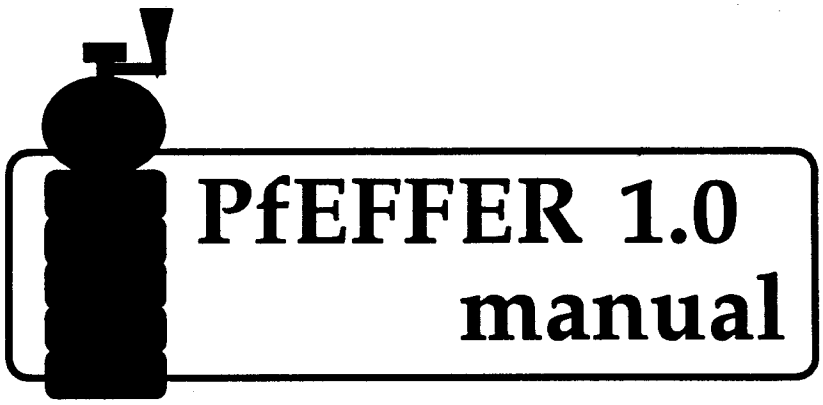

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Kansas Geological Survey
Open-file Report

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CONTENTS

PREFACE

Software development was undertaken with the financial, data, and beta testing support of 12 independent and major oil and gas companies who operate in Kansas. They are:

Amoco Production Company
Charter Production Company/Mustang Oil and Gas, Inc., Wichita
General Atlantic Resources, Inc., Denver
J. M. Huber Corporation, Amarillo
Hugoton Energy Corporation, Wichita
John O. Farmer, Inc., Russell
McCoy Petroleum Corporation
Mobil Exploration and Production U.S., Inc.
OXY USA, Inc., Oklahoma City
Phillips Petroleum Company, Bartlesville
Ritchie Exploration, Inc., Wichita
Vastar (ARCO), Houston

We are indebted to the Kansas Technology Enterprise Corporation (KTEC) who also provided financial support for this project.

The Software was developed for a number of reasons:

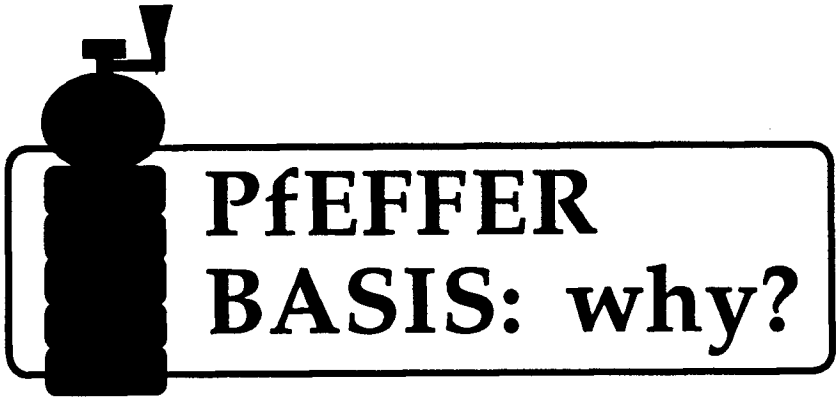
(1) To provide cost-effective log analysis software as a Visual Basic add-in that could be run on a PC using EXCEL, a spreadsheet program that is used widely throughout the energy industry;
(2) To allow data to be accessed easily, either from digital LAS files or from manual input;
(3)To use the numerical processing and graphics capabilities of the spreadsheet medium to make classical log analysis calculations while simultaneously displaying crossplots for pattern recognition;
(4) To augment the traditional log analysis methods with techniques that incorporate estimations of pore size, permeability, and mineralogy in extensions of the Pickett plot (the "Super Pickett plot");
(5) To design the program as a tool to improve the use of log analysis in characterizing reservoirs, detecting heterogeneities, and deciphering subtle pay zones;
(6) To provide a mapping capability, so that spatial variations in reservoir properties could be mapped between wells;
(7) To emphasize user-friendliness so that the log analyst, geologist, or reservoir engineer who is a casual computer user can rapidly become a proficient user;
(8) To provide a design base for the production of more advanced versions of PfEFFER to include more options and capabilities.

ABOUT THIS MANUAL

This manual is divided into two major parts: a "basis" section that covers the theory (the "Why?") of petrophysical analysis that underlies the design of PfEFFER, and a "praxis" section (the "How?") that guides the reader through the operations of the software.

The equations and models of the BASIS section are firmly grounded in the classic relationships of Archie, but are extended to productivity interpretations linked with bulk volume water, permeability predictions, and the incorporation of capillary pressure information. The Pickett plot plays a central role in the methodology as a graphical space to map all of these relationships. The complexity of even mildly heterogeneous reservoirs is such that crossplots are essential medium to unravel complex associations. Standard log analysis equations plot as straight lines in Pickett plot space and are useful as delimiters of trends and boundaries. However, the clouds of points crossplotted from reservoir zones commonly form clusters and arabesques that reflect variations in rock-type, pore geometry, and height within a hydrocarbon column. Part of the task of the analysis is to resolve the plotted patterns into fundamental petrofacies that control flow units. Once the pattern structure is understood, useful conclusions can be made that extend the traditional log analysis results of porosity and water saturation into productivity, water-cut, and permeability.

The PRAXIS section describes the file structure of PfEFFER and takes the user through each of the software operations using real data in hands-on demonstrations. In order to benefit most from this section, the reader should use the PfEFFER files supplied with this manual. These consist of two LAS files: 12345a.las and 12345b.las; a well workbook, OZ.XLS; and a set of well workbooks for mapping that form an OZMA series. The reason for the Oz terminology in these demonstrations is to maintain the confidentiality of data supplied to us by participating companies, while enjoying the benefits of real world data.


PfEFFER
BASIS: why?

Introduction

Fifty years after it was introduced, the Archie equation remains the keystone of log analysis for the solution of water saturation of potential oil and gas zones (Figure 1):

$$S_w = \left(\frac{a}{\Phi^m} * \frac{R_w}{R_t} \right)^{\frac{1}{n}}$$

The equation is actually made up of two separate equations. The first describes the relationship of the ratio of the resistivity of a water saturated rock, Ro, to its formation water resistivity, Rw, to the fractional porosity, Φ:

$$\frac{R_o}{R_w} = \frac{a}{\Phi^m}$$

This resistivity ratio is also known as the "formation factor", F. The second equation relates the ratio of the observed formation resistivity, Rt, to its expected resistivity, Ro, if it was completely saturated with water, to the fractional water saturation, Sw:

$$\frac{R_t}{R_o} = \frac{1}{S_w^n}$$

The equations are universally applied to reservoir fluid calculations from wireline logs in "clean" (shale-free) formations. Even when specialized equations are applied to clastic reservoirs that are markedly shaley, these same equations are adaptations of the Archie equation that accommodate shale effects.

The application of the Archie equations presuppose a knowledge of the parameters, or at least reasonable estimates of them, in order to calculate acceptable water saturations. Formation water resistivity can usually be established from field measurements and/or log analysis estimations. However, the quantities of *a*, *m* (the "cementation factor"), and *n* (the saturation exponent) are usually unknown and their values are given as a matter of experience. The range of values for *m* and their relationship with rock texture has been the subject of much measurement and discussion. By contrast, the variability of *n* is less well understood, but is generally taken to be the number 2 (at least, in water-wet zones). The problem is further compounded by the realization that these "constants" are only likely to remain so in relatively homogeneous reservoirs, where rock texture and pore geometry remain fairly uniform. Continuing advances in theory and measurement demonstrate that simple models may be poor (and puzzling) representations, or even downright misleading in heterogeneous and complex reservoirs that are the targets of many of today's energy companies.

All of these uncertainties have been known for many years and have been a factor in the popularity of crossplotting methods, of which the Pickett plot is probably the most well-known. When Dick Pickett introduced his plot (Pickett, 1966), he emphasized that it should not merely be used as a graphical substitute

for calculations that could be done with a slide rule. Instead, it was to be a means for pattern recognition, so that trends and discriminations within the clouds of crossplotted points could be related to pay zone evaluation and reservoir structure.

On a more pragmatic note, the former widespread use of chart methods was, of course, due to the fact that calculators had not been invented and computers were not widely available. However, even today, the same plots are displayed on computer monitor screens as a reconnaissance device to recognize reservoir patterns and to validate the values of parameters used in log analysis equations. Newer concepts of textural controls on productivity can be evaluated immediately on these plots and used in the distinction of potential pay and assessment of likely water cut. Contour lines of bulk volume water may be plotted directly as cut-off boundaries for immediate decisions concerning testing or abandonment. Some interpretations of permeability are also possible in favorable situations.

These more perceptive uses of crossplots reflect a clearer understanding of the role of pore size and geometry in the determination of reservoir characteristics. This knowledge has come from geological studies of the relation between rock textures and the depositional and diagenetic history of the rock, as well as engineering studies of productivity as related to porosity, water saturation, and rock type. New insights have gone a long way to the explanation as to why some zones that appear to be wet have significant production, while other, supposedly good pay zones, produce only water.

The interactive spreadsheet style of program has added a tremendous new capability to computing. Changes in values of key parameters can be "hardwired" by equation links to automatically modify estimates of all petrophysical quantities within a coherent framework. Alternatives can be evaluated rapidly either to give "best-case" and "worst-case" solutions, or as a means to narrow down the most feasible values of key parameters that collectively make the most sense of the data that are analyzed. These programs typically provide serviceable graphics, so that the crossplot consequences of any combination of values can be shown almost immediately. The pattern recognition skills of the user can then be applied to the situation. In the case of a log analysis problem, pattern recognition is not merely the ability to recognize anonymous trends and clusters, but the evaluation of these in the light of what is now known concerning sedimentary facies, grain and crystal size, capillary pressure, fluid saturations, permeabilities, pore geometry, and other factors. Collectively, the results of these effects are seen in the creation of "petrofacies", associations of common attributes of rock textures, pore types, and related properties. In some cases, petrofacies will be modeled adequately by linear or curvilinear trends; in other cases, they will be better represented by localized data clouds.

$$F = \frac{R_o}{R_w} = \frac{a}{\Phi^m}$$

$$I = \frac{R_t}{R_o} = \frac{1}{S_w^n}$$

$$S_w = \left[\frac{a}{\Phi^m} * \frac{R_w}{R_t} \right]^{1/n}$$

Figure 1: The "Archie equation" (in the box) and its component Archie equations that govern completely water-saturated non-conductive rocks (the F relationship) and partially water-saturated non-conductive rocks (the I relationship).

KEY:
F= Formation factor; Ro= resistivity of rock completely saturated with a brine whose resistivity is Rw; F is the fractional porosity; *a* is a constant (often taken to be unity) and *m* is the cementation exponent; I is called the Resistivity index; Rt is the actual rock resistivity; Sw is the fractional water saturation; and *n* is the saturation exponent (often approximated by a value of 2).

In the following section, we will review the Pickett plot in its traditional usage and then move to the incorporation of other models, equations, and measurements that markedly extend the power of the classical plot.

Fundamentals of the Pickett plot

The principles of the Pickett plot will be illustrated with a hypothetical data set of resistivity and porosity values logged in a sandstone with "Archie rock" properties and a simple reservoir profile (Figure 2). The example consists of a pay section at irreducible water saturation (zones A-E), a transition zone (Zone F), above a water leg (zones G-J). The "formation" of the demonstration is the "Rottweiler Sandstone" which is very loosely modeled after a generalized Rotliegendes Sandstone reservoir from the North Sea. The sandstone has been logged in the hypothetical wildcat , Toto Rottweiler #1. We will suppose that the log analyst has no idea whatsoever concerning either the formation water resistivity or any of the other parameter values that he or she would need to solve the Archie equations. However, the log analyst is very familiar with the Pickett plot and sets to work to evaluate the section.

The Pickett plot is made on conventional double logarithmic (to base ten) scale graph paper. An examination of a crossplot of the porosity and resistivity values of the ten zones (Figure 3) shows a pattern that is easy to interpret. Zones A to E have much higher resistivities than zones H to J, even though they have similar porosities, and suggests that these zones may have appreciable hydrocarbon content. Zone F is intermediate between these two clusters, and its depth relationship to them indicates that it may be in a transition zone. The zone H-J trend of a systematic decline in resistivity with porosity also favors their interpretation as possible water zones.

These qualitative generalizations can be made considerably more specific, using the mathematical properties of the graph form and its ability to represent many useful petrophysical relationships. The basic method for the plot that bears his name was described by Pickett (1966). In a later paper, Pickett (1973) described in detail the pattern recognition properties of the plot which made it a particularly powerful method for log interpretation. The mathematics of the Pickett plot are simpler than those of the Hingle plot (Hingle, 1959), and is another transformation of the Archie equation:

$$S_w^n = \frac{aR_w}{\phi^m R_t}$$

Rearranging the Archie equation and substituting the resistivity index, I, gives :

$$R_t = \frac{aR_w I}{\phi^m}$$

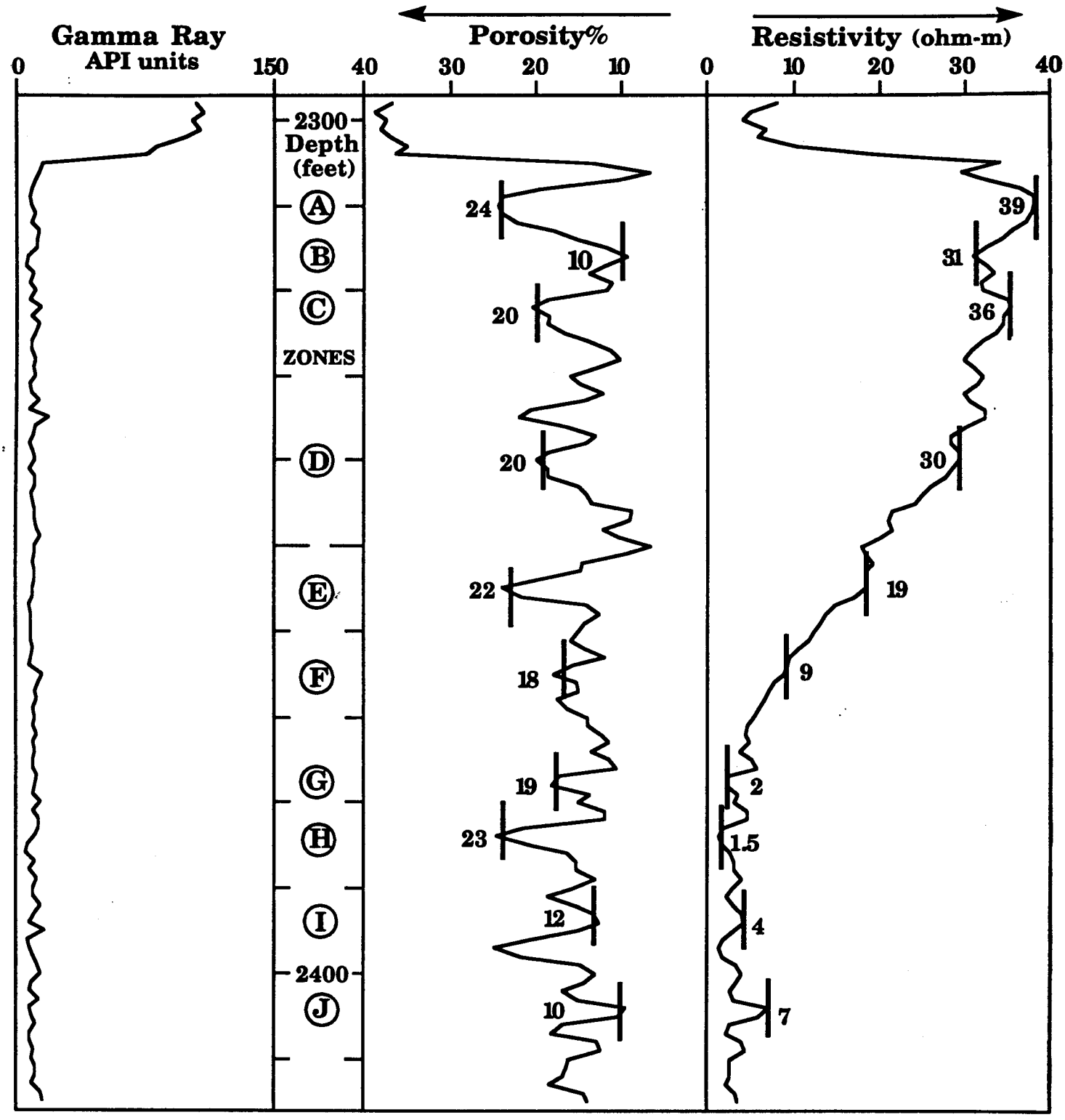


Figure 2: Gamma ray, porosity, and resistivity logs of a section of the Rottweiler Formation (Triassic), an oil-productive sandstone.

Taking logarithms, the equation becomes:

$$\log R_t = \log(aR_w) - \log I - m\log\phi$$

which describes a family of parallel lines for different resistivity index values whose slope is the negative of the cementation exponent (-*m*). When the resistivity index, I is unity, the line is the water line with an intercept equal to *a**Rw. Other resistivity lines are displaced to the northeast and are drawn easily as lines parallel to the water line and with resistivities which are the water line resistivities multiplied by the index at common values of porosity.

In common with most visual methods, these concepts are more obvious when sketched out graphically, as in figures 4 to 6. The water line can be established by eye, or numerically, by stipulating the formation water resistivity, Rw, and the Archie constants of *a* and *m* (Figure 4). Many log analysts prefer to work with the value of *a* held at a value of unity. Using this convention, the intercept is equated directly with Rw, and the slope of *m* becomes an average estimate of cementation factor within the reservoir. If a trend of (relatively) low resistivity points is suspected to sketch out a water line, then the exact position can be established through the selection of water resistivity and Archie constants that are most compatible with preexisting knowledge while simultaneously honoring the graphed data points in a convincing manner. (The use of an interactive graphics computer program is most effective for this type of operation.)

In our hypothetical example, the intercept of the water line predicts a formation water resistivity of 0.10 ohm-m and a cementation factor, *m*, of 1.8 (assuming the *a* constant to be one). In a real analysis, these numbers would have local implications that could be assessed for credibility. The cementation factor of the "Rottweiler sandstone" implies that the sandstone is moderately cemented; the formation water resistivity would be compared with available measurements of Rottweiler water resistivities in the immediate area.

The location of other water saturation lines will be on the higher resistivity side of the water line (which is the 100% water saturation line). They all have the same slope of -*m*, and so are parallel. The resistivity index, I, for any given water saturation determines the value of Rt on the associated line at any porosity as a multiple of Ro on the water line at the same porosity. This concept is explained graphically on figures 5 and 6.

Crossplotted points that lie above the water line have water saturations of less than 100% and complementary hydrocarbon saturations. However, their location on the plot does not immediately answer the question concerning the fluids the zones will produce when either tested or perforated. Water free

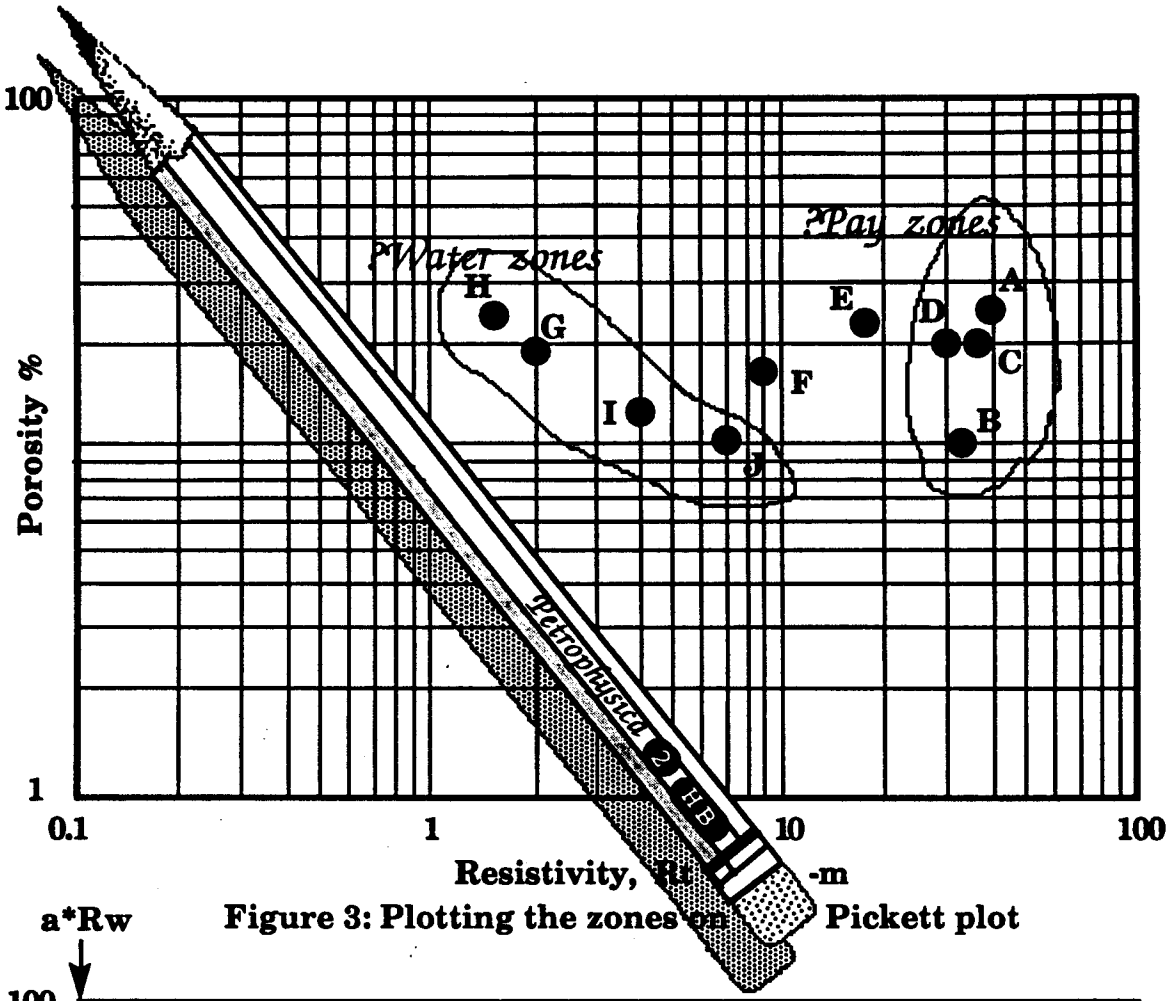


Figure 3: Plotting the zones on Pickett plot

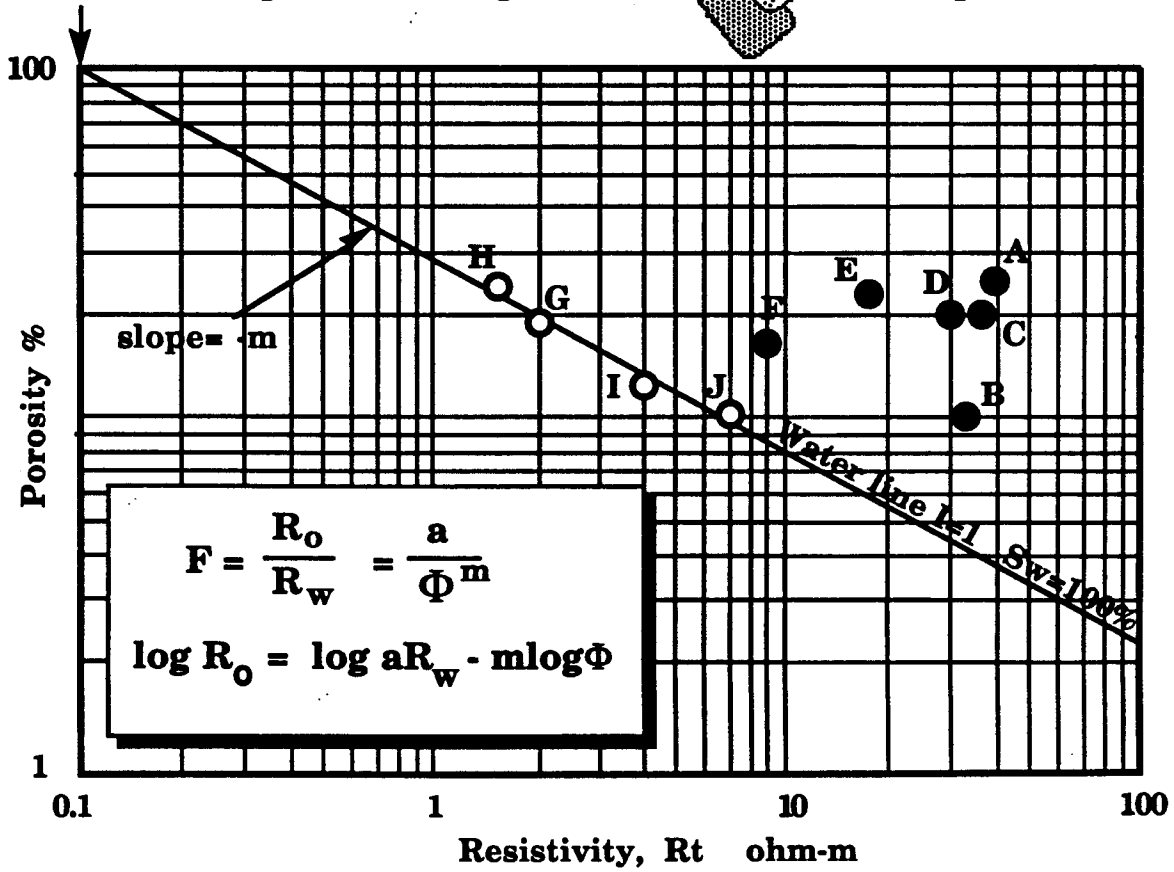


Figure 4: Location of the "water line"

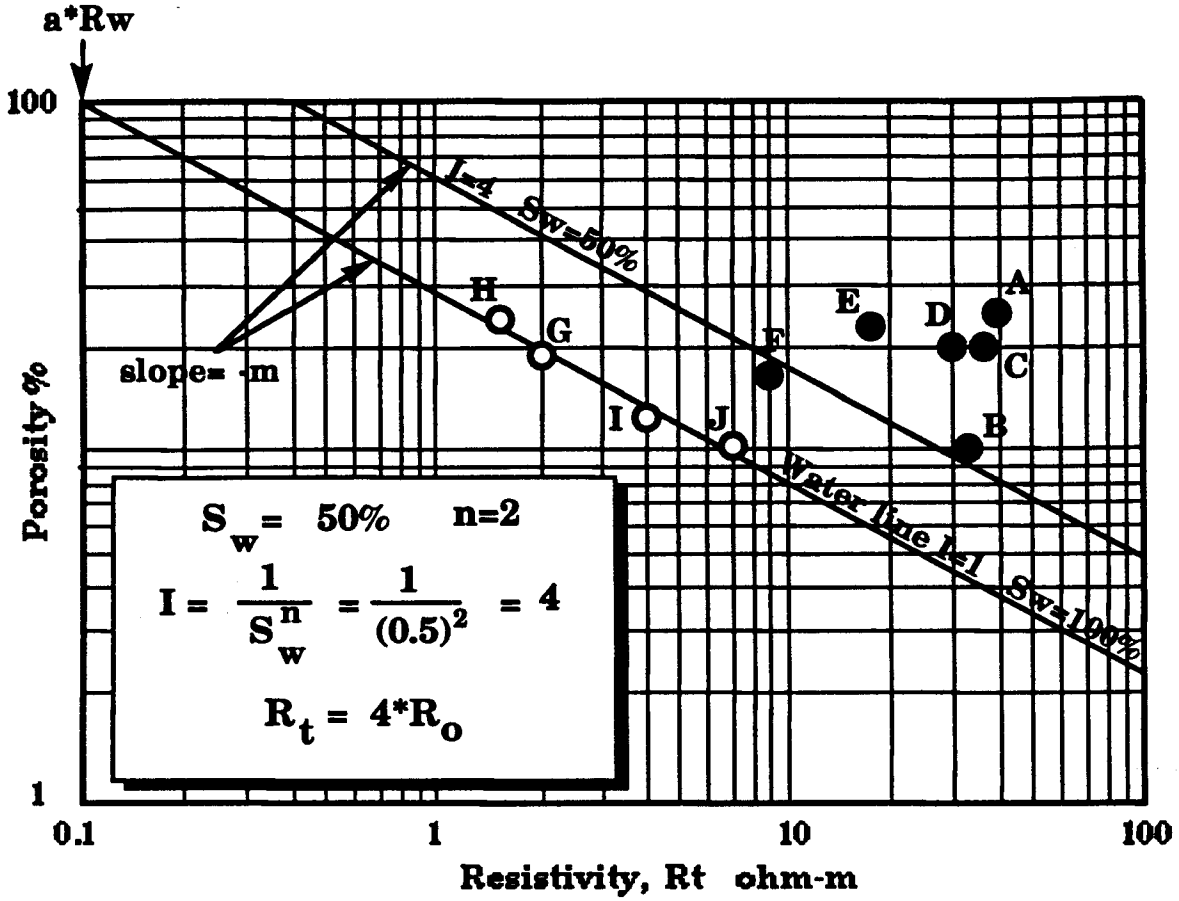


Figure 5: Location of the 50% water saturation line

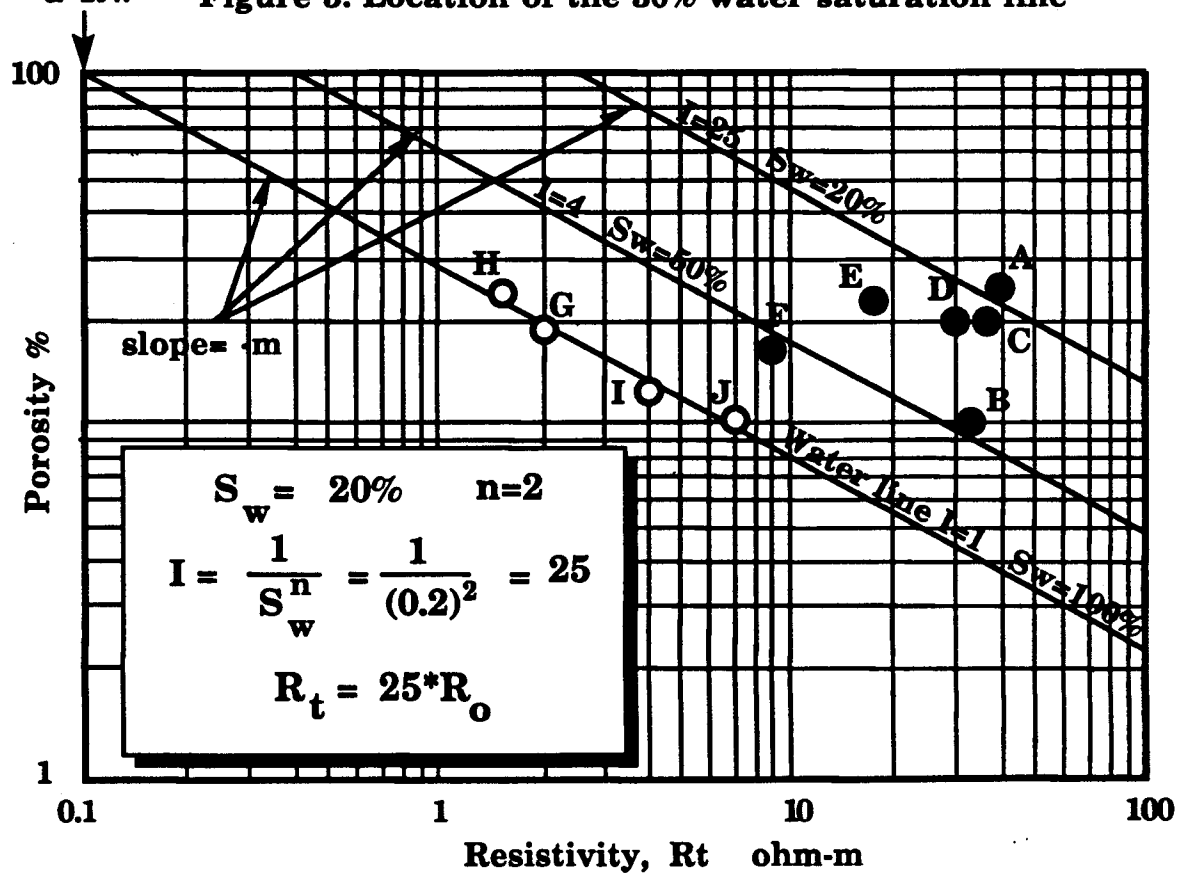


Figure 6: Location of the 20% water saturation line

hydrocarbons, water-cut hydrocarbons or water alone are all possibilities. The product of porosity and water saturation is the bulk volume of water (BVW) which can give important clues to producibility when related to pore character and reservoir type.

