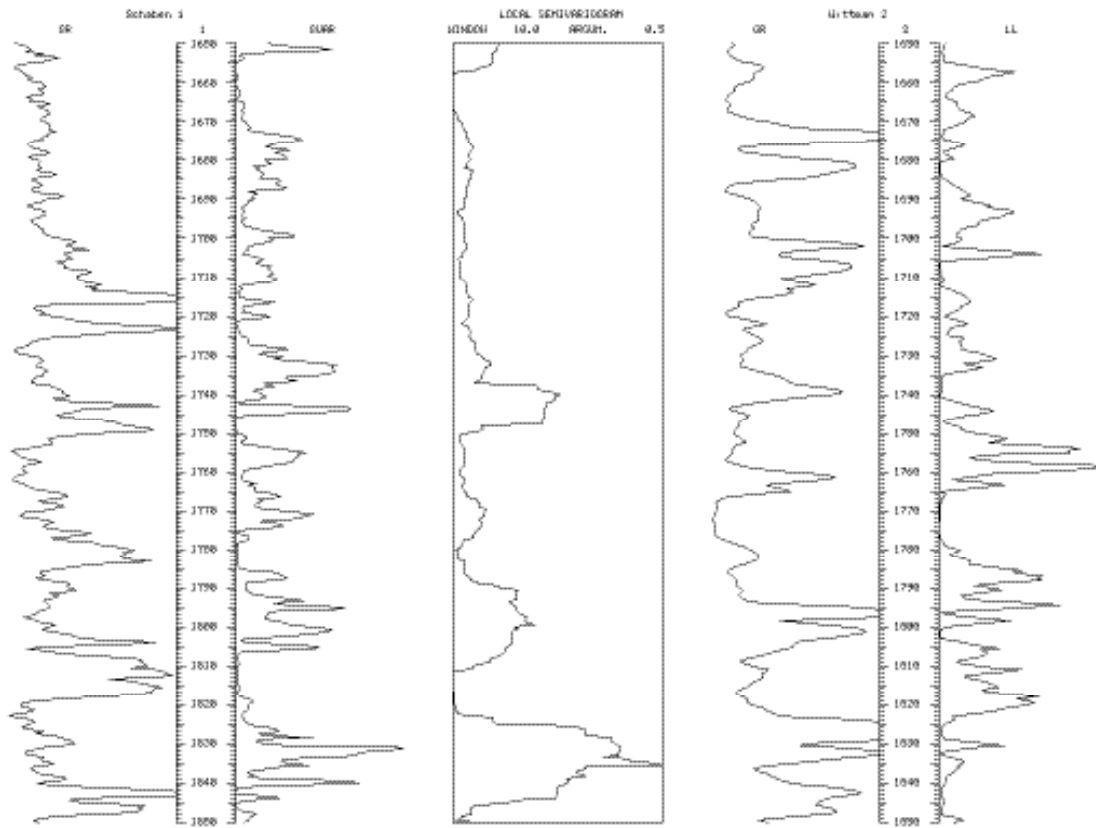


Figure 6.11. Value of (0.5) for log intervals of 10 ft at Schaben 1.

potential log was that commonly there was a drift in values due to increase in the salinity of the formation water. For best results, such trend must be eliminated. Because the trend is gradual, it can be approximated by a straight line or a low order polynomial, which must be an envelope to the right-side excursions of the log.

Option BL in the Analysis and Transformation menu allows experimentation with the envelope that, after subtraction from the raw values, should produce a corrected log with right-hand side excursions aligned along a vertical line. It is recommended to try and display with the help of command PL results obtained trying all reasonable polynomial degrees. The best corrected log should be saved into the well/log database, but only once the user is certain about a particular correction because changes are permanent and irreversible. The corrected data overwrite the values entered at the time of loading the log into the well/log database. Figure 6.12 shows an example using the menu in Figure 6.13. In this example, a simple linear shift suffices to make a satisfactory correction. The spontaneous potential log in Figure 6.12 (a) was originally entered into the well/log database with a polynomial correction of degree zero. Figure 6.14 is the corresponding shell window report.

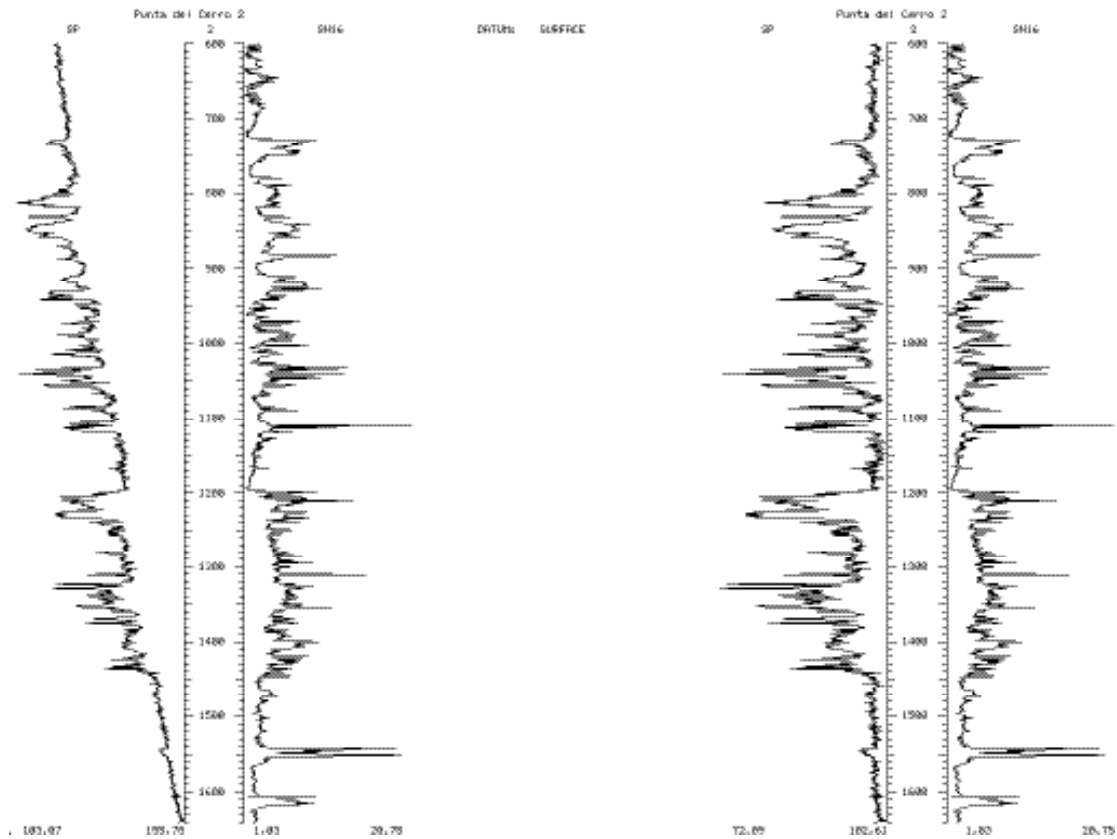


Figure 6.12. Spontaneous potential log from a Chilean well: (a) before and, (b) after correction of base line.

CORRECT THE SPONTANEOUS POTENTIAL BASE LINE

```

CR -- CORRECT THE REFERENCE SPONTANEOUS POTENTIAL LOG          YES
P1 -- POLYNOMIAL DEGREE                                         1

CM -- CORRECT THE MATCHING SPONTANEOUS POTENTIAL LOG          NO

SA -- SAVE CORRECTIONS IN DATABASE                              YES

RE -- RETURN TO PREVIOUS MENU
GO -- CORRECT BASE LINES

PLEASE ENTER YOUR SELECTIONS: go

```

Figure 6.13. Menu to correct base lines.

CORRECTION OF BASE LINE FOR SPONTANEOUS POTENTIAL LOG

INFORMATION ABOUT THE REFERENCE LOG

DEPTH INTERVAL FOR THE LOG IS 580.00 TO 1620.00

POLYNOMIAL DEGREE 1

COEFFICIENTS OF THE REGRESSION EQUATION

	1	2
1	93.460	0.037148

NUMBER OF SAMPLES	:	39
SUMS OF SQUARES DUE TO REGRESSION		4568.4
TOTAL SUM OF SQUARES	:	4743.4
CORRELATION COEFFICIENT	:	0.98138

CORRECTION PERMANENTLY MADE IN DATABASE.

Figure 6.14. Shell window report for a base line correction.

Trend removal

If the user considers that any of the up to four logs involved in the correlation of a pair of wells needs removal of a trend, option RT can perform the transformation through polynomial fitting. The difference with the previous option BL is that option RT uses a least square fitting to all the readings of a given log, not only the maxima, but both menus have the same options.

The trend removal is not kept permanently in the well/log database. The transformation lasts for the current execution of the program only.

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 through option SL. Standardization improves processing accuracy, which may be relevant on dealing with logs that have numerically large readings. Figure 6.15 shows a menu to standardize the resistivity logs of wells Schaben 1 and Wittman 2 and Figure 6.16 is the shell window report.

The standardization remains effective during the current execution of the program only.

Wireline log clipping

Logs in general and resistivity logs in particular tend to have outliers on the high side of the interval of variation. Such outliers may be defective readings that should be corrected or real values to keep. It is highly recommended that editing

STANDARDIZE WELL LOG VALUES

```

RS -- STANDARDIZE REFERENCE SHALE LOG                      NO
S2 -- STARTING DEPTH FOR REFERENCE SHALE LOG, FEET        1452.00
E2 -- ENDING DEPTH FOR REFERENCE SHALE LOG, FEET          2181.00

RC -- STANDARDIZE REFERENCE CORRELATION LOG                YES
S1 -- STARTING DEPTH FOR REFERENCE CORRELATION LOG, FEET  1452.00
E1 -- ENDING DEPTH FOR REFERENCE CORRELATION LOG, FEET    2181.00

MS -- STANDARDIZE MATCHING SHALE LOG                      NO
S4 -- STARTING DEPTH FOR MATCHING SHALE LOG, FEET        1452.00
E4 -- ENDING DEPTH FOR MATCHING SHALE LOG, FEET          2181.00

MC -- STANDARDIZE MATCHING CORRELATION LOG                YES
S3 -- STARTING DEPTH FOR MATCHING CORRELATION LOG, FEET  1452.00
E3 -- ENDING DEPTH FOR MATCHING CORRELATION LOG, FEET    2181.00

RE -- RETURN TO PREVIOUS MENU
GO -- STANDARDIZE LOGS
    
```

PLEASE ENTER YOUR SELECTIONS:

Figure 6.15. Menu for the standardization of logs.

PARAMETERS BEFORE THE STANDARDIZATION

	REFERENCE WELL LOGS SHALE CORRELATION	MATCHING WELL LOGS SHALE CORRELATION
MEAN	15.1296	73.0294
STANDARD DEVIATION	21.3959	92.7396

Figure 6.16. Shell window report after standardization of logs.

of logs be done prior to enter then into the well/log database. If necessary, however, option TL in the Analysis and Transformation menu (Figure 6.1) allows the user to correct abnormally high values after loading the logs. Figure 6.17 shows a menu to lower to 200 ohm-m²/m all resistivity values above such threshold. Figure 6.18 is the corresponding shell window report.

The truncation lasts for the current execution of the program only. To replicate the clipping, it will have to be repeated on every execution of the program.

TRUNCATE HIGHEST WELL LOG VALUES

ORIGINAL RANGE FOR REFERENCE SHALE LOG IS	21.40	TO	110.00
ORIGINAL RANGE FOR REFERENCE CORRELATION LOG IS	1.31	TO	315.00
ORIGINAL RANGE FOR MATCHING SHALE LOG IS	13.60	TO	110.00
ORIGINAL RANGE FOR MATCHING CORRELATION LOG IS	1.64	TO	743.27
RS -- TRUNCATE REFERENCE SHALE LOG AT			110.00
RC -- TRUNCATE REFERENCE CORRELATION LOG AT			315.00
MS -- TRUNCATE MATCHING SHALE LOG AT			110.00
MC -- TRUNCATE MATCHING CORRELATION LOG AT			743.27
RE -- RETURN TO PREVIOUS MENU			
GO -- EXECUTE THE TRUNCATIONS			

PLEASE ENTER YOUR SELECTIONS: rc 200 mc 200 go

Figure 6.17. Menu for the truncation of logs.

NEW MAXIMUM VALUES AFTER TRUNCATION

REFERENCE WELL LOGS		MATCHING WELL LOGS	
SHALE	CORRELATION	SHALE	CORRELATION
-----		-----	
	200.00		200.00

Figure 6.18. Example of shell window report after truncation of logs.

Chapter 7: Determination of correlations

We explained in Chapter 3 the theoretical approach employed by CORRELATOR to establish lithostratigraphic correlations. Chapter 7 contains detailed explanations on how to bring theory to practice.

To determine correlations, let us begin by choosing Correlation Finding option in the Main menu (Figure 4.1). After properly selecting the well/log database, the correlation database, and the pair of wells to correlate—operations previously explained in Chapter 5—the display will be that in Figure 7.1.

```

CORRELATION FINDING MENU

WB -- SELECT WELL/LOG DATABASE FILE          ->
WS -- SELECT WELLS                          ->
CB -- SELECT CORRELATION DATABASE           ->
SH -- STANDARDIZED SHALE SIMILARITY FOR A SINGLE LEVEL ->
CL -- CORRELATION COEFFICIENT FOR A SINGLE LEVEL ->
WL -- WEIGHTED CORRELATION COEFFICIENT FOR A SINGLE LEVEL ->
WI -- WEIGHTED CORRELATION COEFFICIENT FOR AN ENTIRE INTERVAL ->
RD -- REGRESSION ON DIFFERENCE IN ELEVATION

RE -- RETURN TO MAIN MENU

PLEASE ENTER YOUR SELECTION:
```

Figure 7.1. Correlation Finding menu.

Weighted correlation coefficient for a single level

Choose option WL in the Correlation Finding menu. Figure 7.2 exhibits such menu after changing the default parameters to a reference interval centered at 1895 ft (577.6 m) and a length twice the range of the semivariogram for the correlation log—12 ft (3.7 m)—which in this particular case is exactly the bed thickness. The search interval is defined by the depths to its top and bottom—in this example, the top and bottom of the digitized interval.

The result for this set of parameters is in Figure 7.3. The interval best correlating with another interval of the same length, is centered at 1850.5 ft (564 m), which is the correct answer according to the opinion of experts on the geology of this area. The strength of the matching is 0.772 in a scale (-1,1). On the other hand, the best inverse matching is -0.51, which is a mathematical curiosity of no interest in lithostratigraphic correlation.

WEIGHTED CORRELATION FOR A SINGLE REFERENCE LEVEL

DEPTH INTERVAL ON REFERENCE WELL IS 1452.00 TO 2181.00 FEET
 DEPTH INTERVAL ON MATCHING WELL IS 1439.00 TO 2141.50 FEET

CC -- CENTER OF CORRELATION INTERVAL, FEET 1895.00
 CL -- LENGTH OF THE CORRELATION INTERVAL, FEET 12.00
 TS -- TOP OF SEARCH INTERVAL, FEET 1439.00
 BS -- BOTTOM OF SEARCH INTERVAL, FEET 2181.00

RE -- RETURN TO PREVIOUS MENU
 GO -- FIND BEST MATCH

PLEASE ENTER YOUR SELECTIONS: go

Figure 7.2. Menu to find the best match for standardized shale similarity.

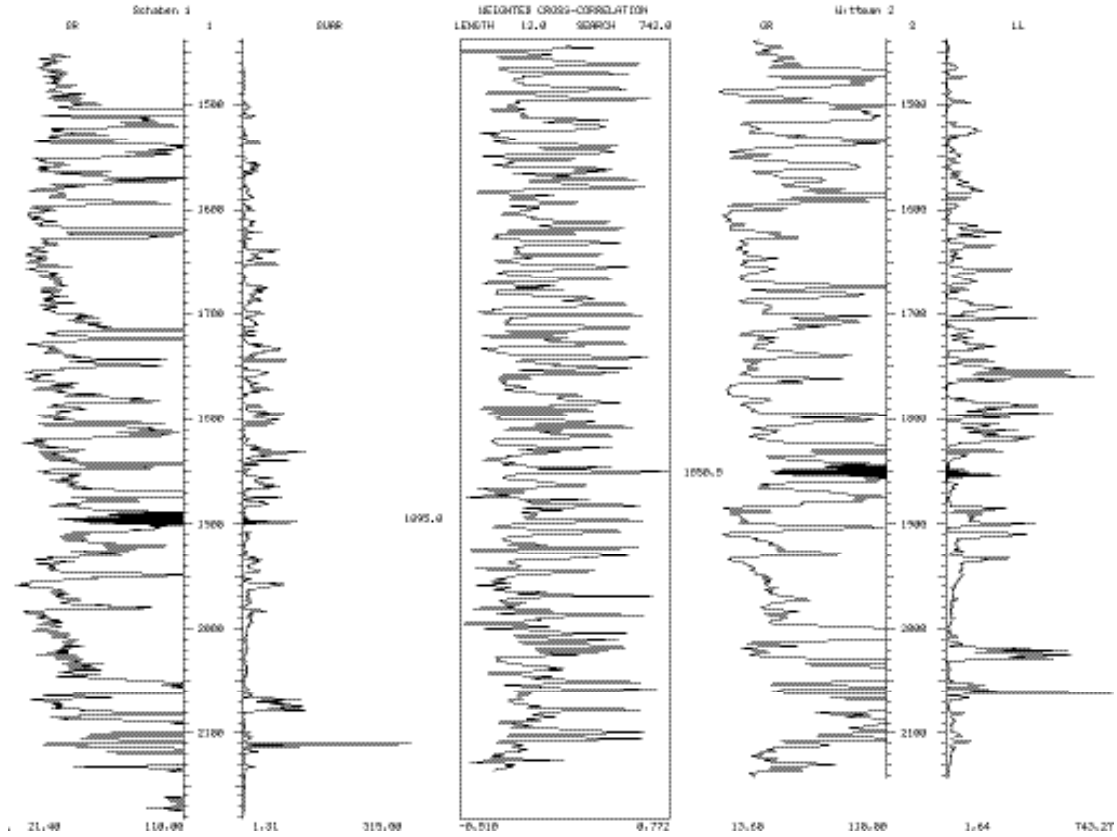


Figure 7.3. Weighted cross-correlation coefficient for an interval of 12 ft centered at 1895 ft at well Schaben 1.

Correlation saves at a correlation database

CORRELATOR allows saving different sets of correlations as separate documents in the correlation database that we have called interpretations. Figure 7.4 displays the menu for the saving option SA, which can be accessed from commands WL and WI in the Correlating Finding menu (Figure 7.1) after generating new correlations.

After identifying the interpretation, it is indeed possible to preserve the correlations for further use. Saving correlations in one or several interpretation is the basis for building up interpretations along cross sections, one pair of wells at a time. Figure 7.5 shows the confirmation report that will appear on the command window.

Standardized shale similarity for a single level

If the user is interested on separating the weighted correlation coefficient in its components, the programs allows the calculation of the standardized shale similarity and Pearsonian correlation coefficient separately. Option SH in the Correlation Finding menu has the same parameters than option WL in the previous section. Figure 7.6 displays the results for SH when using the same parameters than WL in Figure 7.2.

```

                                SAVE CORRELATIONS

CD -- CORRELATION INTERPRETATION IDENTIFICATION          *????*
SO -- SAVE OPTION -- APPEND, NEW, REPLACE                 NEW
RE -- RETURN TO PREVIOUS MENU

PLEASE ENTER YOUR SELECTIONS:
```

Figure 7.4. Menu for the saving of correlations in the correlation database.

```

                                SAVE CORRELATIONS
                                -----

WELL          1  VS 2

NUMBER OF CORRELATIONS ADDED IS                               1

NUMBER OF CORRELATIONS FOR INTERPRETATION IS                 1
```

Figure 7.5. Shell window report after saving correlations in the correlation database.

The best correlating interval is essentially the same. The small difference of 1 ft (0.3 m) may be due to offset in the registration of the gamma-ray log relative to the Guard log. The strength of the similarity is 0.933 in a scale from 0–1.

Pearsonian correlation coefficient for a single level

Selection of option CL at the Correlation Finding menu, duplication of parameters from the previous options, and execution of menu result in the display in Figure 7.7. The answer is completely wrong this time, which illustrates the convenience of using the standardized shale similarity jointly with the correlation coefficient in the form of weighted correlation coefficient.

Weighted correlation coefficient for an interval

While a detailed examination of every single correlation may be necessary for a few critical correlations, serious application of the program instead requires capabilities for the quick generation of large number of correlations. Such is the role of the alternative WI in the Correlation Finding menu, which offers great flexibility. Figure 7.8 displays a sensible set of parameters for the case of well Schaben 1.

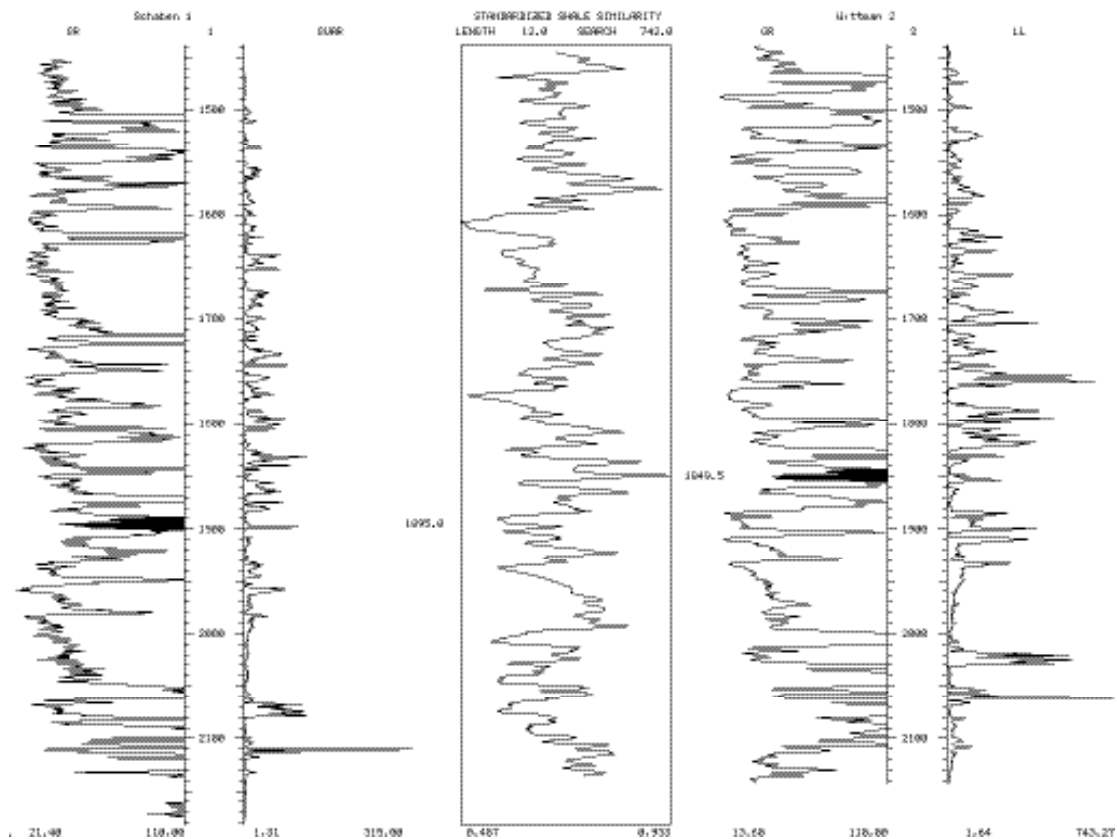


Figure 7.6. Standardized shale similarity for an interval of 12 ft centered at 1895 ft at well Schaben 1.

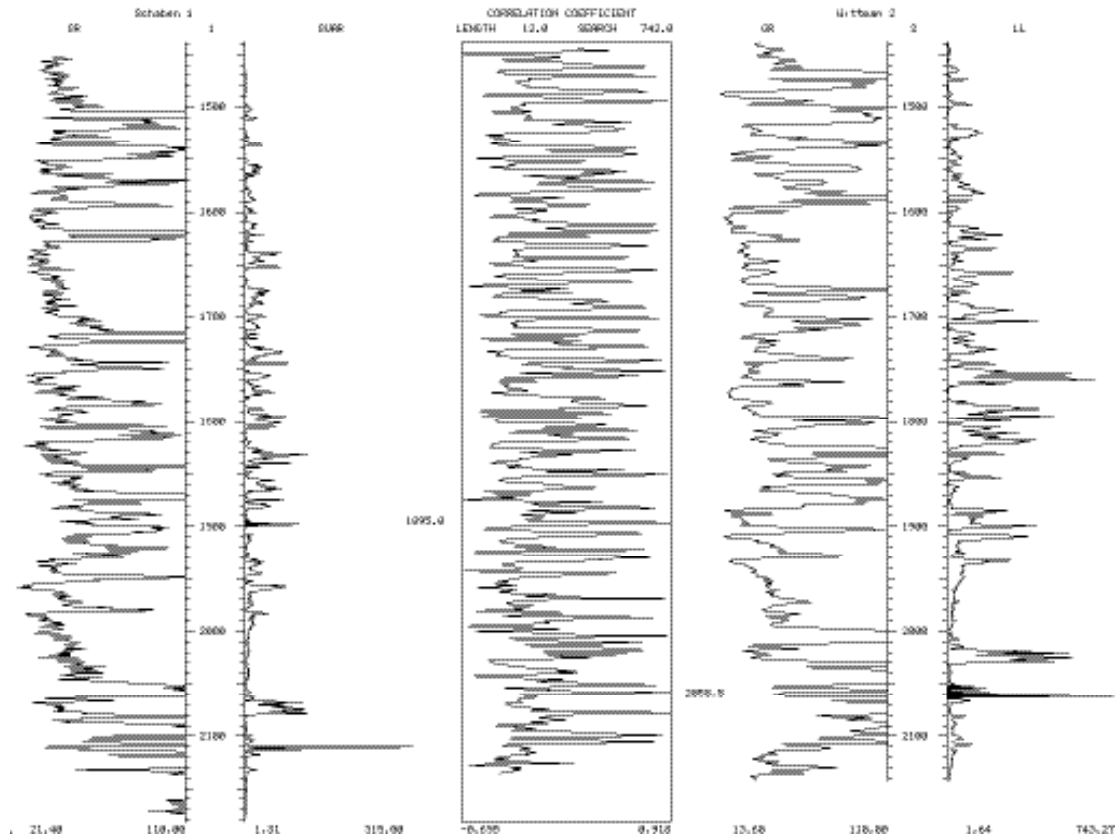


Figure 7.7. Correlation coefficient for an interval of 12 ft centered at 1895 ft at well Schaben 1.

Although the option is perfectly capable of generating correlation correlations for the entire digitized interval in the reference well, for the sake of brevity we opted for a 10-ft (3 m) interval only. The interval to display must be any interval enclosing the correlation interval in the reference well. The default value of 0.5 for the minimum correlation strength is a good threshold. Positive values below 0.5 indicate weak correlations the user does not want to rely on unless absolutely necessary, for example, on a difficult section to correlate. Negative values are of no interest in lithostratigraphic correlation.

Best guides for setting correlation length are:

- not to exceed twice the value of the semivariogram range, which 6 ft for Schaben 1;
- to consider at least 20 measurements.

We went for 11 ft (3.4 m) as a trial value that proved to be acceptable.

According to the calculation of a single correlation for depth 1895 (577.6 m), the correlated interval was 44.5 ft (13.6 m) higher at the matching well. Here we have presumed about the same apparent dip on picking a value for the offset. Finally, there is the problem of where to search for the correct match. Although a

search from top to bottom is always possible, it is not an efficient and realistic choice. Too restricted a search, on the other hand, may leave the true solution outside the search interval, which will assure a wrong answer. Thus, the best search interval is the shortest interval that includes the solution, which is certainly easier to postulate than quantify. In this case, considering the proximity to a confirmed correlation, we feel that twice the range of the semivariogram is a safe search length. Note that here, differently from the specification of search interval in command WL previously described in this chapter, the search interval is determined by its center and width.

The way the offset and the search interval operate is the following. For example, to search the interval that correlates with the 11-ft (3.4 m) interval centered at 1900 ft (579.1 m), CORRELATOR starts searching for the best weighted correlation coefficient from the reference elevation of 1900 ft (579.1 m) plus the offset minus half the search length to the reference elevation plus the offset plus half the search length, or (1843, 1867 ft) (561.8, 569.1 m). Figure 7.9 is a rendition of the results at the CORRELATOR window, which are also listed in the shell window shown in Figure 7.10.

```

WEIGHTED CORRELATION FOR AN INTERVAL

DEPTH INTERVAL ON REFERENCE WELL IS  1452.00 TO  2181.00  FEET
DEPTH INTERVAL ON MATCHING WELL IS    1439.00 TO  2141.50  FEET

ND -- STARTING DEPTH FOR PLOTTING, FEET                1820.00
XD -- ENDING DEPTH FOR PLOTTING, FEET                  1950.00
SC -- STARTING DEPTH FOR CORRELATION, FEET              1890.00
EC -- ENDING DEPTH FOR CORRELATION, FEET                1900.00

AC -- AUTOMATIC COMPUTATION OF CORRELATION LENGTH      NO
CF -- CORRELATION LENGTH AS A FRACTION OF THE ROCK UNIT  NO
CL -- CORRELATION LENGTH, FEET                          11.00

AO -- AUTOMATIC COMPUTATION OF CORRELATION OFFSET      NO
CO -- CORRELATION OFFSET, FEET                          -45.00

SL -- SEARCH LENGTH, FEET                               24.00
CO -- CORRELATION DISPLAY CUTOFF                        0.50

RE -- RETURN TO PREVIOUS MENU
GO -- CALCULATE CORRELATIONS

```

PLEASE ENTER YOUR SELECTIONS:

Figure 7.8. Example of menu to produce several weighted correlations in one batch.

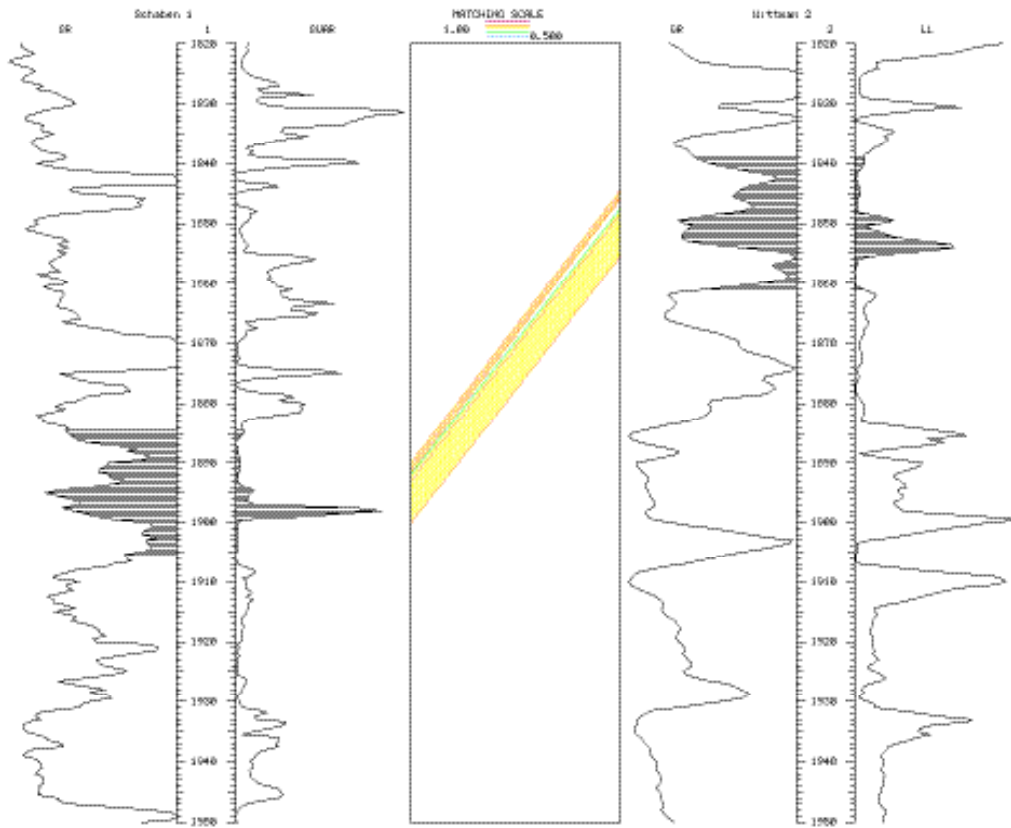


Figure 7.9. Display of several weighted correlations generated in one pass.

Note that now, instead of displaying all weighted correlation curves, the program just draws tie lines between the centers of the intervals with the best matches. Each match, in addition to the correlation between the centers, implies correlation of the top reading in the reference interval with the top reading in the matching interval, correlation of the second highest reading in the reference interval with the second highest reading in the matching interval, and so on. The total number of correlated levels in a pair of correlating intervals is one plus the interval length divided by the sampling interval, 23 readings for the correlations generated with the menu in Figure 7.8.

Upon going back to the menu that generated the correlations, the menu will offer the user two more options: redisplay the correlations or save them. If the user decides for the saving, the CORRELATOR window will display a menu similar to that in Figure 7.4.

TABLE OF CORRELATIONS FOR WELLS
 1 (Schaben 1) AND 2 (Wittman 2)

WELL DATA FILE: WL.DATABASE

DATUM: SEA LEVEL
 WELL 1 2248.0 FEET
 WELL 2 2261.0 FEET

REFERENCE LOGS GR - GUAR
 MATCHING LOGS GR - LL
 DIGITIZATION INTERVAL 0.5 FEET
 SEARCH LENGTH 48.0 FEET
 CORRELATION DISPLAY CUTOFF 0.500

DATA - RESULTS

WEIGHTED CROSS-CORRELATION DIF. W. C.-C.
 LENGTH OFFSET FROM TO ELEV. COEFFICIENT
 FEET FEET FEET FEET FEET
 =====

11.0	-45.0	1890.0	1844.5	-45.5	0.842	****
11.0	-45.0	1890.5	1845.0	-45.5	0.824	**
11.0	-45.0	1891.0	1845.5	-45.5	0.828	**
11.0	-45.0	1891.5	1846.0	-45.5	0.834	***
11.0	-45.0	1892.0	1847.5	-44.5	0.678	
11.0	-45.0	1892.5	1848.0	-44.5	0.786	
11.0	-45.0	1893.0	1848.5	-44.5	0.808	
11.0	-45.0	1893.5	1849.0	-44.5	0.799	
11.0	-45.0	1894.0	1849.5	-44.5	0.771	
11.0	-45.0	1894.5	1850.0	-44.5	0.768	
11.0	-45.0	1895.0	1850.5	-44.5	0.771	
11.0	-45.0	1895.5	1851.0	-44.5	0.773	
11.0	-45.0	1896.0	1851.5	-44.5	0.772	
11.0	-45.0	1896.5	1852.0	-44.5	0.771	
11.0	-45.0	1897.0	1852.5	-44.5	0.776	
11.0	-45.0	1897.5	1853.0	-44.5	0.779	
11.0	-45.0	1898.0	1853.5	-44.5	0.779	
11.0	-45.0	1898.5	1854.0	-44.5	0.777	
11.0	-45.0	1899.0	1854.5	-44.5	0.781	
11.0	-45.0	1899.5	1855.0	-44.5	0.789	
11.0	-45.0	1900.0	1855.5	-44.5	0.801	

CORRELATION ON REFERENCE WELL : 21.0 FEET
 WEIGHTED CORRELATION ON REFERENCE WELL : 16.5 FEET
 AVERAGE WEIGHTED CORRELATION COEFFICIENT : 0.786

Figure 7.10. Shell window report for the correlations in Figure 7.9.

Differences in elevation between correlating intervals

The whole exercise of lithostratigraphic correlation is based on the presumption of an organized deposition and preservation of sediments. If such assumption is true, for a given pair of wells, changes in correlation with depth should also display systematic variations. Figure 7.11 contains a list of correlating intervals that were determined using option WL previously discussed in this chapter. As it can be observed at the graph in Figure 7.12, such correlations indeed show a trend that can be characterized by a third degree polynomial. This possibility of finding trends in the fluctuations in correlations will be later exploited in this chapter to rationalize the setting of the correlation search interval, thus the term anchoring correlations used to describe them in this manual.

```

PROCESSING PARAMETERS AND CORRELATION RESULTS FOR
*****
WELLS 1 (Schaben 1      ) AND 2 (Wittman 2      )
*****

          DATUM: SEA LEVEL   ( 2248.0; 2261.0)
          REFERENCE LOGS     GR  - GUAR
          MATCHING LOGS      GR  - LL

          BASIC INFORMATION                FINAL RESULTS

CORREL SEARCH SEARCH DISPLAY REFER. MATCH  DIF.  WEIGHTED CORREL.
LENGTH LENGTH OFFSET CUTOFF  DEPTH  DEPTH  DEPTH  COEFFICIENT
FEET     FEET  FEET          FEET   FEET   FEET
=====
24.0     742.0   0.0   -1.000   1500.0  1463.0  -37.0   0.820  **
24.0     742.0   0.0   -1.000   1555.0  1520.0  -35.0   0.782
24.0     742.0   0.0   -1.000   1700.0  1658.0  -42.0   0.677
24.0     742.0   0.0   -1.000   1745.0  1705.0  -40.0   0.774
24.0     742.0   0.0   -1.000   1795.0  1753.0  -42.0   0.620
24.0     742.0   0.0   -1.000   1830.0  1784.5  -45.5   0.726
24.0     742.0   0.0   -1.000   1900.0  1855.5  -44.5   0.758
24.0     742.0   0.0   -1.000   1985.0  1934.5  -50.5   0.743
24.0     742.0   0.0   -1.000   2065.0  2015.5  -49.5   0.777
24.0     742.0   0.0   -1.000   2115.0  2066.0  -49.0   0.624
    
```

Figure 7.11. Listing of anchoring correlations for wells Schaben 1 and Wittman 2.

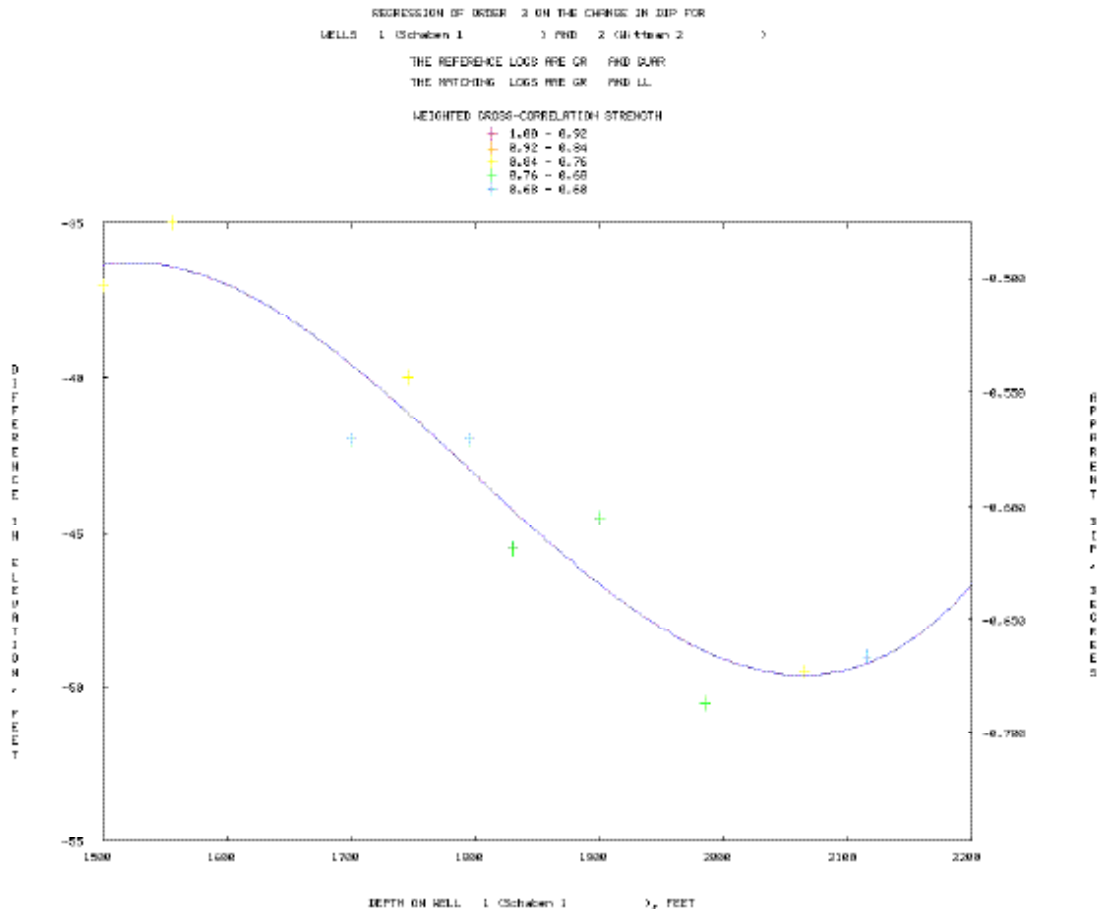


Figure 7.12. Regression of differences in elevation for the correlations in Figure 7.11.

The selection of the reference elevations in Figure 7.11 was based on a graph of the slope of the local semivariogram discussed in Chapter 6. The length of the correlation was purposely set at four times the length of the semivariogram range to capture only correlation with a signature length larger than average.

Preparation of graphs such as Figure 7.12 is possible through the use of option RD at the Correlation Finding menu. Figure 7.13 contains the parameters to generate the graph and Figure 7.14 contains a short version of the statistical report, which proves that in this case a polynomial of degree 3 can capture fluctuation in differences in elevation with a maximum discrepancy of less than 5 sampling intervals for a goodness of fit of 92%. Execution of the menu for option RD needed for this example requires a change in the default selection for the correlation interpretation, which is explained in the next section. Upon calculation of the regression, the results of up to 10 regressions can be saved together with the correlation results in each interpretation. Replacements and deletions are also possible when more than one regression are saved with the interpretation.

Selection of a correlation interpretation

As mentioned previously in this chapter, a fundamental capability of CORRELATOR is the progressive saving of satisfactory results in the correlation database in partitions called interpretations. Every one of the multiple menus dealing with interpretations has the option to select the interpretation of choice. Figure 7.15 displays the menu and selections that allowed picking the second interpretation.

```
REGRESSION ON DIFFERENCE IN ELEVATION

REFERENCE WELL ( 1): Schaben 1
MATCHING WELL ( 2): Wittman 2
INTERPRETATION (2): Anchoring correlations

CI -- SELECT CORRELATION INTERPRETATION                ->
ND -- MINIMUM DEPTH FOR REGRESSION, FEET                1500.00
XD -- MAXIMUM DEPTH FOR REGRESSION, FEET                2115.00
MC -- MINIMUM WEIGHTED CORRELATION COEFFICIENT          0.600
PD -- POLYNOMIAL DEGREE. A NEGATIVE DEGREE DISPLAYS DATA ONLY 3
LI -- LIST DETAILED REPORT                              NO

RE -- RETURN TO CORRELATION FINDING MENU
GO -- CALCULATE REGRESSION COEFFICIENTS
```

PLEASE ENTER YOUR SELECTIONS:

Figure 7.13. Menu used to generate Figure 7.12

```
ORDER OF EQUATION:          3
NUMBER OF OBSERVATIONS:     21
TOTAL SUM OF SQUARES:       251.50
TOTAL SUM OF SQUARES DUE TO REGRESSION:      232.05
TOTAL SUM OF SQUARES DUE TO DEVIATION:       19.451
MAXIMUM UNDERESTIMATION:    -2.15605
MAXIMUM OVERESTIMATION:     2.42383
GOODNESS OF FIT:            0.922660
CORRELATION COEFFICIENT:    0.960552
```

Figure 7.14. Shell window summary report for the regression in Figure 7.12.

SELECT A CORRELATION INTERPRETATION

#	DESCRIPTION	TOP	BOTTOM	# CORR	# REGS
1	Figure 7.7	1890.0	1900.0	21	0
2	Anchoring correlations	1500.0	2115.0	10	0

CI -- CORRELATION INTERPRETATION NUMBER 1

RE -- RETURN TO PREVIOUS MENU

GO -- SELECT CORRELATION INTERPRETATION

PLEASE ENTER YOUR SELECTIONS: ci 2 go

Figure 7.15. Menu to select a correlation interpretation.

The last column in the header denotes the number of regressions on differences in elevation for the interpretation. Such number is 0 in this example because the exhibit in Figure 7.15 took place before the execution of the option RD that led to the storage of the regression parameters.

Guided search

Two sections above we showed that differences in elevation for correlating intervals may have a systematic variation that can be partly modeled by a polynomial. Given sufficient control points, the fit is never perfect, otherwise fitting a polynomial would be the solution to the correlation problem. The dispersion, however, is an indication of actual deviation of the true correlations around the polynomial and is typical of the uncertainty associated to spatial estimation problems.

CORRELATOR takes advantage of polynomial fitting to differences in elevation between correlating levels to guide the search of lithostratigraphic equivalence by weighted correlation. To take advantage of this capability, activate the automatic computation of correlation offset in the menu in Figure 7.8. The program will respond by requesting the location of the regression equation. Selection of option RG will lead to a menu that will allow the selection of the interpretation first and then the regression equation. Figure 7.16 shows the menu to select the regression that we saved using the anchoring correlations in Figure 7.12.

Proper selection of a regression equation takes care of the determination of the center of the search interval automatically, leaving only the problem of determination of the search-interval length. When using a regression on anchoring correlations to offset the search, a good indication of true offset between the unknown correlation is the absolute value of the maximum fitting error. Under no circumstances the length of the search should be less than twice such error, with three to four times such value being a sufficiently conservative

value to include, under most circumstances, the true answer inside the search interval. For the case of Schaben 1, the absolute value of the maximum error is 2.4 ft (0.73) m. Hence the length of the search interval should be at least 5 ft (1.5 m), preferably 10 ft (3 m) to provide for search of correlations that could deviate even more from the polynomial trend than the anchoring correlations in Figure 7.11 saved as Interpretation 2.

Figure 7.17 shows all the correlations between 1700–1760 ft (518.2–536.5 m) in the reference well that are obtained using automatic search with the polynomial derived from the anchoring correlations and a search length of 10 ft (3 m). Correlation length and cutoff remain the same as those in Figure 7.8. Storage location for regressions and storage for correlations are independent, so for example, the new correlations can be stored as a third interpretation.

Automatic variable correlation length

This section concludes the explanation of parameters in the important menu in Figure 7.8. There are three parameters in such menu related to correlation length. So far we have dealt with fix length only, fix length that we have recommended to be one to twice the semivariogram range.

The value 50% shale content is an important value in CORRELATOR. In a binary classification, everything that is above such value, is considered a shale, everything at that level or below, is regarded a clean unit. This binary lithological classification is the key to automatically determine correlation intervals proportional to the thickness of those shales and clean units.

```

SELECT REGRESSION EQUATIONS

# DEGREE      TOP      BOTTOM    CUTOFF    ERROR
1      3      1500.0    2115.0    0.000    MINIMUM  MAXIMUM  CORR.
                                           -2.156    2.424    COEF.
                                           0.9606

-----

CI -- SELECT CORRELATION INTERPRETATION          -->
SE -- REGRESSION EQUATION TO SELECT              0

RE -- RETURN TO PREVIOUS MENU

PLEASE ENTER YOUR SELECTIONS: se 1 go

```

Figure 7.16. Menu to select a regression equation stored in the correlation database.

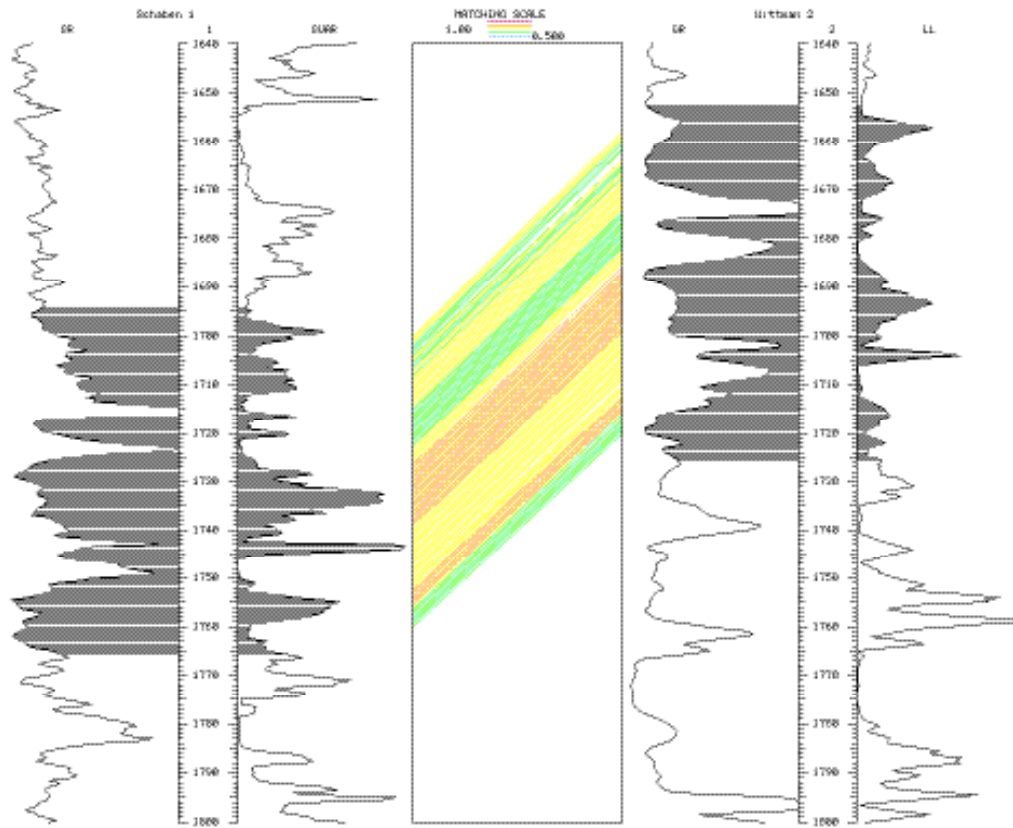


Figure 7.17. Example of weighted cross-correlations obtained using automatic calculation of search interval.

Option CF in the WI menu takes a fix fraction of the shale or clean units to which the level in the reference well belongs. The default value is 2/3. The problems with this option are the very thin and very thick units. Units too thin produce too short correlation intervals. When intervals are too short, the signature lack character and there is a tendency to generate correlations at random. The opposite happens for units too thick. The signature is too complex, so the correlations tend to be too weak because of the impossibility to find good matches in the matching well.

Option AC is an improvement of option CF that intends to eliminate the problems created by units with extreme thickness. The user has to enter reference values of thickness and an associated fraction. The correlation length remain constant outside these thickness values. The default values are:

Lower bound for the rock unit length, feet	10.0
Optimal fraction at that lower bound	1.0
Upper bound for the rock unit length, feet	100.0
Optimal fraction at that upper bound	0.2

For these parameters, no correlation interval will be less than 10 ft (3 m), no one will be larger than 20 ft (6 m), and correlation length will vary linearly between those two values. Proper calibration may be time consuming, but be worth the effort in critical areas hard to correlate. In the particular case of wells Schaben 1 and Wittman 2, there is no advantage of variable length over straight 11-ft (3.4 m) length.

The problem of abnormal correlations

Erroneous correlations may happen because the reference interval is indeed more petrophysically similar to the wrong interval in the matching well than to the actual lithostratigraphically equivalent interval, such as the example in Figure 7.18. Remember that despite the heavy overlapping between successive intervals, correlation of a new interval is done independently of previous results for the same pair of wells and from other pairs of wells.