Incorporation of Bulk Volume Water (BVW) lines

The idealized reservoir profile in Figure 7 shows the expected fluid production as a function of water saturation, porosity and height in a homogeneous petrofacies. The relationships reflect buoyancy pressure of the hydrocarbons that penetrate progressively smaller pore throats at greater column heights and a tendency for larger pore throats in higher porosity zones. High in the reservoir, the water saturations of zones will approach an "irreducible" water saturation that is determined by their pore geometry. Sometimes this saturation is called "immobile" or "ineffective", because high-pressure laboratory tests show that these saturations are not absolutely irreducible. However, the "irreducible" water saturation generally marks a point at which hydrocarbons have permeated the entire macropore system and are subject to Darcian fluid flow and most of the remaining water is held either at grain surfaces or within micropores by capillary forces.

The plot of porosity against water saturation (Fig. 7) shows the hyperbolic trend at "irreducible" saturation that is typical of many reservoirs. The hyperbola is approximated by the function:

$$c = \Phi . S_{wi}$$

This general inverse relationship between irreducible water saturation and porosity that was noted by several early authors, including Archie (1952). They correctly attributed differences in the curvilinear trends to differences in reservoir pore sizes. This is because irreducible water saturation is controlled by surface tension at the internal surfaces and capillary pressure. While zones at irreducible water saturation in a moderately homogeneous reservoir should lie on a common curve, transition zones will be displaced to higher values of bulk water volume (Φ*Swi). The distinction is important, because it determines which zones should produce water-free oil or gas, and which should produce water or water-cut hydrocarbon. Computations of bulk volume water are therefore a critical additional step in log analysis for the assessment of producibility, as pointed out by Morris and Biggs (1967), Asquith (1985) and others.

Buckles (1965) made an extensive numerical analysis of reservoir measurements and concluded that the quadrilateral hyperbolic function:

$$\phi S_{wi} = c$$

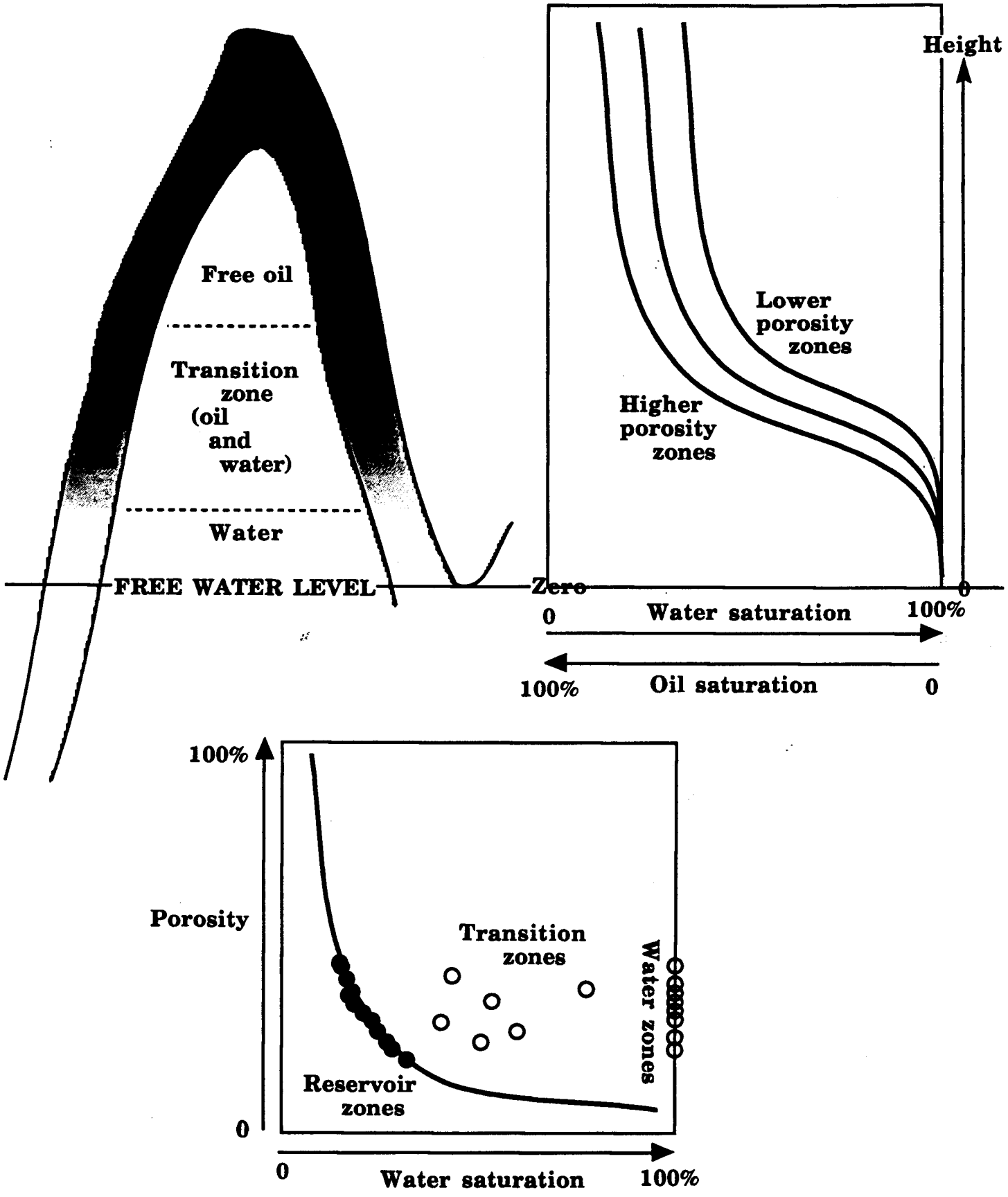


Figure 7: Generalized reservoir profile with matched water saturation-height plot and porosity-water saturation crossplot.

was a good first-order approximation to real field data. Low values of *c* reflected large average pore sizes, high values were linked with finer pores, as a direct consequence of a control by internal surface area. The critical hyperbolae that match different values of *c* can be drawn on a water saturation -porosity plot (often known as a "Buckles plot") either on arithmetic scale or (less commonly) on a logarithmic scale (Figure 8). An advantage of the log scale format is that the hyperbolic curves plot as straight lines.

The quantity *c*, is simply the irreducible bulk volume water (BVWi) which will be effectively a constant, provided that there is a limited range in pore size. Zones with comparable pore size that have higher values of bulk water volume should be water-cut or totally water-bearing. When computed for a field or reservoir, the characteristic value is often known as the "Buckles number".

The zones from the hypothetical Rottweiler Sandstone example are plotted on these variants of the Buckles plot in Figure 8. If this was a real data set, then the hyperbolic trend of zones A-E, coupled with their low Buckles number of about 0.05, would be highly suggestive of zones at irreducible saturation. Water-free production would be expected for these zones, in contrast with Zone F which should produce mostly water with little or no hydrocarbons. (Obviously, no hydrocarbons would be expected from zones
G-J.)

What are the values of *c* that should be expected for any given reservoir? The answer may be given either with respect to the type of reservoir rock or in terms of the values that have been reported from nearby fields that have produced from the same formation. So, for example, Asquith (1985) suggests rule-of-thumb numbers for carbonates keyed to pore type. Alternatively, expectations may be linked with geological formation, such as shown in the guide of critical BVWs reported by Bill Guy (Fig. 9), based on his extensive log analysis experience of Kansas fields.

Rather than tying our estimates to unique values of critical BVW, we can expand our consideration to ranges observed in field data. Reservoir values of *c* are shown plotted as cumulative frequency curves in the upper part of Figure 10 for carbonate reservoirs with vugular and intercrystalline/intergranular porosities (based on data from Chilingar et al, 1972) and for sandstones (using data from Bond, 1978). The data show systematic trends that reflect distinctions in internal surface area, and provide values that are useful in the following analysis. In the lower part of Figure 10, an example is shown of cumulative frequency curves plotted from data of well-known Texas carbonate reservoirs. Pickett (1973) had recognized that reservoir zones at irreducible water saturation should tend to lie on a steeper linear trend, whose intercept with the water line reflected the grain- or pore-size. This observation reflects the fact that the

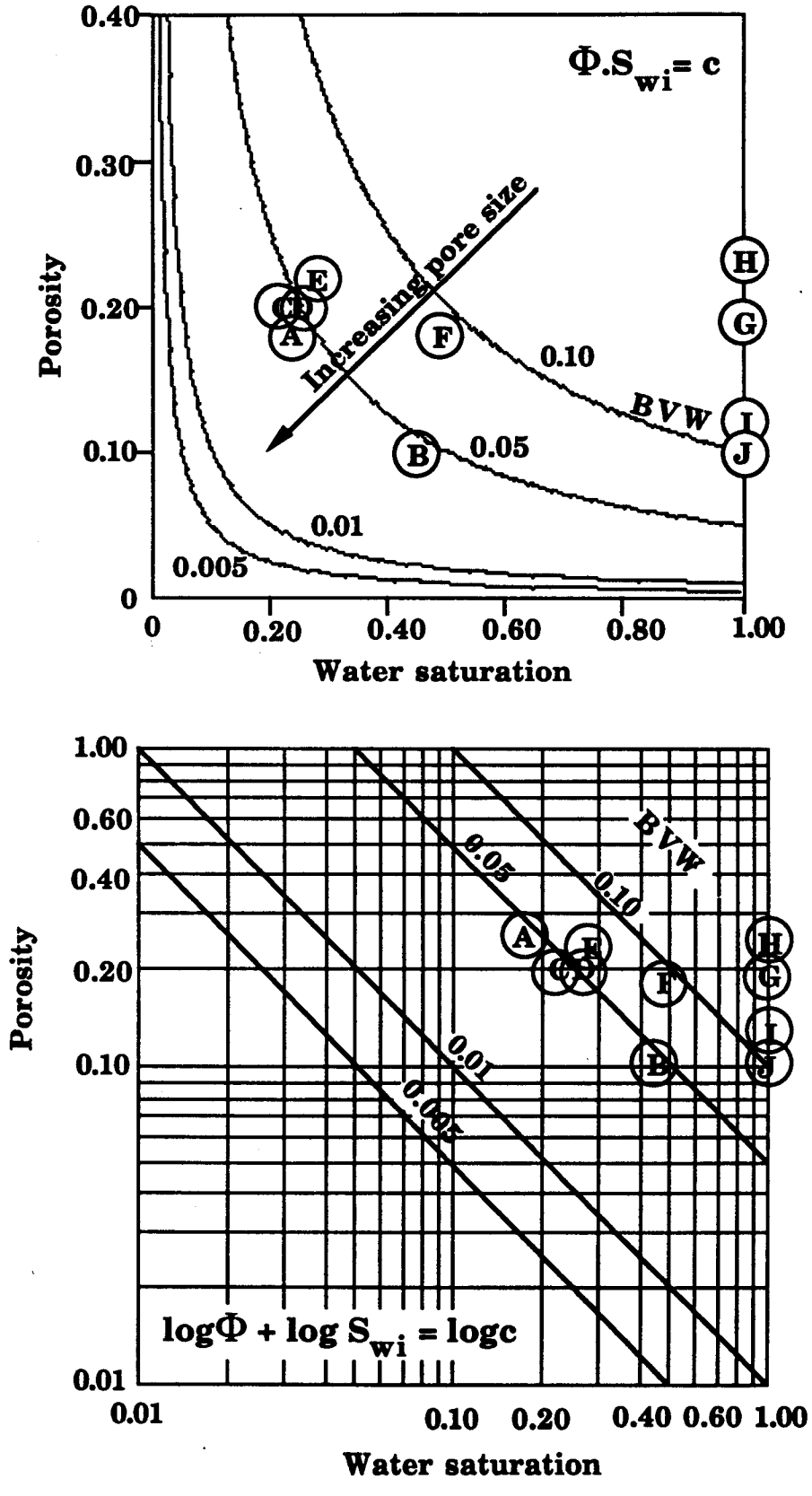


Figure 8: **Buckles plots: Contours of bulk volume water (BVW) on graphs of water saturation versus porosity,arithmetically scaled (above) and logarithmically-scaled (below). Zones A-J are from the Rottweiler Sandstone.**

	RESERVOIR	CRITICAL BVW
PERMIAN	Chase Group	
	Herington	.03-.06
	Krider	.035-.045
	Winfield	.04-.06
	Towanda	.045-.055
	Fort Riley	.05-.07
PENNSYLVANIAN	Toronto	.035
	Lansing	
	Uplift	.02-.03
	Hugoton Basin	
	Oolicastic	.04-.05
	Intergranular	.08
	Kansas City	
	Oolicastic	.02-.045
	Intergranular	.05-.08
	Marmaton	.038-.045
	Morrow	
	Clean	.01-.04
	Clay-filled	.05-.15
MISSISSIPPIAN	Dolomite	.02-.04
	"Chat"	
	Macroporosity	.06-.085
	Microporosity	.15-.25
	St.Louis	.04-.065

Figure 9: Typical values of critical bulk volume water (or Buckles number) for reservoirs in Kansas. These "rule-of-thumb" ranges were developed on the basis of extensive field experience.

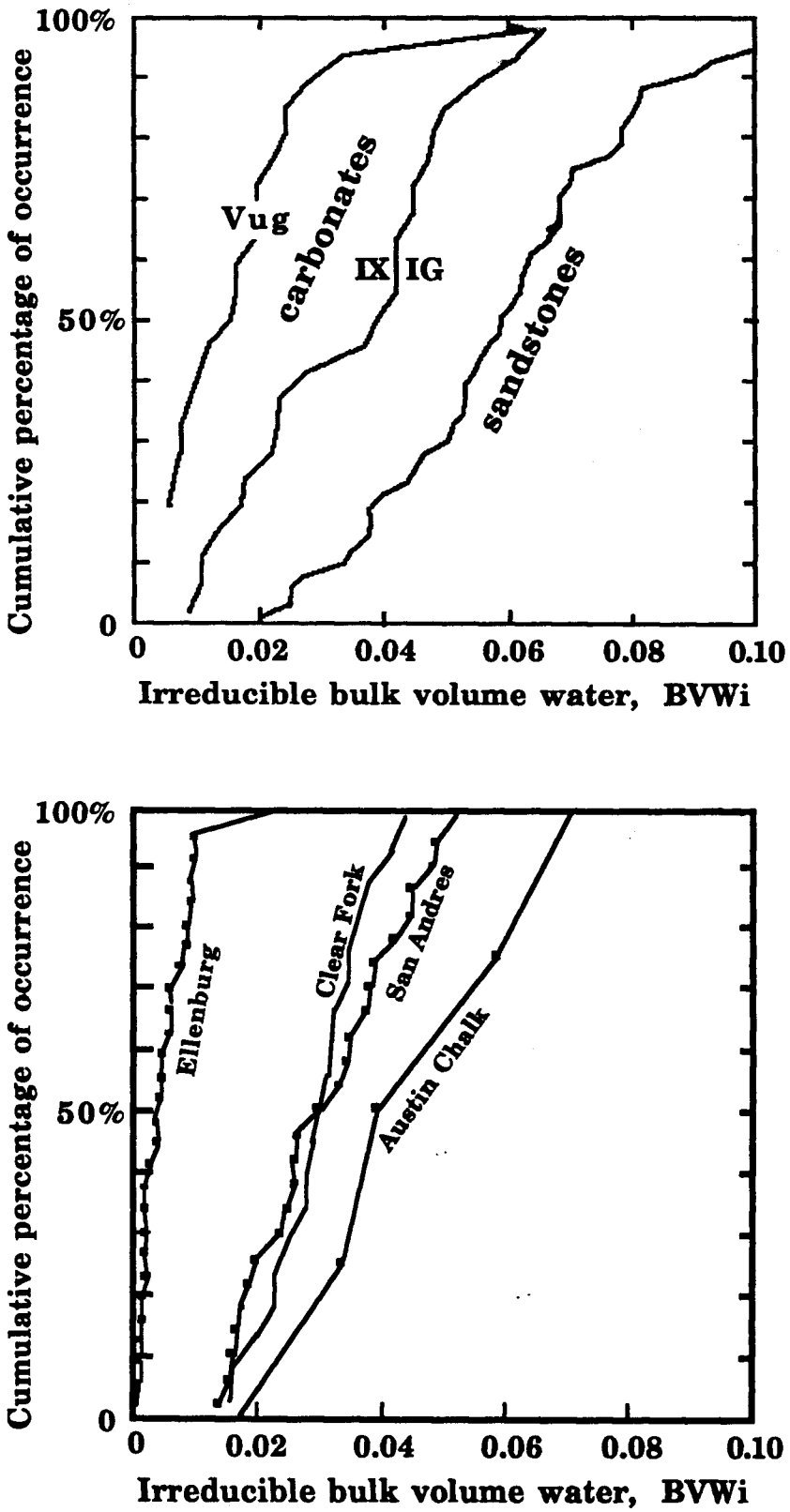


Figure 10: Cumulative frequency plots of irreducible bulk volume water (or Buckles number) for carbonate reservoirs by pore type (above) and by formation (below). Pore-type data extracted from Chilingar *et al* (1972); formation data from Texas.

hyperbolic relationship of :

$$\phi S_{wi} = c$$

can be linearized to :

$$\log S_{wi} = \log c - \log \phi$$

Substituting the Archie equation solution for water saturation and rearranging, the relationship becomes :

$$\log R_t = \log(aR_w) - n\log c + (n-m)\log \phi$$

which describes a line on the Pickett plot with a slope of (n-m) and an intersection with the water line at a porosity corresponding to the water line .

Greengold (1986) was the first to describe the systematic graphic properties of the irreducible bulk volume water on the Pickett plot. When the cementation and saturation exponents are equal, zones at irreducible water saturation should follow a line parallel to the porosity axis (Figure 11). Otherwise, the line will be inclined according to whether the saturation exponent is greater or less than the cementation exponent.

The parameters that determine the line give a powerful new means to extend the function of the Pickett plot beyond its traditional roles of cementation exponent and formation water resistivity. If the irreducibly saturated zones form a coherent trend, then the saturation exponent can be estimated directly from the plot for water saturation calculations, while the producibility will be indicated for any zone.

Bulk volume water contour lines are plotted for the Rottweiler sandstone on the Pickett plot used earlier (Figure 12). As observed before, zones A to E tend to follow a Buckles number value of about 0.05. The linear trend reflects a matching hyperbolic trend if the zones were plotted in a linear porosity - water saturation scaled graph (as seen in Figure 8). In fact, this adaptation of the Pickett plot represents the incorporation of the "Buckles plot".

Addition of predicted permeability contours

The most simple quantitative methods to predict permeability from logs have been keyed to empirical equations of the type : $k = P\Phi^Q$
where P and Q are constants determined from core measurements, and applied

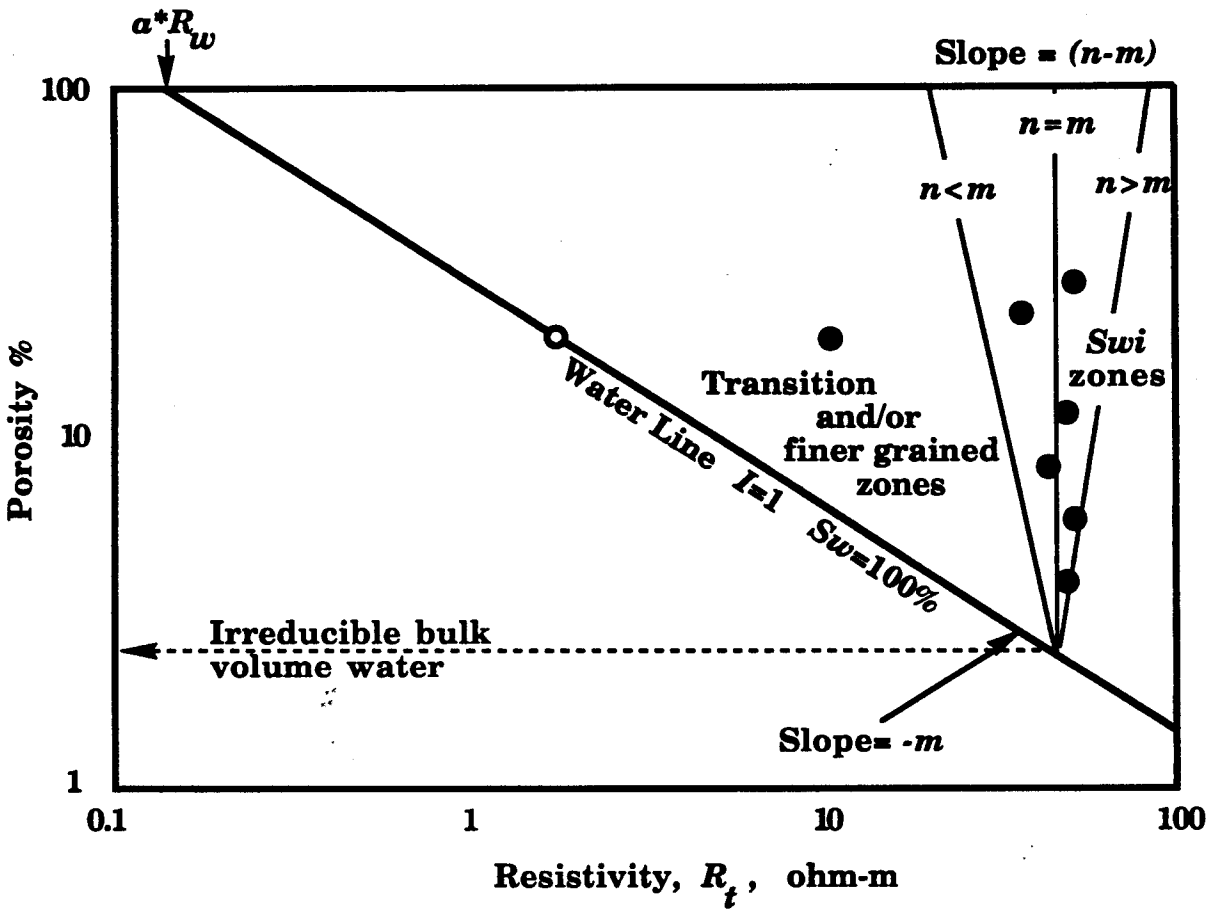


Figure 11: Location of irreducible bulk volume water (Buckles number) trend on the Pickett plot.

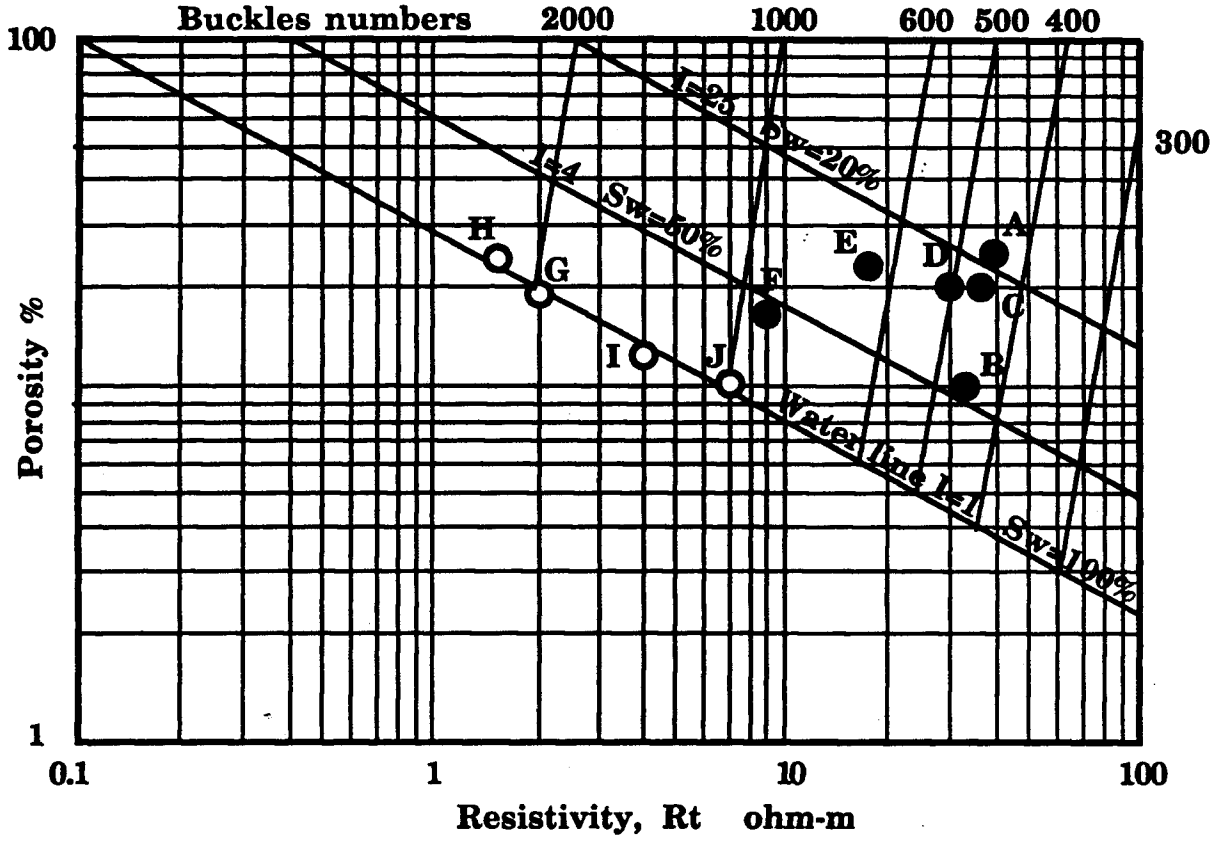


Figure 12: Location of Buckles lines on the Pickett plot of Rottweiler Sandstone data.

to log measurements of porosity (Φ) to generate predictions of permeability (K). The relationship is linearized if the equation is logarithmically transformed to:

$$\log k = \log P - Q \log \Phi$$

When applied to special cases of homogeneous sandstones, the results may be adequate, but prediction errors are often large in typical sandstones, and the errors in predicted permeability commonly range across orders of magnitude when applied to carbonates. The reason for this is that permeability is not exclusively determined by pore volume, but is also controlled by internal surface area, pore network tortuosity, pore throat geometry and other variables.

If a usable relationship can be developed between permeability and porosity, then the results can be plotted directly on the Pickett plot as permeability contours that track directly on their associated porosity value. This simple equivalance results because the equation gives a unique permeability prediction value for each porosity value. The predictions from these lines will only hold true in situations where the grain/pore size does not vary much.

Changes in pore size will influence permeability because they are accompanied by corresponding changes in internal surface area. Smaller pore sizes generate larger surface area and a matching reduction in permeability; larger pore sizes are linked with higher permeabilities. The interrelationships are contained in the classic Kozeny-Carman equation :

$$K = \frac{A\Phi^3}{(1-\Phi)^2 S^2}$$

which incorporates the specific surface area, S. as an additional variable to estimate permeability.

The specific surface area is the ratio of surface area to volume of framework solid and is difficult to measure directly by conventional methods. However, the specific surface area is inextricably linked with pore size, which in turn controls irreducible water saturation. Wyllie and Rose (1950) proposed a modification of the Carman-Kozeny equation that substituted irreducible water saturation for the specific surface area term:

$$k = \frac{P\Phi^Q}{S_{wi}^R}$$

The irreducible water saturation term in the modified equation functions as a powerful surrogate variable for specific surface area, and this accounts for the improvement in permeability estimates when incorporated with porosity.

The Wyllie-Rose relationship is a generalized equation that requires the determination of values for the constants P,Q, and R to be calibrated from core measurements. Probably the most widely-used version of this equation is the "Timur equation" for sandstones. Timur (1968) developed an equation which

linked permeability with both porosity and irreducible water saturation (S_{wi}) in sandstones, based on laboratory measurements of core. The results showed a considerable improvement in permeability estimation over those based on porosity values alone. However, notice that the use of irreducible water saturation as an input variable restricts the predictions to hydrocarbon reservoir zones.

Solutions to equations of the Wyllie-Rose type can be plotted as predicted permeability lines directly on the Pickett plot, because a logarithmic transformation of the equation leads to:

$$\log k = \log P + Q \log \Phi - R \log S_{wi}$$

As an example, contours of permeability as predicted by the Timur equation are drawn on the Rottweiler Sandstone Pickett plot in Figure 13. If zones A to E are at irreducible water saturation, then their predicted permeabilities can be read directly from interpolation between the permeability contours. If zone F is a transition zone with the same pore structure as the reservoir zones, then its permeability will be found by moving along the porosity line to the irreducible trend and reading the matching permeability value. If, however, Zone F is not a transition zone but is at irreducible saturation, then the permeability can be read directly. The permeability will be lower than in the first alternative, because its relatively higher water saturation would imply that the pore size was finer.

In the petrofacies computer program, the Timur equation values are entered as default values of P,Q, and R. Unless the default values are modified, permeability prediction lines will be drawn based on this equation. It should always be remembered that the Timur relationship was developed for sandstones. An equivalent general formula for carbonates is unrealistic because of the high variability of carbonate pore geometries. However, equivalent relationships for specific carbonate pore types should be feasible, based on the analysis of core measurements.

A generalized "permeability index" of Pi can be a useful measure of relative permeability as set by the ratio:

$$Pi = \frac{\Phi}{S_{wi}}$$

This relationship can be seen as a Wyllie-Rose equation that is stripped of its constants. The units of Pi are dimensionless and the values should show an approximate monotonic relationship with conventional permeabilities. The permeability index has been found useful as a simple measure to track textural changes in a reservoir section and for the mapping of generalized permeability changes across a field. Notice that the measure is ONLY valid when the zone water saturation is at irreducible level. In all other cases, water saturation will be higher and so the permeability measure will be reduced to lower values. Therefore, use of the permeability index should be restricted to the hydrocarbon column of a reservoir unit.

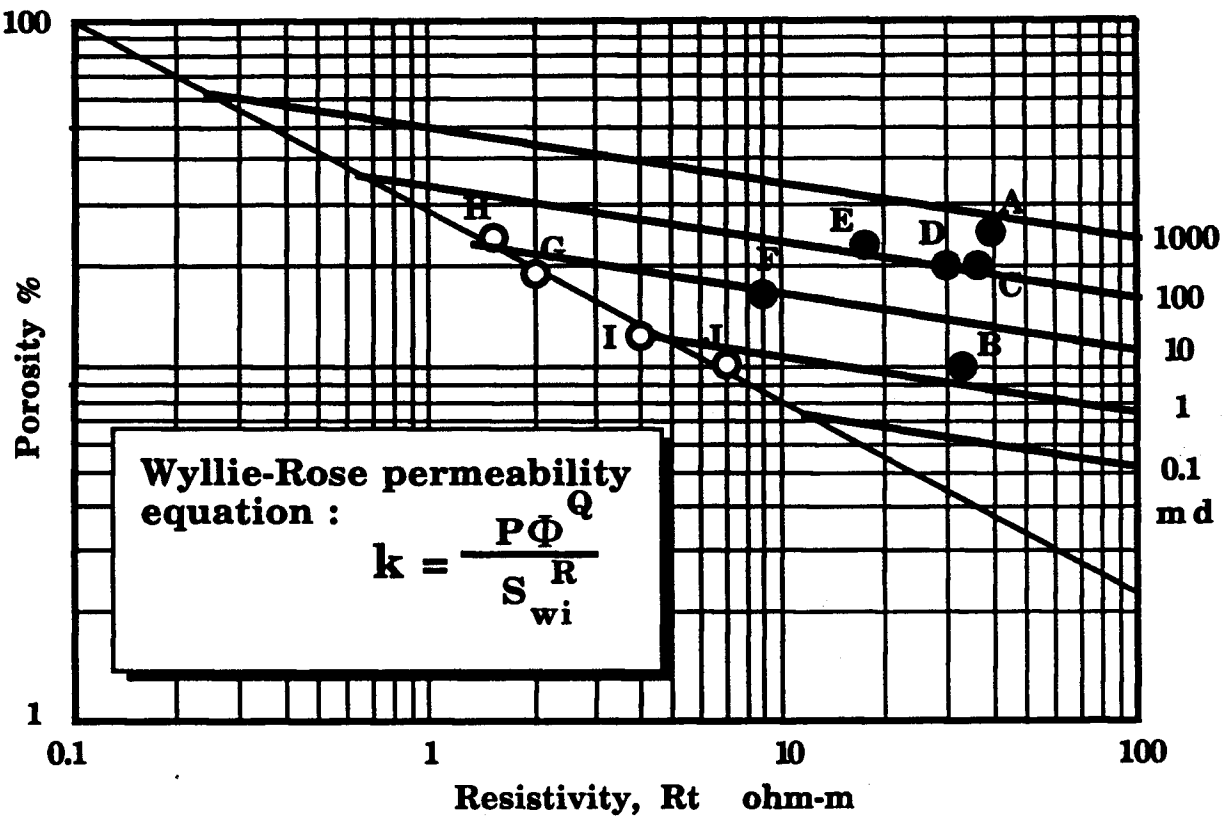


Figure 13: Permeability contours drawn on Pickett plot of Rottweiler Sandstone data, using a Wyllie-Rose relationship of permeability with both porosity and irreducible water saturation. The contours honor the Timur equation form which was developed for sandstones.