Knowledge-based systems are exceptionally qualified to learn from experts and produce diagnostics based from the experience passed to the system, such as inspecting a table of correlations and deciding which correlations are perfectly acceptable and which are suspect to be in error. A dialog between the expert system and the user appears in Figure 7.19

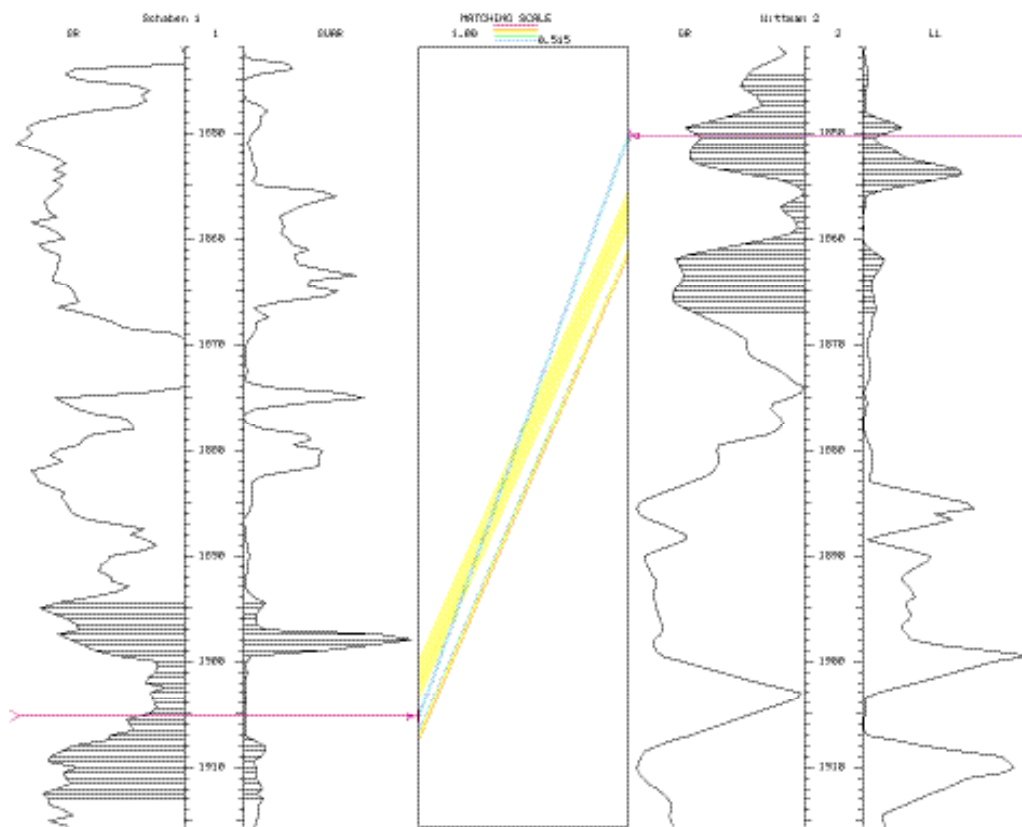


Figure 7.18. Example of abnormal correlation.

**** CORRELATIONS FROM 1905.0 TO 1905.5 FEET SHOULD BE ELIMINATED. IS YOUR ANSWER Y (YES), N (NO), W (WHY), OR S (STOP): w

SOME CHARACTERISTICS OF THE BUNDLES INVOLVED IN THE ANALYSIS

REFERENCE DEPTH FEET	MATCHING DEPTH FEET	AV. DIFFER. IN ELEVATION FEET	AV. WEIGHTED CORR. COEF.	NUMBER OF CORRELATIONS
1900.0	1855.5	-44.5	0.801	1
1900.0 TO 1903.5	1855.5 TO 1859.0	-44.5	0.767	8
1905.0 TO 1905.5	1850.0 TO 1850.5	-55.0	0.540	2 *
1906.5 TO 1907.5	1861.5 TO 1861.5	-45.8	0.712	3

THE FOLLOWING RULE WAS SUCCESSFULLY TESTED:

ELIMINATE LOWER BUNDLE OF CROSSING CORRELATIONS.

BECAUSE:

- THE DIP IS ABNORMAL FOR THE LOWER BUNDLE.
- THE CORRELATION IS THE WEAKEST FOR THE LOWER BUNDLE.
- THERE IS A GAP AROUND THE LOWER BUNDLE.

PLEASE ANSWER Y (yes) OR N (no): DO YOU WANT TO ELIMINATE THE CORRELATIONS NOW: y

Figure 7.19. Expert-system dialog to decide the fate of an abnormal correlations.

Figures 7.18 and 7.19 were generated after inspecting Interpretation 4 with module EC in the Geologic Interpretation menu on display in Figure 7.20. The menu for option EC is in Figure 7.21. Remember that the analysis is made based on bundles of parallel correlation within the same rock unit. Parameters FW and CW are used to relax the condition of perfect parallelism, namely identical apparent dip in the correlations. Two subparallel correlations within the same rock unit are still considered part of the same bundle if the differences in elevation at the reference and matching wells differ by less than the larger of CW and FW times the rock unit length. A value of FW equal to zero, as it is in Figure 7.21, will restrict the comparisons to CW. Parameters CB and FB are similarly used to decide which changes in apparent dip between bundles are acceptable and which ones should be flagged as abnormal.

GEOLOGIC INTERPRETATION MENU

WB -- SELECT WELL/LOG DATABASE FILE -->
WS -- SELECT WELLS -->
CB -- SELECT CORRELATION DATABASE FILE -->
EC -- ELIMINATE CROSSING AND ABNORMAL CORRELATIONS -->
DF -- DETECT FAULTS -->
TP -- PRINT PERSISTENT CORRELATIONS -->
TM -- PRINT MARKERS -->
AD -- PLOT APPARENT DIP DIAGRAMS IN A CROSS SECTION -->
TD -- PLOT TRUE DIP DIAGRAMS IN A CROSS SECTION -->
LP -- PRINT AND PLOT PERSISTENT CORRELATION IN A CROSS SECTION -->
LM -- PRINT AND PLOT MARKERS IN A CROSS SECTIONS -->
PS -- DISPLAY PROPORTION OF SHALE IN A CROSS SECTION -->
PO -- DISPLAY POROSITY IN A CROSS SECTION -->
LL -- DISPLAY LITHOLOGY IN A CROSS SECTION -->
RE -- RETURN TO MAIN MENU -->

PLEASE ENTER YOUR SELECTION:

Figure 7.20. Display of Geologic Interpretation menu after selection of well/log database, correlation database, and a pair of wells.

CORRELATION INTERPRETATION EDITING

REFERENCE WELL (1): Schaben 1
MATCHING WELL (2): Wittman 2
INTERPRETATION (4): Figure 7.18

CI -- SELECT CORRELATION INTERPRETATION, FEET -->

DM -- DEPTH TO START THE INSPECTION, FEET 1900.00
FW -- DIVERGENCE FACTOR WITHIN A BUNDLE, % OF SEARCH INTERVAL 0.0
CW -- CRITICAL DIVERGENCE WITHIN A BUNDLE, FEET 2.0
FB -- DIVERGENCE FACTOR BETWEEN A BUNDLES, % OF SEARCH INTERVAL 0.0
CB -- CRITICAL DIVERGENCE WITHIN A BUNDLE, FEET 5.0

RE -- RETURN TO PREVIOUS MENU
GO -- EDIT INTERPRETATION

PLEASE ENTER YOUR SELECTIONS:

Figure 7.21. Menu employed to edit the abnormal correlation in Figure 7.18.

SORT CORRELATION INTERPRETATION

REFERENCE WELL (1): Schaben 1
MATCHING WELL (2): Wittman 2
INTERPRETATION (2): Anchoring correlations

CI -- SELECT CORRELATION INTERPRETATION ->
RE -- RETURN TO PREVIOUS MENU
GO -- SORT THE CORRELATION INTERPRETATION

PLEASE ENTER YOUR SELECTIONS: go

Figure 7.22. Menu for the sorting of correlations.

To permanently keep the changes in the correlation database, the user has to save the edited interpretation by accepting a new saving option SV that will appear in the EC menu.

Editing of an interpretation with the expert system presumes that correlations are sorted by increasing value in the reference depth.

Correlation sorting by depth

Several applications of the program require that the correlations be sorted by increasing value in the reference depth. Option SO, one of the many utilities in the File Management menu (Figure 5.1), is there to do the job if the correlations have not been saved by increasing depth in the correlation database. Figure 7.22 shows the simple, one step menu required for sorting an interpretation after proper selection of such interpretation.

A brief report on the command window will indicate the successful completion of the operation.

Manual preparation of an interpretation file

Sometimes there is solid external information that may be of help particularly to prepare an interpretation with anchoring correlations. Option MC in the File Management menu (Figure 5.1) allows for the input of correlations directly into the correlation database.

Figure 7.23 offers an example of data preparation to enter a pair of correlating depths. Execution results in an expanded menu, allowing the alternative to save the manual correlation into an existing or new interpretation, not necessarily at the default interpretation 1 in Figure 7.23. The menu to save the correlation will be similar to that in Figure 7.4.

MANUAL PREPARATION OF A CORRELATION INTERPRETATION

REFERENCE WELL (1): Schaben 1
MATCHING WELL (2): Wittman 2
INTERPRETATION (1): Figure 7.7

DR -- DEPTH AT THE REFERENCE WELL, FEET BELOW SEA LEVEL 1508.0
DM -- EQUIVALENT DEPTH AT THE MATCHING WELL, FEET BELOW SEA LEVEL 1470.0

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE CORRELATION INTERPRETATION

PLEASE ENTER YOUR SELECTIONS: go

Figure 7.23. Example of menu to enter correlations established outside CORRELATOR.

This option should be used sparingly, if ever at all. Preference should be given to enter the correlations through options WL or WI in Correlation Finding menu (Figure 7.1). If the correlation is a good one, it will be confirmed and possibly corrected to a more precise equivalence, as is the case with the example in Figure 7.23; reference depth 1508 ft (459.6 m) is really correlating with depth 1471 ft (448.4 m) in the matching well. If the correlation to be entered through option MC cannot be confirmed by option WL, then the correlation is wrong or at best dubious. In either case, the correlation should not be entered into any interpretation. Yet users love to have the possibility to impose correlations, thus the existence of option MC. Refrain from using it!

Manual elimination of correlations

Just as the user can add correlations manually to an interpretation, she or he can also delete any correlations. This is another option that should be employed as a last resort. Activation of the option also requires access to the File Management menu (Figure 5.1). Figure 7.24 display a menu resulting from the execution of option DL, which requires previous selection of well/log database, correlation database, well pair, and interpretation. In this instance, the database and well selections are the same ones used previously. The default interpretation is the first one.

Deletions are permanent. Hence, having decided to eliminate correlations, the program will ask for a confirmation to minimize the possibility to eliminate correlations by mistake. Figure 7.25 show the program window warning for the case of attempting to eliminate the last correlation in the first interpretation. Actual elimination of correlations generates a report such as Figure 7.26 in the shell window.

DELETE CORRELATIONS FROM INTERVAL

REFERENCE WELL (1): Schaben 1
MATCHING WELL (2): Wittman 2
INTERPRETATION (1): Figure 7.9

MINIMUM CORRELATION DEPTH, FEET	1890.00
MAXIMUM CORRELATION DEPTH, FEET	1900.00
CI -- SELECT CORRELATION INTERPRETATION	->
ND -- TOP OF INTERVAL TO BE DELETED, FEET	-1.0
XD -- BOTTOM OF INTERVAL TO BE DELETED, FEET	-1.0
RE -- RETURN TO FILE MANAGEMENT MENU	
GO -- DELETE CORRELATIONS FROM INTERVAL	

PLEASE ENTER YOUR SELECTIONS:

Figure 7.24. Menu for the deletion of correlations.

**** 1 CORRELATION(S) WILL BE DISCARDED

RE -- STOP DELETION OF SUCH CORRELATION(S)
GO -- PROCEED WITH THE DELETION(S) AS PLANNED

PLEASE ENTER YOUR SELECTIONS:

Figure 7.25. Warning in an attempt to eliminate correlations.

```
CORRELATION DELETION
*****
REFERENCE WELL      1
MATCHING WELL      2
TOP FOR DELETION, FEET      1890.00
BOTTOM FOR DELETION, FEET   1890.00
CORRELATIONS DISCARDED      1
```

Figure 7.26. Shell window report on eliminated correlations.

Chapter 8: Correlation display

Upon establishing some correlations, the most direct utilization of them is straight display and listing. This chapter offers several alternatives for such capabilities. In all instances, we will presume previous loading of the well/log database and the correlation database.

Window graphical display of correlations

For rendition of correlations at the program window, choose the Correlation Display option in the Main menu (Figure 4.1). Figure 8.1 shows the Correlation Display menu after selecting the well/log database and the correlation database. The option that makes window displays of correlations is command WD. Its execution presumes prior selection of the pair of wells, operation covered in Chapter 6, and choosing of an interpretation, covered in Chapter 7. After selecting the wells, execution of the menu in Figure 8.1 will result in another menu, shown in Figure 8.2 after changing the setting to the values of interest. Execution of the menu in Figure 8.2, results in Figure 8.3.

Note that it is possible to independently set the correlated interval and the interval to display. Setting them both to (1640, 1800 ft) (499.9, 548.6 m) would generate the same display as in Figure 7.17. The correlated interval cannot go beyond the interval to display.

```

CORRELATION DISPLAY MENU

WB -- SELECT WELL/LOG DATABASE FILE          ->
CB -- SELECT CORRELATION DATABASE           ->
WS -- SELECT WELL PAIR                      ->
PC -- PLOT CORRELATION INTERPRETATIONS      ->
RE -- RETURN TO MAIN MENU

OTHER OPTION INCLUDE:

WL -- WINDOW LISTING OF A CORRELATION INTERPRETATION
WD -- WINDOW DISPLAY OF A CORRELATION INTERPRETATION
CP -- COPY A CORRELATION INTERPRETATION INTO A PRINTING FILE

WL, WP, AND CP REQUIRES PREVIOUS EXECUTION OF OPTION WS.

PLEASE ENTER YOUR SELECTION:
```

Figure 8.1. Correlation Display menu.

WINDOW DISPLAY OF A CORRELATION INTERPRETATION

REFERENCE WELL (1): Schaben 1
 MATCHING WELL (2): Wittman 2
 INTERPRETATION (3): FIGURE 7.17

DEPTH INTERVAL ON REFERENCE WELL IS 1452.00 TO 2181.00 FEET
 DEPTH INTERVAL ON MATCHING WELL IS 1439.00 TO 2141.50 FEET

```

CI -- SELECT CORRELATION INTERPRETATION                               ->

ND -- MINIMUM DEPTH TO DISPLAY, FEET                                1640.00
XD -- MAXIMUM DEPTH TO DISPLAY, FEET                                1800.00
NC -- MINIMUM CORRELATION DEPTH, FEET                               1710.00
XC -- MAXIMUM CORRELATION DEPTH, FEET                               1750.00

RE -- RETURN TO CORRELATION DISPLAY MENU
GO -- DISPLAY THE FILE
    
```

PLEASE ENTER YOUR SELECTIONS:

Figure 8.2. Menu for window display of correlations.

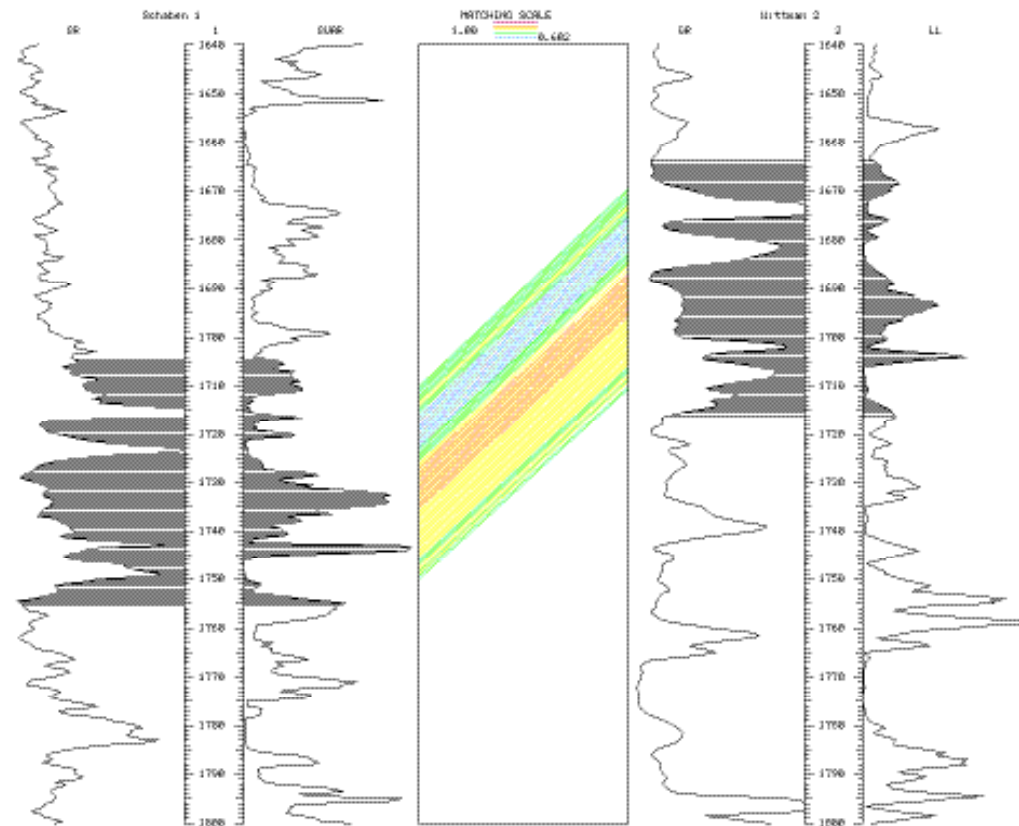


Figure 8.3. Window display of correlations.

So far, all graphical displays of results have been electronic. The reason is that, up to now, most of the results have been basic results, not necessarily final results of lithostratigraphic interest. Option PC does offer the possibility to prepare hardcopies of correlations. However, handling the option requires previous skills that we will explain first in the next sections.

Selection of file to store graphical display

The default option for the file name to store a graphical display is PLOT.COR and the default option for graphical encoding is one suitable for a Calcomp plotter. Use option PL in menu Settings and Preferences to override these options. Figure 8.4 displays the menu after selecting preparation of a page size cross section to be stored as PostScript code in a file named FIGURE.8.10.PS.

In case a display ends up being physically larger than the dimensions specified here, the program will rescale the cross section automatically to fit the specified size, rather than trimming it. The plotting file will not accept multiple cross sections. In case there is the need to really prepare several cross sections, each one will have to go into a separate file. If the user accidentally saves several plotting files to the same graphic file, only the last one will be preserved.

Selection of file to print report

All reports have been written on the shell window on the presumption that they are mostly temporary documents. Their value is primarily to confirm the proper selection of options and its parameters, and the adequacy of the results. Most hardcopy displays of cross sections generate a hardcopy report also, which by default goes to file PRINT.COR. Use option PR to change the file name. Its menu is in Figure 8.5.

```

INITIALIZE A PLOTTING FILE

FN -- NAME OF THE PLOTTING FILE                               FIGURE.8.10.PS

PL -- SELECT CODE -- CALCOMP (C) OR POSTSCRIPT (P)          POSTSCRIPT

PS -- SET PAPER SIZE                                         1
  1 = A (8.5 X 11)      4 = D (22 X 34)      7 = G (50 X 100)
  2 = B (11 X 17)      5 = E (34 X 100)     8 = A4 (8.75 X 11.75)
  3 = C (17 X 22)      6 = F (44 X 100)     9 = A3 (11.75 X 16.5)

MA -- SET MARGIN SIZE OF PAPER                               0.25

RE -- RETURN TO FILE MANAGEMENT MENU
GO -- INITIALIZE THE PLOT FILE

PLEASE ENTER YOUR SELECTIONS: go

```

Figure 8.4. Change of default options for a plotting file.

INITIALIZE A PRINTER FILE

```
FN -- NAME OF THE PLOTTING FILE                *????*
RE -- RETURN TO FILE MANAGEMENT MENU

PLEASE ENTER YOUR SELECTIONS:
```

Figure 8.5. Change name for a printing file.

Storage of a selection of interpretations

In chapter 6, we explained how to select a pair of wells from a well posting and we explained how to select an interpretation in Chapter 7. Option PS in the File Management menu (Figure 5.1) allows the saving to a file of multiple interpretations to be used in a single hardcopy display. The option is more convenient the more times the same cross section will be displayed and the larger is the number of wells. Figure 8.6 shows the menu after selection of 12.SOURCE as the name for the file and initializing it. To actually build the file, select the first well, and then for every successive well, select the interpretation involving correlations with the previous well, and commit the selection entering GO before choosing the next well number.

Figure 8.7 shows the shell window report at the end of a selection involving wells 1 and 2 and their Interpretation 2. In the present version of the program, the maximum number of wells to select is 21.

Drawing specifications

CORRELATOR offers great flexibility in the hardcopy preparation of cross sections, which implies the setting of a large number of parameters. Considering that often each cross section is displayed with little modifications in the drawing specifications, in an effort to simplify the process, the program requires that the user prepares a specification file prior to preparing any cross section. To produce such file, select option PC in the File Management menu (Figure 5.1). Execution of such menu generates another menu in display in Figure 8.8, which is so extensive that it is in two windows.

PREPARATION OF A SOURCE FILE

```
FN -- NAME OF THE SOURCE FILE                12.SOURCE
SA -- START A NEW FILE (S) OR ADD TO AN EXISTING FILE (A)      ADD
WS -- WELL SEQUENTIAL NUMBER                                0

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE SOURCE FILE
```

PLEASE ENTER YOUR SELECTIONS:

Figure 8.6. Menu to select and save interpretations making a cross section.

```

SOURCE FILE
*****

SOURCE FILE NAME          12.SOURCE

NUMBER OF WELLS          2

      WELL SEQUENTIAL NUMBER      CORRELATION ID
      -----
      1                1                7
      2                2                0

```

Figure 8.7. Shell window report at the end of saving a selection of interpretations in a file.

The two titles refer to an optional header to go at the top of the cross section. Keep them blank if you do not want to use them. CORRELATOR can draw stratigraphic columns and faults, but we will defer their usage and explanation to the last two chapters. To avoid segmentation in the display of tie lines in cross sections involving more than 2 wells, the program offers parameter PW to display the logs for the first and last wells in the cross section only.

Internally the program works with depth below the reference surface, which is commonly sea level. Selection of different datums allows to hang the cross section from different reference levels, thus making possible the preparation of stratigraphic cross sections, which is covered in Chapter 10. For the purpose of display, additional options include use of elevation for the vertical scale and adoption of the original log depth, which results in cross sections similar to the popular practice of hanging paper copies of logs on walls. When Figure 8.8 is executed after modifying some of the default options, it generates the shell window report in Figure 8.9.

All drawing specification files are fixed-length files, 81 characters long with a label SPEC as the first four characters.

Hardcopy display of correlations

Figure 8.10 is a hardcopy display of the anchoring correlations in Figures 7.11 and 7.12. We generated Figure 8.10 employing option PC in the Correlation Display menu after executing the menu in Figure 8.4, and loading the well/log database and the correlation database. Figure 8.11 is a view of the PC menu before selecting the file with the drawing specifications and after loading the correlations. The loading of the correlations generates the menu in Figure 8.12.

PREPARATION OF SPECIFICATION FOR CROSS SECTIONAL DISPLAY

FN -- NAME OF THE FILE WITH SPECIFICATIONS	SCHABEN.SPECS
T1 -- FIRST TITLE	****
T2 -- SECOND TITLE	****
SC -- TEXT IN STRATIGRAPHIC COLUMN TO THE LEFT (L), RIGHT (R), BOTH (B), OR NONE (N)	NONE
LA -- LITHOLOGY IN STRATIGRAPHIC COLUMN TO THE LEFT (L), RIGHT (R), BOTH (B), OR NONE (N)	NONE
DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N)	Y
VS - VERTICAL DEPTH SCALE, FEET/IN	50.00
HS - HORIZONTAL SCALE, FEET/IN	500.00
MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG	-1.00
MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG	-1.00
FM - FAULT MODELING, YES (Y) OR NO (N)	N
MD -- MORE DRAWING SPECIFICATIONS	->
RE -- RETURN TO FILE MANAGEMENT MENU	
GO -- PREPARE THE FILE	

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATION FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY	KANSAS GEOLOGICAL SURVEY
PB -- INTERPRETER	Ricardo A. Olea
PT -- PLATE NUMBER, BLANK TO AVOID POSTING	
LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N)	N
PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E)	A
DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET	10
ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D)	D
DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB)	S
DW -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L)	W
RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES	
GO -- COMMIT THE SELECTIONS	

PLEASE ENTER YOUR SELECTIONS:

Figure 8.8. Menu to set drawing specifications, parts I and II.

FILE WITH SPECIFICATIONS TO PLOT A CROSS-SECTION

FILE NAME: SCHABEN.SPEC
AGENCY: KANSAS GEOLOGICAL SURVEY
PROCESSED BY: Ricardo A. Olea
TITLE: WELLS FROM SCHABEN FIELD, NESS COUNTY, KANSAS
DATUM: SEA LEVEL

PLATE NUMBER: NONE
WELL LABELS: USE THE ACTUAL WELL NAME
LOGS: DISPLAY THEM ALL
DEPTH SCALE ORIGIN: SEA LEVEL
DATUM FOR DISPLAYS: SEA LEVEL
STRATIGRAPHIC COLUMN: NO
LITHOLOGY: NO
PLOT VERTICAL SCALE IS DEPTH
VERT. SCALE: 50.00 FEET/IN
HOR. SCALE: 2000.00 FEET/IN
TICK MARKS: EVERY 10 FEET
MAX. SHALE: 110.000
MAX. CORR.: -1.000
FAULTING: NO FAULTS CONSIDERED
DEPTH SCALE: ALONG THE PAPER WIDTH

Figure 8.9. Example of window report with drawing specifications.

LITHOSTRATIGRAPHIC CORRELATIONS
WELLS FROM SCHABEN FIELD, NESS COUNTY, KANSAS
DATUM: SEA LEVEL

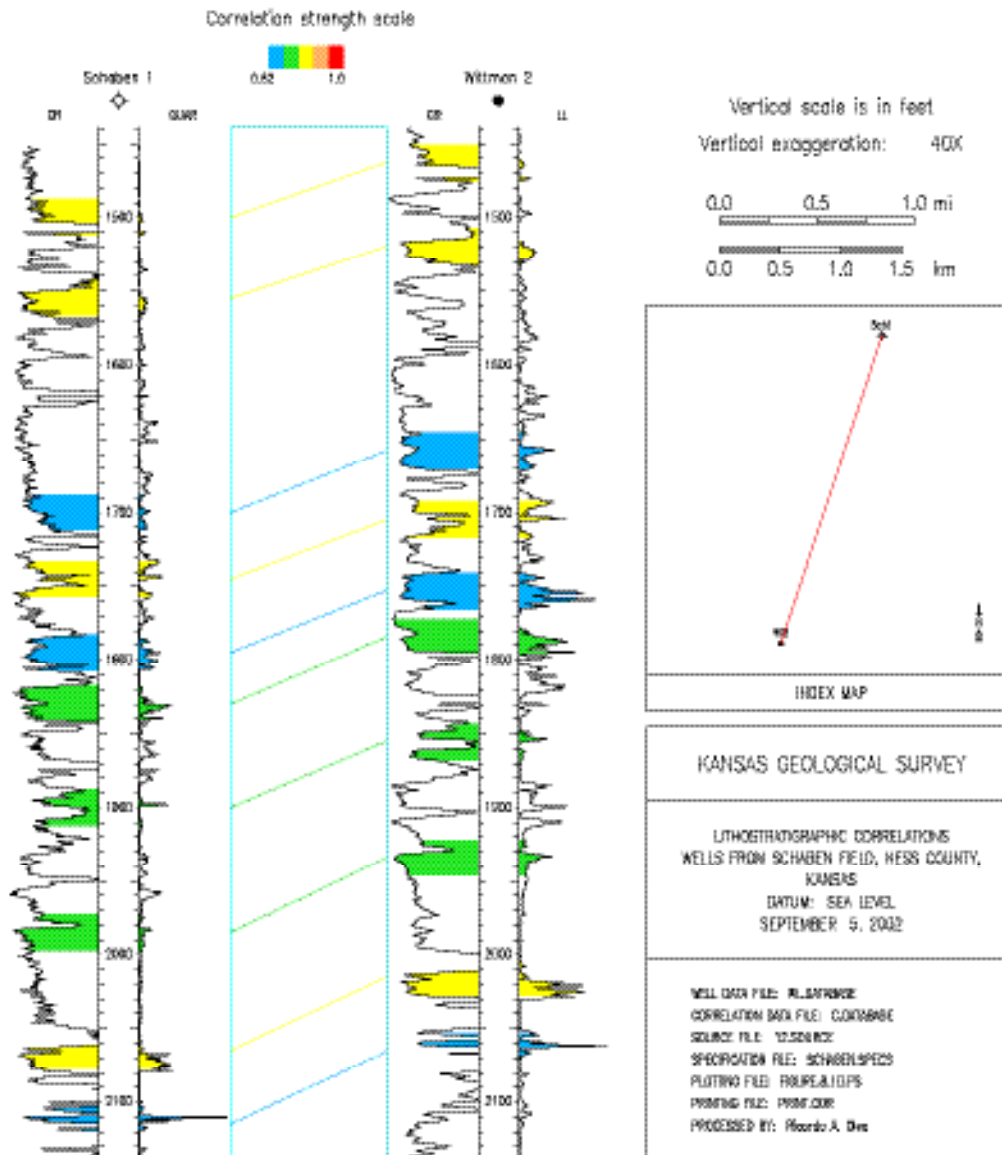


Figure 8.10. Hardcopy display of the correlations in Figures 7.11 and 7.12.

PLOTTING AND PRINTING OF CORRELATION FILES

```
SF -- SOURCE FILE WITH INTERPRETATIONS TO PLOT          12.SOURCE
XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING  -->
SP -- FILE WITH PLOTTING SPECIFICATIONS                *????*
RE -- RETURN TO PREVIOUS MENU
```

PLEASE ENTER YOUR SELECTIONS: Schaben.spec go

Figure 8.11. Plotting menu after first expansion.

```
REFERENCE WELL ( 1): Schaben 1
MATCHING WELL ( 2): Wittman 2

DISTANCE BETWEEN WELLS:  4213.5 FEET

INTERPRETATION (2): Anchoring correlations
NUMBER OF CORRELATIONS IN SELECTED INTERPRETATION:  10

CROSS-SECTION LENGTH:  4213.5 FEET
```

Figure 8.12. Shell window report after loading correlations.

Execution of the menu in Figure 8.11 generates the expanded menu in Figure 8.13, whose execution, in addition to the hard display of Figure 8.10, generates the shell window report of Figure 8.14, a program window preview, and the hardcopy report in Figure 7.11. Not included in Figure 7.11 are three statistics to assess the quality and efficiency of the correlation process. These statistics are useful when comparing the generation of correlations employing different parameters. In the example of the anchoring correlations, these statistics are:

- Correlation on reference well 240.0 ft or 34.9%
- Weighted correlation on reference well 175.2 ft or 25.5%
- Average weighted correlation coefficient 0.730

The percentages are relative to the length of the reference logs in the display.

One can see now the convenience of having previously defined most of the parameters in file SCHABEN.SPECS. The reader can find explanations for the use of parameters SC and LA in the Chapter 10. Option PC allows two types of display, which are controlled by parameter TL. The display mode of Figure 8.10 is similar to the program window mode—Figure 8.3—in which the central track contains one tie line per correlating interval. Such line goes from center to center of the correlating intervals and the color is coded according to the quality of the correlation, with hotter colors denoting stronger correlations. The second alternative controlled by TL allows to draw all tie lines implied between correlating intervals, 23 in the case of 11-ft (3.4 m) correlation intervals sampled every 0.5-ft (0.15 m). Selection of such alternative results in as many lines in the central track as there are shading lines between the well logs.

PLOTTING AND PRINTING OF CORRELATIONS FILES

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS 12.SOURCE
 XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING ---
 SP -- FILE WITH PLOTTING SPECIFICATIONS SCHABEN.SPECS
 T1 -- FIRST TITLE WELLS FROM SCHABEN FIELD, NESS COUNTY, KANSAS
 T2 -- SECOND TITLE DATUM: SEA LEVEL
 SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) NONE
 LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) NONE
 DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N) YES
 ND -- STARTING DEPTH FOR PLOTTING, FEET 1439.00
 XD -- ENDING DEPTH FOR PLOTTING, FEET 2139.00
 VS - VERTICAL DEPTH SCALE, FEET/IN 50.00
 HS - HORIZONTAL DISTANCE SCALE, FEET/IN 2000.00
 TL -- FOR EACH CORRELATED INTERVAL, DISPLAY ALL TIE LINES (A) C
 OR ONLY A LINE FROM CENTER TO CENTER (C)
 FM - FAULT MODELING, YES (Y) OR NO (N) NO
 MD -- MORE DRAWING SPECIFICATIONS -->

RE -- RETURN TO PREVIOUS MENU
 GO -- PLOT CROSS SECTION

PLEASE ENTER YOUR SELECTIONS: tl c go

MORE SPECIFICATION FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY KANSAS GEOLOGICAL SURVEY
 PB -- INTERPRETER Ricardo A. Olea
 PT -- PLATE NUMBER, BLANK TO AVOID POSTING
 LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N) N
 PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E) A
 DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET 10
 ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D) D
 DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB) S
 MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE 110.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE -1.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L) W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
 GO -- COMMIT THE SELECTIONS

PLEASE ENTER YOUR SELECTIONS: tl c go

Figure 8.13. The complete menu, in two parts, to prepare a hardcopy display of correlations.

PLOTTING AND LISTING OF CORRELATION FILES

SOURCE FILE	12.SOURCE
PLOTTING SPECIFICATION FILE	SCHABEN.SPECS
PRINTING FILE	PRINT.COR
PLOT FILE	PLOT.COR
PLOT LENGTH ALONG PAPER ROLL	15.1 INCHES
PLOT WIDTH ACROSS PAPER ROLL	20.0 INCHES
PLOT VERTICAL SCALE IS DEPTH	

Figure 8.14. Shell window report for the hardcopy display and listing of correlations.

WINDOW LIST OF A CORRELATION INTERPRETATION

```

REFERENCE WELL ( 1): Schaben 1
MATCHING WELL ( 2): Wittman 2
INTERPRETATION (2): Anchoring correlations

MINIMUM CORRELATION DEPTH, FEET           1500.00
MAXIMUM CORRELATION DEPTH, FEET           2115.00

CI -- SELECT CORRELATION INTERPRETATION           -->

ND -- MINIMUM DEPTH TO DISPLAY, FEET           1500.00
XD -- MAXIMUM DEPTH TO DISPLAY, FEET           2115.00

RE -- RETURN TO CORRELATION DISPLAY MENU
GO -- LIST THE INTERPRETATION

PLEASE ENTER YOUR SELECTIONS: go
  
```

Figure 8.15. Menu to list correlations in an interpretation.

In all cross sections, CORRELATOR automatically annotates the vertical exaggeration, draws an index map and a horizontal scale bar, and writes processing parameters to an explanation box. Figure 8.10 shows all these features and it shows them at their standard placements. In some other figures, such as Figure 1.1, we manually deleted or moved around some of these features for the sake of a larger display.

```

WL.DATABASE
SEA LEVEL          F R R
Schaben 1          1 14 2248.0 GR  3 110 GUAR  6
Wittman 2          2 11 2261.0 GR  9 110 LL   12
0.50

1  2  4213.50  1  1  1500.00  2115.00
3  1500.00  2115.00  0.000  -2.16  2.42  0.961
-960.5051  1.608111  -0.9167687E-03  0.1702834E-06
1500.00  1463.00  24.0  742.0  0.0 -1.000  0.820 **
1555.00  1520.00  24.0  742.0  0.0 -1.000  0.782
1700.00  1658.00  24.0  742.0  0.0 -1.000  0.677
1745.00  1705.00  24.0  742.0  0.0 -1.000  0.774
1795.00  1753.00  24.0  742.0  0.0 -1.000  0.620
1830.00  1784.50  24.0  742.0  0.0 -1.000  0.726
1900.00  1855.50  24.0  742.0  0.0 -1.000  0.758
1985.00  1934.50  24.0  742.0  0.0 -1.000  0.743
2065.00  2015.50  24.0  742.0  0.0 -1.000  0.777
2115.00  2066.00  24.0  742.0  0.0 -1.000  0.624

```

Figure 8.16. Window display of correlations in an interpretation.

```

CORRELATION INTERPRETATION INTO A PRINTING FILE
*****

REFERENCE WELL ID          1
MATCHING WELL ID          2

FILE CONTAINING THE LISTING  FIG7.11.DOC

```

Figure 8.17. Window report for hardcopy of interpretation.

Window listing of correlations

CORRELATOR offers the option of solely listing correlations, without graphical display. Execution of option WL in menu Correlation Display results in a listing in the shell window after proper selection of the pair of wells and interpretation. Figure 8.15 displays the parameters used to generate the listing in Figure 8.16.

Hardcopy of correlations

The program also can write correlations to a text file only. To select such alternative, choose option CP in the Correlation Display menu, whose parameters are identical to those for the window listing in Figure 8.15. Execution of the same parameters for option CP results in the print out already displayed in Figure 7.11. Figure 8.17 is the corresponding shell window report.

Chapter 9: Selective display of correlations

Sometimes it is of interest to display only some of the tie lines found in the correlation process. This chapter explains how to proceed in two special situations: persistent correlations and marker correlations.

Display and printing of persistent correlations

Rarely are there good correlations from top to bottom for all the pairs of wells in a cross section. Geologically, correlations may be missing because of erosion, non-deposition, faults, or other processes. Correlations may also be absent because the weighted correlation coefficient is below a certain threshold. Figure 9.1 displays all correlations above a threshold of 0.8 for 3 wells in the Schaben field, Kansas. Figure 9.2 shows only those tie lines that allow lateral, uninterrupted tracing of a lithostratigraphic level from one end of the cross section to the other. Lateral persistence in correlations indicates higher lateral homogeneity in deposition of sediments and preservation of petrophysical properties.

Option LP for the plotting and printing of persistent correlations can be found in the Geologic Interpretation menu (Figure 7.20). Hardcopy displays are prepared usually with the intent of generating cross sections larger than the fixed page size of this manual. For a reminder on how to prepare specifications for hardcopy displays, please review the appropriate section in the previous chapter. Menu for LP initially will expand as information is added. Figure 9.3 shows it after specifying the interpretations to display, which generates the shell window report in Figure 9.4.

Figure 9.5 is the full menu for LP after properly selecting the parameters that resulted in Figure 9.2. This menu is in two program windows. Execution of option LP generates a program window preview, the shell window report in Figure 9.6, and automatically writes a listing to the printing file discussed in the previous chapter. Figure 9.7 is a fragment of such report. Note that the report contains an extra column to the right and some statistics to the bottom. Those numbers are related to the closing error that results from starting and ending a cross section at the same well. This feature is extraordinarily useful for further checking of the correlations beyond the more basic capabilities of option EC in the Geological Interpretation menu (Figure 7.20). The two features combine together make CORRELATOR a unique and powerful tool for the computer correlation of wireline logs.

The concept of persistent correlation is equivalent to the more intuitive notion of geologic marker.

LITHOSTRATIGRAPHIC CORRELATIONS
WELLS IN SCHABEN FIELD, NESS COUNTY, KANSAS

DATUM: SEA LEVEL

Correlation strength scale

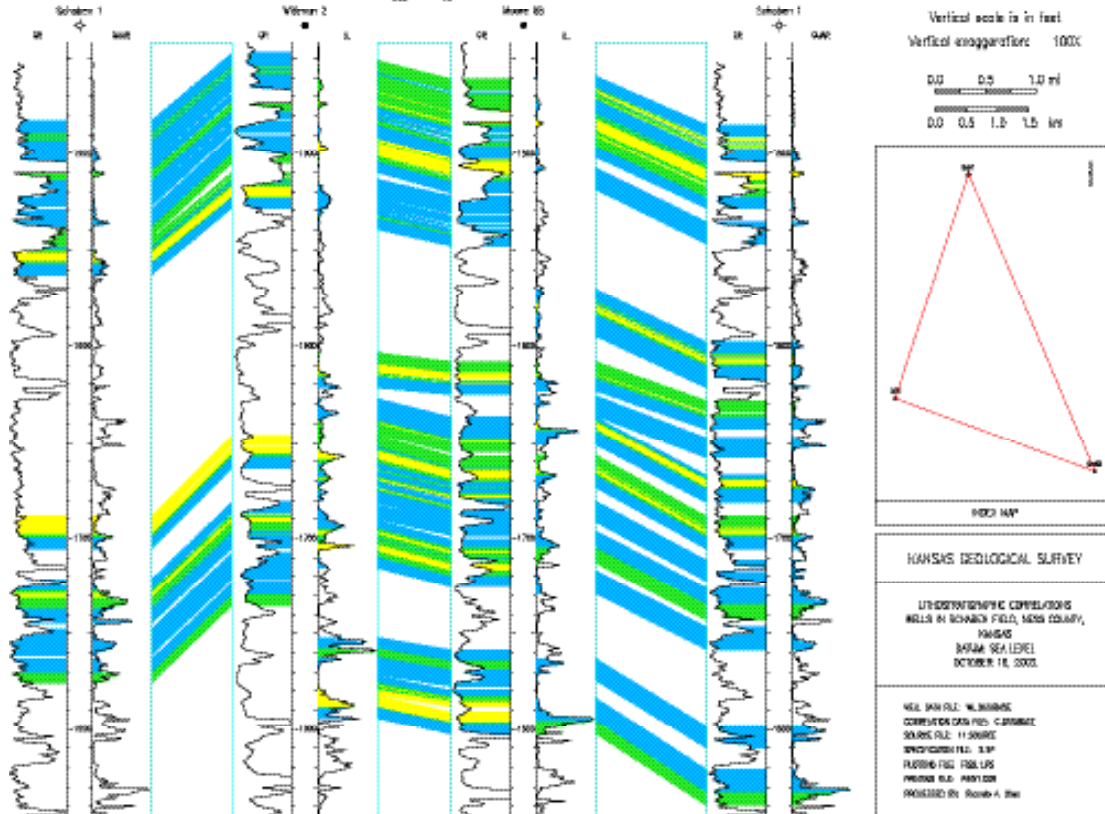


Figure 9.1. Correlations with weighted correlation coefficient above 0.8 in Ness county, Kansas.

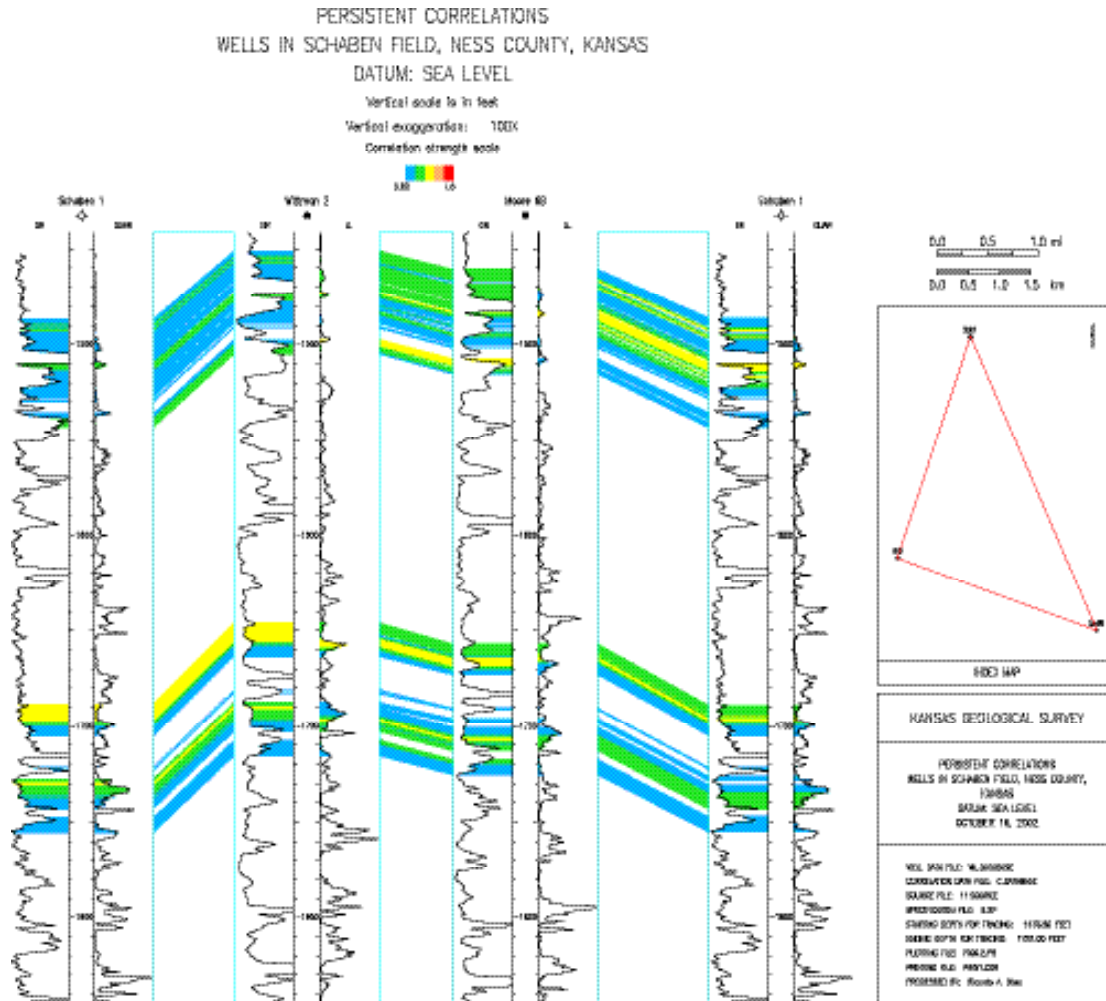


Figure 9.2. Persistent correlation for the cross section in Figure 9.1.

PLOT AND PRINT PERSISTENT CORRELATIONS IN A CROSS SECTION

```

SF -- SOURCE FILE CORRELATION INTERPRETATIONS                11.SOURCE
XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING      ->
SP -- FILE WITH PLOTTING SPECIFICATIONS                       *????*
RE -- RETURN TO PREVIOUS MENU

```

PLEASE ENTER YOUR SELECTIONS: Schaben.spec go

Figure 9.3. Menu for plotting and listing persistent correlations after first expansion.

REFERENCE WELL (1): Schaben 1
MATCHING WELL (2): Wittman 2

DISTANCE BETWEEN WELLS: 4213.5 FEET

INTERPRETATION (7): Figure 9.1
NUMBER OF CORRELATIONS IN SELECTED INTERPRETATION: 138

REFERENCE WELL (2): Wittman 2
MATCHING WELL (3): Moore 6B

DISTANCE BETWEEN WELLS: 3831.1 FEET

INTERPRETATION (2): Figure 9.1
NUMBER OF CORRELATIONS IN SELECTED INTERPRETATION: 270

REFERENCE WELL (3): Moore 6B
MATCHING WELL (1): Schaben 1

DISTANCE BETWEEN WELLS: 5785.0 FEET

INTERPRETATION (2): Figure 9.1
NUMBER OF CORRELATIONS IN SELECTED INTERPRETATION: 158

CROSS-SECTION LENGTH: 13829.6 FEET

Figure 9.4. Shell window report showing interpretations used in preparation of Figure 9.2.

PLOTTING AND PRINTING OF PERSISTENT CORRELATIONS

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS 11.SOURCE
 XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING ---
 SP -- FILE WITH PLOTTING SPECIFICATIONS SCHABEN.SPECS
 T1 -- FIRST TITLE WELLS IN SCHABEN FIELD, NESS COUNTY, KANSAS
 T2 -- SECOND TITLE DATUM: SEA LEVEL
 SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) NONE
 LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) NONE
 DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N) YES
 ND -- STARTING DEPTH FOR PLOTTING, FEET 1441.00
 XD -- ENDING DEPTH FOR PLOTTING, FEET 1844.50
 VS - VERTICAL DEPTH SCALE, FEET/IN 50.00
 HS - HORIZONTAL DISTANCE SCALE, FEET/IN 2000.00
 ST -- STARTING DEPTH FOR TRACING FOR THE LEFTMOST WELL, FEET 1476.50
 ET -- ENDING DEPTH FOR TRACING FOR THE LEFTMOST WELL, FEET 1781.00
 FM - FAULT MODELING, YES (Y) OR NO (N) NO
 MD -- MORE DRAWING SPECIFICATIONS ->

RE -- RETURN TO PREVIOUS MENU
 GO -- PLOT CROSS SECTION

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATION FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY KANSAS GEOLOGICAL SURVEY
 PB -- INTERPRETER Ricardo A. Olea
 PT -- PLATE NUMBER, BLANK TO AVOID POSTING
 LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N) N
 PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E) A
 DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET 10
 ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D) E
 DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB) S
 MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE 110.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE -1.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L) W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
 GO -- COMMIT THE SELECTIONS

PLEASE ENTER YOUR SELECTIONS: vs 25 hs 2500

Figure 9.5. The full menu, in two parts, for the plotting and listing of persistent correlations.

PRINTING AND PLOTTING OF PERSISTENT CORRELATIONS

SOURCE FILE	11.SOURCE
PLOTTING SPECIFICATION FILE	SCHABEN.SPECS
PRINTING FILE	FIG9.7
PLOTTING FILE	FIG9.2.PS
PLOT LENGTH ALONG PAPER ROLL	24.6 INCHES
PLOT WIDTH ACROSS PAPER ROLL	22.1 INCHES
PLOT VERTICAL SCALE IS ELEVATION	

Figure 9.6. Shell window report for option LP in the Geological Interpretation menu.

Printing of persistent correlations

Sometimes, particularly in preliminary results, display of persistent correlations may not be of interest. For those situations, CORRELATOR offers option TP in the Geologic Interpretation menu (Figure 7.20). Option TP will generate only a report of the form listed in Figure 9.7. Without the need to specify plotting options, as shown in Figure 9.8, the menu for option TP is fairly straightforward. Figure 9.9 is the corresponding shell window report.

Hardcopy plotting and printing of markers

Since before the advent of wireline logs, geologists had an inclination to restrict the correlation process to key levels generically called markers. More generally, given any levels at a well, CORRELATOR has the capability to automatically find the lithostratigraphically equivalent elevations for those levels at all the other wells in the same cross section. Figures 9.10 and 9.11 illustrate the form of the hardcopy results. When the wells are in a closed loop, as it is the case of the example, the report includes closure errors, which are the ultimate assessment for the global quality of a computer correlation study. Unless previously arranged, hardcopies will be in default files PLOT.COR and PRINT.COR.

In theory, if the ultimate objective of a study is to display a cross section of traced across correlations, only correlations overlapping the markers are necessary. In practice, especially if the cross section is not in a loop, the more correlations are established, the higher will be the certainty that the interpretations will be free of errors. Interpretations behind Figure 9.10 have correlation strengths as low as 0.5, which allows having a more continuous coverage of the cross section than those in Figure 9.1, with still meaningful correlations. A few correlations were eliminated at the level of the top of the Stanton Limestone in order to create intentionally an instance of interpolated tracing for the purpose to illustrate the capabilities of the program.