Mapping of capillary pressure contours onto the Pickett plot

The use of critical bulk volume water (BVWi) is an empirical application of relationships that are actually controlled by capillary pressure, height of hydrocarbon column, density difference between hydrocarbon and formation water, and other physical properties of a mixed fluid/solid system. Critical BVW concepts are highly effective as aids in assessing productivity but ultimately are simple rules-of-thumb based on field experience. Because bulk volume water is the product of porosity and water saturation, BVW contours are constrained to be straight lines on Pickett plots. As such, the contours can only be trend approximations of real relationships in reservoirs. The laboratory measurement of capillary pressure data on representative reservoir core samples gives explicit information on reservoir properties that reflect pore throat sizes and their control on hydrocarbon saturation and its variation with height in a hydrocarbon column. This information can be mapped directly onto the Pickett plot as discussed below.

Laboratory measurements of capillary pressure reflect the size of pore-throats and their distribution in the rock sample. The procedure most commonly injects mercury under increasing pressure and tracks the change in mercury saturation at each increment of pressure increase. The relationship between the radius of a pore-throat accessible in the mercury/air system and the pressure is given by:

$$r = \frac{107.6}{P}$$

Conversion from the capillary pressures of the laboratory mercury/air system to those of the hydrocarbon/water system within the reservoir utilizes equations that require values for contact angles and interfacial tensions of the components. However, more commonly, laboratory capillary pressures are converted directly into the equivalent height of hydrocarbon that would exert the same buoyancy pressure. This additional step calls on density values for the hydrocarbon and formation because their difference controls buoyancy pressure. Values for all these parameters can be estimated for conversions that are tailor-made for specific reservoirs. Alternatively, "average" values can be compounded into a single conversion constant that is an approximate, but reasonable first order relationship to transform P, the capillary pressure in a mercury/air system to h, the height of hydrocarbon column. For a "typical" oil, a usable relationship is:

$$h = 0.7 \times P$$

and for gas:

$$h = 0.35 \times P$$

A schematic picture of capillary pressure curves is shown in the upper part of Figure 14, where changes in fluid saturation are graphed against capillary

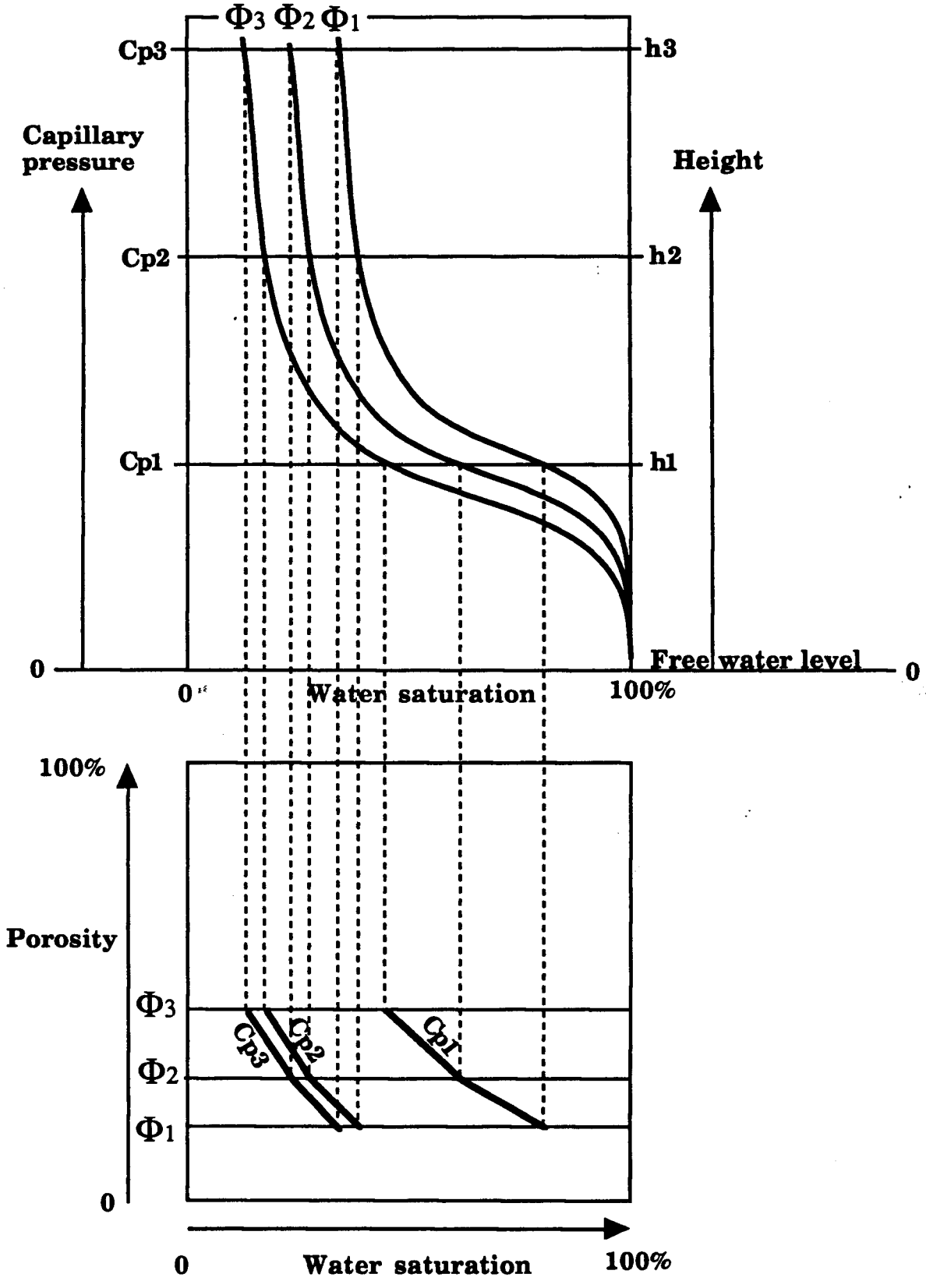
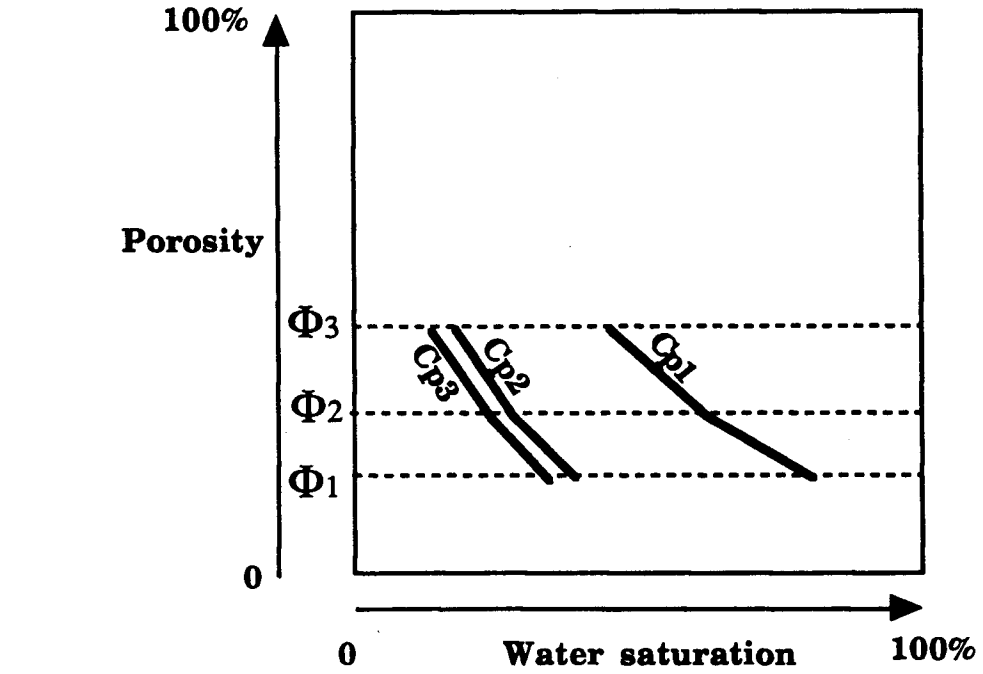


Figure 14: Mapping capillary pressures (or height of hydrocarbon column) to a porosity- water saturation crossplot.

pressure and its equivalent height of hydrocarbon column for three hypothetical core plugs. The three plugs have different porosities but are from a single petrofacies where samples with higher porosities have lower "irreducible" water saturations. The curves are shown in their convention format of saturation-pressure axes. However, the same information may be remapped onto a crossplot with porosity and water saturation axes, as shown in the lower part of Figure 14. This form of presentation is less common, but has been used since at least the fifties when Stewart (1957) reported its application to pay estimation in carbonate reservoirs. The linkage of the remapped points with lines represents the same result that would be obtained by interpolating between the original capillary pressure curves. Interpolation is appropriate when the samples are considered to be from the same petrofacies.

Notice that the crossplot has the same axes as the "Buckles plot" and that the capillary pressure contours conform approximately with hyperbolae that track with constant bulk volume water values. This shows that the productivity/pore size concepts of critical BVW are simply empirical expressions of phenomena controlled by pore throat distributions, capillary pressure, and hydrocarbon column. Notice also that although the capillary pressures are sampled at equal intervals of height, their mapping on the crossplot shows a rapid convergence on a stable boundary where BVW changes only gradually over relative large values of reservoir height.

If capillary pressure data can be mapped in porosity -water saturation space, then they can be mapped on the Pickett plot where the water saturation axis is oblique to the porosity axis (Figure 15). For a perfect "Buckles rock", the pressure contours would follow BVW lines exactly. Otherwise, the contours will follow curved paths that reflect the overall changes in pore-throat distributions with volume of porosity. If samples from radically different petrofacies are mapped collectively, the result will show abrupt changes and disruptions in the contour trends. Essentially, the breaks make the point that the interpolations are invalid and that the samples should be subdivided between sets that produce more harmonious pressure trends. The subdivisions constitute different petrofacies but they are a direct reflection of flow unit types since the differences are controlled by pore-throat distributions. Therefore, mapping of capillary pressure data onto a Pickett plot may be an immediate "answer" to productivity and permeability when the reservoir unit consists of a single petrofacies. However, the method becomes a valuable tool in its own right as a means to differentiate multiple petrofacies/flow units in a heterogeneous reservoir.



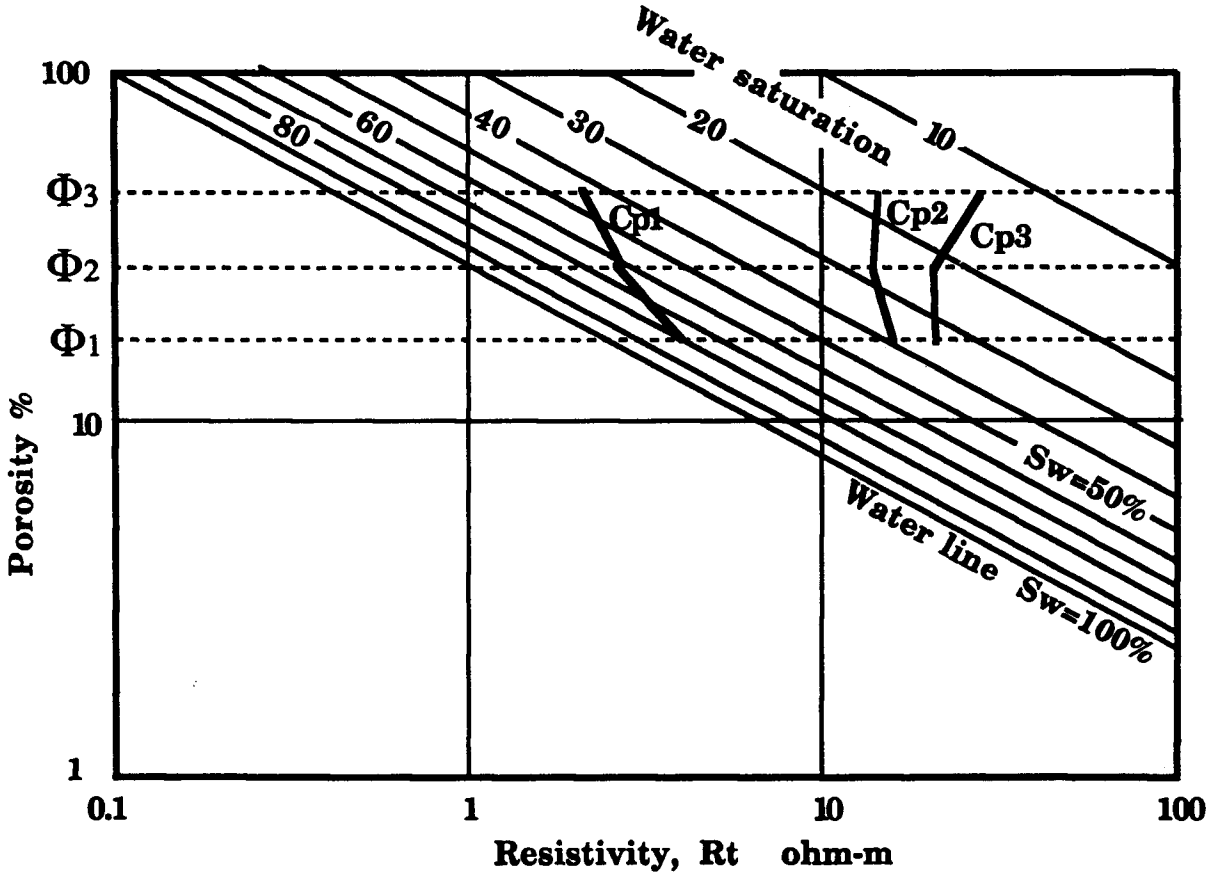


Figure 15: Alternative mappings of capillary pressure in porosity-water saturation space: graphed on orthogonal axes (above); and on oblique axes on the Pickett plot (below).

RHOMAA-UMAA crossplots of rock compositions

The mineralogy of reservoir zones is often tied closely to permeability and productivity in complex lithology reservoirs where differences in petrofacies mirror lithofacies changes. A variety of logs can now be used to characterize mineralogy either in graphic crossplots or by direct computation. A particularly powerful combination for this purpose is provided by the photoelectric index, neutron and density porosity logs. The three logs can be used to compute the two synthetic variables of RHOMAA, which is the hypothetical grain density of the zone, and UMAA, which is its hypothetical matrix volumetric photoelectric absorption index. The condensation of three log measurements to two synthetic variables comes about because the variable of porosity is suppressed, so that RHOMAA and UMAA are controlled exclusively by mineralogy.
Now, because:

$$\rho_b = \phi \cdot \rho_f + (1-\phi)\rho_{ma}$$

then:

$$\rho_{ma} = (\rho_b - \phi \cdot \rho_f) / (1-\phi)$$

ϕ is the true porosity and must be estimated by calculation or crossplot. The grain density is therefore estimated and is:

$$RHOMAA = (\rho_b - \phi_t \cdot \rho_f) / (1-\phi_t)$$

The photoelectric absorption index (Pe) is measured in units of barns per electron. In order to linearize its relation with composition, the variable must be converted to a volumetric photoelectric absorption index (U) with units of barns per cc by:

$$U = Pe \cdot \rho_e = Pe \cdot (\rho_b + 0.1883) / 1.07$$

and approximated by: $U = Pe \cdot \rho_b$

This is the volumetric photoelectric absorption coefficient of the zone (matrix plus fluid). The hypothetical volumetric photoelectric absorption coefficient of the matrix is UMAA. By analogy with the derivation of RHOMAA:

$$UMAA = (U - \phi_t \cdot U_f) / (1-\phi_t)$$

Because the volumetric photoelectric absorption index of water is very small, the formula is sometimes approximated by:

$$UMAA = U / (1-\phi_t)$$

The values can then be located on a RHOMAA-UMAA crossplot (Figure 16) for the solution of compositions within calcite-dolomite-quartz mixtures, as well as the recognition of evaporites, clay minerals, and other components.

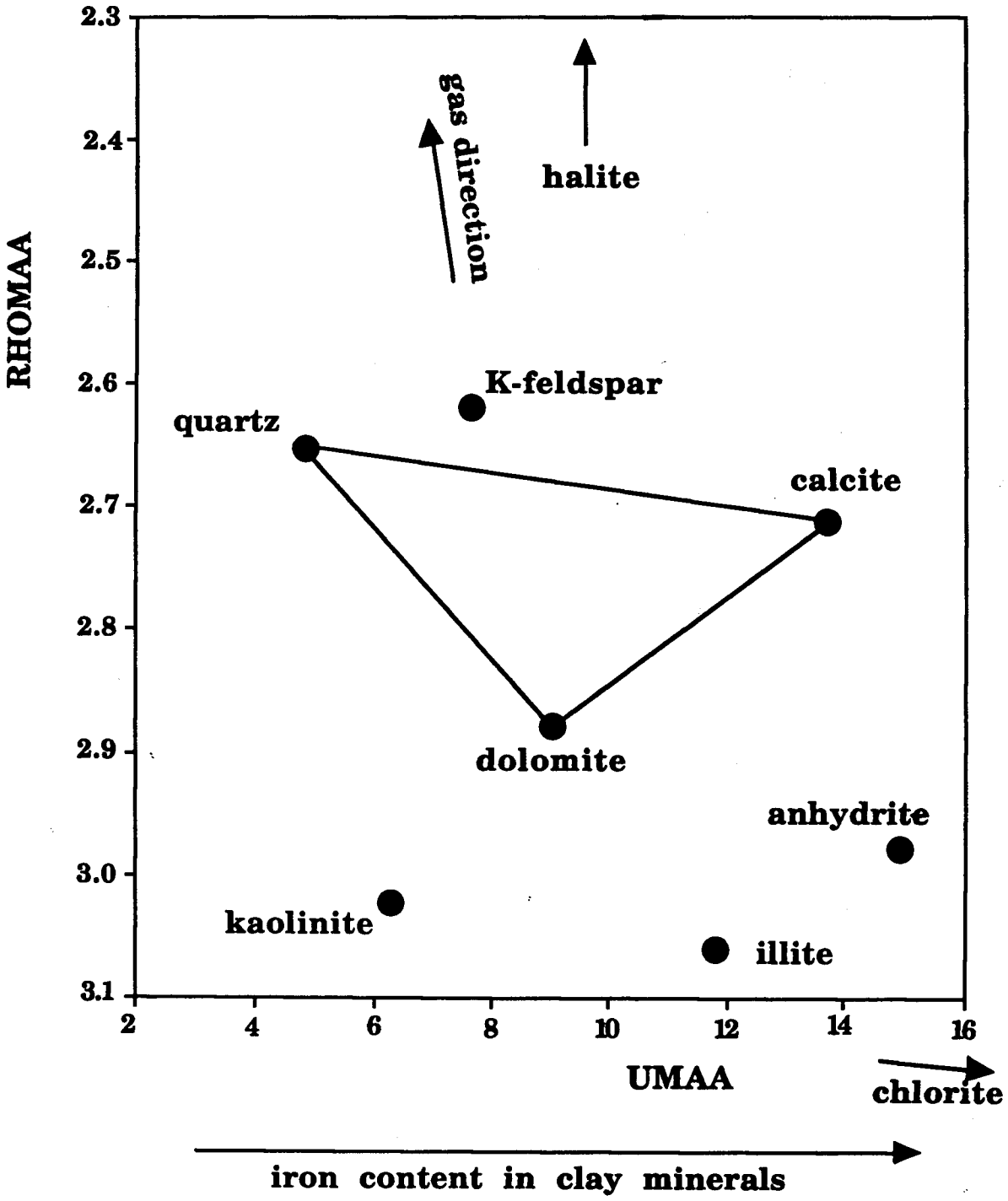


Figure 16: Framework of RHOMAA-UMAA crossplot marked with some common reference minerals and a quartz-calcite-dolomite composition triangle.

Explicit rock composition solutions from RHOMAA-UMAA values

The RHOMAA and UMAA values used to locate zones on the crossplot may also be used to compute rock composition as the proportions of three minerals. The quartz-calcite-dolomite triangle on the RHOMAA-UMAA crossplot of Figure 16 is a graphic presentation of a common (but not unique) three mineral system that could be used. Any zone within the triangle can be resolved as proportions of the three end-members by graphic a scaled subdivision of the triangle. Alternative composition systems can be proposed as dictated by the geology of the reservoir, such as calcite-dolomite-anhydrite. In each case, a unique solution is possible provided that three components are chosen to make a determined system with the two input variables of RHOMAA and UMAA. The two inputs are sufficient, because the component proportions collectively form a closed system.

Alternatively, the composition of any zone may be solved by algebra once the mineral components are specified because:

$$\begin{aligned} V1.RHOMA_{M1} + V2.RHOMA_{M2} + V3.RHOMA_{M3} &= RHOMAA \\ V1.UMA_{M1} + V2.UMA_{M2} + V3.UMA_{M3} &= UMAA \\ V1 + V2 + V3 &= 1.00 \end{aligned}$$

where $RHOMA_{Mn}$ is the grain density of the nth mineral, UMA_{Mn} is its volumetric photoelectric absorption and Vn is its proportion within the rock framework. The three simultaneous equations may be rewritten in matrix algebra notation as:

$$VC = L$$

and the vector of unknown proportions, V, solved by premultiplying the vector of zone log responses and unity, L, by the inverse matrix of C:

$$V = C^{-1}L$$

These operations are easily coded in computer software. When used to solve compositions in a succession of zones, the results may be shown as a continuous compositional profile with depth (Figure 17).

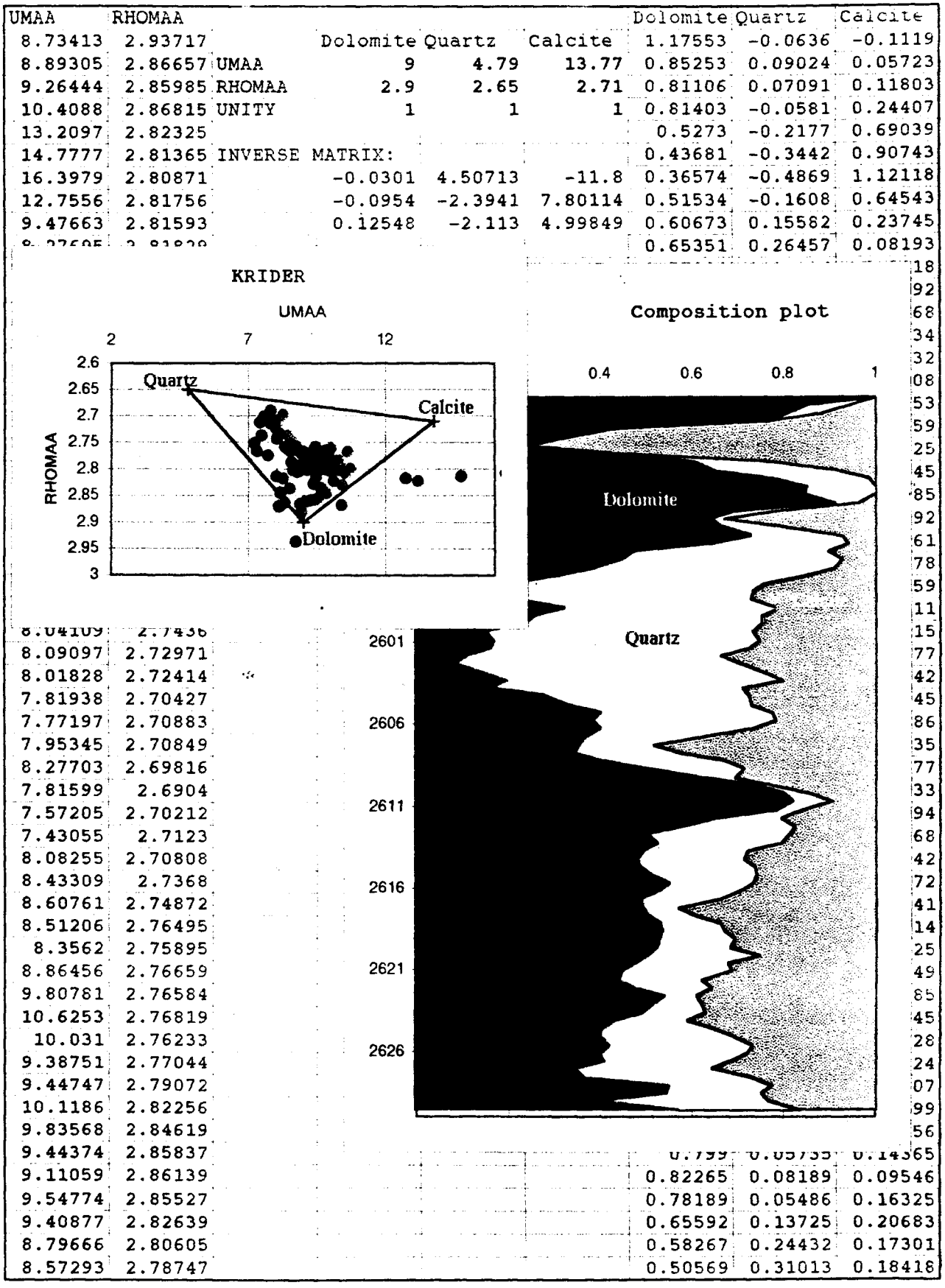


Figure 17: RHOMAA-UMAA plot, compositional computations, and compositional profile of dolomite, quartz, and calcite in a Krider Limestone (Permian Chase Group) section from south-west Kansas.

Petrofacies Mapping

Introduction

The mapping features provided in PfEFFER permit the user to quickly organize reservoir parameters by well and reservoir unit and then generate maps of selected variables derived from PfEFFER. The purpose of the mapping may range from simply evaluating the consistency of the parameters used to generate PfEFFER plots to testing the interwell hydraulic continuity or vertical conformance of a reservoir as revealed through the variables derived from PfEFFER. Questions asked by the user in preparing maps may include -

* Are reservoir constants used consistently through the analysis of multiple wells in a project area?
* Are the reservoir variables continuous or widely variable between wells?
* Are there spatial correlations between variables that suggest continuity?
* Does the spatial distribution of a variable form a geologically recognizable pattern that can aid in assessing the origin and improving the understanding of the reservoir's distribution?
* How are the parameters correlated spatially with test or production data?

The mapping included in PfEFFER provides a "quick look" at the spatial distribution of reservoir parameters. Once the maps are generated as EXCEL charts, EXCEL utilities then provide many features that are useful in modifying, moving, organizing, and presenting the maps. If desired, the worksheet-based plot files that are created can be easily exported to dedicated mapping software for detailed spatial analysis.

Careful correlation of well logs or other subsurface data such as seismic profiles and geologic core and sample descriptions should be done before the PfEFFER analysis as the initial step in partitioning a reservoir into correlatable flow units. Once the logs and associated subsurface data have been correlated, the PfEFFER analysis itself can be used to continue refining these correlations while developing the petrofacies or petrophysical facies.

Parameters that are typically used to characterize a reservoir provide useful constraints about structural attitude, size, shape, and orientation of the reservoir and are mappable through PfEFFER. These parameters include elevation of the top of the reservoir, pay thickness, average porosity, and porosity-feet. However, additional information are needed to further characterize the internal geometry of the reservoir. Internal geometry includes the zonation of pay and nonpay, continuity of nonpay and fluid flow barriers, and distribution of pores and distribution of hydrocarbons

and water. Pore distribution includes porosity, permeability, pore size, and permeability profiles (Sneider and Harris, 1989). PfEFFER can assist in supplying information to help resolve the characteristics of the internal geometry of the reservoir through the derivation of "petrofacies parameters." Mappable petrofacies parameters include:

* Minimum BVW
* Porosity at minimum BVW
* Sw at minimum BVW
* Porosity:Sw ratio at minimum BVW (the P factor, a proxy for permeability)
* Other permeability estimates
* Transmissibility (k*h) estimate based on thickness of pay and estimated permeability
* Capillary pressure and lithology solutions
* Other log attributes

Other useful mapping variables that can be integrated with petrofacies parameters include:

* Structural elevation of the top of the reservoir unit
* Production or test information
* Core analysis and sample descriptions

Maps can be easily augmented by plots of selected variables in the EXCEL environment.

Characterizing the Reservoir Utilizing Petrofacies Mapping

The petrofacies parameters can be used to characterize the reservoir via mapping to reveal spatial information. Parameters are initially read from the Pickett plots as illustrated with an example shown in Figure 1. Minimum BVW is identified for the reservoir unit. The correlation and zonation of the reservoir is a critical step in selecting the petrofacies parameters from the cross plot. The reservoir may contain thin permeability barriers that may create isolated compartments within the reservoir unit. In this example, the reservoir can be divided into four separate potential subzones with each subzones separated by thin, low porosity intervals. The low porosity intervals may limit or prevent vertical communication among the subzones. It may be useful to separately map and compare petrofacies parameters for each subzone, if the lower zones are suspected or have been proven to produce in other areas. The recognition of these subzones multiplies the possible maps that can be generated, but may present opportunities that have not been previously realized.

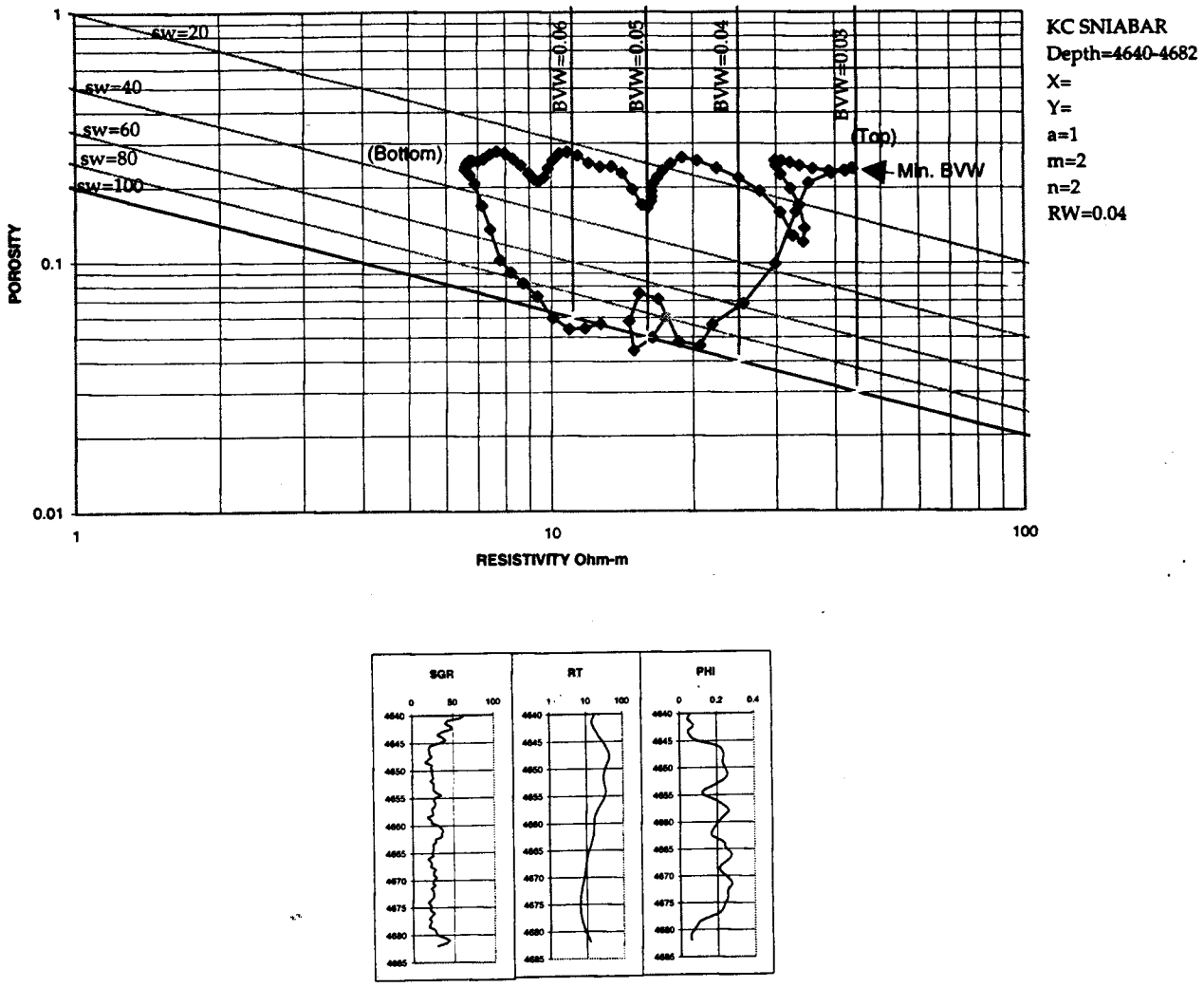


Figure 1. Pickett plot and corresponding well logs illustrating a carbonate reservoir containing four subzones. Position of top and bottom of reservoir unit and minimum BVW are located.