PERSISTENT CORRELATIONS

THE DATUM IS SEA LEVEL
 ALL RESULTS ARE IN FEET

WELLS AND LOGS

	1 Sch1 GR-GUAR	2 Wi2 GR-LL	3 6B GR -LL	1 Sch1 GR -GUAR	CLOSURE ERROR
1	1486.0	1450.5	1460.0	1485.5	0.5
2	1486.5	1451.0	1460.5	1486.0	0.5
3	1487.0	1451.5	1461.0	1486.5	0.5
4	1487.5	1452.0	1461.5	1487.0	0.5
5	1488.0	1452.5	1462.0	1487.5	0.5
6	1488.5	1453.0	1462.5	1488.0	0.5
7	1489.0	1453.5	1463.0	1488.5	0.5
8	1489.5	1454.0	1463.5	1489.0	0.5
9	1490.0	1454.5	1464.0	1489.5	0.5
10	1490.5	1455.0	1464.5	1490.0	0.5
11	1491.0	1455.5	1465.0	1491.0	
12	1491.5	1456.0	1465.5	1491.5	
13	1492.0	1456.5	1466.0	1492.0	
14	1492.5	1457.0	1466.5	1492.5	
			.		
			.		
			.		
183	1751.5	1711.5	1721.5	1751.0	0.5
184	1752.0	1712.0	1722.0	1751.5	0.5
185	1752.5	1712.5	1722.5	1752.0	0.5
186	1753.0	1713.0	1723.0	1752.5	0.5
187	1753.5	1713.5	1723.5	1753.0	0.5
188	1754.0	1714.0	1724.0	1753.5	0.5
189	1754.5	1714.5	1724.5	1754.0	0.5
190	1755.0	1715.0	1725.0	1754.5	0.5

MAXIMUM ABSOLUTE CLOSURE ERROR: 1.5 FEET

AVERAGE ABSOLUTE CLOSURE ERROR: 0.339 FEET

Figure 9.7. Persistent correlations and closure errors for the cross section in Figure 9.2.

PRINTING OF PERSISTENT CORRELATIONS

```

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS          11.SOURCE
XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING    ---
ST -- STARTING DEPTH FOR TRACING FOR THE LEFTMOST WELL, FEET 1476.50
ET -- ENDING DEPTH FOR TRACING FOR THE LEFTMOST WELL, FEET  1781.00

RE -- RETURN TO PREVIOUS MENU
GO -- PRINT
    
```

PLEASE ENTER YOUR SELECTIONS: go

Figure 9.8. Menu to list persistent correlations after selection of interpretations.

LISTING OF PERSISTENT CORRELATIONS

```

SOURCE FILE          11.SOURCE
PRINTING FILE        FIG9.7
    
```

Figure 9.9. Shell window report for listing of persistent correlations.

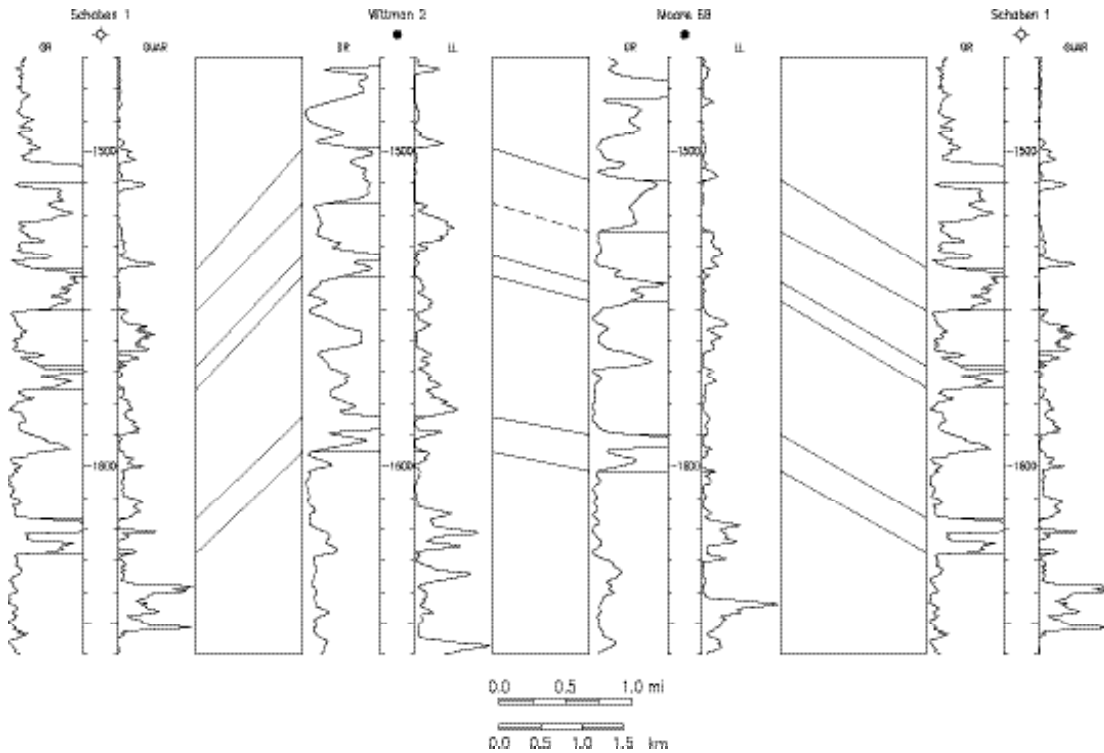


Figure 9.10. Automatic tracing of six formation tops for the same wells in Figure 9.1. The vertical scale is in feet below sea level and has an exaggeration of 125 times relative to the horizontal scale indicated by the bars. Other annotations were eliminated to maximize the size of the figure. A solid tie line denotes a correlation taken directly from one of the interpretation tables; a dashed lined denoted an interpolated equivalence.

LITHOSTRATIGRAPHIC MARKERS

TRACING STARTED FROM WELL Sch1
THE DATUM IS SEA LEVEL
ALL RESULTS ARE IN FEET

WELLS AND LOGS

	1 Sch1 GR-GUAR	2 Wi2 GR-LL	3 Mo6B GR-LL	1 Sch1 GR-GUAR	CLOSURE ERROR	TOPS
1	1537.5	1499.0	1509.0	1537.0	0.5	Douglas Group
2	1550.5	1516.5 I	1525.5	1550.5		Stanton Ls
3	1568.0	1533.0	1541.5	1568.0		Vilas Sh.
4	1575.5	1539.5	1547.5	1575.0	0.5	Plattsburg Ls
5	1616.5	1584.5	1590.0	1616.5		Bonner Sp. Sh
6	1627.5	1595.5	1601.5	1627.5		Wyandotte Ls

MAXIMUM ABSOLUTE CLOSURE ERROR: 0.5 FEET

AVERAGE ABSOLUTE CLOSURE ERROR: 0.17 FEET

Figure 9.11. Report for the tracing of lithostratigraphically equivalent levels in Figure 9.10. The capital “I” denotes that correlation between levels 1516.5 and 1525.5 ft (462.2-465.0 m) resulted from interpolation. All other equivalences come from actual correlations in the interpretations used to prepare the cross section.

The program cannot be responsible for the correspondence between the elevations and the assigned names in the marker file. If in Figure 9.10, for example, the top of the Stanton Limestone in well Schaben 1 is indeed at 1554 ft (473.7 m) instead of 1550.5 ft (472.6 m), the traced correlations will be lithostratigraphically correct but improperly labeled; they will be subparallel to the true top of the Stanton. The user is responsible for proper correspondence between depths and any names entered to the marker file.

Preparation of traced levels requires execution of option LM at the Geologic Interpretation menu (Figure 7.20). Explanations on how to annotate the cross section are delayed until the next chapter. Execution of option LM will generate similar menus to those in Figure 9.3 to 9.6 for the finding of persistent correlations. Other than headers and names of output files, the only difference will be in the full menu (Figure 9.12). Instead of requesting a starting and ending depth for tracing, option LM requests the name for a marker file with the elevations to trace across, plus some ancillary information. Selection of the interpretations was done employing option XS.

PLOT AND PRINT TRACED CORRELATIONS IN A CROSS SECTION

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS *????*

XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING -->

SP -- FILE WITH PLOTTING SPECIFICATIONS SCHABEN.SPECS

T1 -- FIRST TITLE WELLS IN SCHABEN FIELD, NESS COUNTY, KANSAS

T2 -- SECOND TITLE DATUM: SEA LEVEL

SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) NONE

LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) NONE

DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N) YES

ND -- STARTING DEPTH FOR PLOTTING, FEET 1470.00

XD -- ENDING DEPTH FOR PLOTTING, FEET 1660.00

VS - VERTICAL DEPTH SCALE, FEET/IN 20.00

HS - HORIZONTAL DISTANCE SCALE, FEET/IN 2500.00

MF -- NAME OF MARKER FILE WITH DEPTHS TO TRACE ACROSS SCH1.MK

FM - FAULT MODELING, YES (Y) OR NO (N) NO

MD -- MORE DRAWING SPECIFICATIONS -->

RE -- RETURN TO PREVIOUS MENU

GO -- PLOT CROSS SECTION

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATION FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY KANSAS GEOLOGICAL SURVEY

PB -- INTERPRETER Ricardo A. Olea

PT -- PLATE NUMBER, BLANK TO AVOID POSTING

LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N) N

PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E) A

DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET 10

ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D) E

DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB) S

MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG 110.00

MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG -1.00

DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L) W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES

GO -- COMMIT THE SELECTIONS

PLEASE ENTER YOUR SELECTIONS:

Figure 9.12. Full LM menu employed in the preparation of Figure 9.10.

Preparation of marker file

Preparation of a marker file requires prior selection of the well/log database and execution of option PM in the File Management menu (Figure 5.1). First, PM asks for a name for the new file and for the sequential number in the well/log database for the well to start the tracing. If the name is already taken, the program will generate the warning in Figure 4.2. Otherwise, after printing an initial report on the shell window, the program is ready to start accepting levels. To activate such capability, choose option Enter Primary Information (P). Figure 9.13 shows menu PM ready for the saving of the information required to trace the Douglas Group and Figure 9.14 contains the shell window report after input of the information for to the sixth level.

```

                                PREPARATION OF A MARKER FILE

FN -- NAME OF THE MARKER FILE                                SCH1.MK
SA -- START A NEW FILE (S), ENTER PRIMARY INFORMATION (P),   PRIMARY
    OR ENTER INFORMATION TO MODIFY PRIMARY TRACING (M)
DM -- DEPTH TO THE MARKER, DEPTH BELOW SEA LEVEL            1537.00
PN -- PEN NUMBER                                            3
MP -- PAINT CORRELATIONS BETWEEN MARKERS (P),              L
    DRAW MARKER LINES (L), OR DO BOTH (B)
RM -- UP TO 10-CHARACTER REMARK                            Douglas Gr

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE MARKER FILE

PLEASE ENTER YOUR SELECTIONS: go
```

Figure 9.13. Example parameter selection for option PM.

	DEPTH FEET	PEN	DRAWING	REMARKS
1	1537.50	3	L	Douglas Gr
2	1550.50	3	L	Stanton Sh
3	1568.00	3	L	Vilas Sh
4	1575.50	3	L	Plattsburg
5	1616.50	3	L	Bonner Sp.
6	1627.50	3	L	Wyandotte

Figure 9.14. Marker file for the example in Figure 9.10.

Table 9.1 contains specifications for the pen colors. Setting of parameter MP to LINE prepares a display of the type in Figure 9.10. The Paint mode assigns the same color to all tie lines between a marker and the next marker or the bottom of the display. This is different than the prevailing practice in other programs that do a solid coloring between markers, thus eliminating the possibility to display onlaps, offlaps, and lack of correlations. For examples, see Figures 10.15, 11.12, and 11.14. For an appreciation of a serious application, see Olea (2002b).

Figure 9.1. Pen colors determined as combinations of red (R), green (G), and blue (B). Descriptions arranged in alphabetical order by main color.

No.	R	G	B	Color	No.	R	G	B	Color
26	54	80	61	dark aquamarine	24	30	80	20	forest green
3	0	0	0	black, thin line	29	45	66	56	grayish green
1	0	0	0	black, medium line	28	66	100	0	lime green
4	0	0	0	black, ultra thick line	27	56	66	45	olive green
6	0	70	100	blue	60	40	100	60	sea green
64	30	60	100	dark blue	31	0	66	45	ultra dark green
48	60	76	89	dark steel blue	53	84	100	0	yellow green
62	50	90	90	greenish blue	43	55	45	90	indigo
17	66	100	100	light blue	66	50	40	100	dark indigo
44	0	41	89	navy blue	63	60	60	100	light indigo
38	0	50	90	Prussian blue	59	50	100	30	lime
47	66	84	100	steel blue	32	100	20	80	magenta
13	80	70	30	brown	42	80	0	0	maroon
20	60	40	20	dark brown	15	70	0	60	dark maroon
51	80	54	80	rose brown	39	90	40	20	light maroon
33	80	20	70	burgundy	9	100	70	40	orange
49	63	0	89	cherry	68	100	50	30	dark orange
34	80	61	54	chocolate	58	100	85	20	light orange
69	100	30	60	crimson	67	100	60	40	medium orange
37	30	100	100	cyan	21	100	90	30	yellow orange
16	0	100	100	dark cyan	18	100	66	100	hot pink
22	40	100	90	greenish cyan	12	68	60	90	purple
5	0	90	90	light cyan	2	100	0	0	red, thin line
46	10	100	30	emerald	10	100	0	0	red, thick line
23	40	80	30	dark emerald	45	84	0	100	violet red
14	30	100	40	medium emerald	55	100	66	66	salmon
61	40	100	20	light emerald	56	90	0	10	scarlet
19	50	50	50	dark gray	41	80	54	0	sienna
50	80	80	54	greenish gray	35	60	60	80	slate
40	90	90	90	light gray	52	80	74	54	tan
11	85	85	85	medium gray	70	100	100	100	transparent
7	15	90	15	green	36	90	50	100	violet
30	0	80	0	dark green	8	100	100	0	yellow
65	50	50	0	dark olive green	57	100	100	70	light yellow
25	60	89	69	dark sea green	54	100	84	0	orange yellow

Gaps in the sedimentary sequence sometimes do not permit to do all tracings from the same starting well. For example, if the top of the Douglas Group would have been missing in well Wittman 2 and if the interpolated correlation would have been completely wrong, it would have been necessary to correlate the top of the Douglas Group in well Schaben 1 to the top of the Douglas Group in well Moore 6B. The way to incorporate that information into the CORRELATOR tracing will be through option Enter Information to Modify Primary Tracing (M). Well Moore 6B is the matching well in the second pair of wells and would be the first well to suffer the consequences of the hypothetical missing section in a tracing to the right of the starting well. Figure 9.15 shows the parameter selection and Figure 9.16 display the way the marker file would have look like if such modification would have been necessary.

All records in SCH1.MK or any marker files have a fixed-length of 31 characters, including a line break.

PREPARATION OF A MARKER FILE

FN -- NAME OF THE MARKER FILE	SCH1.MK
SA -- START A NEW FILE (S), ENTER PRIMARY INFORMATION (P), OR ENTER INFORMATION TO MODIFY PRIMARY TRACING (M)	MODIFY
PO -- SEQUENTIAL NUMBER FOR THE PAIR TO OVERRIDE	2
MO -- SEQUENTIAL NUMBER FOR THE MARKER TO OVERRIDE	1
DM -- OVERRULING DEPTH, FEET BELOW SEA LEVEL	1510.00
RE -- RETURN TO PREVIOUS MENU	
GO -- UPDATE THE MARKER FILE	

PLEASE ENTER YOUR SELECTIONS: go

Figure 9.15. Modification of primary information in correlation tracing.

MARK		1	6	1
1537.50	3	L Douglas Gr		
1550.50	3	L Stanton Sh		
1568.00	3	L Vilas Sh		
1575.50	3	L Plattsburg		
1616.50	3	L Bonner Sp.		
1627.50	3	L Wyandotte		
MODIFICATIONS				1
1510.00	2			1

Figure 9.16. Marker file for the hypothetical case of a discontinuity in the tracing in Figure 9.10.

Automatic printing of markers

If a display of the tracings is not of interest, the program offers the option of only preparing a printed report. The command allowing such operation is option TM in the Geologic Interpretation menu (Figure 7.20). Figure 9.17 display an example of menu after selecting the wells using the graphical option. Figure 9.18 is the corresponding shell window report. The hardcopy report is the same one as the one for option LM in Figure 9.11.

```
                PRINTING OF SELECTED MARKERS TRACED ACROSS

SF -- SOURCE FILE WITH WELL CORRELATION INTERPRETATIONS      *????*
XS -- SELECT WELLS IN CROSS SECTION FROM GRAPHICAL MENU      ->
MF -- NAME OF MARKER FILE WITH THE ELEVATIONS TO TRACE ACROSS *????*

RE -- RETURN TO PREVIOUS MENU

PLEASE ENTER YOUR SELECTIONS: sch1.mk go
```

Figure 9.17. Example of menu for option TM.

```
                LISTING OF MARKERS TRACED ACROSS
                *****

                SOURCE FILE      *????*
                MARKER FILE      SCH1.MK
                PRINTING FILE     PRINT.COR
```

Figure 9.18. Example of shell window report for option TM.

Chapter 10: Stratigraphic annotations and displays

So far we have been able to prepare different kinds of cross sections displaying correlations with high precision. Lack of annotations permitting to relate the results to the geology of the area, however, takes from the results. This chapter explains how to prepare the stratigraphic columns that geologists use for reference. The chapter concludes with explanations on how to prepare stratigraphic cross sections.

Columnar subdivisions and notes

CORRELATOR allows independent annotation of subdivisions and lithology in a stratigraphic column. For the preparation of any kind of columnar annotation, choose option PA in the File Management menu (Figure 5.1). Figure 10.1 shows the reply required to start annotation of well Schaben 1 in the well/log database, so far extensively used to illustrate this manual. In response, the program generates the shell window report in Figure 10.2.

The program is now ready to accept information for the annotation of as many columns as necessary. They will be displayed from left to right according the sequential order in which they entered the file, starting with the first one in. There are two steps in the preparations of annotations in any column: writing of the header and specification of the vertical subdivisions. The top of each

```
PREPARATION OF FILE WITH STRATIGRAPHIC COLUMN SUBDIVISIONS

FN -- NAME OF THE SUBDIVISION FILE                               SCH1.SCL
SA -- START A NEW FILE (S), ADD A COLUMN HEADING TO AN EXISTING  START
    FILE (C), OR ANNOTATE LAST COLUMN OF AN EXISTING FILE (A)
SN -- WELL SEQUENTIAL NUMBER FOR WHICH THE COLUMN APPLIES      0

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE FILE

PLEASE ENTER YOUR SELECTIONS: sn 1 go
```

Figure 10.1. Opening dialog for option PA.

```
FILE NAME                               SCH1.SCL
SEQUENTIAL NUMBER FOR ANNOTATED WELL    1
NUMBER OF COLUMNS IN THE ANNOTATION    0
NUMBER OF RECORDS IN THE FILE           1
```

Figure 10.2. Beginning of shell window report for option PA.

subdivision is specified by its depth below the reference surface, sea level almost invariably (Figure 5.3). Annotations must be by increasing depth. Otherwise, the program will request to the user to sort the levels. Annotations outside the boundaries of the cross section are ignored. The lines horizontally subdividing the column can be of two types: straight or wavy. Figures 10.3 and 10.4 illustrate the preparation of the first column. The value -999.0 is an arbitrary number outside the boundaries of the cross section indicating a top whose exact depth is unknown.

Figure 10.5 shows the final shell window report after preparing annotations in three columns.

```

PREPARATION OF FILE WITH STRATIGRAPHIC COLUMN SUBDIVISIONS

FN -- NAME OF THE SUBDIVISION FILE                               SCH1.SCL
SA -- START A NEW FILE (S), ADD A COLUMN HEADING TO AN EXISTING COLUMN
      FILE (C), OR ANNOTATE LAST COLUMN OF AN EXISTING FILE (A)
VH -- ANNOTATION DISPLAY—HORIZONTAL (H) OR VERTICAL (V)         H
HD -- UP TO A 40-CHARACTER COLUMN HEADING

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE FILE

PLEASE ENTER YOUR SELECTIONS: vh V hd SERIES

```

Figure 10.3. Example of preparation of a column header.

```

PREPARATION OF FILE WITH STRATIGRAPHIC COLUMN SUBDIVISIONS

FN -- NAME OF THE SUBDIVISION FILE                               SCH1.SCL
SA -- START A NEW FILE (S), ADD A COLUMN HEADING TO AN EXISTING ANNOTATE
      FILE (C), OR ANNOTATE LAST COLUMN OF AN EXISTING FILE (A)
DT -- DEPTH TO TOP OF INTERVAL, FEET BELOW SEA LEVEL ,          -999.0
      FROM SHALLOWEST TO DEEPEST
LT -- TYPE OF LINE FOR TOP—STRAIGHT (S) OR WAVY (W)             S
HD -- UP TO A 40-CHARACTER ANNOTATION                            Upper Pennsylvanian

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE FILE

PLEASE ENTER YOUR SELECTIONS: go

```

Figure 10.4. Example of preparation of an annotation.

STRATIGRAPHIC COLUMN SUBDIVISION FILE

```

FILE NAME                FIG10.5
SEQUENTIAL NUMBER FOR ANNOTATED WELL  1
NUMBER OF COLUMNS IN THE ANNOTATION  3
NUMBER OF RECORDS IN THE FILE        16
  
```

```

COLUMN HEADING                SERIES
ORIENTATION OF ANNOTATIONS    VERTICAL
NUMBER OF ANNOTATIONS         1
NUMBER OF CHARACTERS IN WIDEST ANNOTATION  6
  
```

ANNOTATIONS	DEPTH	LINE
<hr style="border-top: 1px dashed black;"/>		
Upper Pennsylvanian	-999.00	STRAIGHT

```

COLUMN HEADING                GROUP
ORIENTATION OF ANNOTATIONS    HORIZONTAL
NUMBER OF ANNOTATIONS         4
NUMBER OF CHARACTERS IN WIDEST ANNOTATION  11
  
```

ANNOTATIONS	DEPTH	LINE
<hr style="border-top: 1px dashed black;"/>		
Shawnee	-999.00	STRAIGHT
Douglas	1537.31	STRAIGHT
Lansing	1550.26	STRAIGHT
Kansas City	1616.50	STRAIGHT

```

COLUMN HEADING                FORMATION
ORIENTATION OF ANNOTATIONS    HORIZONTAL
NUMBER OF ANNOTATIONS         7
NUMBER OF CHARACTERS IN WIDEST ANNOTATION  17
  
```

ANNOTATIONS	DEPTH	LINE
<hr style="border-top: 1px dashed black;"/>		
Oread Ls	-999.00	STRAIGHT
	1537.31	STRAIGHT
Stanton Ls	1550.26	STRAIGHT
Vilas Sh	1568.12	STRAIGHT
Plattsburg Ls	1575.48	STRAIGHT
Bonner Springs Sh	1616.50	STRAIGHT
Wyandotte Ls	1627.61	STRAIGHT

Figure 10.5. Final shell window report for the preparation of a file with the subdivisions in the stratigraphic column of well Schaben 1.

Preparation of a stratigraphic column is not a stand-alone option; it is an accessory in commands for the preparation of any of the types of hardcopy cross sections described in the previous chapter or in the following one. Figure 10.6 is the hardcopy of an LM cross section (Figure 9.12), annotated entering the file in Figure 10.5 by setting parameter SC equal to L. CORRELATOR allows annotation at both ends of a cross section, choice that was avoided not to clutter the figure. For an additional example, see Figures 10.14 and 10.15.

Like in the case of the marker files discussed in Chapter 9, the program does not have information or capabilities to verify the accuracy of the data going into the annotation files. In that aspect of the preparation of the cross sections, the programs is purely following drawing instructions. It is up to the user to make sure that all information is geologically correct.

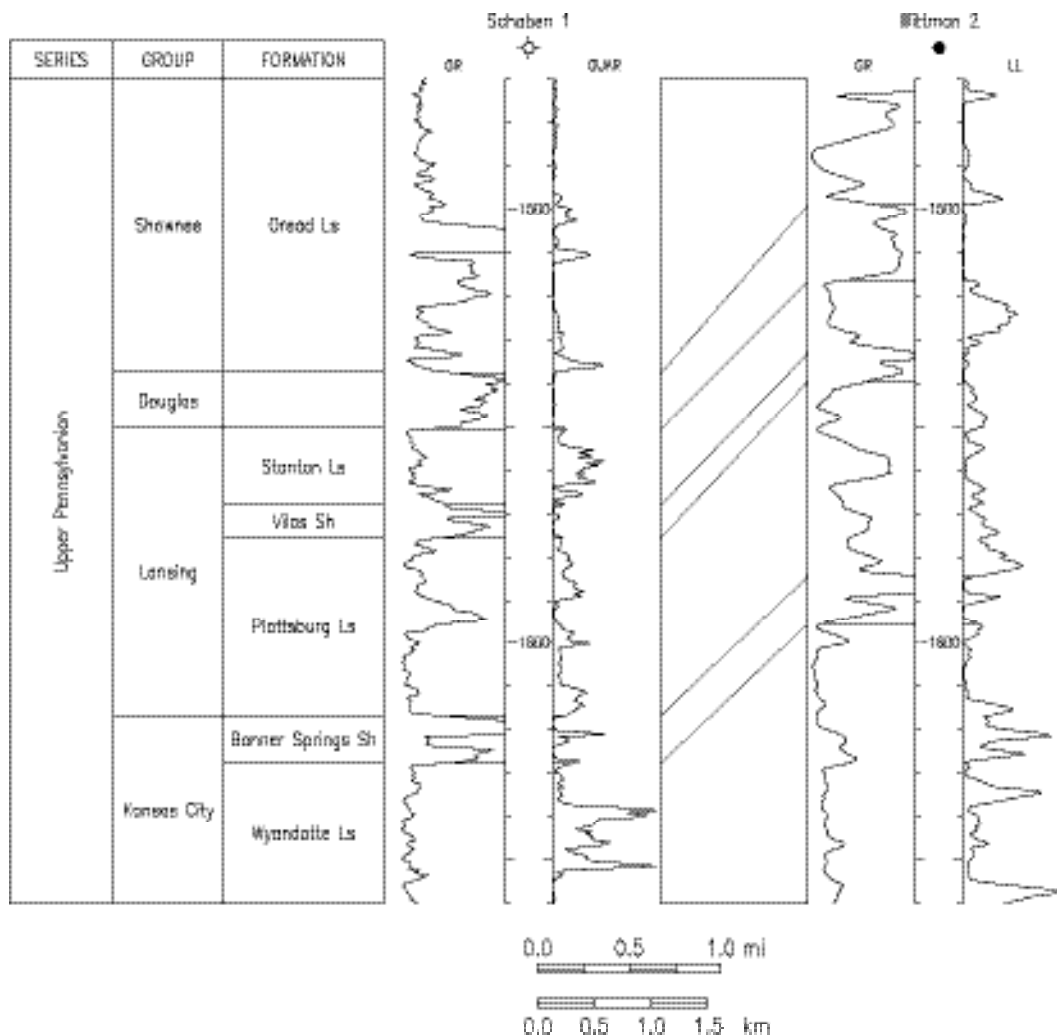


Figure 10.6. Annotation of a cross section using the file in Figure 10.5. Vertical exaggeration is 125 times. Part of legend removed for display simplicity. For location of wells, see Figure 9.1.

PREPARATION OF FILE TO ANNOTATE LITHOLOGY IN STRATIGRAPHIC COLUMN

```
FN -- NAME OF THE FILE                               FIG10.9
SN -- SEQUENTIAL NUMBER FOR WELL TO ANNOTATE        1

ND -- SHALLOWEST DEPTH TO ANNOTATE                 1452.00
XD -- DEEPEST DEPTH TO ANNOTATE                     2181.00

RE -- RETURN TO PREVIOUS MENU

PLEASE ENTER YOUR SELECTIONS: xd 1700.00 go
```

Figure 10.7. Menu PL ready to prepare a lithology file.

```
                LITHOLOGY ANNOTATION FILE
                *****

MARKER FILE NAME:          FIG10.9
FILE VALID FOR WELL:      Schaben 1 ( 1)
NUMBER OF BEDS IN THE FILE:  24
```

Figure 10.8. A shell window report for option PL.

Each record in the stratigraphic column subdivision file is 51 characters long, including a line break.

Lithological annotations

The second element in a stratigraphic column is the lithology, which CORRELATOR displays with partial help from the shale log. Option PL in the File Management menu prepares a file showing every single interval with proportion of shale larger than 50%. The next three figures (Figures 10.7-10.9) show the PL menu ready to generate a lithology file for well Schaben 1; its shell window report; and the output file, whose records are all 21 characters long, counting a line break.

All levels coded sh are tops of bed with more than 50% of shale, which for the purpose of annotation, the program treats them all as one lithology, whether the proportion is 50.01% of 100%. Levels without a lithology code are clean levels. In its present form, CORRELATOR is unable to automatically identify the type of clean lithology. The problem has to be resolved externally to the program—wireline log analysis package, driller logs, cores, drill chips—and the results manually coded into the lithology file. In the particular case of this interval of well Schaben 1, all clean beds are limestones. CORRELATOR can annotate nine types of clean lithologies according to the following codes:

LITH	1	34
1451.50		S
1498.88	sh	G
1499.03		G
1503.34	sh	G
1509.82		G
1511.63	sh	G
1521.87		S
1527.81	sh	G
1528.58		G
1532.63	sh	G
1534.03		G
1537.31	sh	G
1550.26		S
1564.32	sh	G
1564.87		G
1568.12	sh	G
1575.48		S
1590.78	sh	G
1595.49		G
1616.73	sh	G
1621.36		G
1623.76	sh	G
1627.61		G

Figure 10.9. Lithology file for well Schaben 1 as generated by option PL.

- Anhydrite ah
- Chalk ck
- Coal cl
- Dolomite dl
- Granite gn
- Limestone ls
- Salt st
- Sandstone ss
- Undecided bl or blank spaces

Codes G and S indicate the type of transition from one lithology to another. The latter denotes abrupt transition, which is annotated with a solid line at the contact. Otherwise the transition is gradual, in which case no horizontal line is specially drawn to separate the lithology types.

A lithology file for well Moore 6B was prepared in a way entirely similar to the preparation of the lithology file for well Schaben 1. In both files, all blank codes were changed to ls and all transition codes G were modified to S. Figure 10.10 shows a cross section with lithology annotation at both ends using such files. Its generation required use of option LM in the Geological Interpretation menu (Figure 7.20), setting option LA to BOTH in the full LM menu, and entering

the names of both lithology files. The next section contains an example of stratigraphic column incorporating both subdivisions and lithology annotations.

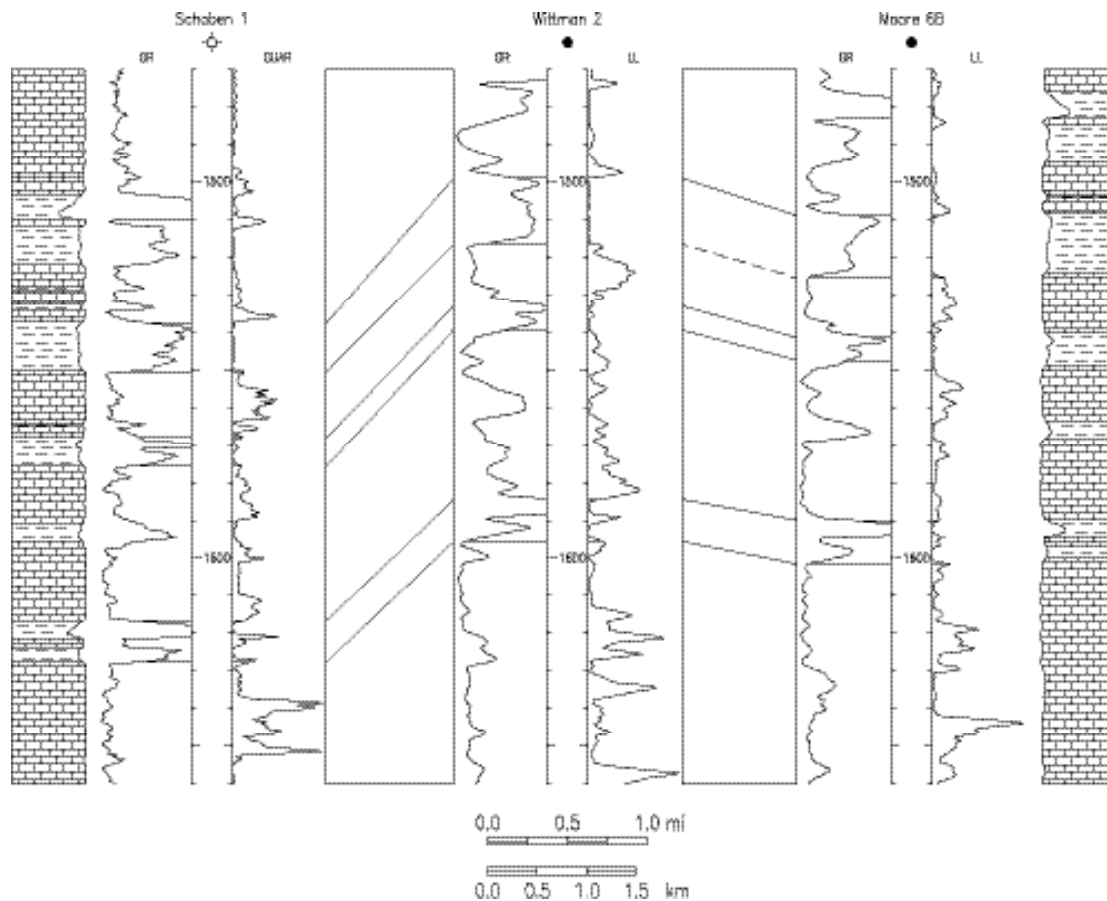


Figure 10.10. Example of lithological annotation.

Datum files for stratigraphic cross sections

Preparation of stratigraphic cross sections “hung” from a datum representing a stage of smooth relief in the history of the basin is a useful tool for the study of sedimentary processes. CORRELATOR is capable of preparing stratigraphic cross sections by processing information about the present depth to a reference surface of choice at every well in the cross section. Writing such information into a file compatible with CORRELATOR specifications requires execution of option PD in the Data Management menu (Figure 5.1). Each record has exactly 11 characters. We will prepare a stratigraphic cross section for the wells in Figure 9.1. Hence, the datum file requires values for the four wells in the closed section, Schaben 1 counting twice. The PD menu has two levels, illustrated in Figures 10.11 and 10.12. Figure 10.13 displays the shell window report upon at completion.

PREPARATION OF A DATUM FILE

```
FN -- NAME OF THE DATUM FILE                HEEBNER.DATUM
SA -- START A NEW FILE (S), ADD TO AN EXISTING FILE (A)          START

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE DATUM FILE

PLEASE ENTER YOUR SELECTIONS: go
```

Figure 10.11. Initial display of PD menu.

PREPARATION OF A DATUM FILE

```
FN -- NAME OF THE DATUM FILE                HEEBNER.DATUM
SA -- START A NEW FILE (S), ADD TO AN EXISTING FILE (A)          ADD
DF -- DEPTH TO DATUM, DEPTH BELOW SEA LEVEL                      0.00

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE DATUM FILE

PLEASE ENTER YOUR SELECTIONS: df 1503.5 go
```

Figure 10.12. The PD menu ready to add depth values to the datum file.

```
          DATUM FILE
          *****

DATUM FILE NAME          HEEBNER.DATUM
NUMBER OF DATUM VALUES      4

                                DEPTH
                                FEET
                                -----
                                1      1503.50
                                2      1466.50
                                3      1476.50
                                4      1503.50
```

Figure 10.13. Example of shell window report for option PD.

PLOT AND PRINT TRACED CORRELATIONS IN A CROSS SECTION

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS FIG10.15.SOURCE
 XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING -->
 SP -- FILE WITH PLOTTING SPECIFICATIONS SCHABEN.SPECS
 T1 -- FIRST TITLE
 T2 -- SECOND TITLE
 SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) LEFT
 SL -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE LEFT FIG10.5
 LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) LEFT
 LL -- NAME OF LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE LEFT FIG10.9
 DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N) NO
 DF -- DATUM FILE WITH DEPTHS FOR NEW REFERENCE SURFACE HEEBNER.DATUM
 AD -- ELEVATION ABOVE DATUM FOR STARTING PLOTTING, FEET 20.00
 BD -- DEPTH BELOW DATUM FOR ENDING PLOTTING, FEET 148.00
 VS - VERTICAL DEPTH SCALE, FEET/IN 20.00
 HS - HORIZONTAL DISTANCE SCALE, FEET/IN 3000.00
 MF -- NAME OF MARKER FILE WITH DEPTHS TO TRACE ACROSS FIG10.15.MK
 FM - FAULT MODELING, YES (Y) OR NO (N) NO
 MD -- MORE DRAWING SPECIFICATIONS -->

RE -- RETURN TO PREVIOUS MENU
 GO -- PLOT CROSS SECTION

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATION FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY KANSAS GEOLOGICAL SURVEY
 PB -- INTERPRETER Ricardo A. Olea
 PT -- PLATE NUMBER, BLANK TO AVOID POSTING
 LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N) N
 PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E) A
 DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET 10
 ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D) E
 DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB) S
 MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE 110.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE -1.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L) W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
 GO -- COMMIT THE SELECTIONS

PLEASE ENTER YOUR SELECTIONS:

Figure 10.14. Example of preparation of stratigraphic cross section with stratigraphic column employing command LM.

Figures 10.14 and 10.15 summarize the use of all three forms of files described in this chapter: stratigraphic column subdivision file, stratigraphic column lithology annotation file, and datum file. In addition, to increase display diversity, the pen mode and numbers were changed from those in file SCH1.MK in Figure 9.14 to those in a file called FIG10.15.MK in display in Figure 10.16. It was necessary to add a seventh dummy level above the upper boundary of the cross section to be able to paint above the Douglas Group. In terms of changing from the main reference surface—sea level—to a datum such as the top of the Heebner, note that now the interval to display is specified as the spread above and below the datum instead of by depth.

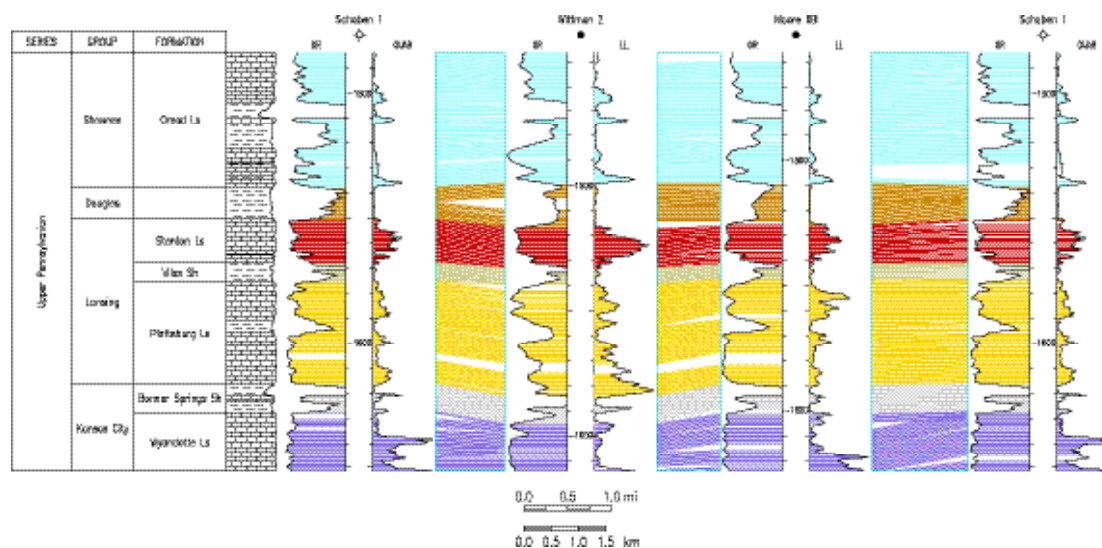


Figure 10.15. Stratigraphic cross section, with stratigraphic column, for the same wells in Figure 9.1. Color here is used to differentiate formations. The datum is the top of the Heebner shale, the shallowest shale in the display, while labels in vertical scale still denote elevation. The vertical exaggeration is 150 times. Legend partially eliminated to maximize size of display.

	DEPTH FEET	PEN	DRAWING	REMARKS
1	-999.00	17	P	
2	1537.50	41	P	Douglas Gr
3	1550.50	56	P	Stanton Sh
4	1568.00	50	P	Vilas Sh
5	1575.50	54	P	Plattsburg
6	1616.50	11	P	Bonner Sp.
7	1627.50	43	P	Wyandotte

Figure 10.16. Shell window report for marker file FIG10.15.MK employed in the preparation of Figure 10.15.

Chapter 11: Beyond correlations

Within a lithostratigraphic context, manual correlation or computer correlation using programs other than CORRELATOR does not go beyond what we covered in the previous chapters. Wireline logs, however, for a long time, have had an untapped potential. Here, we have done our best to exhaustively explore the analysis of two logs per well with the assistance of a computer. Topics covered in this chapter are mostly novel and include:

- Apparent dip diagrams
- True dip diagrams
- Fault detection
- Fault modeling
- Spatial variation of proportion of shale
- Spatial display of porosity
- Spatial display of fluctuations in lithology

At this point, we will be building heavily on procedures learned in previous chapters. In particular, all the analyses in this chapter presume previous preparation of correlation interpretations, preferably interpretations with overlapping correlation intervals from top to bottom of the zones of interest.

As the number of files involved in the processing of the information reaches its maximum, we will concentrate on explaining solely those files and menus not yet covered that are central to Chapter 11.

Apparent dip diagrams

Figures 11.1 and 11.2 illustrate a first example of innovation. Figure 11.1 shows the conventional way to display lines of correlation. The difference in elevation between the extremes of any tie line and the distance between the correlated wells define a triangle. The angle opposite to the difference in elevation is the inclination of the tie line. Figure 11.2 is no more than a hardcopy graph of the vertical variation of the tie line angles. Displays follow the convention of showing the inclination as a symbol made of a solid dot and a short line. The colors denote the strength of the correlation, location of the dot shows the magnitude of the inclination and the short line indicates the azimuth. By convention, only the reference well appears in the displays.

Preparation of apparent dip angles requires execution of option AD in the Geologic Interpretation menu (Figure 7.20). Figure 11.3 displays the full menu after loading the well/log database and the correlation database plus selection of the interpretation and the file with display specifications.

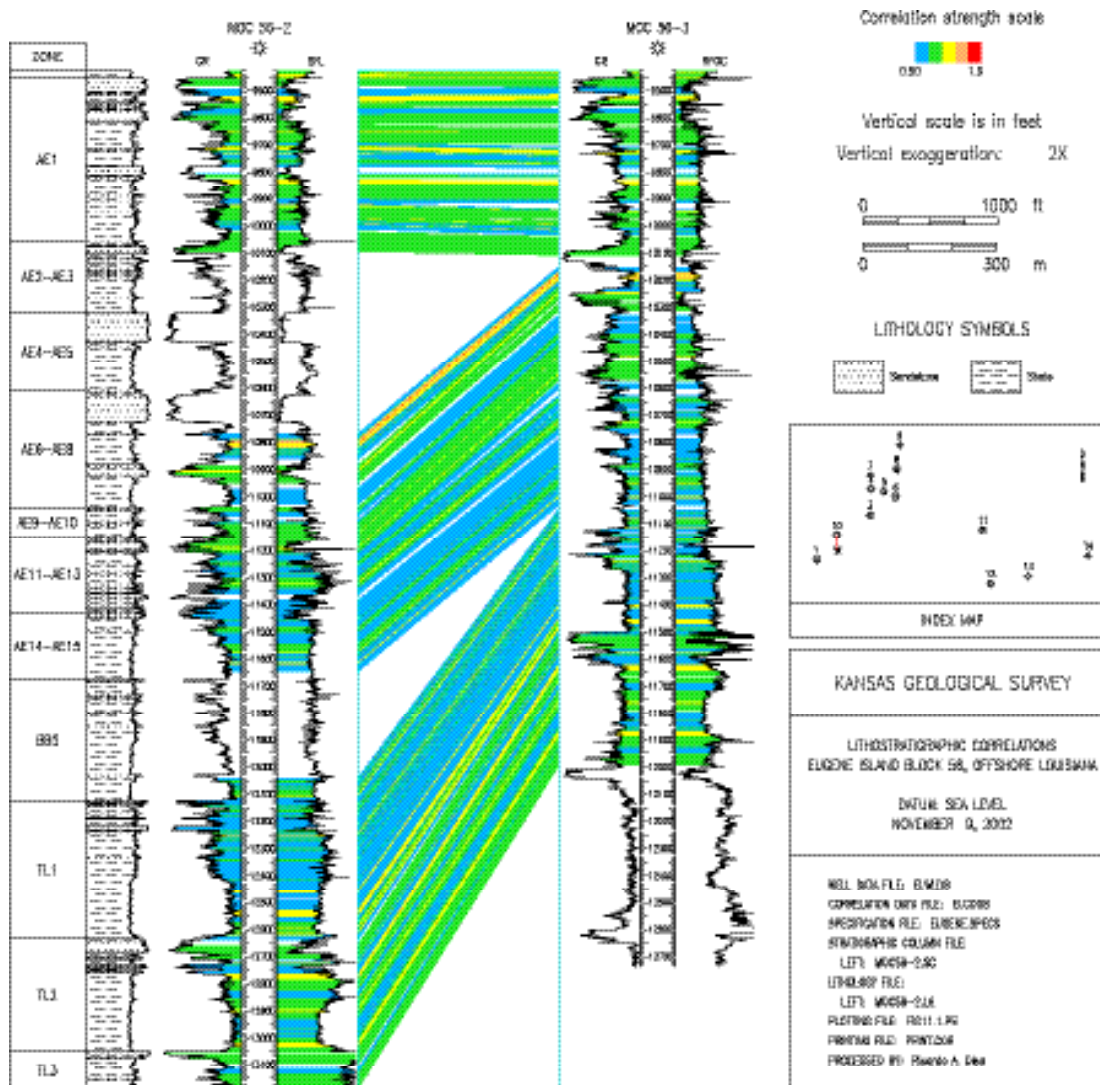


Figure 11.1. Tie lines for a pair of wells in Eugene Island Block 56, offshore Louisiana.

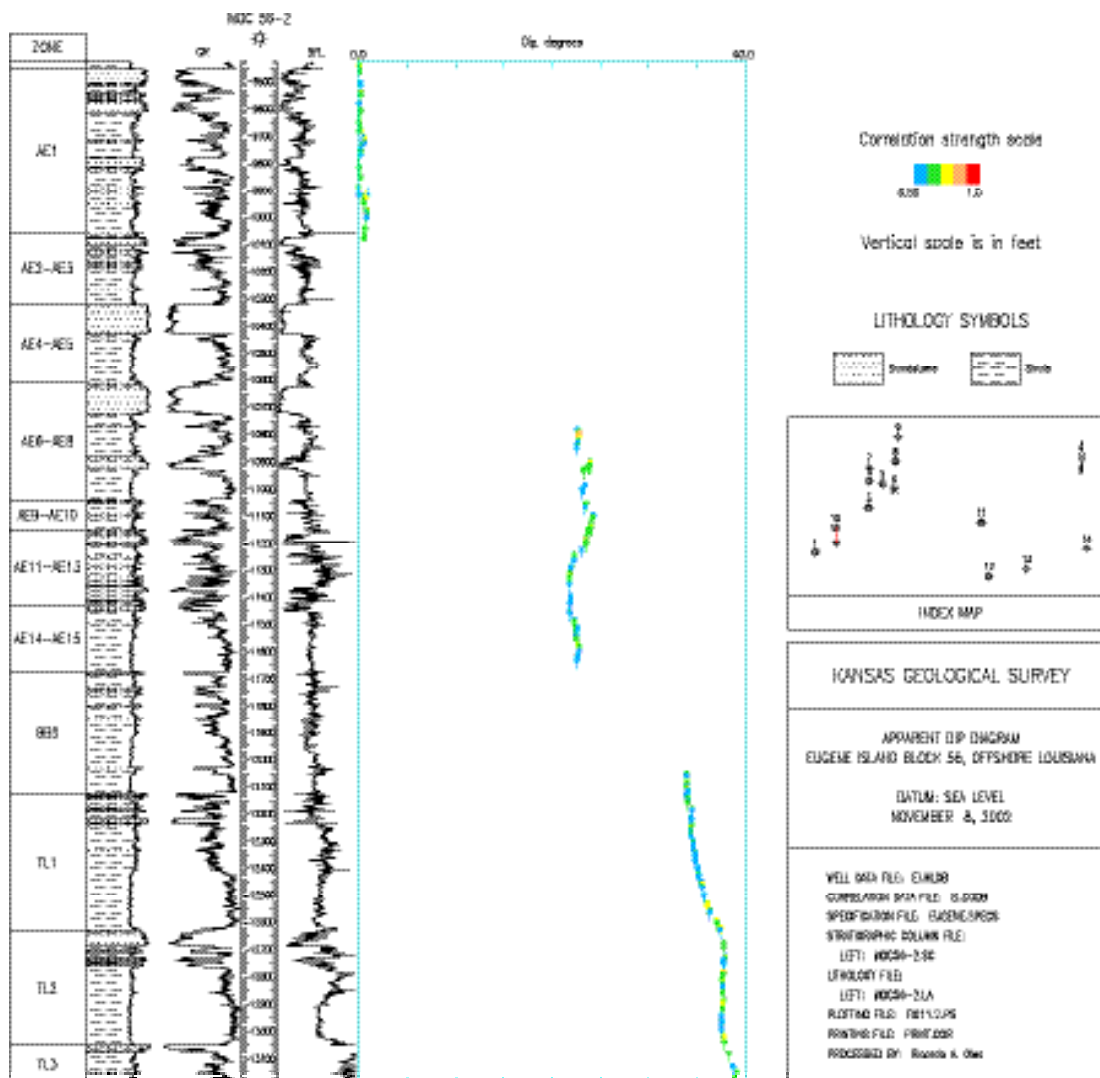


Figure 11.2. Tie lines in Figure 11.1 converted to apparent dips.

PREPARATION OF APPARENT DIP DIAGRAMS

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS *???*
 XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING ->
 SP -- FILE WITH PLOTTING SPECIFICATIONS EUGENE.SPECS
 T1 -- FIRST TITLE EUGENE ISLAND BLOCK 56, OFFSHORE LOUISIANA
 T2 -- SECOND TITLE DATUM: SEA LEVEL
 SC -- TEXT IN STRATIGRAPHIC COLUMN TO LEFT (L) OR NONE (N) LEFT
 SL -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE LEFT MOC56-2.SC
 LA -- LITHOLOGY IN STRATIGRAPHIC COLUMN TO LEFT (L) OR NONE (N) LEFT
 LL -- LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE LEFT MOC56-2.LA
 DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N) YES
 ND -- STARTING DEPTH FOR PLOTTING, FEET 9348.50
 XD -- ENDING DEPTH FOR PLOTTING, FEET 13201.50
 VS - VERTICAL DEPTH SCALE, FEET/IN 200.00
 HS - HORIZONTAL DISTANCE SCALE, FEET/IN 5.00
 ST -- STARTING DEPTH FOR DIAGRAMS, FEET 9370.00
 ET -- ENDING DEPTH FOR DIAGRAMS, FEET 13201.50
 MD -- MORE DRAWING SPECIFICATIONS ->

RE -- RETURN TO PREVIOUS MENU
 GO -- PLOT CROSS SECTION

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATIONS FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY KANSAS GEOLOGICAL SURVEY
 PB -- INTERPRETER Ricardo A. Olea
 PT -- PLATE NUMBER, BLANK TO AVOID POSTING
 LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N) N
 PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E) A
 DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET 10
 ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D) E
 DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB) S
 MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE -1.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE 2.00
 VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
 DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L) W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
 GO -- COMMIT THE SELECTIONS

PLEASE ENTER YOUR SELECTIONS:

Figure 11.3. Menu employed in the generation of Figure 11.2.

Apparent dip diagrams are a more elaborated, hardcopy version of the type of graphs already used in Chapter 7 to fit polynomials to define the center of correlation search intervals (Figure 7.12). Figure 8.10 is a display of the tie lines associated to Figure 7.12. There, it looks like the tie lines are perfectly parallel. Yet, the graph unequivocally shows that there is a subtle systematic variation in the apparent dips. The fluctuations are more evident in Figure 11.2.

Execution of command AD generates a screen preview and a hardcopy report of the same form as the listing in Figure 7.11. By selecting several successive interpretations, it is possible to generate as many consecutive apparent dip diagrams as there are pairs of wells in a cross sections.