Maps of minimum BVW and associated porosity and water saturation of an apparent correlatable zone can suggest indications of lateral continuity. For example, uniform, consistent trends of the petrofacies parameters such as increasing minimum BVW and water saturation vs. declining elevation of the reservoir suggest that the reservoir unit is continuous between the wells (Figure 2). These relations can be further explored through the use of tailored plots in EXCEL such min. BVW vs. elevation of the top of the reservoir. Lack of lateral continuity of a reservoir unit between well locations may be expressed by contrasting values and lack of consistency among parameters. Complex maps accompanied by spatial contrasts in production data would suggest presence of lateral heterogeneities.

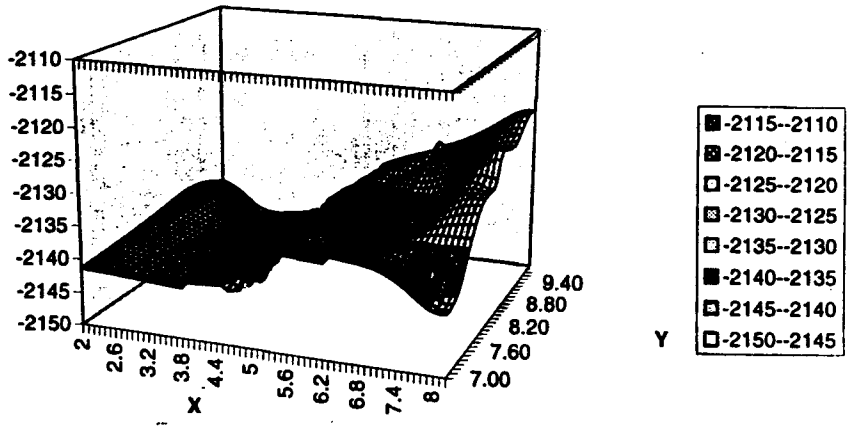


Figure 2. Subsea elevation of the top of the reservoir unit.

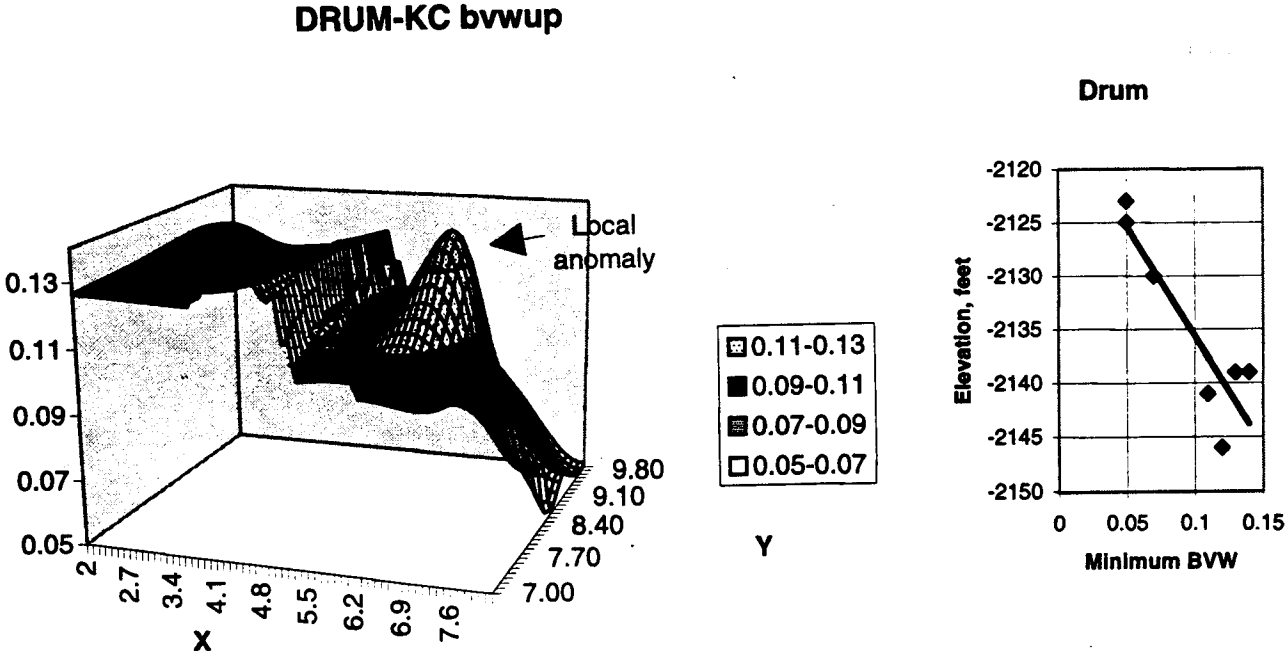


Figure 3. Three dimensional view of the minimum BVW and a plot of minimum BVW vs. subsea elevation of the top of the reservoir unit.

Reservoirs may be compartmentalized into separate flow units or subzones. The Pickett cross plot example shown in Figure 1 suggests that the reservoir is comprised of four subzones. The undulating, nearly horizontal oriented trend of data points in the crossplot of Figure 1 suggests that this well penetrated a reservoir that contains a long transition zone. The approximately constant porosity trend along

which resistivity steadily decreases downward through the reservoir (from left to right on the crossplot) is a common signature for a transition zone. This rather continuous trend suggests that these subzones are in hydraulic communication. The minimum BVW in the upper subzone appears to be near an irreducible value likely containing bypassed pay, while the lower subzones have higher BVW's and are within a transition zone. Alternatively, a decreasing pore size in these successive subzones may have produced the progressively higher BVW's. Either samples or production test data could confirm these relationships.

Lateral variations of the subzones may present very complex geometries that control fluid flow that are not revealed at the stage when logs are initially correlated. Subzones of a reservoir can especially present problems in correlation due to the potential for lateral discontinuities, e.g. shingling of porous zones separated by low porosity intervals (Figure 4).

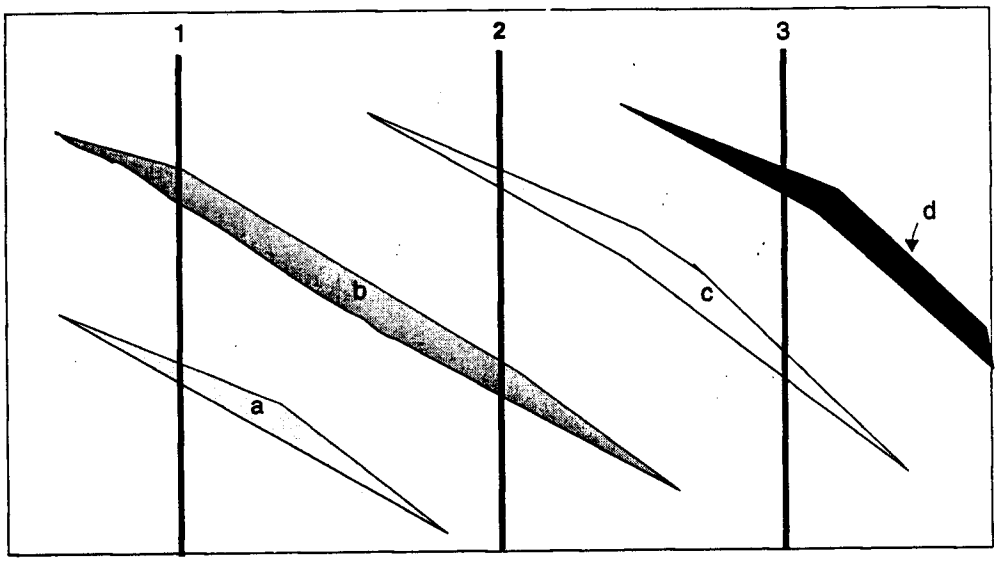


Figure 4. Four shingled porous and permeable subzones in a reservoir unit penetrated by three wells. Each well encounters two subzones. Only one subzone is common to the offsetting well.

In this example the same number of shingled compartments may be present in each well presenting the appearance of a simple layered reservoir. In fact, the subzones in this example lap out updip or downlap downdip (Figure 4). The use of petrofacies parameters may help resolve the correlation problem posed by this

example in that the petrofacies of each subzone may be sufficiently different to distinguish them as separate units, e.g., pore type or hydrocarbon charging (reservoir energy). Also each subzone may exhibit different lateral trends that may be revealed during mapping. It may be necessary to map different sets of subzones before a good match is found. Of course, if production and sample data are available or possible analogs exist, this information can be used to help strengthen or resolve the correlations.

Other spatial patterns can possibly explain production anomalies such as pods of larger, more permeable pores in carbonate grainstones (e.g., lower BVW) or different lenses or channels of laterally offsetting sandstone reservoirs (Figures 5 and 6, pods in grainstone shoal and lenticular point bar deposits).

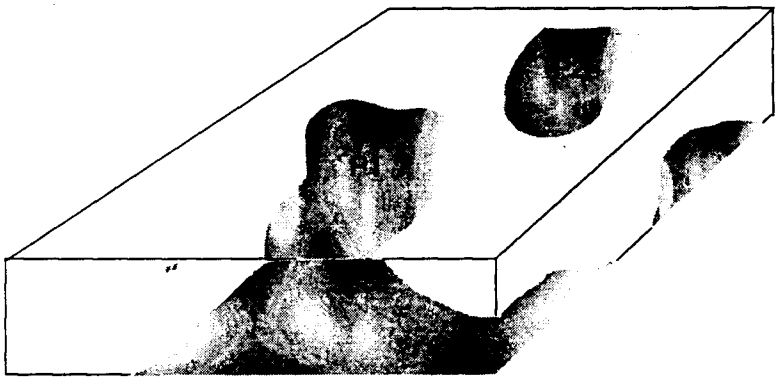


Figure 5. Pods of grainstone shown in a block diagram.

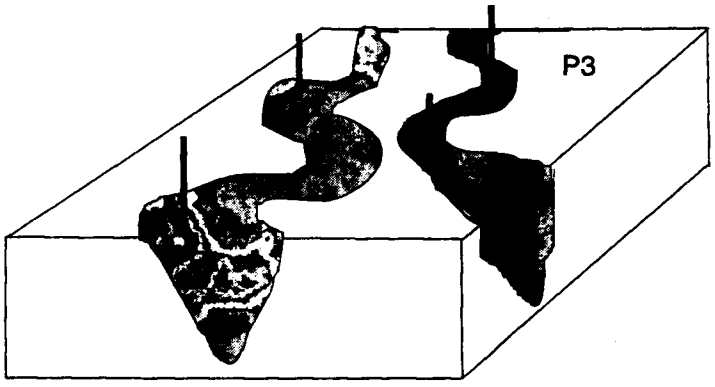


Figure 6. Lenticular sandstones shown in block diagram.

Maps of the same parameter can be compared among different reservoirs, e.g., in a stacked commingled succession of reservoirs, to reveal trends and areas with contrasting values. This knowledge can be important in selecting and designing appropriate improved oil recovery options. Certain commingled zones may be underproduced or even bypassed during primary production or waterflooding.

Estimated permeability values and perhaps transmissibility (k*h) provide additional parameters to map and possibly permit modeling of production outcomes for new recovery methods that are being considered. Vertical conformance may also be characterized by calculating the Dykstra-Parsons coefficient using the estimated permeability data. Other related permeability information may be obtained through laboratory analyses and incorporated empirically with the log data using the spreadsheet, e.g., relative permeability and residual oil saturation.

In general, mapping of petrofacies parameters can be useful in making reservoir management decisions such as preventing well abandonments, improving oil and gas recovery, and selecting appropriate technologies. Specifically, mapping may be useful in evaluating underproduced zones, discerning subtle bypassed zones, and defining vertical conformance and lateral continuity.

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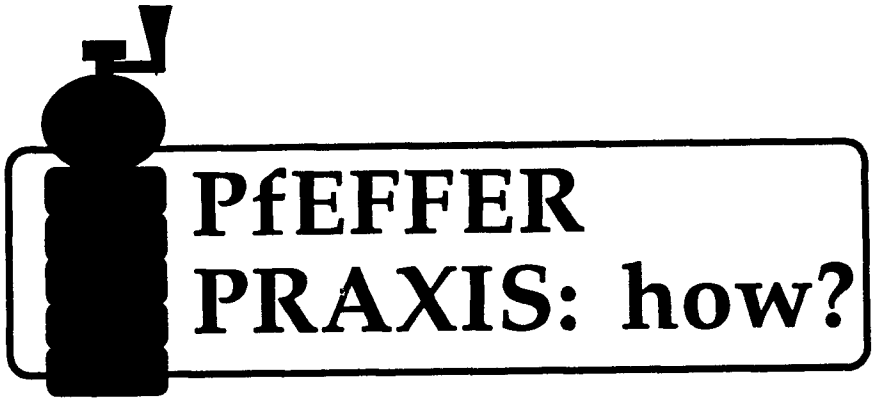

PfEFFER
PRAXIS: how?

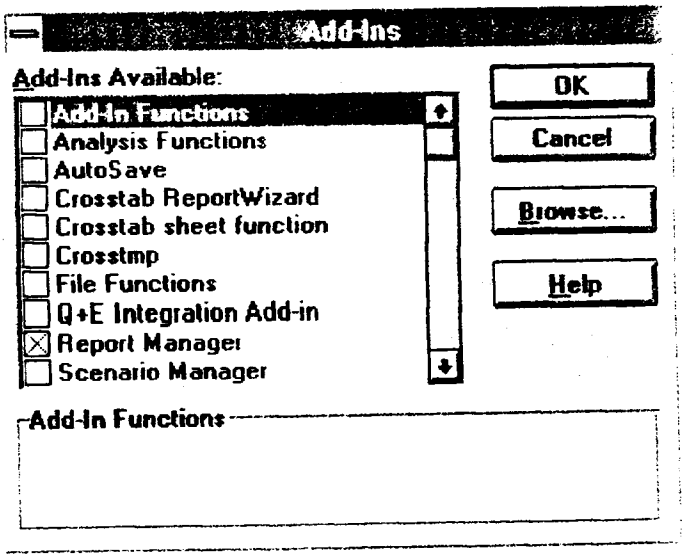
INSTALLATION OF PFEFFER ADD-INS

Installing Pfeffer Add-ins

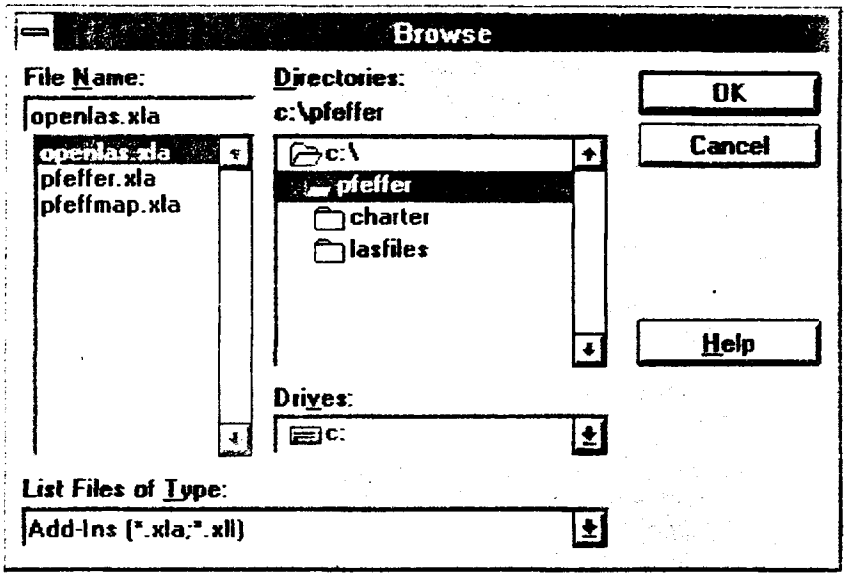
The Pfeffer software consists of three separate add-ins for Excel, one for importing LAS files, one containing the mapping operations, and the main Pfeffer add-in allowing for the production and annotation of Pickett plots along with other operations. On the distribution diskette for Windows, these add-ins are contained in the files **openlas.xla, pfeffmap.xla,** and **pfeffer.xla** respectively. The names of the files on the Macintosh distribution diskette are **OpenLAS Add-In, Pfeffmap Add-In,** and **pfeffer mac Add-In.** On either platform the installation process consists of copying the three files from the distribution diskette to a subdirectory or folder on your computer's hard drive and then loading the add-ins into Excel using the **Add-Ins...** item on the **Tools** menu.

You may copy the files to any location on your hard drive that you prefer. On a number of computers there is a folder or subdirectory entitled something like **add_ins** or **addins** contained within the Excel folder or directory and intended as a location for user-supplied add-ins. You may place the add-ins in such a directory or some other existing directory. If you prefer, you may create a new directory for the purpose of storing the Pfeffer software. The only caveat is that once you have loaded the add-ins, Excel will always expect to find the files in the same place and under the same names. If you move or rename the files after you have first loaded them into Excel, Excel will complain that it cannot find the files and you will have to go through the process of locating and loading them again.

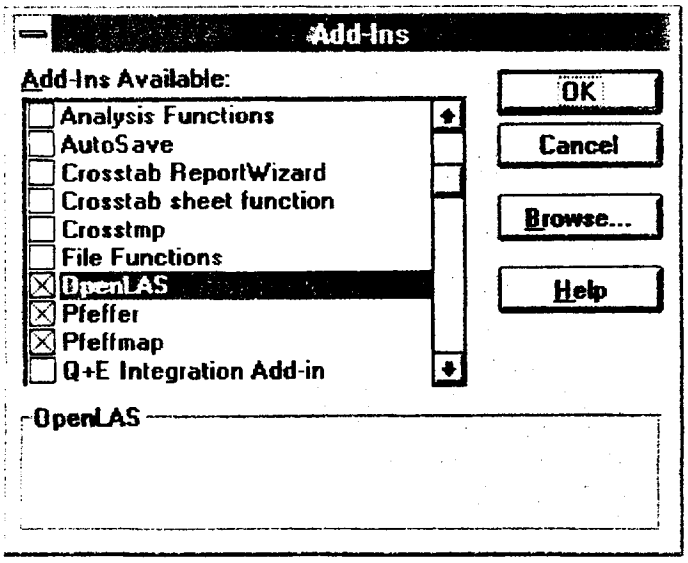
To load the files after they have been copied to the hard drive, start up Excel and then select the **Add-Ins...** item on the **Tools** menu. You will then be presented with the **Add-Ins** dialog box...



Each of the three add-ins can be added to the **Add-Ins Available** list by clicking on the **Browse...** and using the resulting **Browse** dialog box to locate and open the add-in file.



In the Browse dialog box shown, the file **openlas.xla**, located in the **pfeffer** directory, has been selected. (On the Mac the corresponding file will be **OpenLAS Add-In**.) The file may be opened by double-clicking on its name or clicking on the **OK** button when the file name is selected. The OpenLAS add-in will then be added to the **Add-Ins Available** list on the **Add-Ins** dialog box. Repeat the process, selecting **pfeffmap.xla** and **pfeffer.xla** to load the Pfeffmap and Pfeffer modules respectively. Once you have done this, all three add-ins should appear in the Add-Ins Available list and all three should be checked, as shown below.....



Once you click on the **OK** button, Excel will load the three add-ins, resulting in the addition of the **Import LAS file** and **Create Template** items to the **File** menu, the addition of a **Mapping** menu, and the addition of the toolbar for the main Pfeffer add-in.

Any of the add-ins may be 'unloaded' by selecting **Add-Ins...** again from the **Tools** menu and unchecking the box to the left of the add-in name in the **Add-Ins Available** list. The add-in will remain in the list and can be reloaded at a later time by checking the corresponding box again (assuming the add-in file has not been moved or renamed).

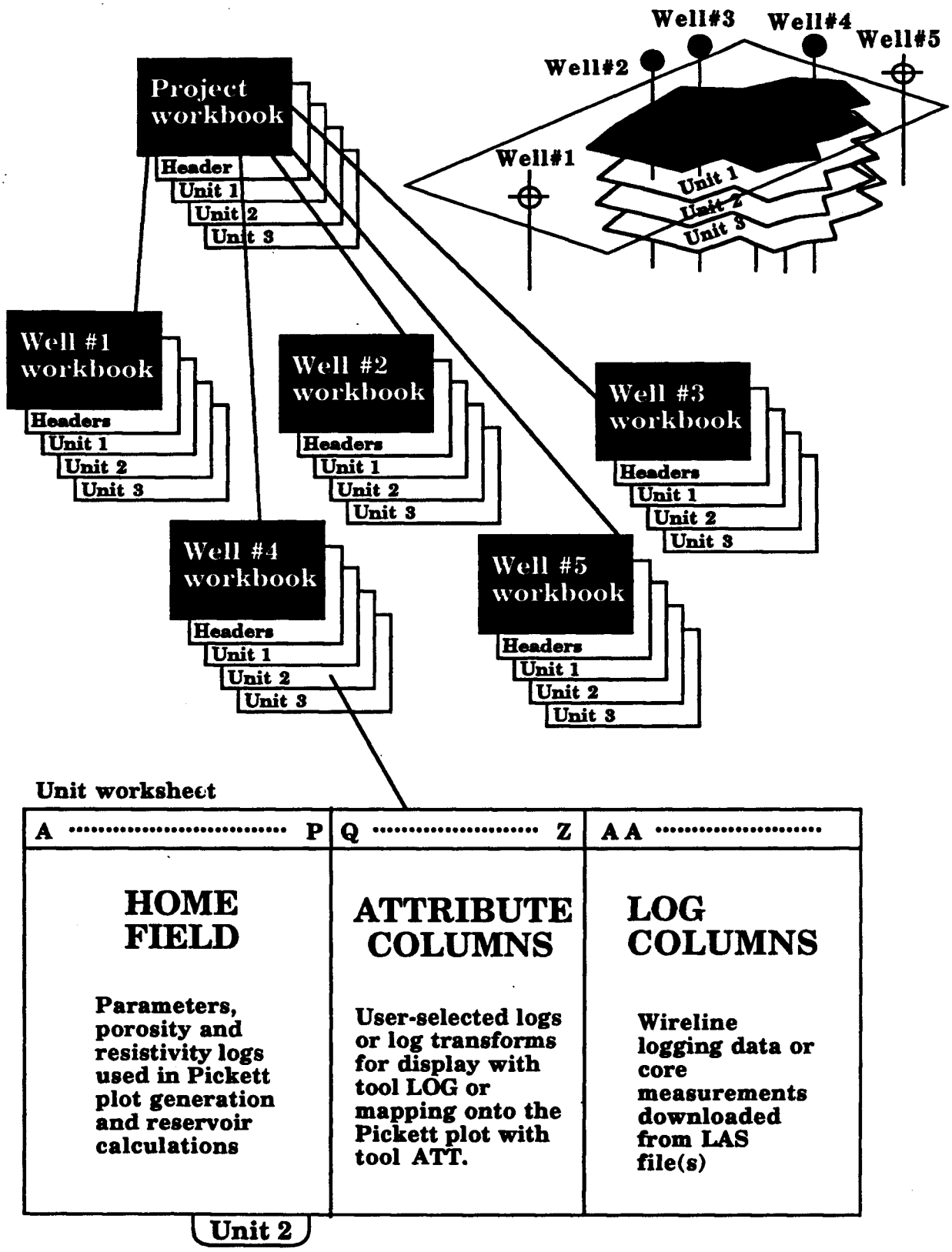
PfEFFER FILE ORGANIZATION

A single EXCEL workbook is used to organize all the well log information for a particular well. We will refer to this workbook as a **well workbook** (even when the well is a dry hole). Each **well workbook** contains **unit worksheets**. A unit is a stratigraphic subdivision as defined by the user. So, a unit may be a formal geologic formation, a reservoir interval, or a reservoir subdivision. Data may be typed in manually from blue-line logs into a well workbook created by the **Create template** option (see CREATE TEMPLATE). Alternatively, logging data may be downloaded for multiple units from an LAS file by using the **Import LAS** option (see IMPORTING LAS FILES). A **project workbook** is a master file that contains summary information from multiple wells within a lease, field, or other map area. The contents of the **project workbook** are linked dynamically with the **well workbooks**, so that changes within the **well workbooks** are carried automatically to the **project workbook** The project **workbook** also contains some simple mapping functions, so that the spatial variation of structure, thickness, and petrophysical variables may be displayed in either two or three dimensions. The **project workbook** is also useful as a means to monitor consistencies in analyses and parameters between wells and to troubleshoot apparent anomalies.

These concepts are clarified in the schematic figure of PfEFFER file organization. The hypothetical area has an oilfield with three producing wells and two nearby dry holes ; the field produces from three reservoir zones (units 1. 2, and 3). Segments of the logs run in all five holes are stored in five **well workbooks** as matched with the depth intervals of each of the three units. The first worksheet of each **well workbook** is designated as **Headers** and contains well information entered either by the user or transcribed from the headers of LAS files when using the **Import LAS** option. Each unit in each well is identified by a unique **unit worksheet** within the well's **well workbook**. Summary information from the **unit worksheets** within the five **well workbooks** are stored in matching **unit worksheets** of the **project workbook**. The **Header sheet** of the **project workbook** summarizes well information extracted from the **Headers sheets** of the **well workbooks**.

The structure of a single **unit worksheet** is shown in the figure for the Sniabar sheet of the OZ.XLS file. The unit worksheet is divided between a **home field** (columns A to P), the ten **attribute columns** (columns Q to Z), and the **log columns** (columns AA onwards). As the name should indicate, the **home field** is the key area of the **unit worksheet** for the PfEFFER analysis.

Cells A1 and A2 contain the name of the well and the stratigraphic unit, respectively. The names are entered either manually or automatically



PfEFFER file hierarchy

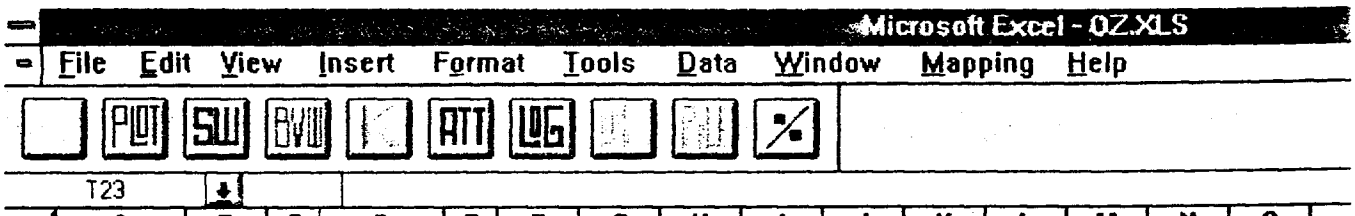
as part of the **Import LAS** procedure. Columns A and B contain the names and values of Archie and other parameters. These parameters are:

X and **Y** : the well geographic coordinates;
A : the "Archie constant";
M : the "cementation exponent":
N : the "saturation exponent":
RW : the formation water resistivity at formation temperature;
CTHK : the cumulative unit thickness summed from column E
AVPHI : the average porosity computed as a thickness-weighted mean of porosities in column G);
FTOIL : cumulative feet (or meters) of oil (or gas) computed from data in columns E, G, and K;
KB : Elevation of Kelly Bushing either transcribed by the LAS Import option or entered manually;
P, Q, and **R** : parameters of the Wyllie-Rose equation used to estimate permeability from porosity and irreducible water-saturation.

The parameters **A, M, N** and **RW** control the intercept and angle of lines drawn on the Pickett plot as well as the reservoir characteristics computed in the homefield. These parameters may be "known" or can be resolved as part of the PfEFFER analysis through reasoning and experimentation with trial values.

Columns C, D, and E contain zone identification (either letter or number), zone depth, and zone thickness. The design will allow both "traditional" analysis of zones with unequal thicknesses as read manually from peak and trough features, as well as digital analysis where log data sampled at a constant depth increment (typically half a foot) has been copied from electronic records. Columns F and G contain true resistivity (**RT**) and fractional porosity (**PHI**) data that is graphed onto the Pickett plot and the reservoir calculations in columns H to O. Resistivity logs read from an LAS file will be copied out in the **log columns** (columns AA and beyond). The user will select which resistivity log should be copied into column F as **RT**. Note that several different kinds of resistivity log can be entered into this column, so that invasion effects can be monitored and moveable hydrocarbons evaluated. **PHI** must contain fractional (as opposed to percentage) data and is generally equated with "true porosity". At the user's discretion, **PHI** be derived from a single porosity log (sonic, density, or neutron) stored in the log columns or computed as a function of several porosity logs, using EXCEL's standard formula functions.

Column H contains **RWA**, the reconnaissance (or apparent) water resistivity for each zone, based on the Archie parameters in columns A and B and the zone porosity (**PHI**) and resistivity (**RT**) values. The value is



T23

TOTO OZ #1
KC SNIABAR

PARAMETERS	
X	
Y	
A	1
M	2
N	2
RW	0.04
CTHK	42.5
AVPHI	0.19
FTOIL	5.75
KB	
P	8581
Q	4.4
R	2

ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C	P	THKPHTPSW	
1	4640	0.5	17.43	0.06	0.06	11.17	2.16	0.80	0.05	0.07	0.03	0.01
2	4640.5	0.5	16.4	0.05	0.04	16.06	2.01	0.99	0.05	0.05	0.02	0.00
3	4641	0.5	14.99	0.044	0.03	20.38	1.90	1.17	0.05	0.04	0.02	0.00
4	4641.5	0.5	14.62	0.058	0.05	11.99	2.07	0.91	0.05	0.06	0.03	0.00
5	4642	0.5	15.36	0.075	0.09	7.11	2.30	0.68	0.05	0.11	0.04	0.01
6	4642.5	0.5	16.86	0.071	0.09	7.89	2.29	0.68	0.05	0.10	0.04	0.01
7	4643	0.5	18.67	0.048	0.04	17.36	2.02	0.96	0.05	0.05	0.02	0.00
8	4643.5	0.5	20.69	0.046	0.04	18.65	2.03	0.95	0.04	0.05	0.02	0.00
9	4644	0.5	21.95	0.056	0.07	12.71	2.19	0.76	0.04	0.07	0.03	0.01
10	4644.5	0.5	25.55	0.068	0.12	8.58	2.41	0.58	0.04	0.12	0.03	0.01
11	4645	0.5	29.9	0.099	0.29	4.10	2.86	0.37	0.04	0.27	0.05	0.03
12	4645.5	0.5	33.03	0.16	0.84	1.57	3.66	0.22	0.03	0.73	0.08	0.06
13	4646	0.5	35.18	0.208	1.52	0.92	4.32	0.16	0.03	1.29	0.10	0.09
14	4646.5	0.5	39.31	0.228	2.04	0.77	4.66	0.14	0.03	1.63	0.11	0.10

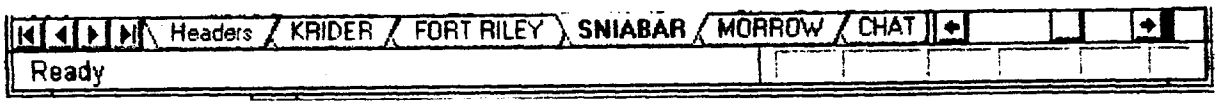
HOME FIELD: Fundamental log data for Pickett plot and reservoir parameter calculations

P	Q	R	S	T	U	V	W	X	Y	Z
	ATT#1	ATT#2	ATT#3	ATT#4	ATT#5	ATT#6	ATT#7	ATT#8	ATT#9	ATT#10

ATTRIBUTE COLUMNS:
Logs or log transforms for log display (LOG) or mapping onto the Pickett plot (ATT)

AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM
	DEPTH	ILD	ILM	SFLU	SP	BMIN	BMNO	CALI	CGR	PHID	DRHO	PHIN
	4640	17.433	14.584	15.995	-2.779	13.461	6.1211	9.3672	47.627	0.0253	0.0038	0.094
	4640.5	16.396	15.177	14.011	-3.318	55.719	26.797	9.3594	45.364	0.0226	0.0002	0.077

LOG COLUMNS:
Digital logs read from LAS file as well as core or other depth-indexed data



Structure of UNIT WORKSHEET in a WELL WORKBOOK
(In this example, the Sniabar in the OZ.XLS workbook)

computed so that any change in the parameter or log values will cause changes in **RWA**. When the formation water resistivity is unknown but the Archie parameters are either known or reasonably estimated, the column may be used to establish the formation water resistivity by the classic Rwa technique described in most log analysis texts.