True dip diagrams

Correlation of three or more wells in an area offers the possibility to calculate true dips for any three successive wells in a cross section. Three points at the same lithostratigraphic surface define a plane cutting such surface at those three locations. The smoother the surface and the closer the points, the more such plane will be indistinguishable from the true geologic surface. CORRELATOR can almost instantaneously find points on the same lithostratigraphic surfaces by using the same capabilities that allow the preparation of cross sections displaying markers (Chapter 9). Conversion of the spatial location of three points to the inclination of the plane through the three points is known in geology as the three-point problem (Olea, 1994a). Figure 11.4 is the true dip diagram corresponding to the correlations in Figure 11.5.

Preparation of true dip diagrams requires execution of option TD in the Geologic Interpretation menu (Figure 7.20). All necessary input information to enter into CORRELATOR and the final menu is the same as that required for the generation of apparent dip diagrams. The main difference is that it is not possible to generate several true dip diagrams in one run of option TD.

The symbols used to display results are the same vectors employed for the rendition of apparent dips. For maximum stability in the results, it is recommended that posting of the three wells involved in the calculation of true dip diagrams be as close as possible to the vertices of an equilateral triangle. By convention, CORRELATOR requires that in case of interest on the display of a stratigraphic column, the data input must be for the middle well common to the two pairs of interpretations on which the diagram is based, which in the case of Figure 11.4 is well McCoy 1.

Except for the scale, conceptually the CORRELATOR diagrams of true dips are not much different from the conventional dipmeter diagrams obtained by correlating three or more resistivity logs simultaneously measured inside the same well. Experts have devoted great effort to assign geological meaning to different patterns of variations in the vectors or tadpoles, as they are more commonly known (Rider, 1996, Chapter 12). Such body of knowledge transfers directly to this new form of dipmeter tool.

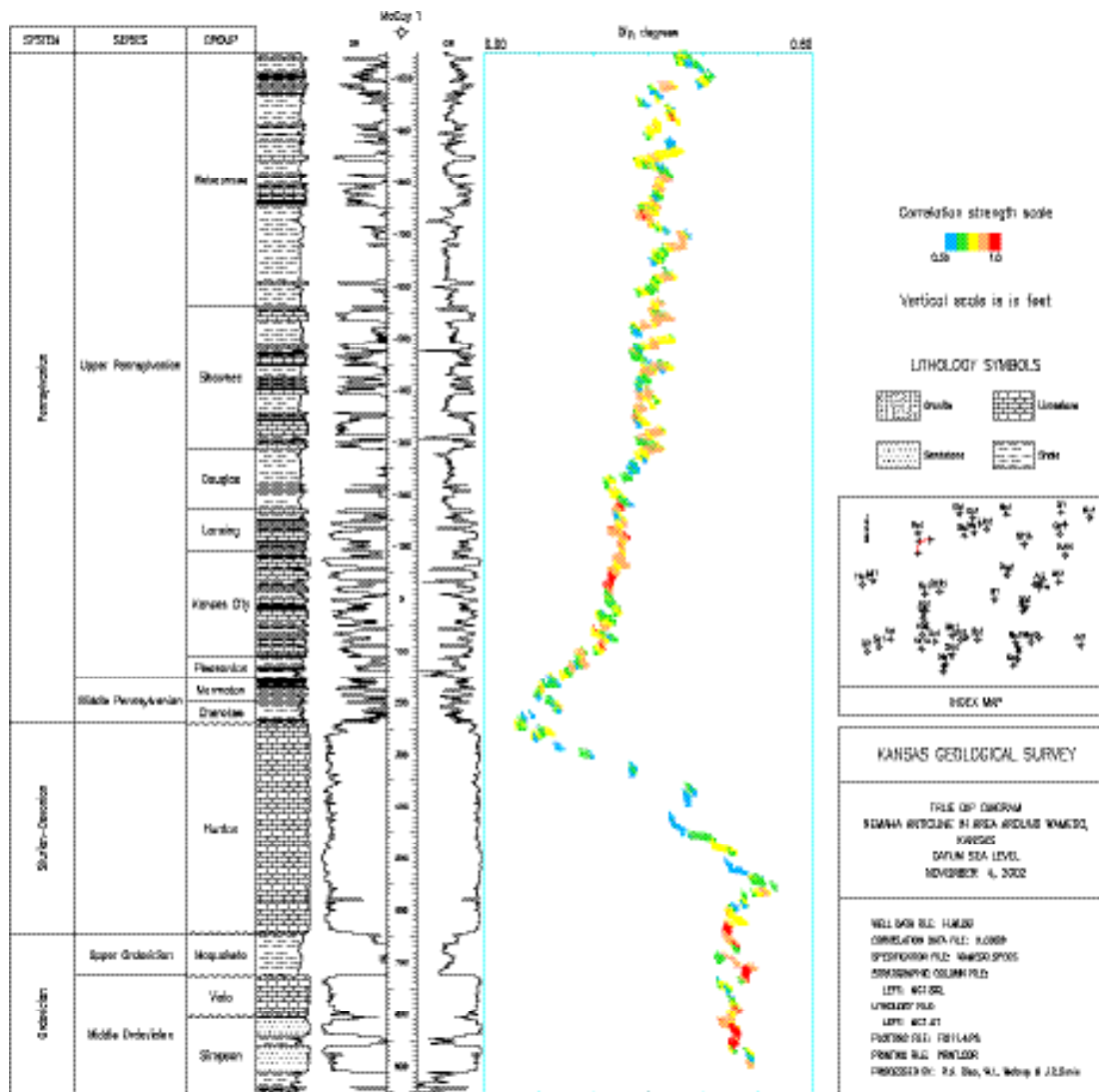


Figure 11.4. True dip diagram for three wells in the Nemaha anticline near Wamego, Kansas.

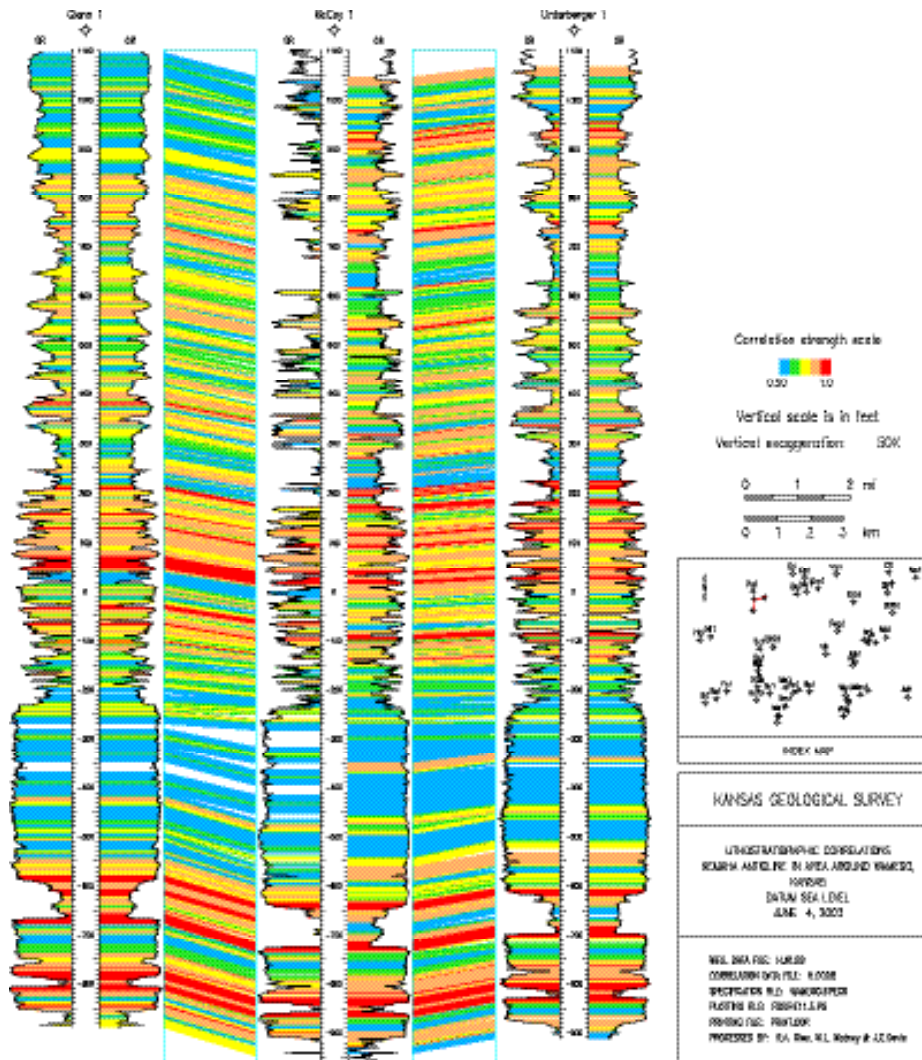


Figure 11.5. Correlations at the three wells in Figure 11.4.

Detection of faults

Normal faults produce dip diagrams such as the one in Figure 11.2. The converse is not true. Other geological processes, such as erosion, also result in dip diagrams with sudden shifts in the tadpoles. If knowledge about an area favors faults over other processes, CORRELATOR has option DF in the Geological Interpretation menu (figure 7.20) to assist in the inference of fault intersections and section losses. The analysis goes by pairs of wells and requires prior loading of the well/log database and correlation database. As shown by Figure 11.6, the menu for the option is fairly straightforward. According to the report in Figure 11.7, two faults are intersecting well MOC 56-3.

Analysis by option DF requires that correlations in the interpretation to be analyzed be sorted by increasing depth.

FAULT DETECTION

REFERENCE WELL (2): MOC 56-2
 MATCHING WELL (10): MOC 56-3
 INTERPRETATION (2): All correlations

CI -- SELECT CORRELATION INTERPRETATION -->
 LS -- MINIMUM LOSS SECTION TO CONSIDER, FEET 100.00
 RE -- RETURN TO PREVIOUS MENU
 GO -- FIND FAULTS

PLEASE ENTER YOUR SELECTIONS: ls 200 go

Figure 11.6. Menu for the generation of report in Figure 11.7.

DETECTION OF POTENTIAL FAULTS IN THE CROSS-SECTION COMPRISING WELLS
 2 (MOC 56-2) AND 10 (MOC 56-3)

REFERENCE LOGS GR-SFL

MATCHING LOGS GR-RFOC

MINIMUM SECTION LOSS 200.0 FEET

CORRELATED INTERVALS:

WELL 2: 9423.5- 13186.5 FEET

WELL 10: 9422.0- 11993.5 FEET

DISTANCE BETWEEN WELLS: 1479. FEET

WHAT IS MISSING FUZZY BOUNDARIES		WHERE IS MISSING FAULT INTERSECTION LIKELY		
WELL	INTERVAL FEET	WELL	DEPTH FEET	SECTION LOSS FEET
2	10095.0-10770.0	10	10109.5-10153.5	631.0
2	11645.5-12040.0	10	11030.5-11047.5	377.5

Figure 11.7. Shell window report indicating where is likely that a well intersected a fault.

Fault modeling from first principles

CORRELATOR allows storage of fault information in fault files, one per cross section. In the most general case, the faults may be normal growth faults. The program does not handle inverse faults. Each file may contain parameters defining as many fault planes as necessary. Such parameters are of two types: orientation of the fault plane and displacement as revealed by missing section. The variable missing section for levels in the upthrow, $U_i(z_u)$, can be entered as a tabulation of n different linear functions of the form:

$$U_i(z_u) = d_i + e_i(z_u - c_i), \text{ for } a_i \leq z_u \leq b_i; 1 \leq i \leq n$$

where:

z_u is depth at the upthrow-well end of the tie line intersected by the fault;

a_i is the upper range of validity of the function;

b_i is the lower range of validity of $U_i(z_u)$;

c_i is a constant base depth, $a_i \leq c_i \leq b_i$;

d_i is a constant value of missing section; and

e_i is a constant rate of change for missing section.

The value of a_i for the every plane has the additional effect of defining the starting depth for the fault—no fault trace is drawn above a_i . If z_d is the depth of a level at the downthrow whose depth at the upthrow is z_u , then missing section $D_i(z_d)$ must be equal to $U_i(z_u)$. The program automatically determines in which block is the end of any tie line and calculates the appropriate $U_i(z_u)$ or $D_i(z_d)$, provided that $e_i > -1$ and if $n \geq 2$ then $U_i(b_i) = U_{i+1}(a_{i+1}), 1 \leq i \leq n-1$.

Continuing with the Eugene Island example used in this chapter, analysis of other pairs of wells and other general information about the area confirm the existence of the two faults in the report in Figure 11.7. They are two growth faults with the shallower one intersecting both wells and the deeper one intersecting well MOC 56-2 below the bottom of the well.

Preparation of a fault file requires dealing with several menus for the same command PF in the File Management menu (Figure 5.1). Initially, the menu will ask for a file name. Proper response will generate a second menu of the form in Figure 11.8. CORRELATOR is now ready to read in the geometric characteristics of the fault plane, illustrated in Figure 11.9. Finally, each plane will require specification of at least one set of parameters for a missing section function $U_i(z_u)$. Figure 11.10 shows a program window with parameters to define the fourth of such functions for the shallower of the two faults intersecting well MOC 56-3. Records in fault files are all of length 51, a line break included.

Figure 11.11 is the fault file report upon completing all specifications based mostly on the fault detection report and the apparent dip diagram. Figure 11.12 is an example of use of the file in conjunction with command LM (Figure 7.20) under mode Both for parameter MP in the marker file (Figure 9.13). In this case, the fault plane introduces the effect of faulting on the tie lines in Figure 11.1.

PREPARATION OF A FAULT FILE

FN -- NAME OF THE FAULT FILE	FIG11.11
SA -- START A NEW FILE (S), DEFINE A FAULT PLANE IN AN EXISTING FILE (P) OR ENTER MISSING SECTION TABLE (T)	START
DG -- FAULT DIP UNITS, DEGREE (D) OR GRADIENT (G)	GRADIENT
RE -- RETURN TO PREVIOUS MENU	
GO -- UPDATE THE FAULT FILE	

PLEASE ENTER YOUR SELECTIONS: go

Figure 11.8. Example of second stage menu for command DF.

PREPARATION OF A FAULT FILE

FN -- NAME OF THE FAULT FILE	FIG11.11
SA -- START A NEW FILE (S), DEFINE A FAULT PLANE IN AN EXISTING FILE (P) OR ENTER MISSING SECTION TABLE (T)	FAULT PLANE
SN -- SEQUENTIAL NUMBER FOR THE WELL INTERSECTED BY THE FAULT	2
DI -- DEPTH TO THE INTERCEPTION, FEET BELOW SEA LEVEL	11660.00
AZ -- FAULT AZIMUTH, COUNTERCLOCKWISE DEGREES FROM EAST	305.00
TD -- FAULT TRUE DIP, GRADIENT	1.25
PN -- PEN NUMBER	3

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE FAULT FILE

PLEASE ENTER YOUR SELECTIONS: go

Figure 11.9. Example of third stage menu for command DF.

PREPARATION OF A FAULT FILE

FN -- NAME OF THE FAULT FILE	FIG11.11
SA -- START A NEW FILE (S), DEFINE A FAULT PLANE IN AN EXISTING FILE (P) OR ENTER MISSING SECTION TABLE (T)	TABLE
DT -- DEPTH FOR TOP OF INTERVAL AT UPTHROW, FEET	11075.00
MS -- MISSING SECTION, FEET	625.00
RI -- RATE OF INCREASE IN MISSING SECTION WITH DEPTH	-0.0575
RD -- BASE DEPTH, FEET	11075.00

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE FAULT FILE

PLEASE ENTER YOUR SELECTIONS: go

Figure 11.10. Example of fourth stage menu for command DF.

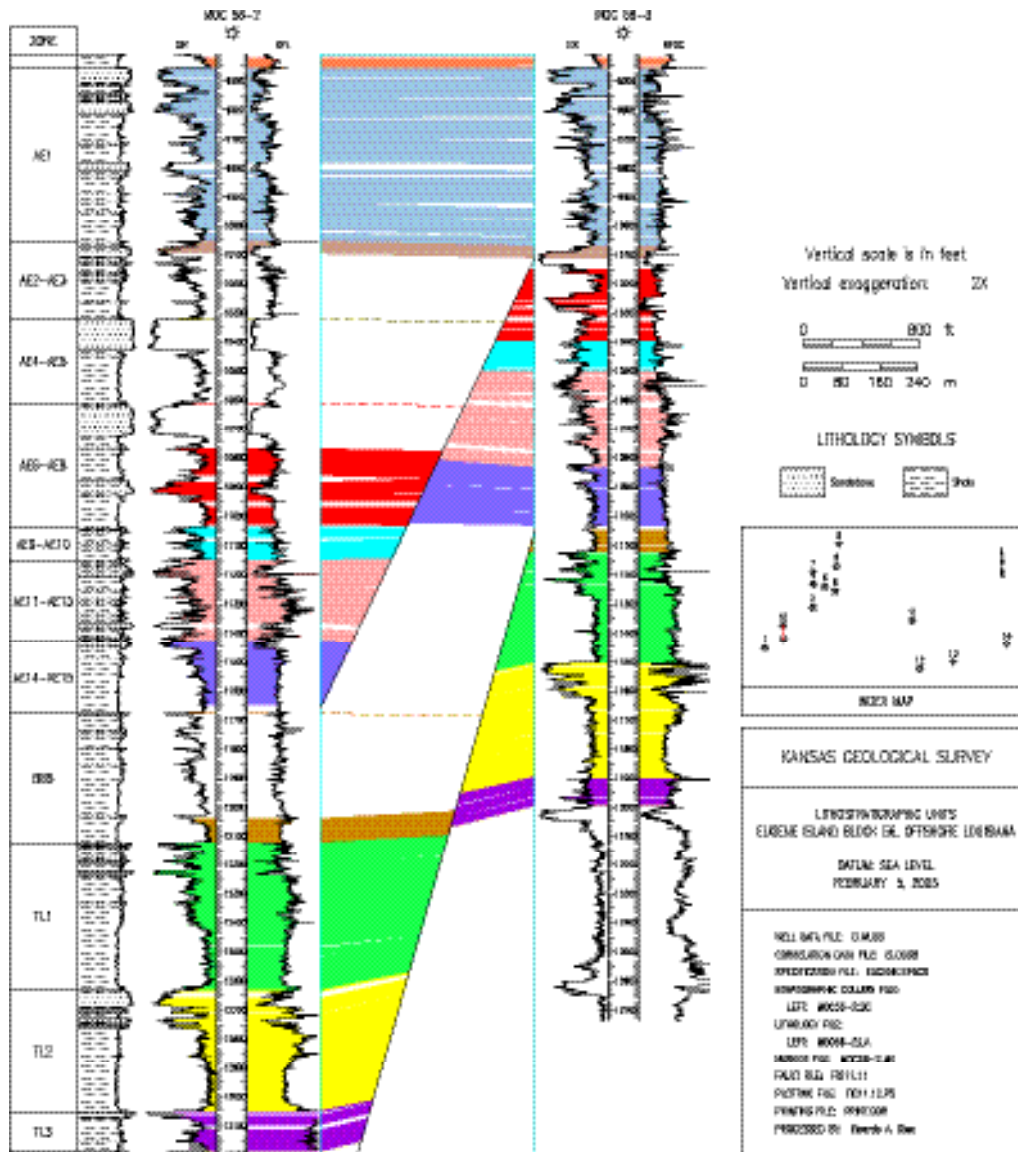


Figure 11.12. Example of fault modeling for two wells in Eugene Island, offshore Louisiana.

a fault—the Humboldt Fault—running north-northeast a short distance to the east. The Humboldt Fault is a major fault in the American Midwest several hundred miles long. Yet, such a fault was not possible to detect in the area using command DF because the fault is steep and intercepts neither of the wells in the cross section nor any of the other 48 wells analyzed in the area (Olea et al., 2002).

Figure 11.14 is special in two additional ways. First, in all interpretations such as this one starting close to the surface, the program employs the kelly-bushing elevation to approximate the surface topography. Secondly, the figure is an example of cross-section prepared employing one wireline log per well. At wells with log display, every log appears in two different scales, with the log in the place of the correlation log being a mirror image of the shale log.

DETECTION OF POTENTIAL FAULTS IN THE CROSS-SECTION COMPRISING WELLS
38 (Mansfield 1) AND 39 (Umscheid 1)

REFERENCE LOGS GR-GR

MATCHING LOGS GR-GR

MINIMUM SECTION LOSS 100.0 FEET

CORRELATED INTERVALS:

WELL 38: -935.0- 666.0 FEET

WELL 139: -955.0- 523.0 FEET

DISTANCE BETWEEN WELLS: 10167. FEET

WHAT IS MISSING FUZZY BOUNDARIES		WHERE IS MISSING FAULT INTERSECTION LIKELY		
WELL	INTERVAL FEET	WELL	DEPTH FEET	SECTION LOSS FEET
38	134.5-275.0	39	121.5-123.0	139.0

Figure 11.13. Example of detection of disruption in the sedimentary sequence due to unconformity.

Proportion of shale

So far, we have used wireline logs exclusively to infer the subsurface geometry of the stratigraphic succession based on weighted cross correlation, which involves comparison of strings of measurements rather than the use of individual readings. In the remainder of the manual, we will describe three applications where the pair of logs are used twice, once as strings of observations to define the architecture and a second time as point measurements to render spatial variation of a petrophysical property. Command PS in menu Geologic Interpretation (Figure 7.20) is a first instance devoted, in this particular case, to show variation in the amount of shale. Figure 11.15 displays an illustrative application and Figure 11.16 shows the full menu after selecting the well/log database, the correlation database, the interpretations with the appropriate correlations and the file with the drawing specifications. The full PS menu is fairly similar to the full menus for the other commands for the generation of hardcopies of cross sections. Differences worth mentioning in this case are:

- There is one specific parameter to break the interval of variation of percent shale into classes. Evidently, the more the classes, the higher the resolution of the color scheme. It is the authors' experience, however, that beyond a certain small number, a generous color scheme is

confusing. The program is limited to a maximum of 5 classes, with some possibilities of mergers. Figure 11.15 uses all five classes.

- This is the first application in which we have used option K for parameter DO, which permits display in the same original depth scale in the paper copies or in the LAS files.
- We have used option PW to avoid the display of the intermediate wells.

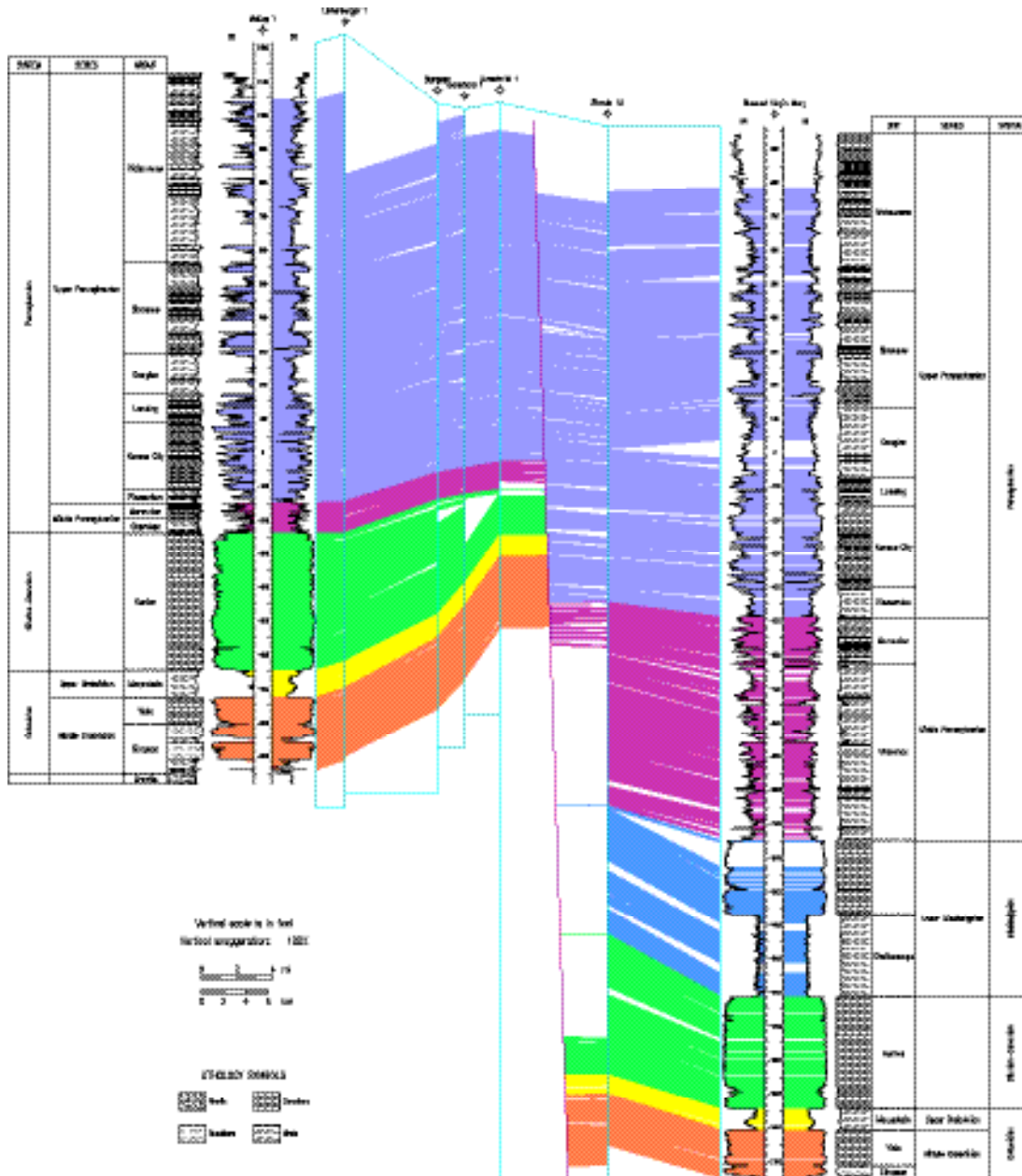


Figure 11.14. Display of unconformity and fault using command LM under painting mode. The cross section runs west-east in Pottawatomie County, Kansas.

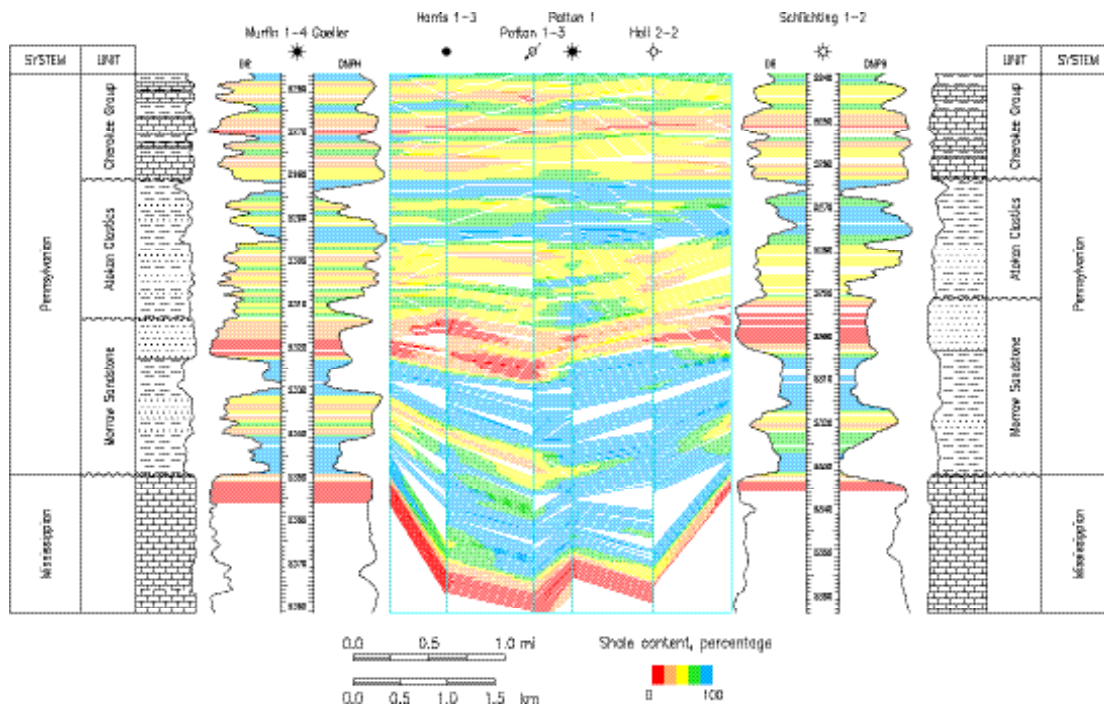


Figure 11.15. Proportion of shale along a west-east cross section in the central portion of the Norcan East field, Minneola Unit, Clark County, Kansas. The datum is the base of the Cherokee Group, the vertical scale is in feet below surface, and the vertical exaggeration is 150 times.

Hardcopy display of porosity

The combination of density and neutron logs nowadays is commonly employed to determine porosity that is largely free of lithologic effects. By averaging the logs on a limestone scale, the effects of dolomite and quartz tend to cancel out, as well as most of the effect of gas, if any (Bateman, 1985, p. 440-441). Hence, each time that all wells in a cross section have these two types of logs, it is possible to have a continuous variation of porosity with depth. The only additional correction needed to produce estimates of true primary porosity, ρ_{sh} , is a correction to eliminate the effect of shale. In a first approximation, for any level:

$$\rho_{sh} = \rho_{DN} - V_{sh} \rho_{sh}$$

where ρ_{DN} is half the sum of the density porosity plus the neutron porosity, V_{sh} is the proportion of shale, and ρ_{sh} is the apparent porosity of a typical shale.

HARDCOPY DISPLAY OF THE PROPORTION OF SHALE

```

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS          FIG11.15.SOURCE
XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING    ->
SP -- FILE WITH PLOTTING SPECIFICATIONS                     MINNEOLA.SPECS
T1 -- FIRST TITLE      NORCAN EAST FIELD, MINNEOLA UNIT, CLARK COUNTY, KANSAS
T2 -- SECOND TITLE          DATUM: BASE OF PENNSYLVANIAN
SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N)  BOTH
SL -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE LEFT    M1-4G.SCL
SR -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE RIGHT    S1-2.SCR
LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N)  BOTH
LL -- NAME OF LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE LEFT  M1-4.LA
LR -- NAME OF LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE RIGHT  S1-2.LA
DA -- USE SEA LEVEL      AS DATUM, YES (Y) OR NO (N)          NO
DF -- DATUM FILE WITH DEPTHS FOR NEW REFERENCE SURFACE        PENN.DATUM
AD -- ELEVATION ABOVE DATUM FOR STARTING PLOTTING, FEET        25.00
BD -- DEPTH BELOW DATUM FOR ENDING PLOTTING, FEET              105.00
VS - VERTICAL DEPTH SCALE, FEET/IN                             14.00
HS - HORIZONTAL DISTANCE SCALE, FEET/IN                        2100.00
NC -- NUMBER OF CLASSES: FIVE(5), MERGE 4 & 5 (4), MERGE 1 & 2
      AND 3 & 4 (3), OR MERGE 1 & 2 & 3 AND 4 & 5 (2)          5
FM - FAULT MODELING, YES (Y) OR NO (N)                        NO
MD -- MORE DRAWING SPECIFICATIONS                             ->
RE -- RETURN TO PREVIOUS MENU
GO -- PLOT CROSS SECTION
  
```

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATIONS FOR THE DRAWING OF A CROSS SECTION

```

AG -- AGENCY          KANSAS GEOLOGICAL SURVEY
PB -- INTERPRETER     R. Olea, S. Bhattacharya, and P. Gerlach
PT -- PLATE NUMBER, BLANK TO AVOID POSTING
LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N)        N
PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E)          E
DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET                 1
ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D)        D
DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB)        K
MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE           160.00
      VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE     -1.00
      VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L)  W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
GO -- COMMIT THE SELECTIONS
  
```

PLEASE ENTER YOUR SELECTIONS:

Figure 11.16. Example of full menu for command PS.

All wells in Figure 11.17 have density and neutron logs, which have been combined into a single density-neutron logs and used as correlation logs. Figure 11.17 is an example of a CORRELATOR cross section for the rendition of log derived porosity corrected by the effect of shale. In cross sections of this type, the readings of both the shale log and correlation logs are used twice, one to establish the architecture of the sediments and then to display a color-coded primary porosity.

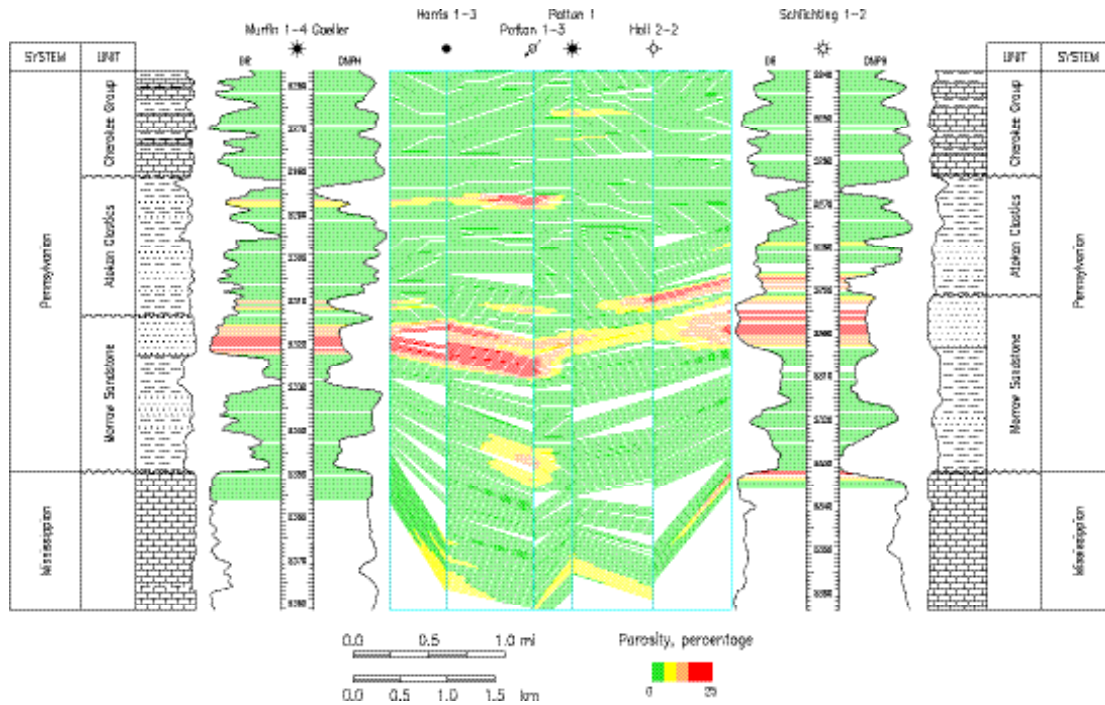


Figure 11.17. Example of display of cross sectional variation of porosity corrected for shale effect for the same wells and drawing specifications as Figure 11.15.

Preparation of porosity cross sections requires execution of option PO in the Geologic Interpretation menu (Figure 7.20). Figure 11.18 displays the particular selection of parameters that resulted in the production of Figure 11.17. The only difference in this full menu relative to the one in Figure 11.16 is the specification of two more parameters. Parameter MP determines the upper limit in the porosity scale; any value larger than MP will be displayed with the same color as a porosity equal to MP. AP specifies the value $_{Sh}$ to correct the log values for the shale effect.

HARDCOPY DISPLAY OF SHALE CORRECTED POROSITY

```

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS          FIG11.15.SOURCE
XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING    ->
SP -- FILE WITH PLOTTING SPECIFICATIONS                     MINNEOLA.SPECS
T1 -- FIRST TITLE      NORCAN EAST FIELD, MINNEOLA UNIT, CLARK COUNTY, KANSAS
T2 -- SECOND TITLE          DATUM: BASE OF PENNSYLVANIAN
SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N)  BOTH
SL -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE LEFT    M1-4G.SCL
SR -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE RIGHT    S1-2.SCR
LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N)  BOTH
LL -- NAME OF LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE LEFT  M1-4.LA
LR -- NAME OF LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE RIGHT  S1-2.LA
DA -- USE SEA LEVEL      AS DATUM, YES (Y) OR NO (N)          NO
DF -- DATUM FILE WITH DEPTHS FOR NEW REFERENCE SURFACE        PENN.DATUM
AD -- ELEVATION ABOVE DATUM FOR STARTING PLOTTING, FEET       25.00
BD -- DEPTH BELOW DATUM FOR ENDING PLOTTING, FEET             105.00
VS - VERTICAL DEPTH SCALE, FEET/IN                            14.00
HS - HORIZONTAL DISTANCE SCALE, FEET/IN                       2100.00
NC -- NUMBER OF CLASSES: FIVE(5), MERGE 4 & 5 (4), MERGE 1 & 2
      AND 3 & 4 (3), OR MERGE 1 & 2 & 3 AND 4 & 5 (2)         4
MP - MAXIMUM VALUE IN POROSITY SCALE, SCALE (0-1)             0.25
AP - APPARENT POROSITY OF SHALE, SCALE (0-1)                 0.23
FM - FAULT MODELING, YES (Y) OR NO (N)                       NO
MD -- MORE DRAWING SPECIFICATIONS                             ->
RE -- RETURN TO PREVIOUS MENU
GO -- PLOT CROSS SECTION
  
```

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATIONS FOR THE DRAWING OF A CROSS SECTION

```

AG -- AGENCY          KANSAS GEOLOGICAL SURVEY
PB -- INTERPRETER      R. Olea, S. Bhattacharya, and P. Gerlach
PT -- PLATE NUMBER, BLANK TO AVOID POSTING
LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N)       N
PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E)         E
DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET                1
ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D)       D
DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB)       K
MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE          160.00
      VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE    -1.00
      VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L)  W
RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
GO -- COMMIT THE SELECTIONS
  
```

PLEASE ENTER YOUR SELECTIONS:

Figure 11.18. Menu employed in the generation of Figure 11.17.

Hardcopy display of lithology

CORRELATOR is capable of displaying not only the geometry of the beds but its dominant mineralogy as well. Generation of lithological cross sections requires execution of option LL in the Geologic Interpretation menu (Figure 7.20). Figure 11.19 is a rendition of the cross section that appeared in the program window after execution of the menu in Figure 11.20. The same display was also automatically saved to file FIG11.19.PS for further generation of a hardcopy, such as the one in this manual.

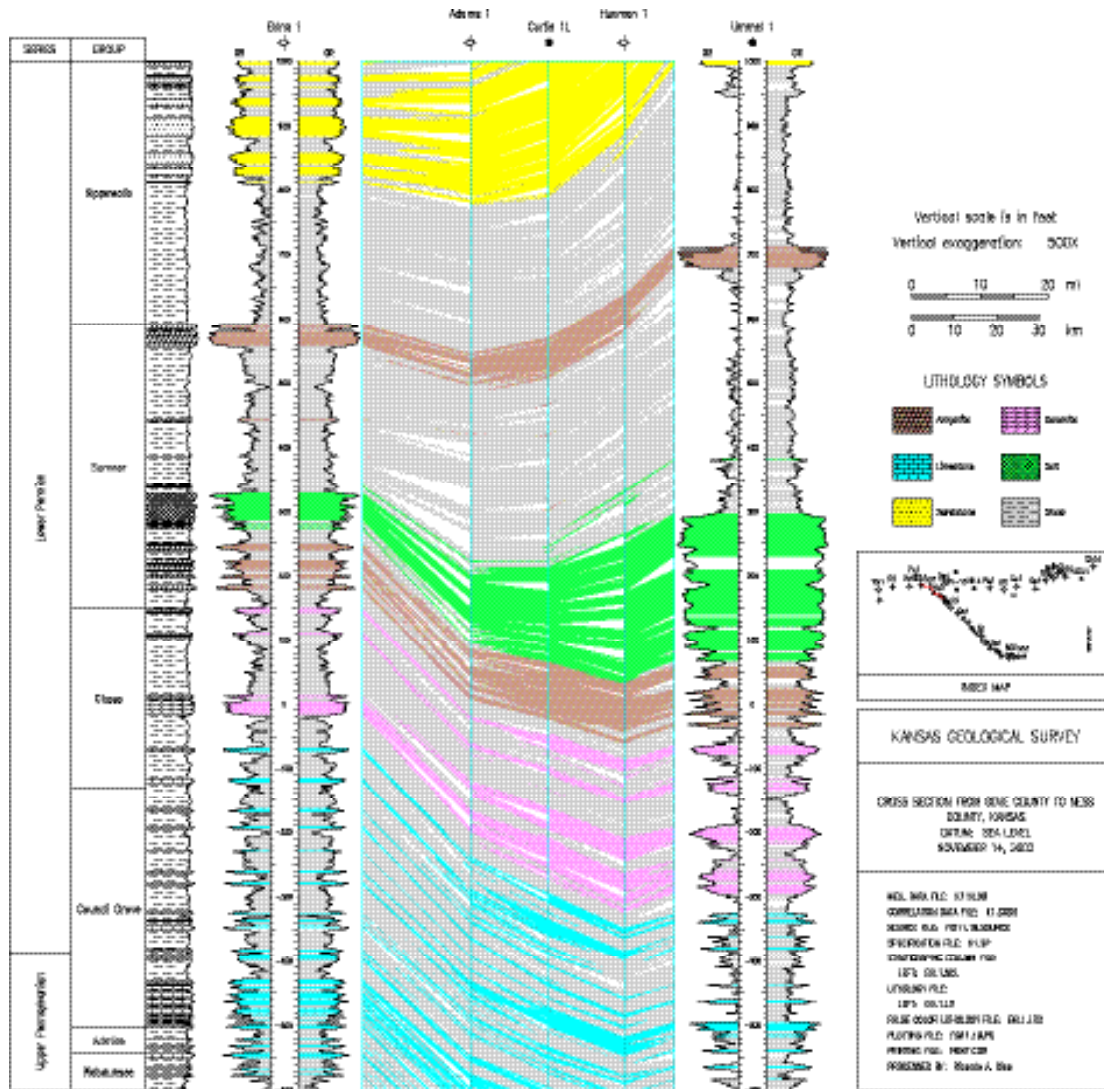


Figure 11.19. Display of cross sectional variation in lithology, Ness to Gove counties, Kansas.

DISPLAY OF LITHOLOGY

SF -- SOURCE FILE WITH CORRELATION INTERPRETATIONS FIG11.19.SOURCE
XS -- SELECT INTERPRETATIONS TO PLOT FROM WINDOW POSTING -->
SP -- FILE WITH PLOTTING SPECIFICATIONS K1.SP
T1 -- FIRST TITLE CROSS SECTION FROM GOVE COUNTY TO NESS COUNTY, KANSAS
T2 -- SECOND TITLE DATUM: SEA LEVEL
SC -- TEXT IN STRAT. COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) LEFT
SL -- FILE WITH TEXT FOR STRATIGRAPHIC COLUMN TO THE LEFT EKL1.SCL
LA -- LITHOLOGY IN COLUMN TO LEFT (L), RIGHT (R), BOTH (B), OR NONE (N) LEFT
LL -- NAME OF LITHOLOGY FILE FOR STRATIGRAPHIC COLUMN TO THE LEFT EKL1.LIT
DA -- USE SEA LEVEL AS DATUM, YES (Y) OR NO (N) YES
ND -- STARTING DEPTH FOR PLOTTING, FEET -1000.00
XD -- ENDING DEPTH FOR PLOTTING, FEET 600.00
VS - VERTICAL DEPTH SCALE, FEET/IN 80.00
HS - HORIZONTAL DISTANCE SCALE, FEET/IN 40000.00
LC -- NAME OF FILE WITH LITHOLOGIES TO TRACE ACROSS EKL1.LIT2
FM - FAULT MODELING, YES (Y) OR NO (N) NO
MD -- MORE DRAWING SPECIFICATIONS -->
RE -- RETURN TO PREVIOUS MENU
GO -- PLOT CROSS SECTION

PLEASE ENTER YOUR SELECTIONS:

MORE SPECIFICATION FOR THE DRAWING OF A CROSS SECTION

AG -- AGENCY KANSAS GEOLOGICAL SURVEY
PB -- INTERPRETER Ricardo A. Olea
PT -- PLATE NUMBER, BLANK TO AVOID POSTING
LW -- LABEL WELLS BY SEQUENTIAL NUMBER (S) OR NAME (N) N
PW -- POST ALL (A) OR ONLY EXTREME WIRELINE LOGS (E) E
DT -- INTERVAL BETWEEN DEPTH TICK MARKS, FEET 10
ED -- PLOT VERTICAL SCALE AS ELEVATION (E) OR DEPTH (D) E
DO -- DEPTH SCALE ORIGIN, SEA LEVEL (S) OR SURFACE (KB) S
MS -- MAXIMUM VALUE FOR SHALE LOG. ENTER A NEGATIVE 110.00
VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
MC -- MAXIMUM VALUE FOR CORRELATION LOG. ENTER A NEGATIVE -1.00
VALUE TO SELECT THE MAXIMUM VALUE ON EACH LOG
DS -- DEPTH SCALE ALONG PAPER WIDTH (W) OR ALONG PAPER LENGTH (L) W

RE -- RETURN TO PREVIOUS MENU IGNORING CHANGES
GO -- COMMIT THE SELECTIONS

PLEASE ENTER YOUR SELECTIONS:

Figure 11.20. Example of menu for command LL.

Although it is possible to determine mineralogies using three or more logs, at the present stage, CORRELATOR is not able to automatically identify mineralogies. Similar to the lateral tracing of markers, the program needs the user to properly identify all clean lithologies at a base well, which in the case of Figure 11.19 is the leftmost well. From the base well, the program is capable of automatically tracing the lithologies in all the other wells on the presumption of lateral persistence on the dominant clean mineralogy. The next section contains an explanation on how to prepare such a lithology file at the base well.

Preparation of a lithology file

Option LC in the File Management menu (Figure 5.1) creates files for preparation of lithology cross sections such as the one in Figure 11.19. Preparation of an LC file is a hybrid between the preparation of marker file option (PM) and preparation of file for annotation of lithology in the stratigraphic column option (PL), both in the same File Management menu. Upon loading the well/log database, execution of option LC generated a first menu in Figure 11.21, which is the same as the first menu for option PM. The sequential well number refers to the location of the well in the well/log database.

Second stage is the specification of tops for as many lithology zones as necessary, which requires setting parameter SA to PRIMARY. The clean lithologies on file apply only to those levels with proportion of shale less than 50%, which the program is able to track automatically. Display of the cross section in Figure 11.19 requires specification of six zones of clean lithologies, which were based on drillers' logs and general knowledge of the area. Figure 11.22 shows specification for the last zone. Other possible sources of information are descriptions of cores, well log analysis using multiple logs, and drilling chips. Figure 11.23 contains the final shell window report.

LC files are fixed-length files with each record containing 31 characters, a line break included. Table 11.1 summarizes information about all fixed-length type of files used by CORRELATOR.

```

PREPARATION OF FILE FOR DISPLAY OF LITHOLOGY IN CROSS SECTION

FN -- NAME OF THE MARKER FILE                               EKL1.LIT2
SA -- START A NEW FILE (S), ENTER PRIMARY INFORMATION (P),   START
    OR ENTER INFORMATION TO MODIFY PRIMARY ZONES (M)
SN -- SEQUENTIAL NUMBER FOR THE WELL TO START THE COLORING  4

RE -- RETURN TO PREVIOUS MENU
GO -- UPDATE THE LITHOLOGY FILE

PLEASE ENTER YOUR SELECTIONS: go

```

Figure 11.21. Example of initial menu for option LC in File Management menu.

PREPARATION OF FILE FOR DISPLAY OF LITHOLOGY IN CROSS SECTION

FN -- NAME OF THE MARKER FILE EKL1.LIT2
 SA -- START A NEW FILE (S), ENTER PRIMARY INFORMATION (P), PRIMARY
 OR ENTER INFORMATION TO MODIFY PRIMARY ZONES (M)
 DZ -- DEPTH TO TOP OF ZONE, FEET BELOW SEA LEVEL 60.00
 PM -- CLEAN LITHOLOGY. OPTION: ah, ck, cl, dl, gn, ls, ss, st ls
 RE -- RETURN TO PREVIOUS MENU
 GO -- UPDATE THE LITHOLOGY FILE

PLEASE ENTER YOUR SELECTIONS: go

Figure 11.22. Specification of the dominant clean lithology in a zone at an LC file. Keys for the lithological options are: anhydrate (ah), chalk (ck), coal (cl), dolomite (dl), granite (gn), limestone (ls), salt (st), sanstone (ss).

CLEAN LITHOLOGY FILE

LITHOLOGY FILE NAME EKL1.LIT2
 SEQUENTIAL NUMBER FOR STARTING WELL 4
 NUMBER OF ZONES IN THE FILE 6

	DEPTH FEET	LITHOLOGY	REMARKS
1	-1125.00	ss	Cedar Hill
2	-600.00	ah	St. Corral
3	-350.00	st	Sumner
4	-260.00	ah	Sumner
5	-170.00	dl	Chase
6	60.00	ls	Penn.

Figure 11.23. Shell window report for the lithology file used in the production of File 11.19.

Table 11.1. Fixed-length files used by CORRELATOR

Type	Label	Length Characters	Explanation Pages
Datum	DATU	11	104–105
Drawing specifications	SPEC	81	76–79
Fault	FAUL	51	116–118
Lithology	LIT2	31	128–131
Marker	MARK	31	95–97, 107
Subdivisions in stratigraphic column	SCOL	51	98–101
Lithology in stratigraphic column	LITH	21	102–104

Problems in the lateral tracing of lithologies may require use of mode MODIFY in command LC, which is not the case for Figure 11.19. Figure 11.24 shows the final shell window report in the preparation of an LC file for the case of more complex cross section of which Figure 11.19 is a minor part of (Olea, 2002a). In this case, the base well is the sixteenth well in the cross section, which is the thirty-eighth well in the well/log database. The cross section has twenty pairs of correlated wells. From the base well, tracing progresses to the left for the leftmost 15 wells and to the right for the last five wells.

The logs for the 19th well in the cross section are too shallow to allow correlation for the top of the deepest lithology zone and extrapolation proved to be unsatisfactory. Considering that to the right of well 16 tracing goes from left to right, problems because of missing log reading at the bottom of well 19 first show in well 20, which is the matching well in the 19th pair of wells in the cross section. To by-pass the problematic correlation, the top of the Arbuckle in well 18 was correlated with the top of the Arbuckle in well 20, which is essentially how the problem is solved in manual correlation. The value 3714 in Figure 11.24 is the value of top of the Arbuckle based on skipping well 19.

A similar problem involving two zones happens to logs at well 11 that are too shallow. The main difference is that now the tracing is different because well 11 is to the left of the base well. This requires prior correlation of the bottom two tops in well 12 to the bottom two tops in well 10, and the results used to correctly have the top of the Simpson and the top of the Arbuckle, the first well to suffer the consequences of missing data in the previous well in the tracing. Well 10 is the reference well in the tenth pair of wells.

CLEAN LITHOLOGY FILE

LITHOLOGY FILE NAME WR1.LIT2
 SEQUENTIAL NUMBER FOR STARTING WELL 38
 NUMBER OF ZONES IN THE FILE 14

	DEPTH FEET	LITHOLOGY	REMARKS
1	-4000.00	ck	Niobrara
2	-2750.00	ls	Carl-Ghorn
3	-2384.00	ss	Dak-Chey
4	-1680.00	ah	Nippewala
5	-1622.50	ss	Cedar Hill
6	-1109.00	ah	St. Corral
7	-541.00	st	Sumner
8	-45.00	ah	Sumner
9	142.00	dl	Chase
10	405.00	ls	Penn
11	1914.50	ss	Douglas
12	1959.50	ls	Penn-Miss
13	2676.00	ss	Simpson
14	2800.00	dl	Arbuckle

ZONES TO BE OVERRIDDEN 3

	DEPTH FEET	PAIR	ZONE
1	3714.00	19	14
2	2630.00	10	14
3	2580.00	10	13

Figure 11.24. Shell window report with three examples of overruling the automatic calculation of lithology-zone tops.

References

- Allaud, L. A. and Martin, M. H., 1977, Schlumberger, the History of a Technique: Wiley Interscience, New York, 333 p.
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