Column I calculates **RO**, the resistivity of each zone if it was completely saturated with formation water whose resistivity matched the value recorded in cell B10 and a rock with Archie parameters of cells B7 and B8.

Column J records **MA**, the apparent Archie cementation exponent, calculated under the assumption that the zone is completely water-saturated and that the value in cell B10 is the actual formation water resistivity. This computation is a companion technique to the RWA method, but in this case provides a means to estimate the cementation exponent in water zones where formation water resistivity is known, but the Archie equation parameters are poorly known. The values of **MA** also represent the slopes of an individual water line that result when the zone is located on the Pickett plot and linked with the formation water resistivity intercept.

Column K reports **SW**, the calculated values of proportional water saturation, using the zone porosity (**PHI**) and resistivity (**RT**) value in conjunction with the Archie equation values of a, m. and n, recorded in parameter cells B7, B8, and B9.

Column L displays **C**, a calculation of the fractional bulk volume water in each zone as the product of the fractional porosity and water saturation. As described earlier in this manual, the BVW is often known as the "Buckles number" in reservoir zones at "irreducible" water saturation. The value is controlled primarily by pore size, where large pores cause low Buckles numbers, and small pores are matched by high Buckles numbers. Column M contains **P**, which is the porosity (**PHI**) divided by water saturation (**SW**), and is a broad qualitative measure of permeability in reservoir zones.

Columns N and O list incremental porosity feet (**THKPHI**) and hydrocarbon feet (**TPSW**) calculated by zone. The results are summed in the computation of average porosity (**AVPHI**) and hydrocarbon feet (**FTOIL**) in cells B12 and B13.

The **attribute columns** are set in columns O to Z and titled ATT#1 to ATT#10 in Row 4. Although initially empty, these columns are used as a working area to transcribe logs or log transforms that are specified by the user. Depth-indexed data are copied into one of the **attribute columns** and the title in cell 4 changed to the name of the copied log. The data can then be displayed as log curves through the use of the **LOG** option. Alternatively, the

data can be mapped on to the Pickett plot as a color convention for the plotted symbols using the **ATT** option.

The **log columns** begin at column AA and extend indefinitely to the right. This area is used to store logs copied from an LAS file using the **Import LAS** option. When the **Import LAS** option is launched, the program looks for the first available column to the right of AA. Once located, the option stores the logs desired and records their titles in Row 4 as written on the LAS file. If a well has multiple LAS files, then the logs are entered successively, with no overwriting of records, but a blank column to mark breaks between each LAS set. These logs are the source of resistivity values to be copied into column F of the home field. Typically, a deep-reading resistivity log will be chosen as a best estimate of **RT**, the true formation resistivity. However, the choice of resistivity log to be used is at the discretion of the user. Porosity logs saved in the log columns are used as the basis for **PHI** values used in column G of the home field. Again, the use of single or multiple porosity logs for this purpose is the choice of the user. However, remember that **PHI** values should be written as fractional porosity units.

MAKING A NEW PfEFFER WELL WORKBOOK

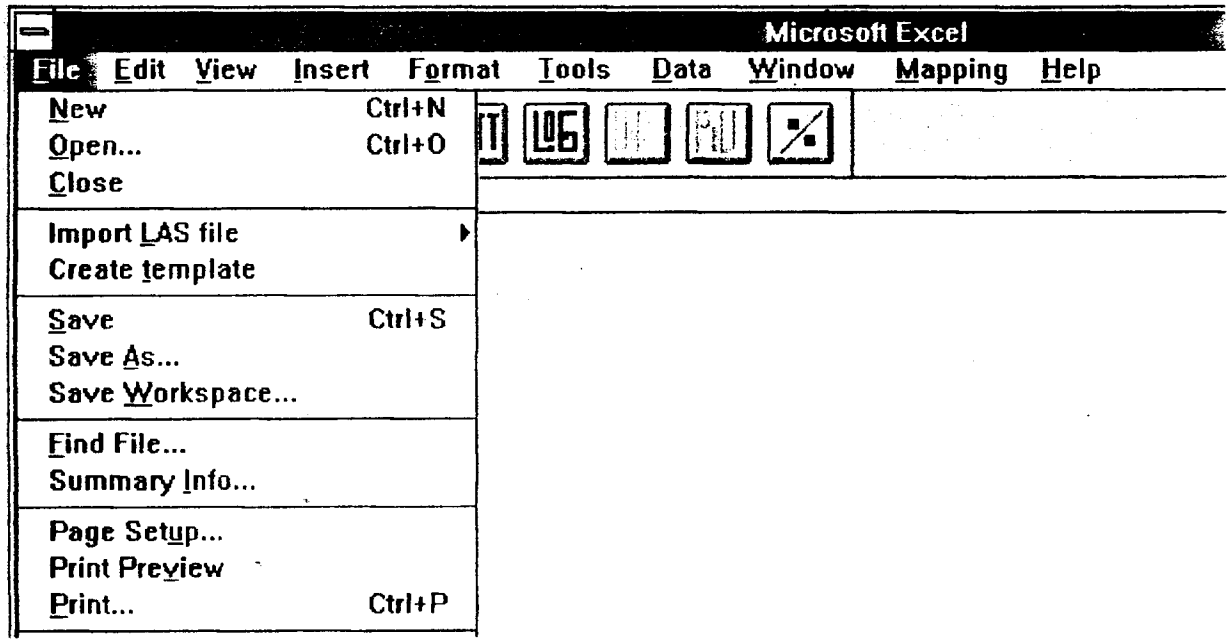
Introduction

There are two ways to make a new **well workbook**. The user can either:

(1) create a template **well workbook** ;

or (2) import an LAS file into an existing **well workbook** or a new **well workbook** created by the import function.

Both options are accessed within PfEFFER by pulling down the **File** menu and highlighting either **Import LAS** or **Create template** :



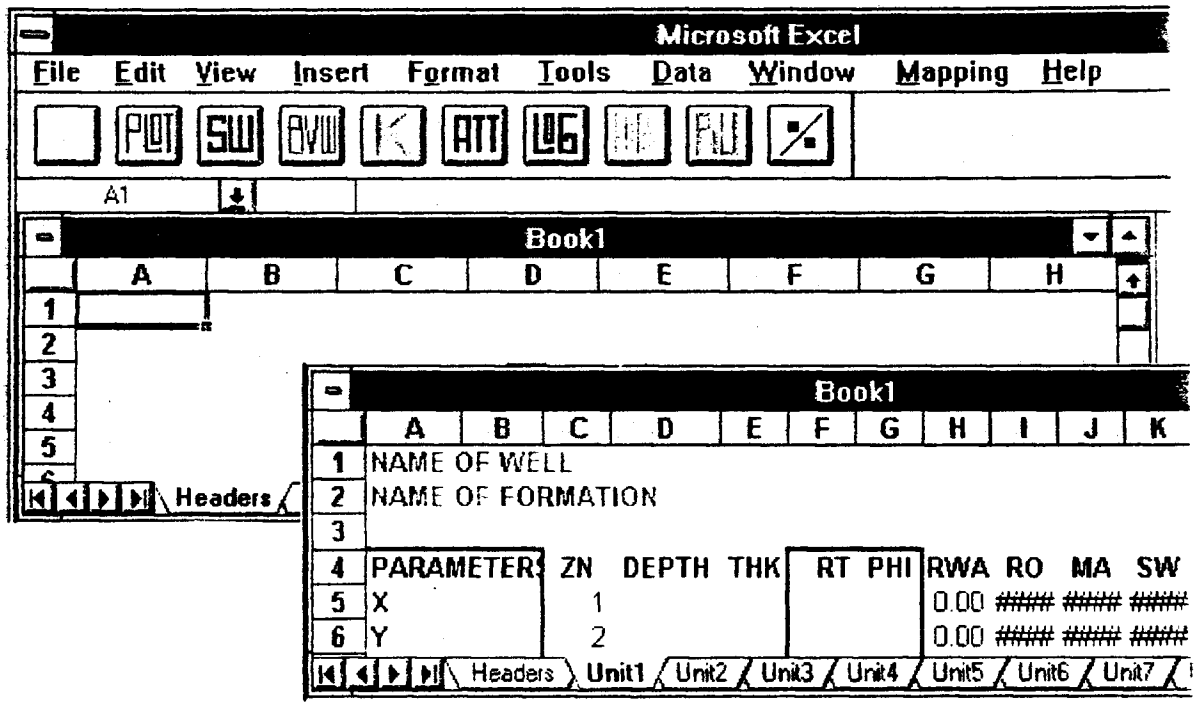
If an LAS file is available, the user will choose **Import LAS**. Otherwise the user will enter data manually from a blue-line log or other source of logging information onto a template **well workbook** made by **Create template**.

CREATE TEMPLATE

When the user selects **Create template**, the option creates a **well workbook**. The first sheet of the workbook is a **Headers** sheet which is blank and designed for the entry of pertinent information for the well which is carried on the header of the well's logs. The **Headers** sheet is succeeded by ten **unit sheets** labeled **Unit 1** through **Unit 10**. Each **unit sheet** has a **home field** and **attribute columns** formatted in the PfEFFER style of titles, values, and formulae. Logging data may be entered onto the template, together with the names of the well and its units. The **well workbook** is automatically given

the arbitrary name of **Book 1**. The user can then save the document with a name or code associated with the well.

IMPORTANT: Note that the **Create template** option is only necessary when there are NO LAS files available. The **Import LAS file** option not only copies logs from LAS files, but also creates PfEFFER well **workbooks** under user direction.



IMPORTING AN LAS FILE

Preamble

The LAS (Log Ascii Standard) is rapidly becoming the accepted industry standard for electronic transmission of digital wireline logs. Earlier digital formats were commonly coded in binary (such as LIS) and so required specialized software to read them. The Canadian Well Logging Society introduced LAS in 1989 as a simple and effective means to transmit digital logs that made them immediately accessible to even a casual user of a PC. An LAS file can be read by a conventional word-processing program and modified if necessary. It can also be opened directly by EXCEL, so that the user can check the file to see well information, types of logs, and other parameters. This capability is also useful for troubleshooting if OpenLAS fails when the file has not been formatted correctly by the rules of the LAS convention. Although the standard functions of EXCEL can be used import an LAS file and create a PfEFFER workbook, the process is generally laborious and can be

```
~Version Information Block
VERS.                  1.20:  CWLS LOG ASCII STANDARD - VERSION 1.2
WRAP.                    NO:  One line per depth step
~Well Information Block
#MENM.UNIT       Data Type    Information
#--------- ---------------    -----------------------------
STRT.FEET              5000:
STOP.FEET              6130:
STEP.FEET               0.5:
NULL.                -999.25:
COMP.                COMPANY:  TOTO PETROLEUM INC.
WELL.                   WELL:  WIZ #1
LOC .               LOCATION:  5-36S-44W
PROV.         OZ
SRVC.       SERVICE COMPANY:  FLYING MONKEYS
DATE.                  DATE:  11/16/95
API .            API NUMBER:  000015129123
~Curve Information Block
#MENM.UNIT        API CODE    Curve Desc
#--------- ---------------    ----------
DEPT.FEET                 :  Depth
DLCL.INCH                 :  Logged
DLDC.GM/C                 :  Logged
DLDN.GM/C                 :  Logge
DLDP.PERC                 :  Logg
DLPE.B/E                  :  Log
DLTN.LBS                  :  Lo
DLGR.API                  :
NCNP.PERC                 :
~Parameter Information Bloc
#MENM.UNIT           Value
#--------- ---------------
HOLE.       WIZ #1:  Hol
VERT.                Fl
HORI.                FE
LEAS.       EMERALD:  Lease
WELL.                 1:
SURV.                 1:  Surv
SECT.              0005:  Survey
TOWN.               036:  Survey tow
TOWN.                 S:  Survey towns
RANG.               044:  Survey range nu
RANG.                 W:  Survey range direc
LATI. :  Latitude
LONG. :  Longitude
ELEV.              3333:  Elevation of measurement re
MEAS.        KELLY BUSHING:  Measurement reference
~A          DEPT     DLCL     DLDC     DLDN     DLDP     DLPE     DLTN     DLGR     NCNP
5000.0000  8.4693   0.0191   2.6107   0.0581   3.1197   1291.0957     73.2372   0.1304
5000.5000  8.4669   0.0213   2.6084   0.0594   3.0820   1301.2539     73.2909   0.1360
5001.0000  8.4732   0.0229   2.6119   0.0574   3.0430   1294.3984     73.4230   0.1389
5001.5000  8.4719   0.0234   2.6184   0.0536   3.0465   1290.8027     73.5193   0.1381
5002.0000  8.4614   0.0234   2.6202   0.0525   3.0776   1276.9355     73.6942   0.1352
5002.5000  8.4552   0.0223   2.6258   0.0492   3.1169   1246.2031     74.3557   0.1293
5003.0000  8.4517   0.0219   2.6291   0.0473   3.1725   1233.2090     75.0554   0.1257
5003.5000  8.4769   0.0219   2.6248   0.0498   3.1670   1249.6133     75.9563   0.1245
5004.0000  8.5177   0.0221   2.6145   0.0559   3.1027   1250.8789     76.9459   0.1263
```

The Log ASCII standard (LAS): First records of 12345A.LAS

frustrating. OpenLAS handles LAS file reading and well workbook construction under user direction so that stratigraphic intervals and log types are selected and extracted in an easy and satisfactory operation.

The OpenLAS add-in module is designed to read information from LAS files into an EXCEL workbook. The user selects the well log variables to be read from the file and also specifies a number of separate 'units' (named depth intervals), each of which will be represented by a separate worksheet in the workbook. Each of these worksheets will be in the proper format for use with the plotting and analysis software described elsewhere in this manual. The intention is that a single workbook will contain the log information for a single well. The user has the option to either create a new workbook to contain the information from an LAS file or to add information from an LAS file to an existing well workbook. The latter option is provided in case the logs from a given well are contained in more than one file.

The software has been shown to work successfully with LAS files either in the version 1.2 or version 2.0 format. Only two aspects of the header information in the LAS file are crucial to the successful operation of the software:

1) The header must contain a 'Curve Information' block beginning with a line whose first two characters are '~C' and otherwise containing only comment lines (beginning with '#') and the lines actually describing the log variables contained in the file. The software uses these lines to determine the number and order of the variables in the file.

2) The data section must be preceded by a line beginning with '~A'. This line usually also contains variable labels, but the presence or absence of these labels is not important to the software, since variable labels are obtained from the Curve Information block. The number of columns of data must match the number of variable information lines contained in the Curve Information block. The operation of the software is unaffected by whether the lines are wrapped (multiple data lines per depth record) or not.

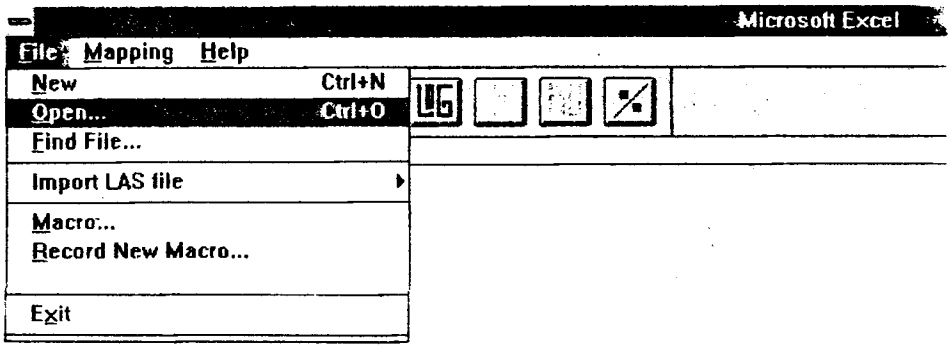
The software will also attempt to read the following information from the LAS file header: the name of the well and the start and stop depth for the logging run (all in the Well Information block) and the Kelly bushing elevation (in a line beginning with the mnemonic "EKB" in the Parameter Information block, if present). The code will continue to operate even if it cannot locate these values.

The header information from the file will be transferred line for line into the first worksheet in the workbook, entitled **Headers**. If you are adding information to an existing workbook, then the software will look for the **Headers** worksheet and append the new header information to it after the last occupied line in the worksheet. If the software cannot find a **Headers** worksheet it will insert a new one as the first sheet in the workbook.

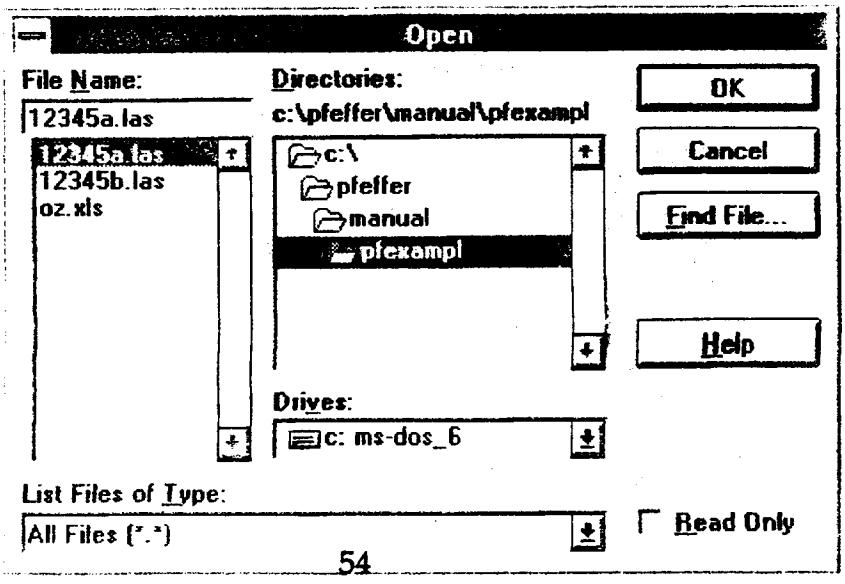
Reading and importing LAS files demonstration

Your PfEFFER program disc has a folder titled **EXAMPLES**. The folder contains files to assist training in PfEFFER option usage. The files **12345a.las** and **12345b.las** are two ASCII files of logs coded in LAS format and will be used to demonstrate the OpenLAS function. These files are from the same well where **12345a.las** is a record of a porosity log run, while **12345b.las** records the resistivity logs made on a separate run. There are many instances where all the logs are merged on a single LAS file, but the use of two files in this demonstration will train the user to handle situations where there are either single or multiple LAS files from a single well.

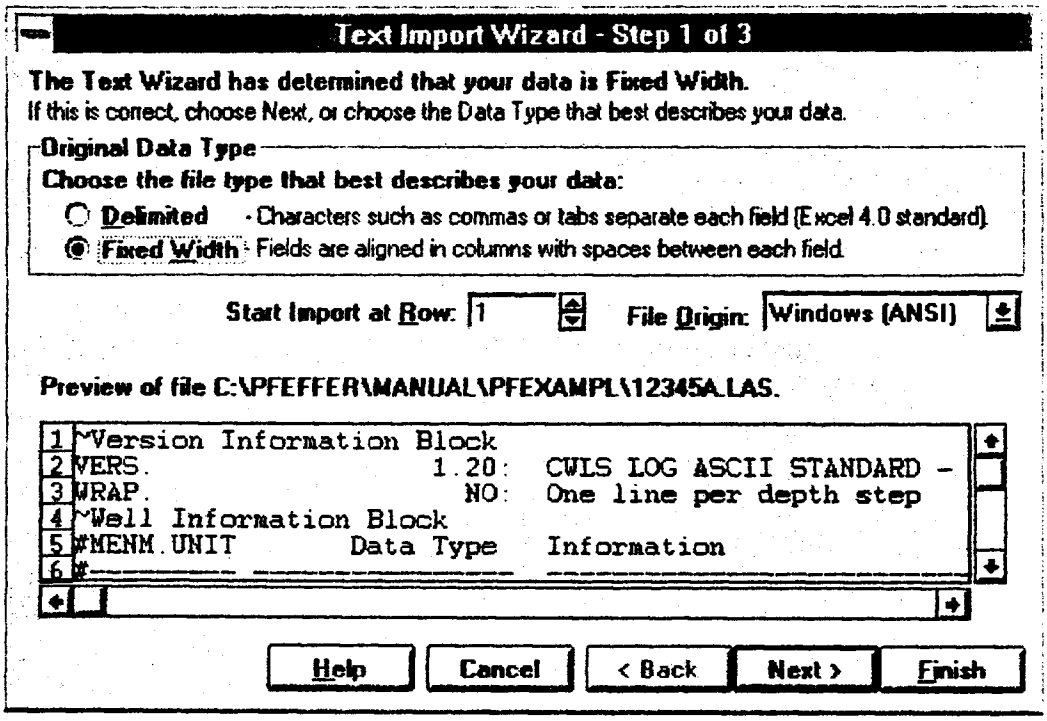
There will be occasions when the user would like to inspect the contents of an LAS file. So, for example, the user may wish to find the identity of the well, the types of logs, depth range, well or log parameters. Alternatively, the user can suspect that the file is not coded correctly in LAS format if the **Import LAS** function fails, and so wishes to examine the file to troubleshoot the problem. The file can be opened either :
(a) from within PfEFFER
by pulling down the **File** menu and selecting **Open** .....



then opening the desired file (in this demonstration, **12345a.las** in the **EXAMPLES** folder) .....

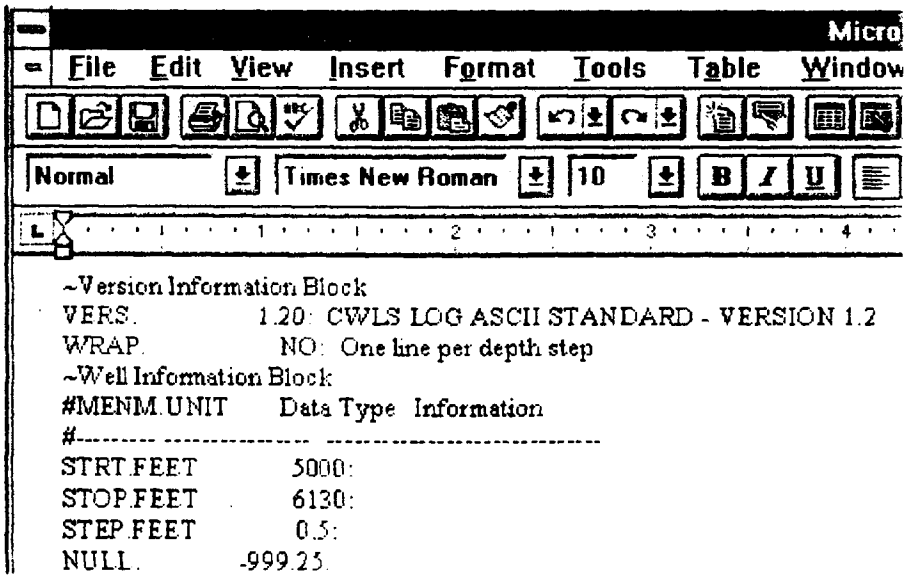


at which point, the **TextImport Wizard** will open the file and show the first few lines in the display window .....



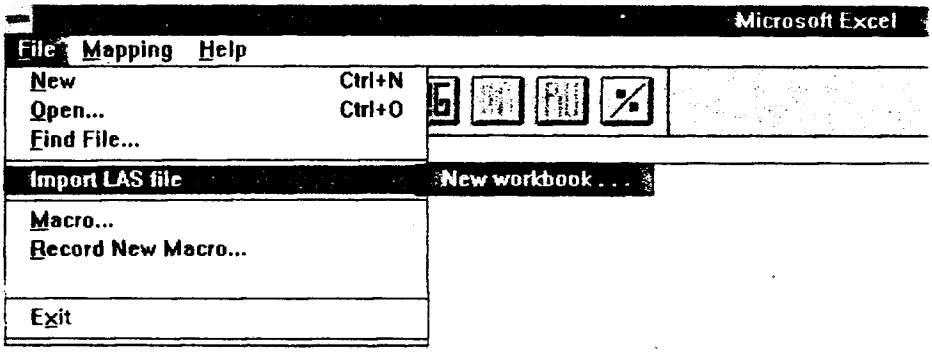
Any line in the file can be examined by using the scroll bar to the right. When the user selects **Cancel**, control is returned to PfEFFER.

or (b) from a word processing program
by choosing **Open** and selecting the desired file .....



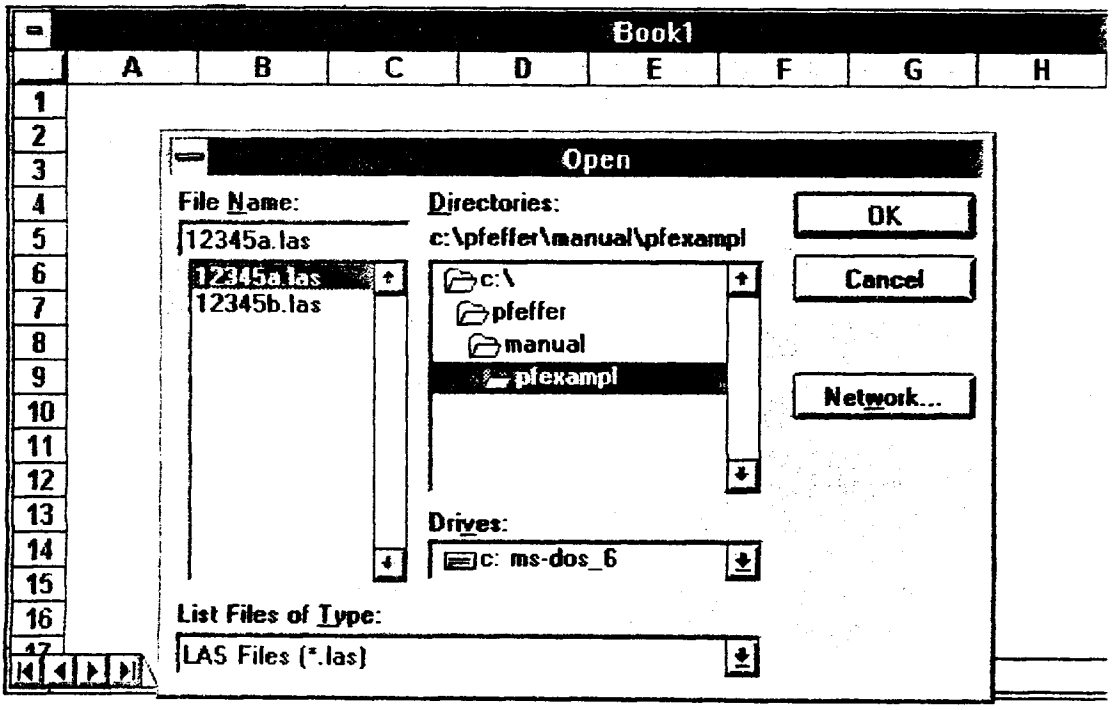
The LAS file is in ASCII format and so can be printed on a hard copy as easily as a business letter.

The **Import LAS** option is launched by pulling on the **File** menu and selecting **Import LAS file**. Two possible results will occur. If no workbook is already open, then the user is presented with no other choice than to create a **New Workbook**...

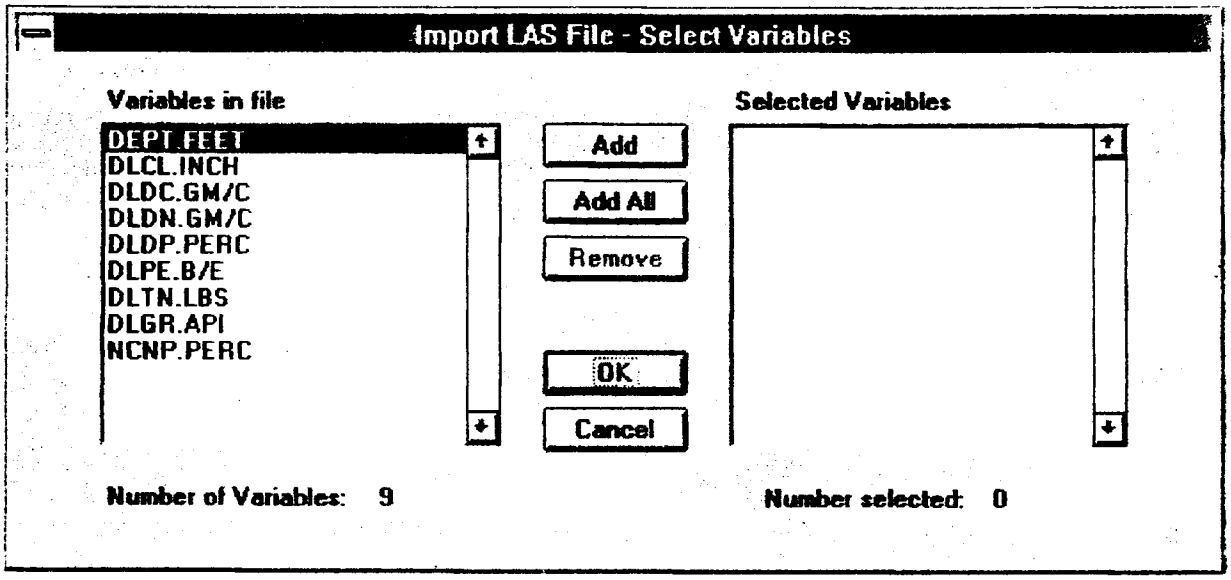


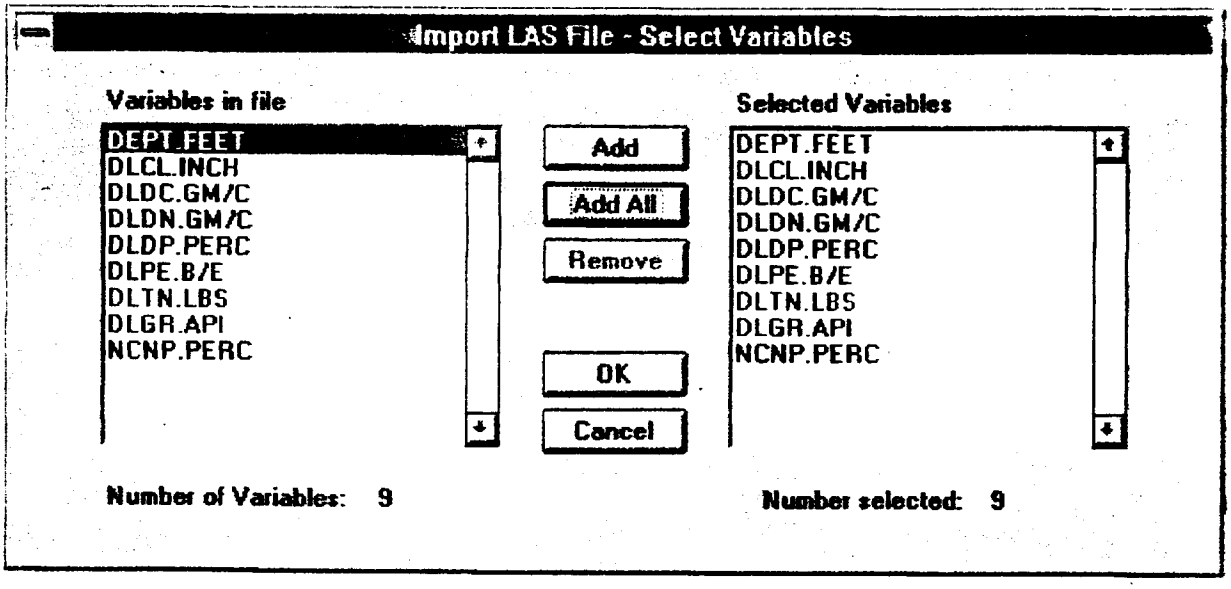
If a workbook is already open then the utility will prompt the user either to create a **New Workbook** (appropriate if the open workbook is unrelated to the logs to be imported) or to **Add to Current** (appropriate if the LAS file contains new logs from the same well as the open workbook). At this point in the demonstration, no well workbook has yet been created, so **New Workbook** will be selected. The **Add to Current** option will be chosen later, once the logs have been loaded from **12345a.las** and we need to add additional logs from **12345b.las**.

When a new workbook is created, the first sheet is titled **Headers** and the user is required to select which LAS file will be imported (in this case **12345a.las**).....



The option then copies the Header information from the LAS file onto the **Headers** sheet of the new workbook, find the name of the logs on the file and presents these to the user as a **Select Variables** panel. The user may select a subset or all of the logs to be copied into the workbook. Note the multiple buttons that allow flexible editing of the choices, so that mistakes can be rectified through the use of **Remove** as well as **Add** .....



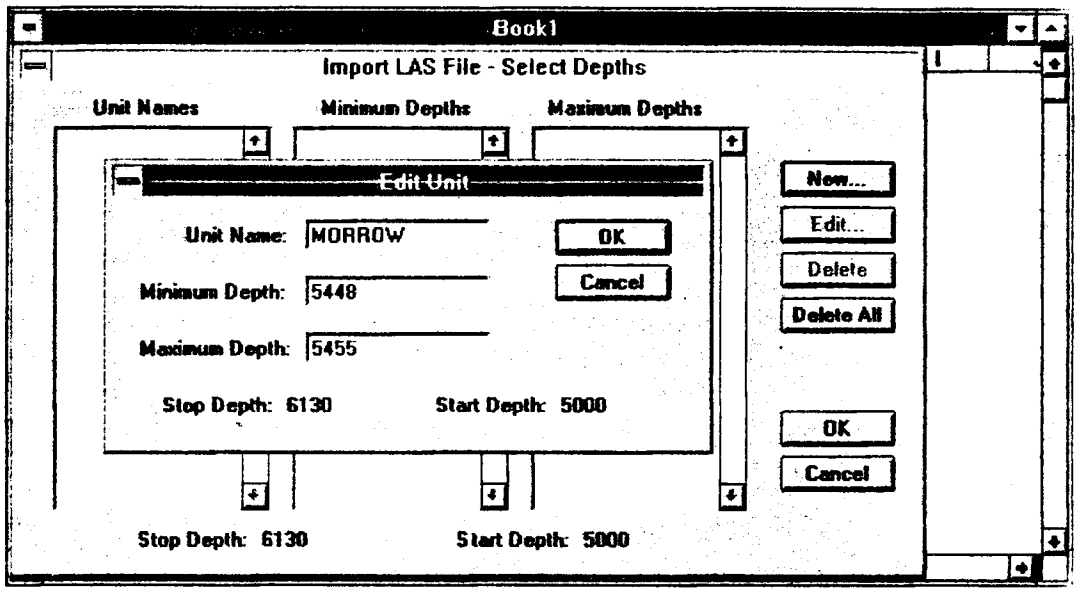


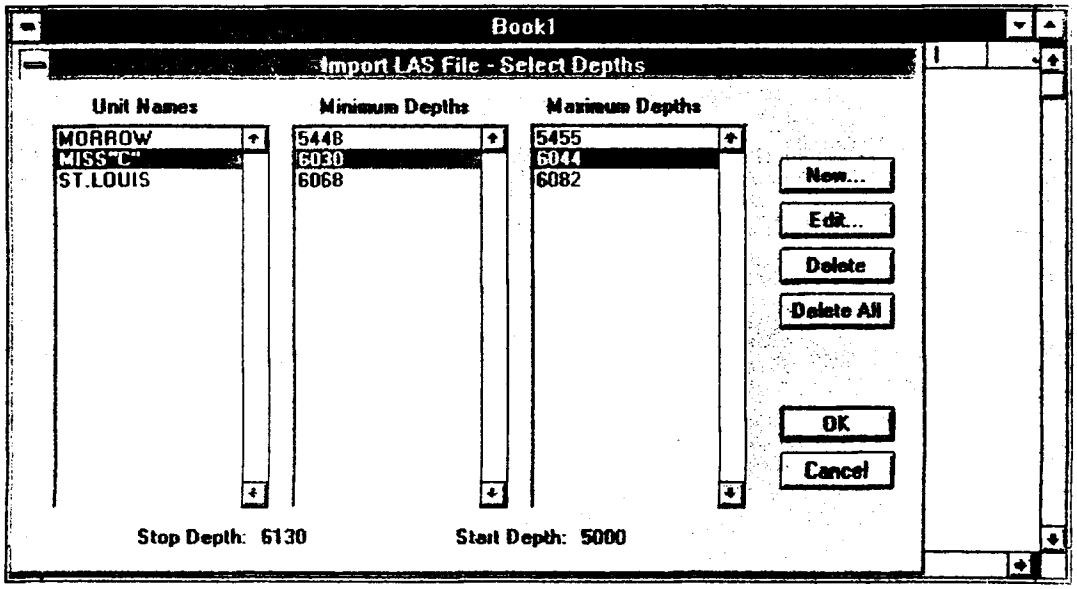
When the user is satisfied with the log choice, the selection is entered by checking the **OK** button.

The user is then presented with a **Select Depths** panel to specify the names of the stratigraphic units and their depth ranges. Notice that the panel alerts the user to the start and stop depths of the log record that the utility has read from the LAS file.

If the **Import LAS** utility has been used earlier in the same session, the unit names and depth ranges will be retained from the earlier run. This short term memory feature is useful when reading multiple LAS files from the same well, so that the stratigraphic information only needs to be entered once.

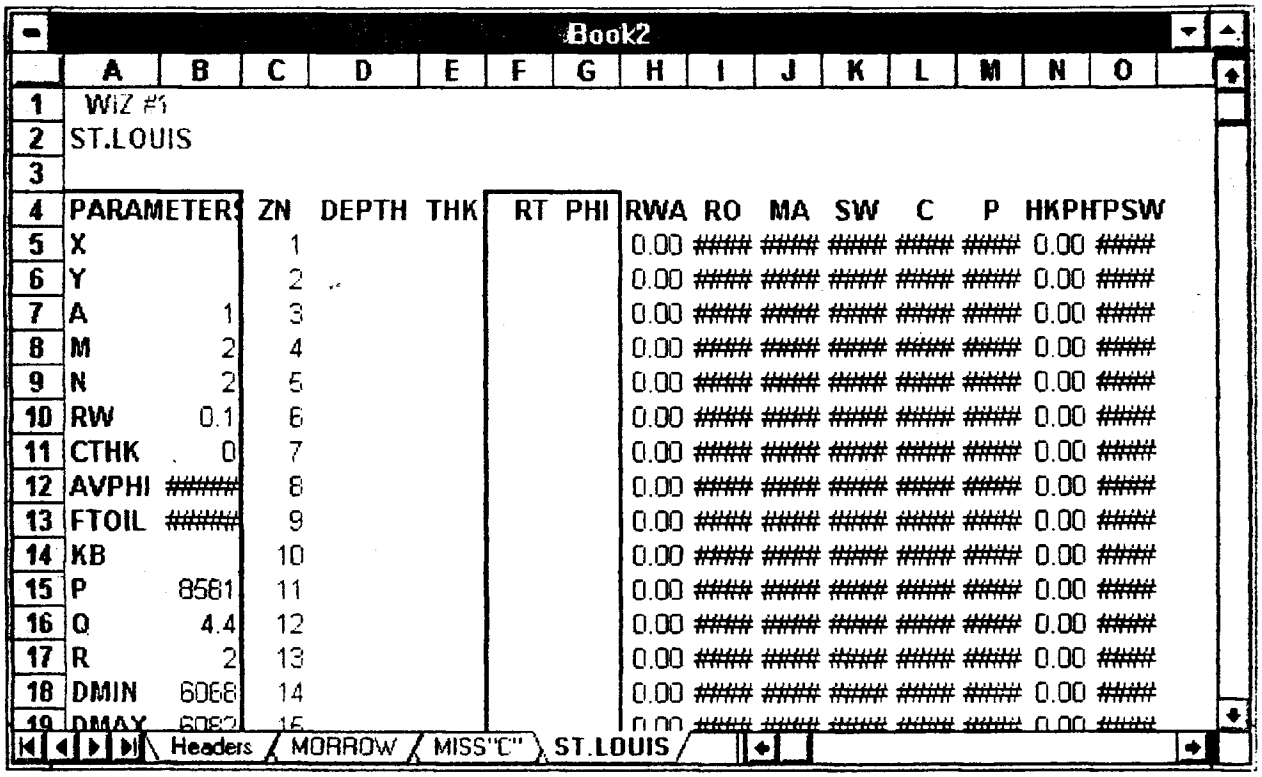
The **New** button sets up an edit panel for the entry of the name and depth boundaries of a new stratigraphic unit. If an existing unit is highlighted on the unit panel it may either be modified (name and/or depths) by selecting the **Edit** button, or deleted entirely by selecting the **Delete** button.....





When the unit information is determined to be complete and correct, the main function of the **Import LAS** function is launched by selecting **OK**. The utility will then create additional sheets in the workbook with one sheet named for each of the units entered.

On each sheet, the utility will transcribe the name of the well from the LAS file into cell A1, and the name of the unit typed by the user into cell A2. The Kelly Bushing elevation will also be copied from the Header into cell B14 provided that the LAS file recorded this with the LAS code annotation of **EKB**. In this example, no KB was entered in the worksheets, because the LAS file listed this as **ELEV** which could denote either KB or ground level. However, the user can type in the KB entry manually.....



Notice that the "Home area" (A to Z columns of the worksheet) are defaulted with null values, because the logging data has been written into the first available columns to the right of column AA .....

Book2

	AA	AB	AC	AD	AE	AF	AG	AH	AI
1		WELL: WIZ #1							
2		FILE: C:\PFEFFER\MANUAL\PFEXAMPL\12345A.LAS							
3									
4		DEPT.FEI	DLCL.INC	DLDC.GM	DLDN.GM	DLDP.PEI	DLPE.B/E	DLTN.LBS	DLGR.AP NC
5		6068	7.9344	0.0093	2.6745	0.0208	4.4273	1452.689	30.4693
6		6068.5	7.9121	0.0104	2.6561	0.0315	4.5161	1450.447	29.8493
7		6069	7.8828	0.0117	2.6079	0.0597	4.5454	1450.324	28.0075
8		6069.5	7.8564	0.0111	2.5552	0.0905	4.5186	1452.289	20.9858
9		6070	7.8458	0.0106	2.5141	0.1145	4.4721	1454.248	16.2266
10		6070.5	7.8352	0.0119	2.4829	0.1328	4.4425	1459.598	15.8378
11		6071	7.8259	0.0155	2.4759	0.1369	4.4308	1465.102	15.9211
12		6071.5	7.8168	0.0226	2.4848	0.1317	4.4205	1466.756	16.044
13		6072	7.7932	0.0305	2.4957	0.1253	4.4115	1467.018	16.1669
14		6072.5	7.7617	0.0364	2.4992	0.1233	4.378	1464.41	16.2416
15		6073	7.7261	0.0397	2.4573	0.1478	4.3415	1457.982	16.2507
16		6073.5	7.6933	0.0387	2.4297	0.1639	4.3285	1449.355	16.2597
17		6074	7.6826	0.0364	2.4209	0.1691	4.3202	1438.988	16.2688
18		6074.5	7.6828	0.0359	2.4352	0.1607	4.3295	1430.334	16.2779
19		6075	7.7134	0.0331	2.4653	0.1431	4.3596	1422.633	16.2396

Headers | MORROW | MISS"C" | ST.LOUIS

The import program has copied the name of the well from the LAS file into Row 1 and given the address of the LAS file in Row 2. This feature allows the user to verify that they have accessed the correct well and used the correct LAS file. The names of the logs in Row 4 are transcribed directly from the LAS file and so therefore will carry the idiosyncrasies of the digitizer rather than honoring any PfEFFER convention.

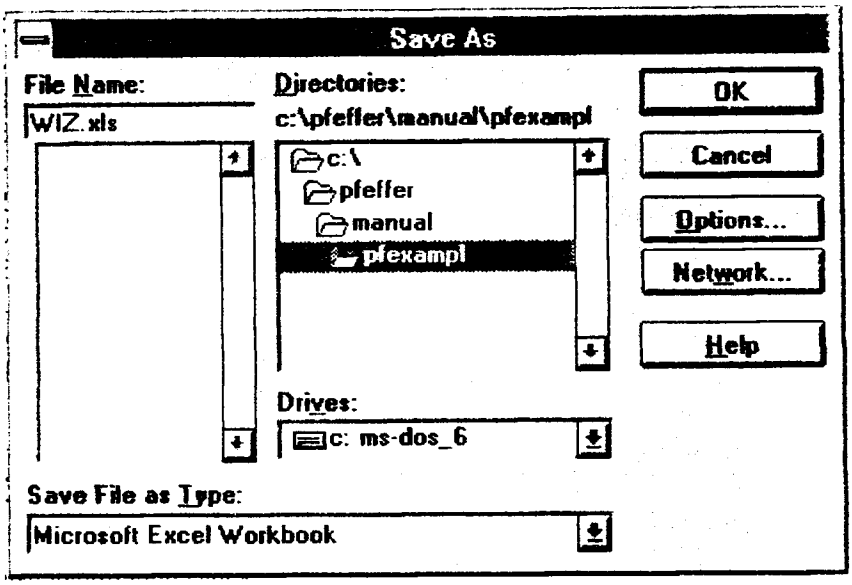
The **Headers Sheet** contains information copied from the header of 12345A.LAS:

Book2

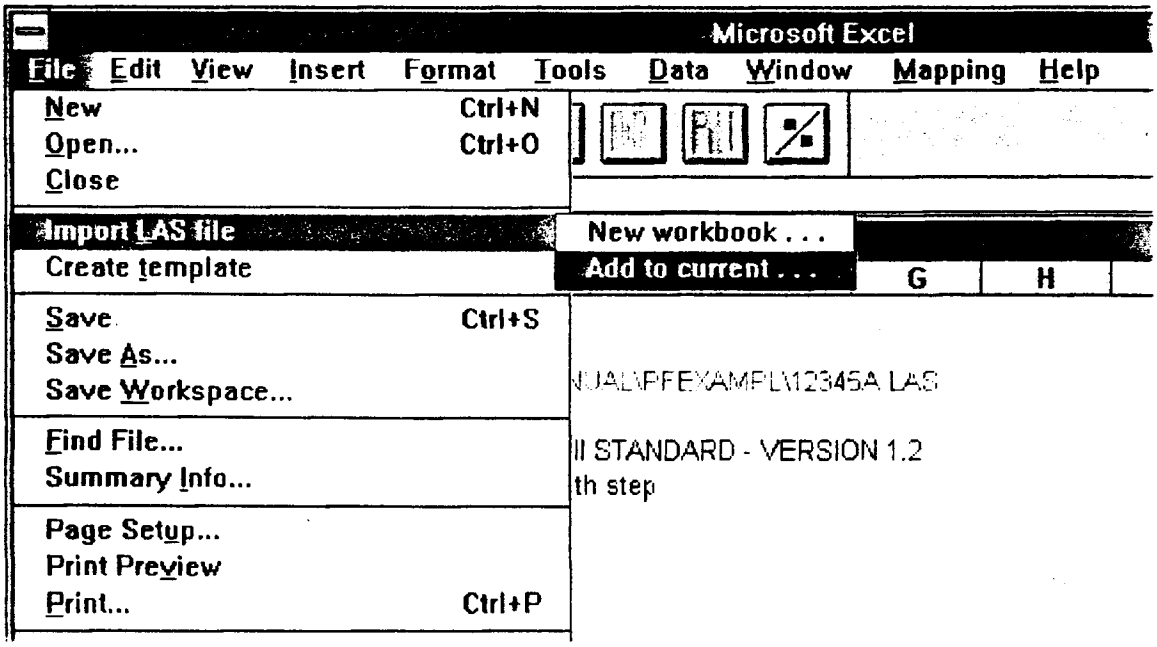
	A	B	C	D	E	F	G	H	I
1									
2									
3	HEADERS FROM FILE: C:\PFEFFER\MANUAL\PFEXAMPL\12345A.LAS								
4	~Version Information Block								
5	VERS.	1.20	CWLS LOG ASCII STANDARD - VERSION 1.2						
6	WRAP.	NO:	One line per depth step						
7	~Well Information Block								
8	#MENM.UNIT	Data Type	Information						
9	#---------	----------	----------						
10	STRT.FEET	5000:							
11	STOP.FEET	6130:							
12	STEP.FEET	0.5:							
13	NULL.	-999.25:							
14	COMP.	COMPANY:	TOTO PETROLEUM INC.						
15	WELL.	WELL:	WIZ #1						

Headers | MORROW | MISS"C" | ST.LOUIS

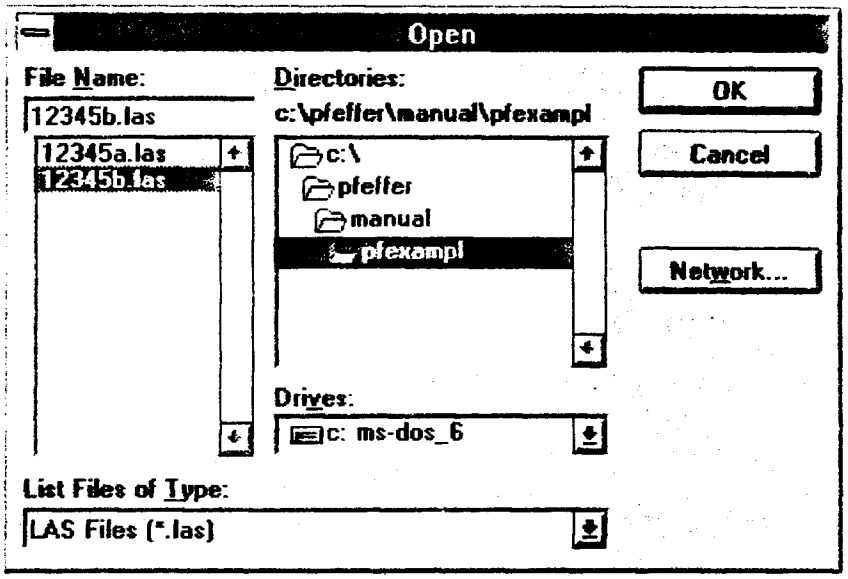
So far, the workbook still carries an anonymous name (in this case, **Book 2**), but can be given a specific name by using **Save As** and typing in an identifier -- **WIZ.XLS** for this example ....



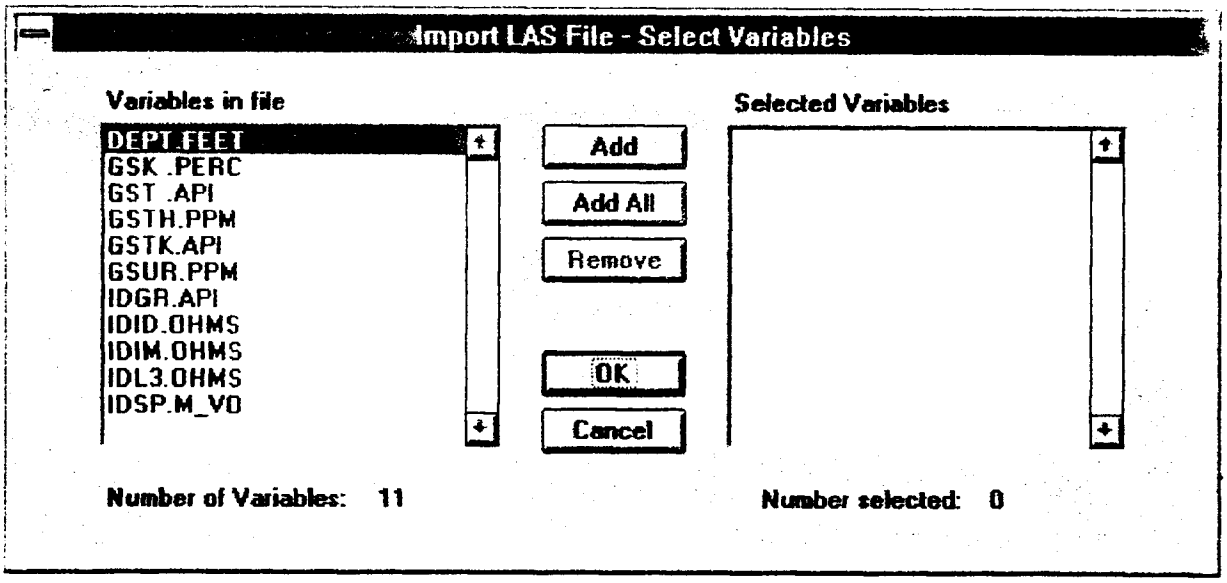
This demonstration uses a case where there were TWO LAS files for the same well: **12345a.las** which contained porosity logs and has been loaded into a PfEFFER workbook, and **12345b.las** which has resistivity logs that need to be added. If we return to the **Import LAS file** selection, we are now offered two options and elect to choose **Add to current**, because we want to download the resistivity logs into our new open workbook ....



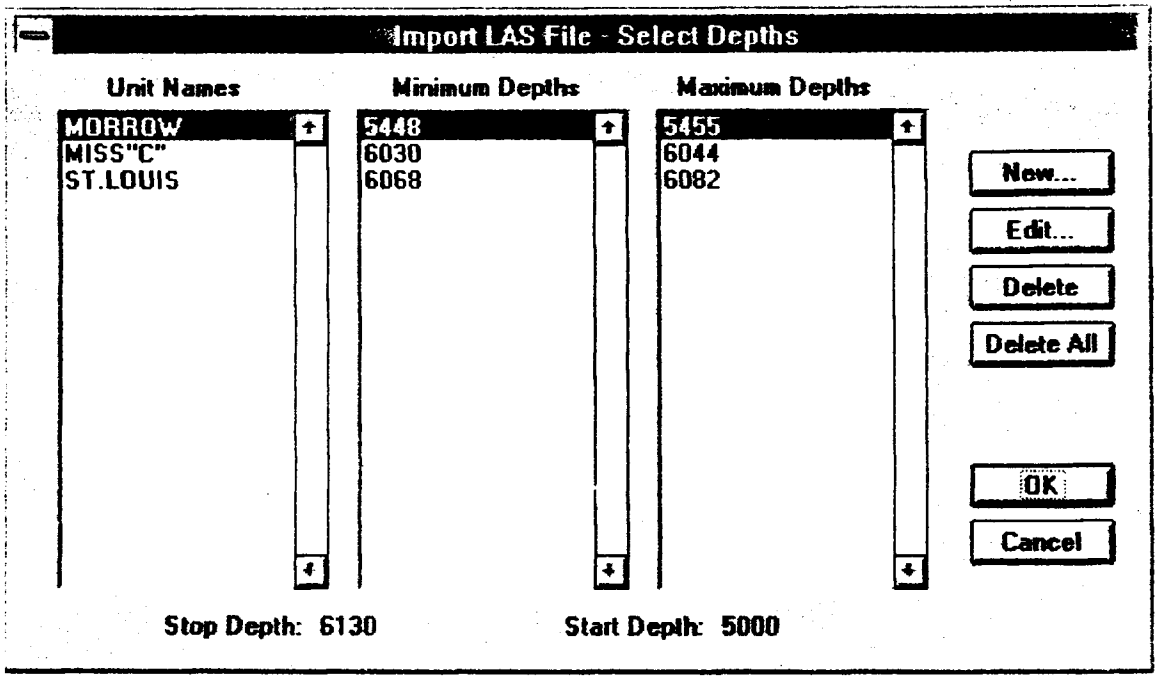
We now choose **12345b.las** ....



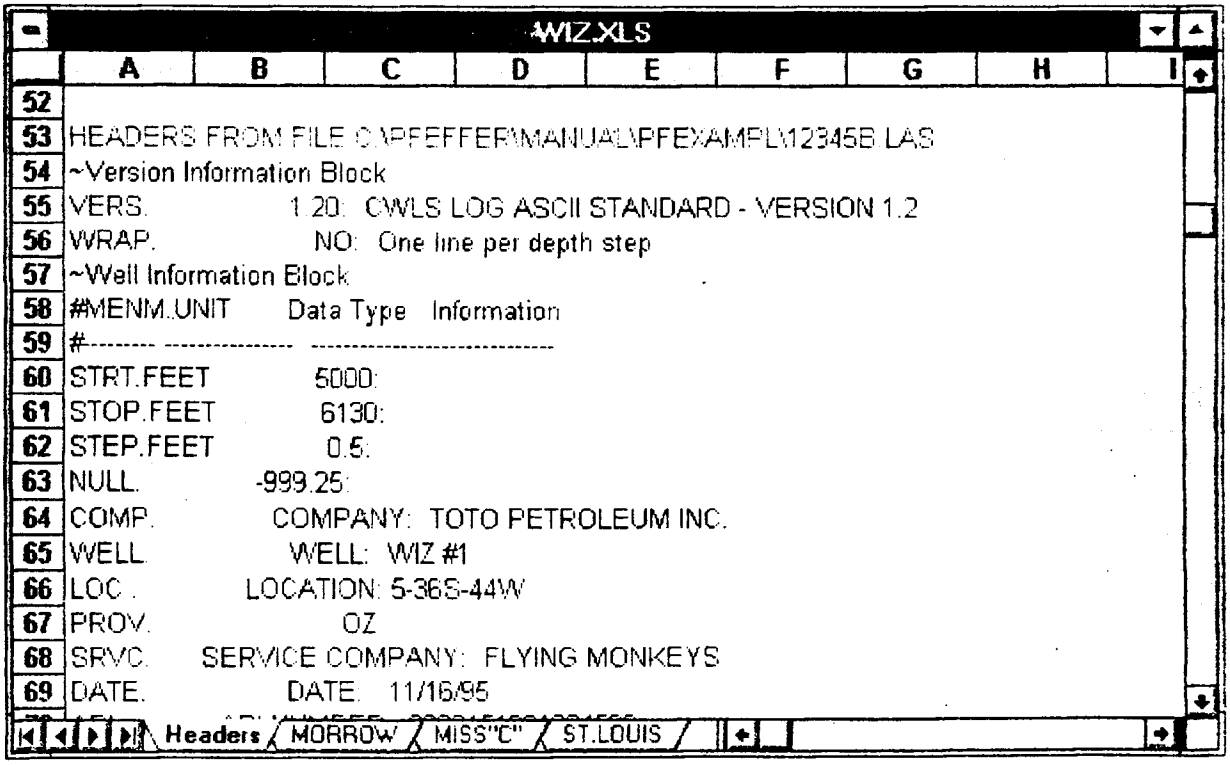
The program reads the names of the logs in this LAS file and presents them to us so that can either select all of them or a sub-set ...



Because we did not close the workbook, the **Import LAS** option has retained the names and depths of the intervals, so that we do not have to type in the same information. However, note that we CAN change the intervals and/or the depth ranges if we wish.



On checking **OK** on the **Depth Select** panel, the program copies the logging data and the Header information from the LAS file into the workbook. Note that the new Header information is appended below any previously stored Header information on the **Headers** worksheet .....



In storing the logging data, the program hunts for empty columns to the right of any previously stored information. For this example, logging data has already been stored up to column AJ from the previous LAS Import operation. The program allows an empty column (in this case, AK) and uses AL as the starting column to store the new data. As before, rows 1 and 2 record the name of the well found on the LAS file and the address of the file from which the data are drawn, as an edit check for the user .....

WIZ.XLS

	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
1			WELL: WIZ #1							
2			FILE: C:\PFEFFER\MANUAL\PFEXAMPL\12345B.LAS							
3										
4	NCNP.PERC		DEPT.FEET	GSK .PER	GST .API	GSTH.PPU	GSTK.API	GSUR.PPU	IDGR.API	IDID.OHMM ID
5	0.0272		6030	0.199	2.4638	0.708	5.9544	2.9646	31.4328	119.6528 1
6	0.0332		6030.5	0.1926	2.5491	0.7169	5.9877	2.9869	35.4233	102.8809, 1
7	0.0447		6031	0.1977	2.4382	0.596	5.6676	2.8678	34.8943	87.141 1

Headers / MORROW / MISS"C" / ST.LOUIS

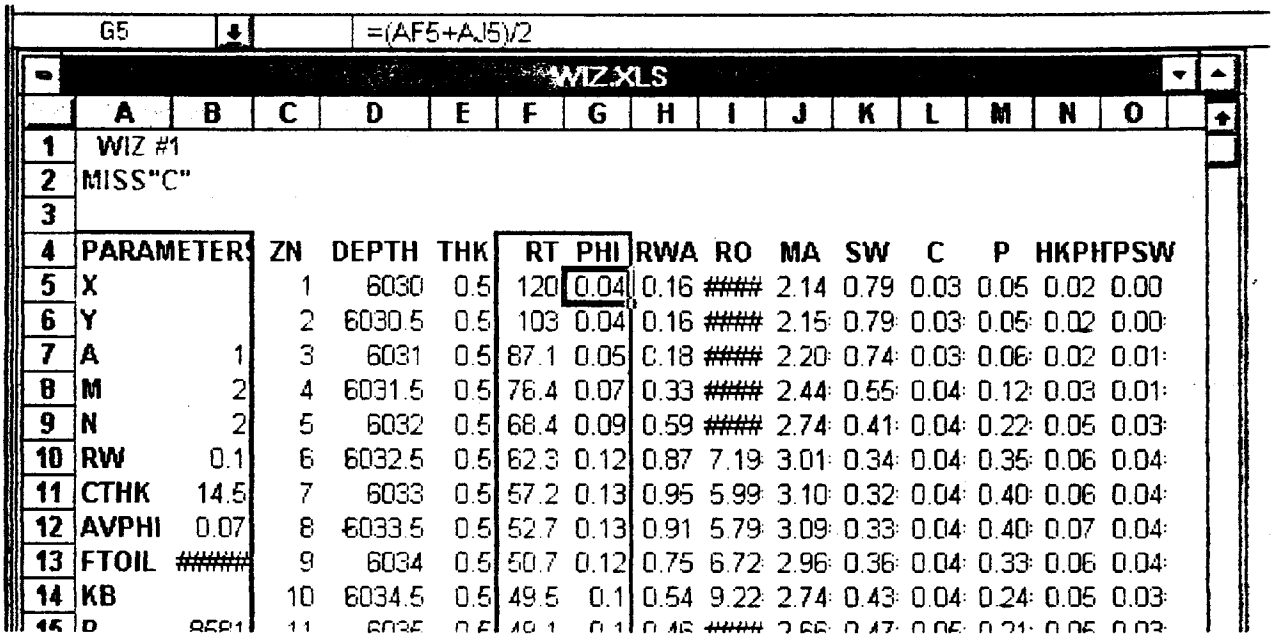
At this point, there is still no information in the Home Area (columns A to Z). However, the logging data that has been loaded in the columns beyond AA can now be used to fill the Home Area. Depth and zone thickness information are entered by standard EXCEL operations of Copy/Paste and data entry or by linking cells by a formula. The true resistivity (RT) values are copied from the resistivity log of the user's choice. Note that this feature allows the user to choose either a deep investigation device for true Rt or to substitute a microresistivity measurement for residual and moveable hydrocarbon evaluation.....

F5 =AS5

WIZ.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	WIZ #1														
2	MISS"C"														
3															
4	PARAMETERS		ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C	P	HKPH	PSW
5	X		1	6030	0.5	120		0.00	####	####	####	####	####	0.00	####
6	Y		2	6030.5	0.5	103		0.00	####	####	####	####	####	0.00	####
7	A	1	3	6031	0.5	87.1		0.00	####	####	####	####	####	0.00	####
8	M	2	4	6031.5	0.5	76.4		0.00	####	####	####	####	####	0.00	####
9	N	2	5	6032	0.5	68.4		0.00	####	####	####	####	####	0.00	####
10	RW	0.1	6	6032.5	0.5	62.3		0.00	####	####	####	####	####	0.00	####
11	CTHK	14.5	7	6033	0.5	57.2		0.00	####	####	####	####	####	0.00	####
12	AVPHI	0.00	8	6033.5	0.5	52.7		0.00	####	####	####	####	####	0.00	####
13	FTOIL	######	9	6034	0.5	50.7		0.00	####	####	####	####	####	0.00	####
14	KB		10	6034.5	0.5	49.5		0.00	####	####	####	####	####	0.00	####
15	D	8561	11	6035	0.5	49.1		0.00	####	####	####	####	####	0.00	####

Similarly, the source of porosity information is also under user control either by copying one of the porosity logs or by a formula conversion of one log or a combination of logs. In the example below, **PHI** has been generated by taking the average of the density porosity (**AF**) and the neutron porosity (AJ) as shown by the formula bar. Please note that Pickett Plot operations will expect to find porosity as a FRACTION rather than percent in the **PHI** column.

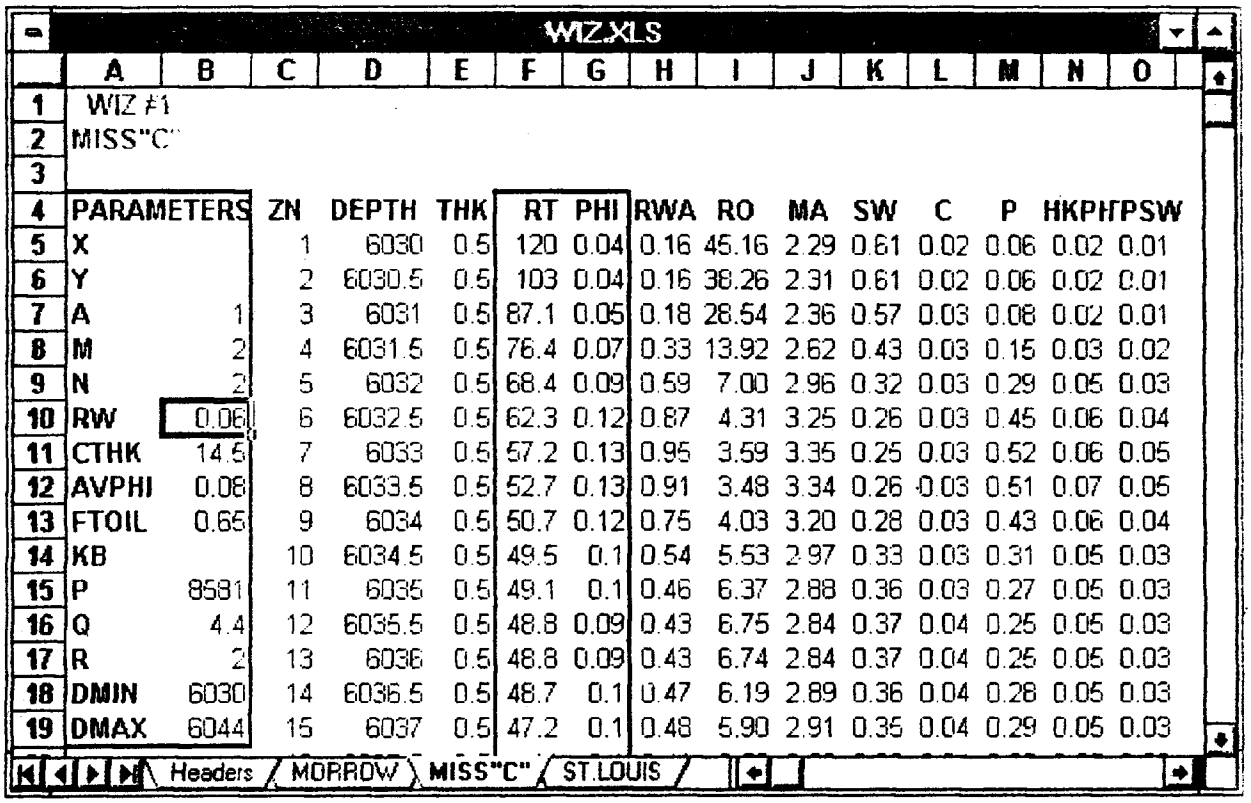


G5 =(AF5+AJ5)/2

WIZ.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	WIZ #1														
2	MISS"C"														
3															
4	PARAMETERS		ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C	P	HKPHI	TPSW
5	X		1	6030	0.5	120	0.04	0.16	####	2.14	0.79	0.03	0.05	0.02	0.00
6	Y		2	6030.5	0.5	103	0.04	0.16	####	2.15	0.79	0.03	0.05	0.02	0.00
7	A	1	3	6031	0.5	87.1	0.05	0.18	####	2.20	0.74	0.03	0.06	0.02	0.01
8	M	2	4	6031.5	0.5	76.4	0.07	0.33	####	2.44	0.55	0.04	0.12	0.03	0.01
9	N	2	5	6032	0.5	68.4	0.09	0.59	####	2.74	0.41	0.04	0.22	0.05	0.03
10	RW	0.1	6	6032.5	0.5	62.3	0.12	0.87	7.19	3.01	0.34	0.04	0.35	0.06	0.04
11	CTHK	14.5	7	6033	0.5	57.2	0.13	0.95	5.99	3.10	0.32	0.04	0.40	0.06	0.04
12	AVPHI	0.07	8	6033.5	0.5	52.7	0.13	0.91	5.79	3.09	0.33	0.04	0.40	0.07	0.04
13	FTOIL	######	9	6034	0.5	50.7	0.12	0.75	6.72	2.96	0.36	0.04	0.33	0.06	0.04
14	KB		10	6034.5	0.5	49.5	0.1	0.54	9.22	2.74	0.43	0.04	0.24	0.05	0.03
15	D	8581	11	6035	0.5	49.1	0.1	0.46	####	2.66	0.47	0.05	0.21	0.05	0.03

The **Parameter Columns** A and B should now be adjusted for values of the Archie equation values of **A**, cementation exponent **M**, saturation exponent **N**, and formation water resistivity, **RW** that are appropriate for the formation. The spreadsheet will then automatically calculate **RWA** (apparent water resistivity), **RO** (estimated resisistivity of the zone if completely water saturated), **MA** (apparent cementation exponent), **SW** (water saturation), **C** (bulk volume water), **P** (porosity divided by water saturation), **THKPHI** (incremental porosity feet), **TPSW** (incremental hydrocarbon feet). Cumulative unit values are summed and stored in the **Parameter Columns** as thickness (**CTHK**), average porosity porosity (**AVPHI**), and oil-feet or gas-feet (**FTOIL**).



WIZ.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	WIZ #1														
2	MISS"C"														
3															
4	PARAMETERS		ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C	P	HKPHI	PSW
5	X		1	6030	0.5	120	0.04	0.16	45.16	2.29	0.61	0.02	0.06	0.02	0.01
6	Y		2	6030.5	0.5	103	0.04	0.16	38.26	2.31	0.61	0.02	0.06	0.02	0.01
7	A	1	3	6031	0.5	87.1	0.05	0.18	28.54	2.36	0.57	0.03	0.08	0.02	0.01
8	M	2	4	6031.5	0.5	76.4	0.07	0.33	13.92	2.62	0.43	0.03	0.15	0.03	0.02
9	N	2	5	6032	0.5	68.4	0.09	0.59	7.00	2.96	0.32	0.03	0.29	0.05	0.03
10	RW	0.06	6	6032.5	0.5	62.3	0.12	0.87	4.31	3.25	0.26	0.03	0.45	0.06	0.04
11	CTHK	14.5	7	6033	0.5	57.2	0.13	0.95	3.59	3.35	0.25	0.03	0.52	0.06	0.05
12	AVPHI	0.08	8	6033.5	0.5	52.7	0.13	0.91	3.48	3.34	0.26	0.03	0.51	0.07	0.05
13	FTOIL	0.65	9	6034	0.5	50.7	0.12	0.75	4.03	3.20	0.28	0.03	0.43	0.06	0.04
14	KB		10	6034.5	0.5	49.5	0.1	0.54	5.53	2.97	0.33	0.03	0.31	0.05	0.03
15	P	8581	11	6035	0.5	49.1	0.1	0.46	6.37	2.88	0.36	0.03	0.27	0.05	0.03
16	Q	4.4	12	6035.5	0.5	48.8	0.09	0.43	6.75	2.84	0.37	0.04	0.25	0.05	0.03
17	R	2	13	6036	0.5	48.8	0.09	0.43	6.74	2.84	0.37	0.04	0.25	0.05	0.03
18	DMIN	6030	14	6036.5	0.5	48.7	0.1	0.47	6.19	2.89	0.36	0.04	0.28	0.05	0.03
19	DMAX	6044	15	6037	0.5	47.2	0.1	0.48	5.90	2.91	0.35	0.04	0.29	0.05	0.03

Headers / MORROW / MISS"C" / ST.LOUIS /

There will be instances with either the Archie constants or/and the water resistivity are unknown or can only be estimated. The reconnaissance values of **RWA** and **MA** may be used in an iterative procedure to resolve such uncertainties. Provisional Pickett plots based on parameter estimates will also be helpful in finding good values for these reservoir descriptors.

MAKING A PICKETT PLOT

Introduction

PfEFFER makes a Pickett plot from information it draws from the **home field** of a unit worksheet. The coordinates of the **zones** on the plots are set by values found in the **RT** and **PHI** columns. The position and orientation of the water saturation and bulk volume water (BVW) lines are controlled by the Archie equation parameters and formation water resistivity (**RW**) values recorded in the **parameter columns** (A and B). The parameter values may either be known, estimated or guessed. A fundamental rationale for this program is to provide the means to resolve problems and to reduce uncertainty : solving by doing.

In this demonstration, we will use the Sniabar unit found on the OZ.XLS example well workbook. The Pickett plot is launched by clicking the **PLOT** button on the toolbar. The user is then presented with a **plot panel** for the selection of porosity and resistivity ranges of the Pickett plot. The plot will be rounded off to the nearest decade. A poor choice of range by the user can be remedied easily by rerunning **PLOT** and selecting a better framework range for the plotted data.

File Edit View Insert Format Tools Data Window Mapping Help

S27

OZ.XLS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	TOTO OZ #1														
2	KC SNIABAR														
3															
4	PARAMETER		ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C	P	THKPHTPSW	
5	X		1	4640	0.5	17.43	0.06	0.06	11.17	2.16	0.80	0.05	0.07	0.03	0.01
6	Y		2	4640.5	0.5	16.4	0.05	0.04	16.06	2.01	0.99	0.05	0.05	0.02	0.00
7	A	1	3	4641	0.5	14.99	0.044	0.03	20.38	1.90	1.17	0.05	0.04	0.02	0.00
8	M	2	4	46							0.91	0.05	0.06	0.03	0.00
9	N	2	5								0.68	0.05	0.11	0.04	0.01
10	RW	0.04	6	46							0.68	0.05	0.10	0.04	0.01
11	CTHK	42.5	7								0.96	0.05	0.05	0.02	0.00
12	AVPHI	0.19	8	46							0.95	0.04	0.05	0.02	0.00
13	FTOIL	5.75	9								0.76	0.04	0.07	0.03	0.01
14	KB		10	46							0.58	0.04	0.12	0.03	0.01
15	P	8581	11								0.37	0.04	0.27	0.05	0.03
16	Q	4.4	12	46							0.22	0.03	0.73	0.08	0.06
17	R	2	13								0.16	0.03	1.29	0.10	0.09
18			14	46							0.14	0.03	1.63	0.11	0.10
19			15								0.13	0.03	1.76	0.12	0.10
20			16	46							0.13	0.03	1.88	0.12	0.10
21			17								0.13	0.03	1.86	0.12	0.10
22			18	46							0.13	0.03	1.77	0.12	0.10
23			19	4649	0.5	36.89	0.232	2.10	0.74	4.71	0.14	0.03	1.68	0.12	0.10

PLOT

POROSITY

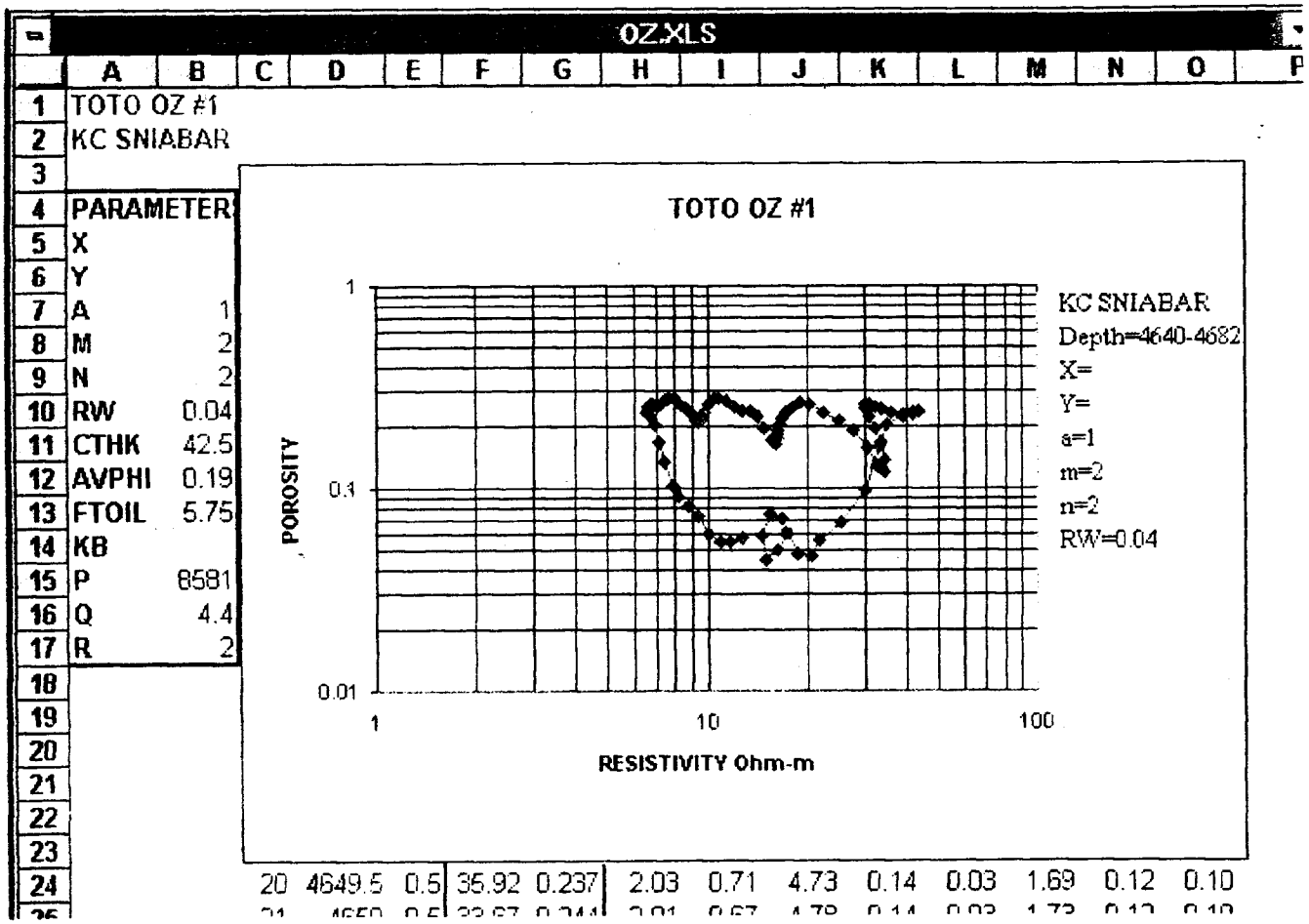
Minimum : 0.01 Maximum : 1

RESISTIVITY

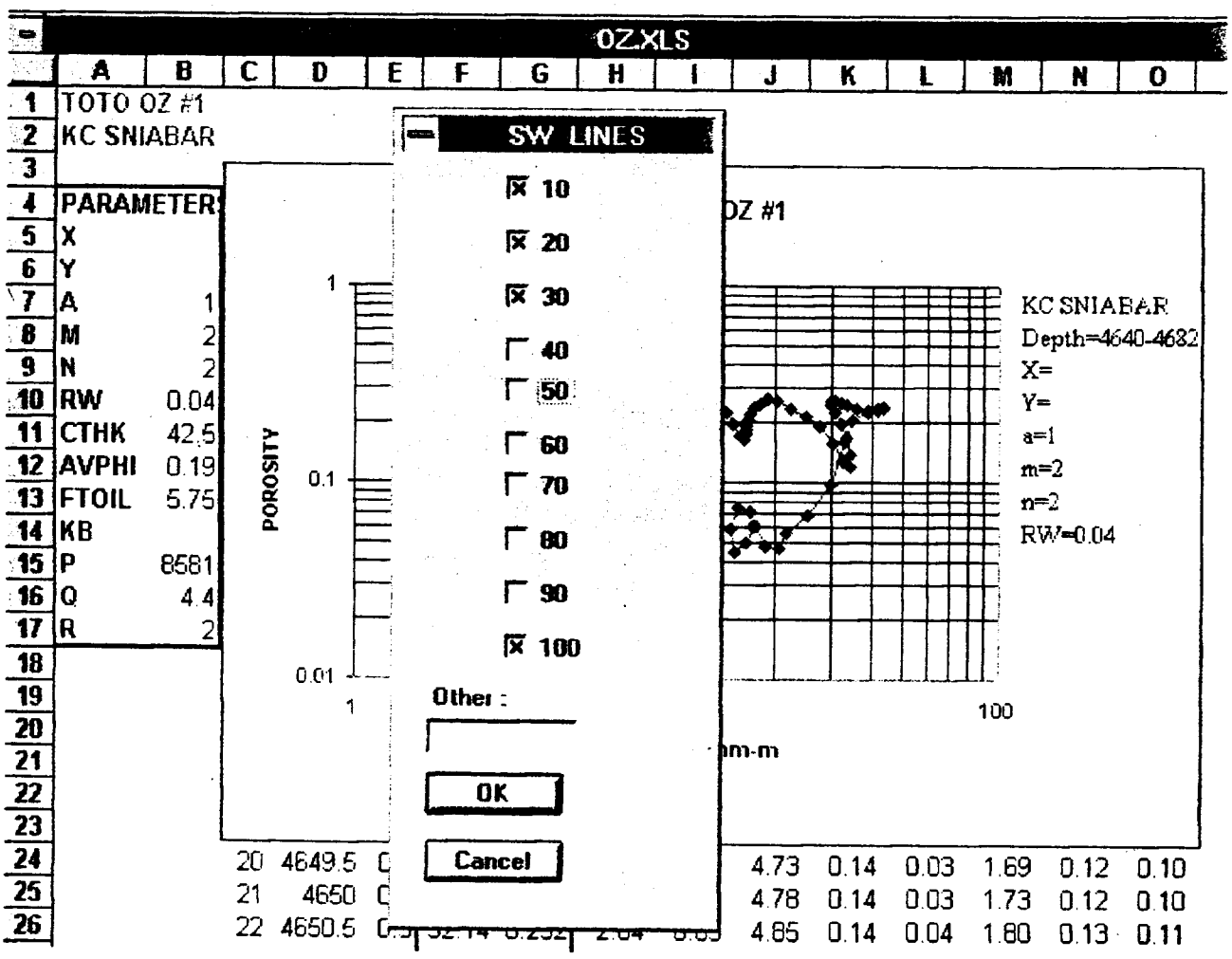
Minimum : 1 Maximum : 100

Cancel OK

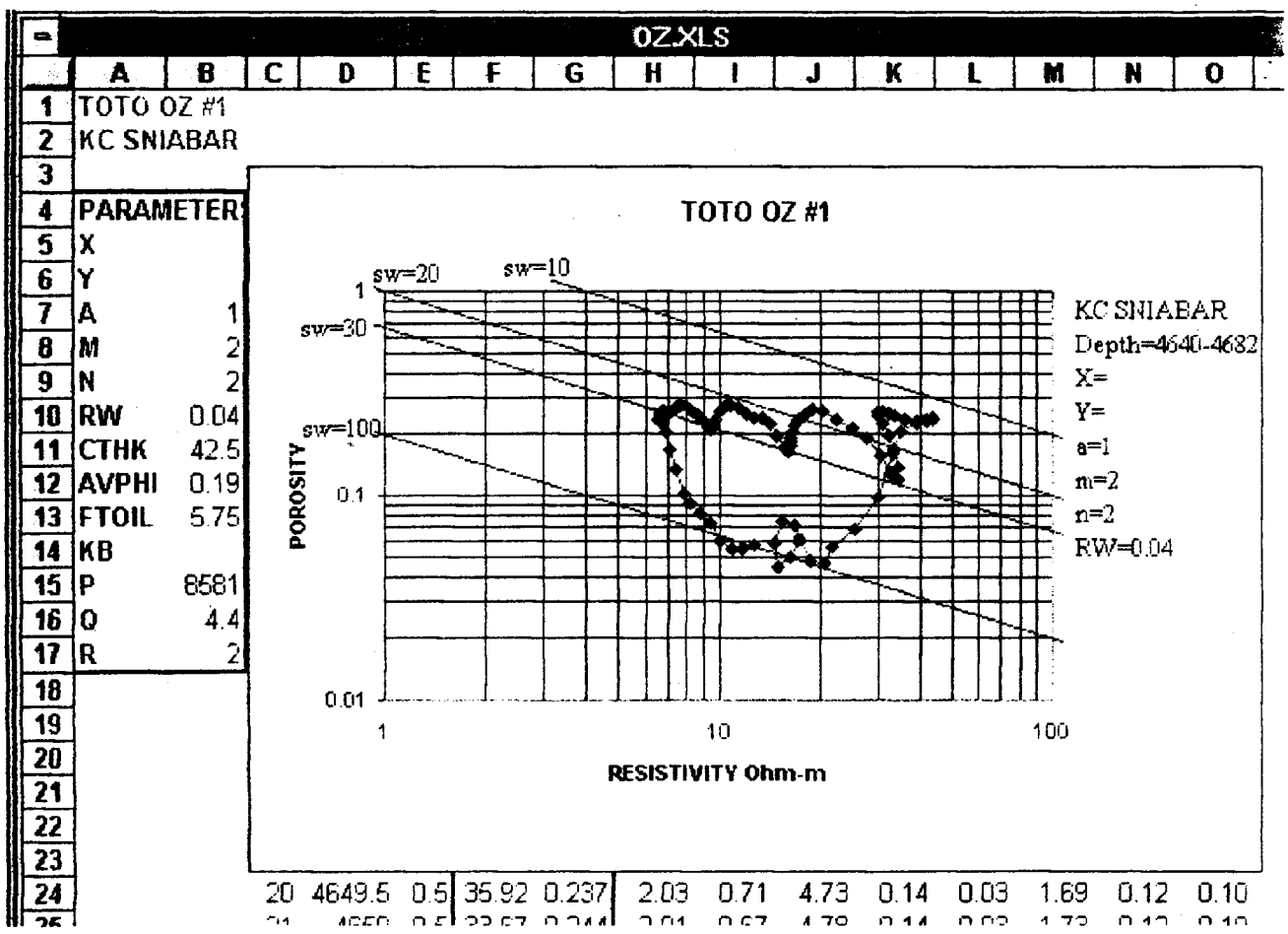
When the **OK** button is selected on the **plot panel**, the program generates a crossplot of resistivity (**RT**) and porosity (**PHI**) values recorded for the depth interval of the **unit sheet**. Notice that the plot also caries the name of the well as written in cell A1, the unit name as recorded in cell A2, the depth range of the unit, as well as the X and Y coordinates, Archie equation constants, and formation water resistivity from the **parameter column B**. The plot may be moved or stretched like other EXCEL objects. The graphic file can also be modified with additions of text and symbols by using standard EXCEL graphic options.



Selection of the **SW** button triggers the **SW LINES panel**. The "radio dial" format allows the user to check off a set of water saturation lines. In this Sniabar example, we have elected to plot lines at 10, 20, 30, and 100 percent values. The line for 100% water saturation is commonly called the "water line". Notice that a slot marked **Other** at the bottom of the panel allows the user to type in another water saturation line whose value is not among those in the button selection. (Another useful feature is that if a line or lines need to be removed from a subsequent Pickett plot, this can be achieved by recalling the **SW LINES panel** using the **SW** button, and "deselecting" the unwanted lines.) When the user is satisfied (at least provisionally) with the water saturation values for line plotting, the **OK** button is checked.



The water saturation lines are located on the plot as dictated by the parameter values in **parameter column B**. The intercept of the water line is located at **A*RW** on the total porosity axis (fractional porosity of value 1). The slope is the same for all water saturation lines and is controlled by the Archie cementation exponent, **M**. The spacing of the water saturation lines is a function of the Archie saturation exponent, **N**. The water saturation lines are colored blue and labeled with their SW values in percent. Remember that if the user wishes to eliminate lines or insert additional water saturation lines, this may be achieved by selecting the **SW LINES panel** (by pressing the **SW button**) and changing the line selection.



THE "SUPER-PICKETT PLOT" OPTIONS

The crossplotting of zone values of porosity and resistivity on logarithmic- scale axes and the location of water saturation lines is the standard Pickett plot. It can be thought of either as a geometric realization of the algebra of the Archie equation or as a remapping of data from porosity-resistivity space to porosity-water saturation space.

"Super-Pickett" options are extensions of the classic plot to incorporate additional petrophysical equations or mappings of petrophysical data. The options in this version of PfEFFER are:

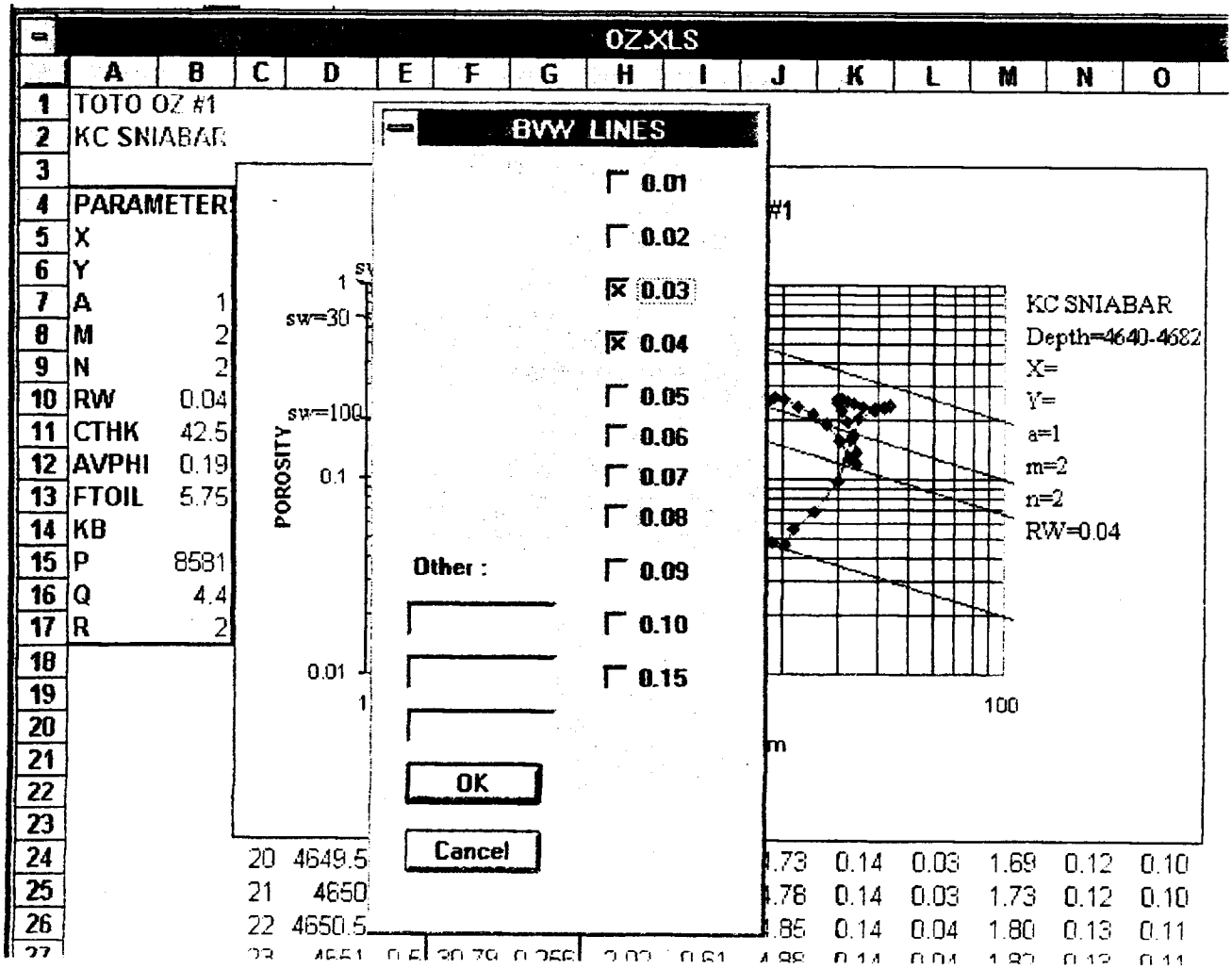
- Bulk volume water (BVW) lines for evaluation of pore size and reservoir productivity assessment using Buckles number concepts;
- Predicted permeability lines based either on porosity or on porosity and "irreducible" water saturation as predictors;
- Color coding of plotted zones to reflect depth, lithology or other property as an additional attribute mapped onto the Pickett plot;
- Capillary pressure data contoured on the Pickett plot either as pressure or equivalent height of oil or gas column above free water level.

Plotting Bulk Volume Water (BVW) lines

We continue the demonstration with the Sniabar unit sheet on the OZ.XLS workbook with the plotting of bulk volume water (BVW) lines.

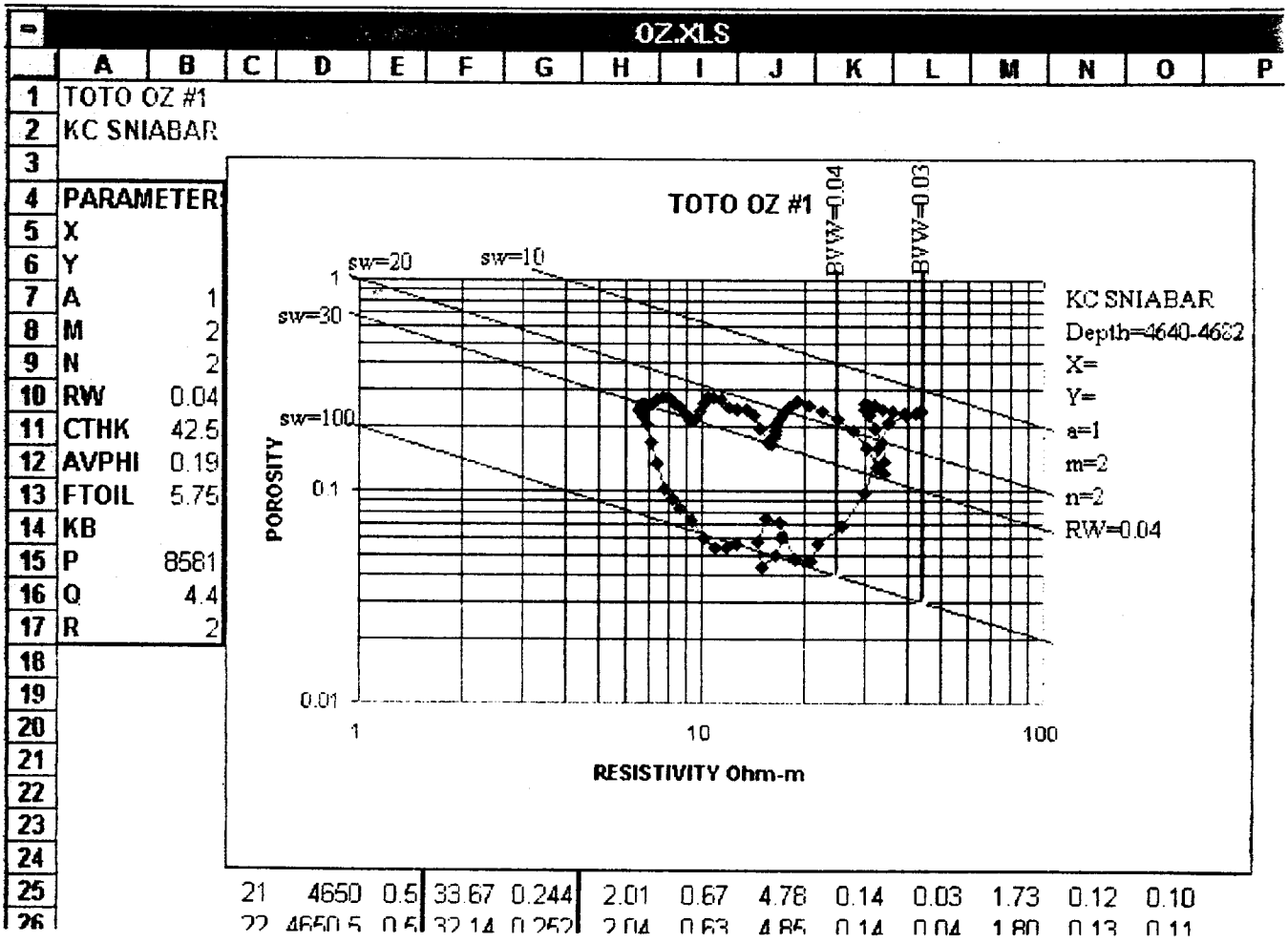
Bulk volume water lines may be plotted on a Pickett plot by clicking the **BVW** button. The **BVW LINES panel** then appears with a radio-dial format for the selection (or deselection) of BVW values recorded in fractional values. Notice that up to three additional BVW values may be typed in to match user-selected values. The user's choice of values is usually dictated by considerations of the likely Buckles number that would discriminate productive zones in the unit analyzed. The Buckles number will reflect typical pore size in the reservoir rock and, to a lesser degree, the height in the hydrocarbon column. In this example, we have elected to plot BVW lines of 0.03 and 0.04 on the Sniabar Limestone Pickett plot, following the broad rule-of-thumb that 0.04 is a useful production discriminator in carbonates.

Additional lines may be added and others removed on the Pickett plot through recall of the BVW lines panel by clicking the **BVW** button. This feature allows a relaxed analysis in which casual initial choices can be sharpened after visual inspection of the Pickett plot.



The bulk volume water (BVW) lines are plotted in red on the Pickett plot and tagged as BVW with their associated values. In this example, the BVW lines are vertical because the cementation exponent, **M** is equal to the saturation exponent, **N**. Otherwise, the BVW lines would lean to the right if **N>M**, and would lean to the left if **N<M**. Regardless of their angle, all BVW lines will intersect the water line (water saturation of 100%) at a porosity value equal to their BVW value.

The zones that plot to the right (higher resistivity) in the Sniabar limestone example suggest a productive interval. The points that trail to the left indicate a transition zone whose looping character probably reflects a stacked sequence of units rather than a homogeneous reservoir.



Plotting predicted permeability lines

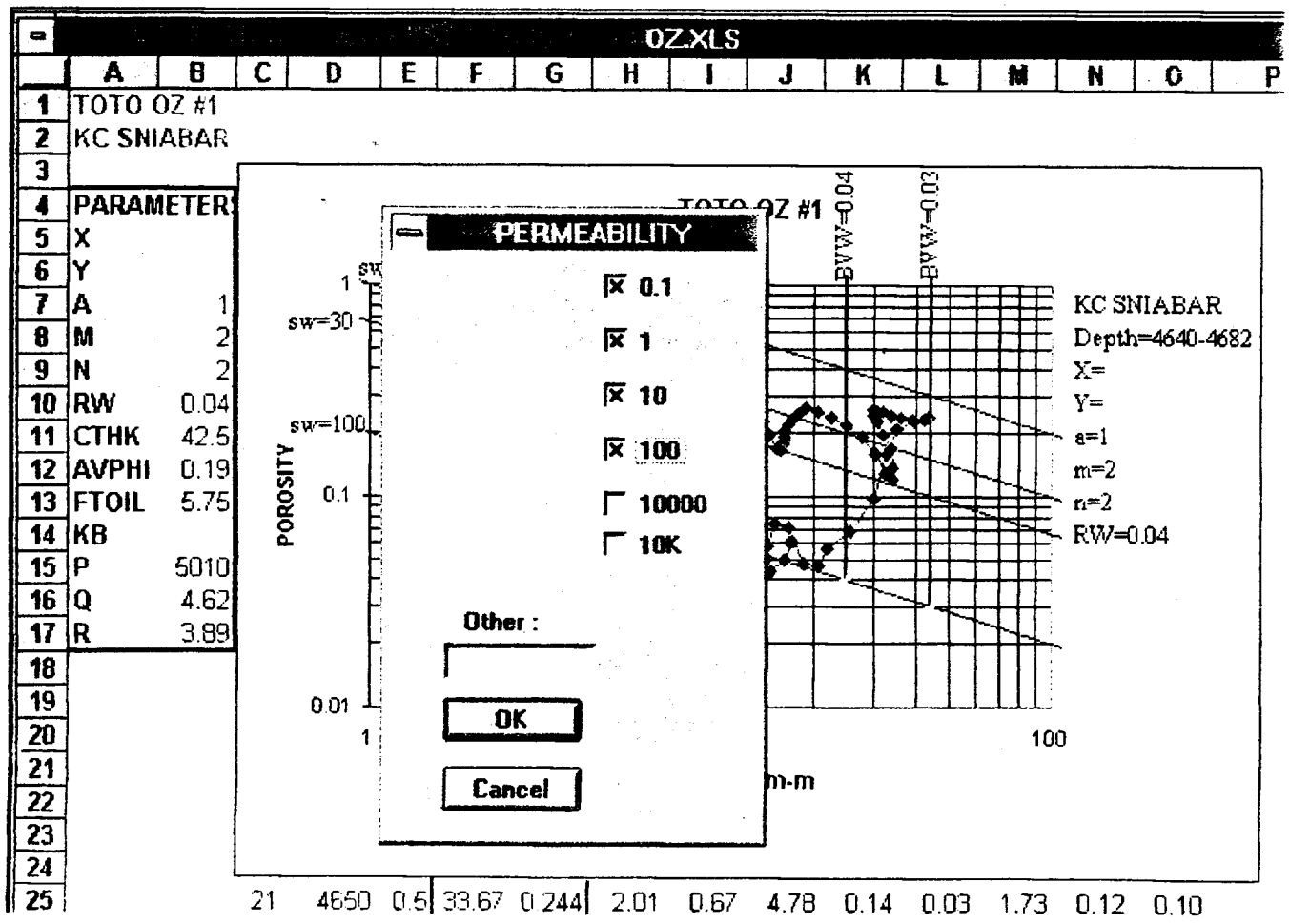
When button **K** is selected, the user is presented with a **PERMEABILITY panel**. As with the other panels, the choice is arranged in a radio-dial format, so that permeability values can be selected or deselected. Notice that another permeability chosen can be typed into the slot marked **Other**.

The permeability will be computed as a prediction keyed to porosity and "irreducible" water saturation using the Wyllie-Rose relationship of:

$$k = \frac{P\Phi^{Q}}{S_{wi}^{R}}$$

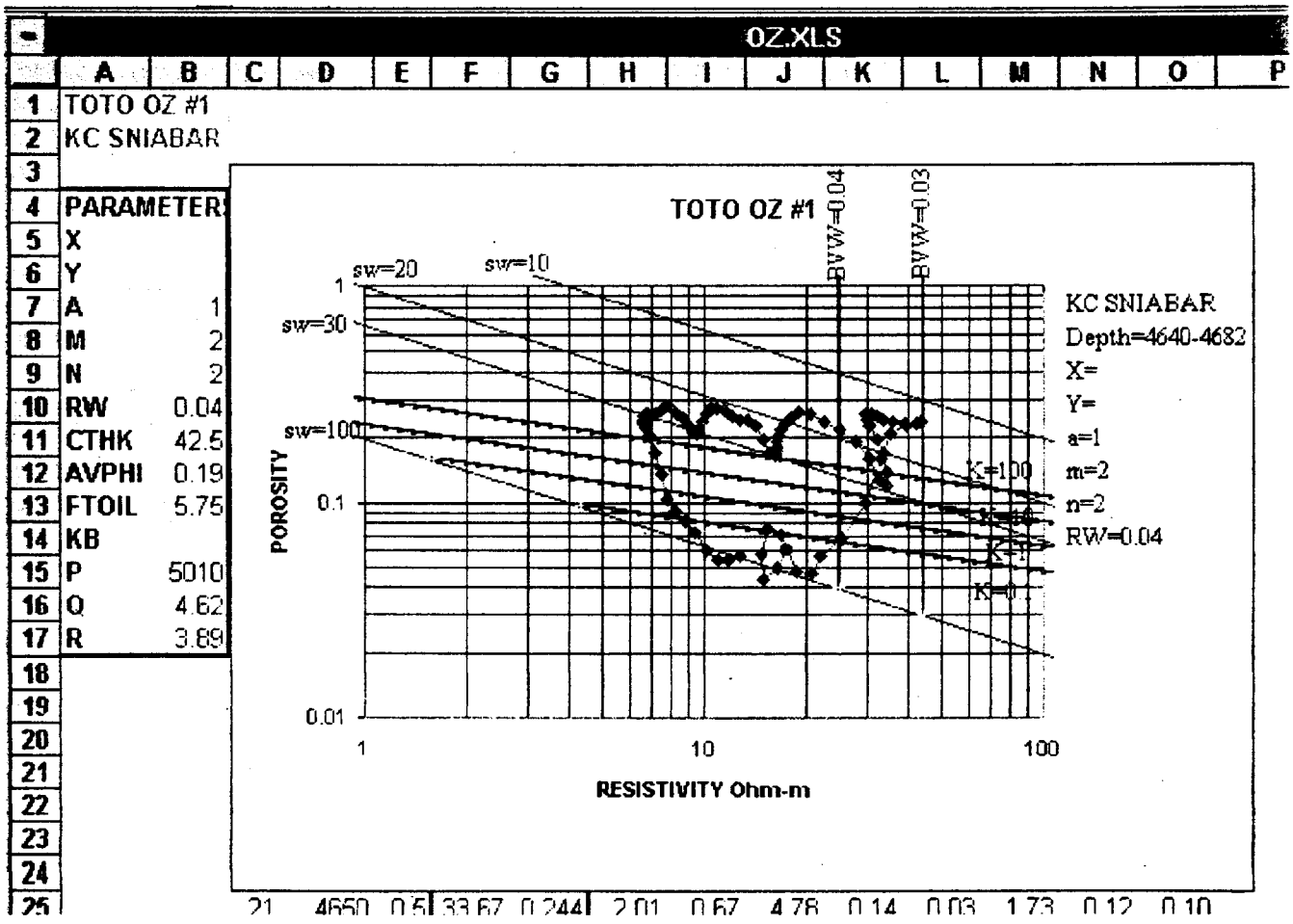
where **P, Q,** and **R** are constants, whose values are located in **parameter column B** at rows 15, 16, and 17.

The PfEFFER default values for **P, Q,** and **R** are those of the Timur equation which are appropriate for predicting permeability in typical sandstones. The values are not appropriate for limestones and so substitute values have been inserted in this example and are based on a highly generalized relationship from carbonate reservoir data. In all cases, the onus lies with the user to accept or substitute usable values for **P, Q,** and **R**.



The predicted permeability lines are drawn in green. Even if the equation parameters are essentially correct, the predicted permeabilities will only be valid when zones are at "irreducible" water saturation. Therefore, the user needs to establish a trend of points that appears to represent a reservoir section or propose an irreducible BVW value (Buckles number) based on reservoir rock type. Zones along a reservoir trend can be concluded to be approximately at "irreducible" water saturation and so their predicted permeabilities deduced from interpolation between permeability contours.

All other zones represent either transition zones or water zones and therefore are not at "irreducible" water saturation. However, their permeabilities can be estimated by migrating each zone Pickett plot coordinate location along its porosity line to the BVW line considered to represent "irreducible" reservoir conditions, and then interpolating between permeability contours.



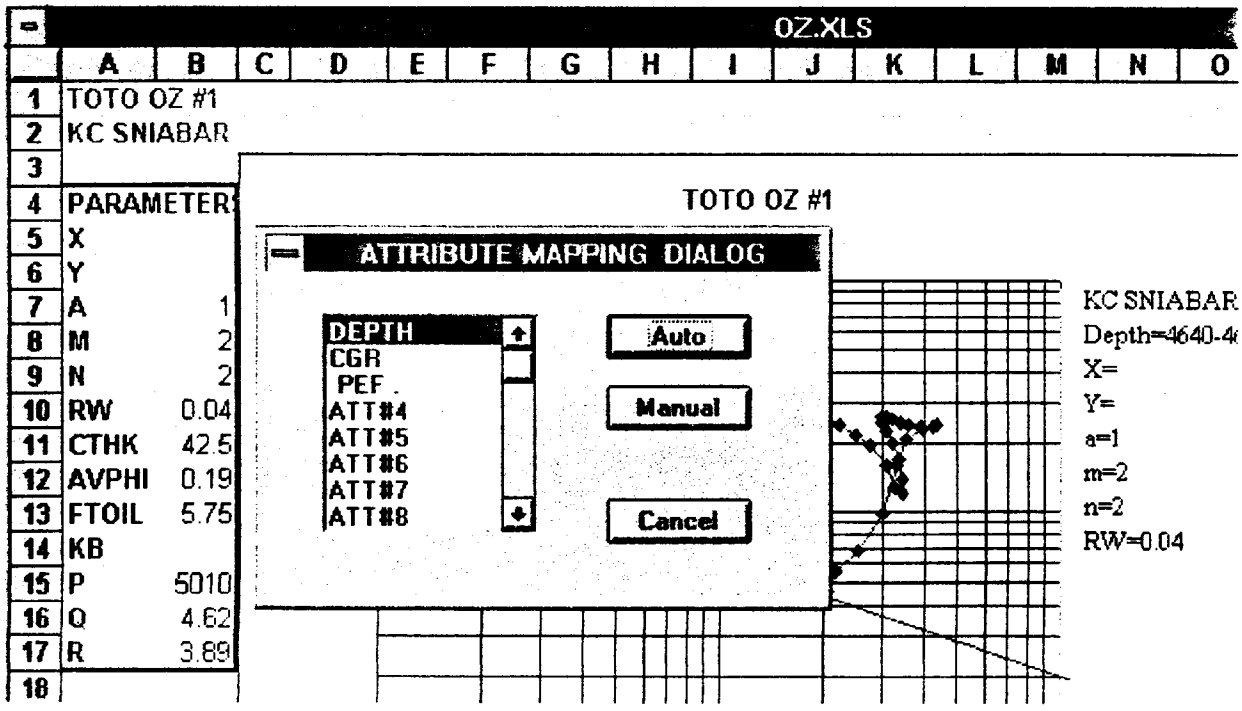
Plotting attribute values on the Pickett plot

Attributes are any kind of numerical values that the user chooses and are stored in the **attribute columns** as ATT#1 to ATT#10. Most commonly, the attributes will be filled with either logs or log transforms copied from data in the **log columns**. However, depth is a also a useful attribute to display on the Pickett plot, while the user may decide to code shows, perforation intervals or other measures as a reference variable on the Pickett plot. In this example, depth, CGR (computed gamma-ray) and PEF (photo-electric factor) have been copied into the first three attribute columns. Note that these three attributes can be displayed as logs by using **LOG**.

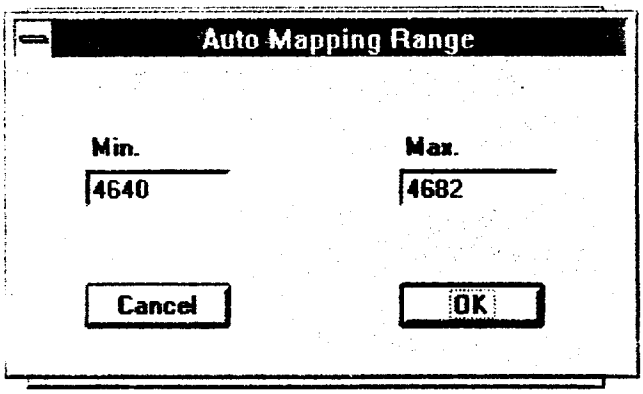
OZ.XLS

	P	Q	R	S	T	U	V	W	X	Y	Z	AA	A
1													
2													
3													
4		DEPTH	CGR	PEF	ATT#4	ATT#5	ATT#6	ATT#7	ATT#8	ATT#9	ATT#10		DEP
5		4640	47.6275	3.95117									
6		4640.5	45.3636	4.42188									4
7		4641	28.7498	4.58203									
8		4641.5	27.4052	4.42969									4

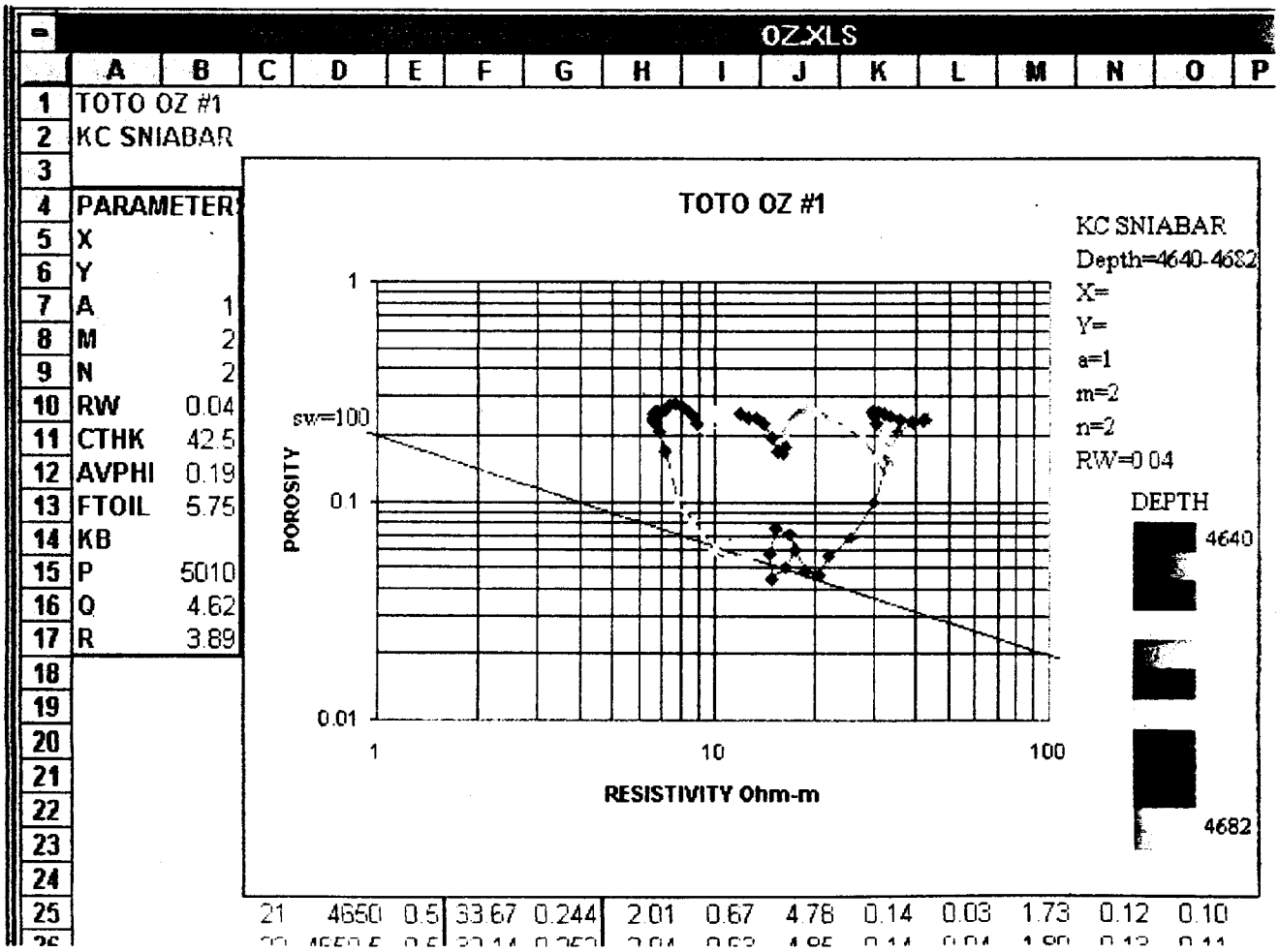
When the button **ATT** is selected, an **ATTRIBUTE MAPPING DIALOG panel** appears. The window shows the names of the ten **attribute columns** as read from the contents of cell 4 in each column. The user selects which attribute is to be mapped (in this example, depth) onto the Pickett plot. The data may be mapped either by **Auto** or **Manual**. If **Auto** is selected .....



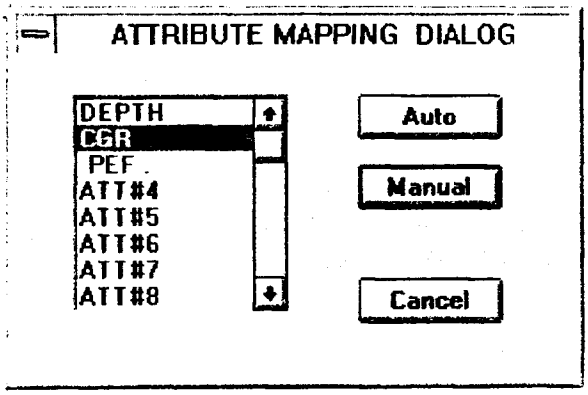
..... the **Auto Mapping Range panel** appears with a display of the minimum and maximum values of the chosen attribute. The user may choose to change the range to different values. Values outside the modified range will not be colored. Acceptance of the original or modified range is entered by clicking on **OK**.

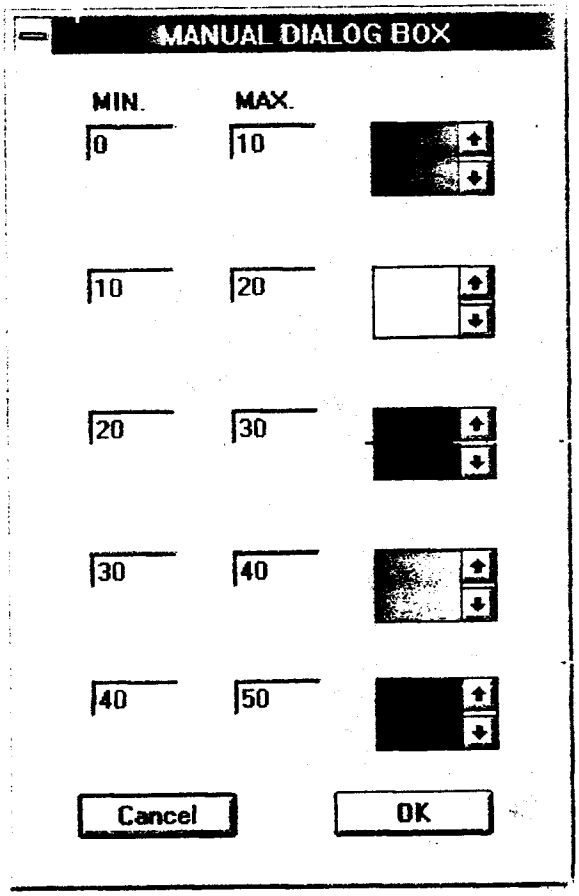


Points on the Pickett plot are now matched with colors referenced to ten equally spaced divisions of the range. A color key is placed to the right of the Pickett plot area.



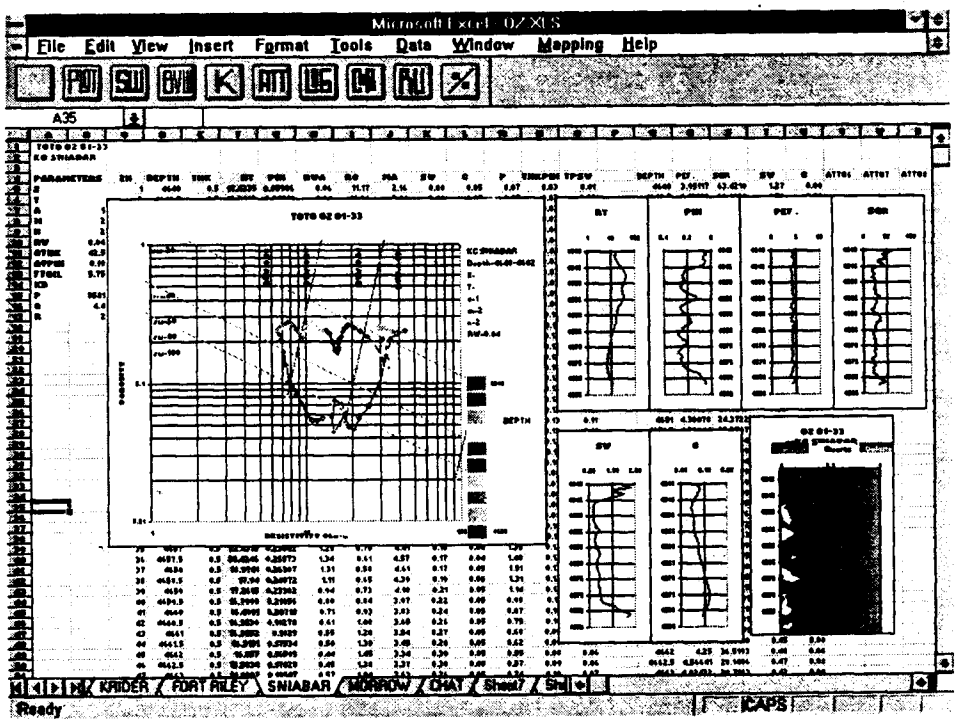
Alternatively, the user can select the **Manual** option and click **OK**, in which case a **Manual Dialog Box** is presented. Ranges for colors can then be typed in manually to allow unequal ranges or color subsets. In the example shown, the CGR (computed gamma ray) variable has been selected and the user has typed in gamma ray ranges for five colors.





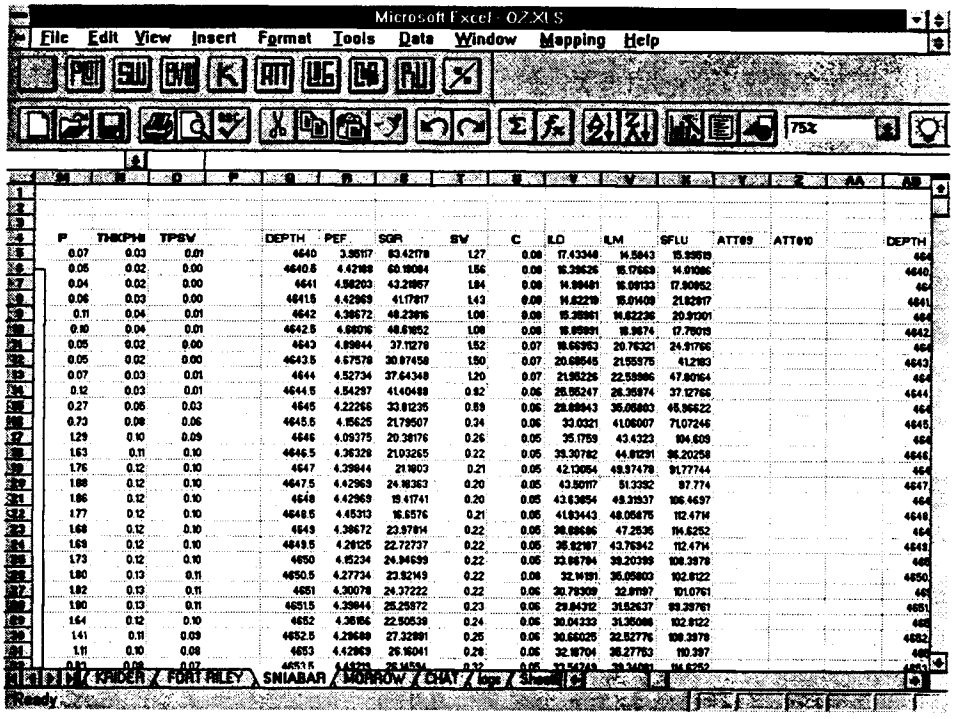
Plotting log curves

The **LOG** module generates separate depth plots (charts) of selected well logs. This module provides the ability to quickly view the log data once the log information has been imported or entered manually. The depth plot can be tailored to particular needs using standard EXCEL commands, such as to make a presentation-quality output in conjunction with display of other graphical information....



Log data can also be copied to become part of other documents. Plots can also be reorganized, resized, annotated and moved to other positions of the spreadsheet to assist in the analysis and summary of results. Charts can be selected together by depressing the shift key while clicking the mouse, "shift-clicking." Once selected the charts can be lengthened or moved to other areas of the spreadsheet *en masse*.

The log data was originally read into the **Log Area** of the spreadsheet by the **Las Import Module** or was entered in manually. In order to use the **LOG** Module, the log data need to be copied from the **Log Columns** of the **Reservoir Unit Worksheet** to one of the ten **Attribute Columns** using the EXCEL copy utility.

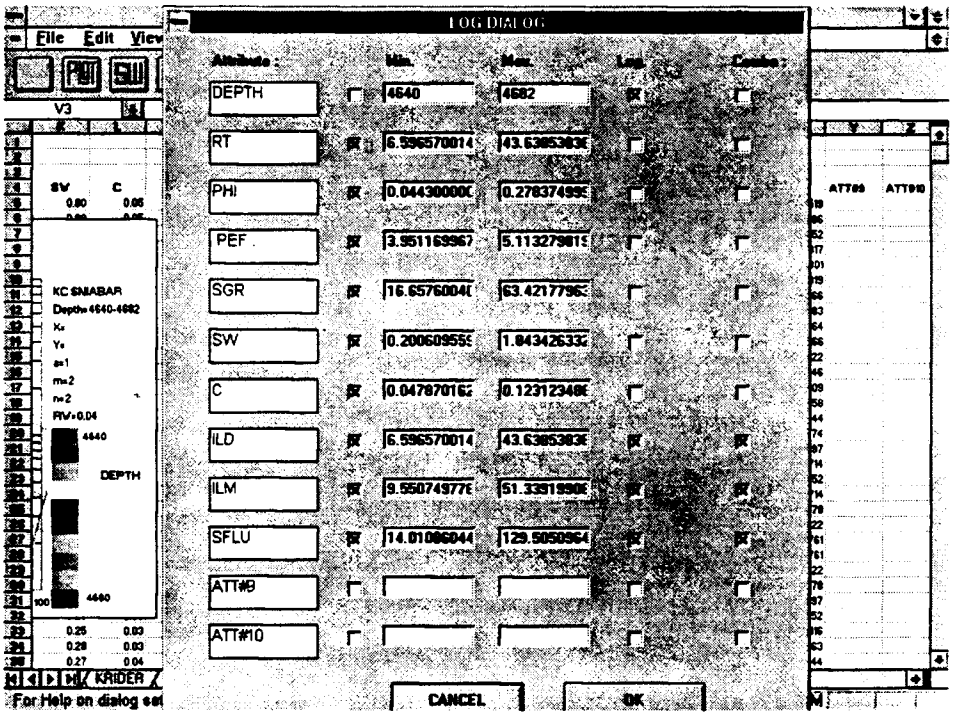


Other relevant data that can be plotted by depth can be placed in the **Attribute Columns**. These data might include Sw, BVW, and estimated permeability copied from the **Home Area**. The column of data to be copied should be pasted into one of the **Attribute Columns** using the **Paste Special** option in **Edit Menu** of EXCEL. In this option the **Paste Values** should be selected in order to avoid address conflicts. Information to be plotted need to have numerical entries for each depth. Other data such as lithology and reservoir information such as core analyses can also be included here to assist in the analysis.

The **LOG** module is activated by clicking the **LOG** button on the **PfEFFER Toolbar**. The dialog box displays the headers for each of the logs that have been moved to the **Attribute Area** of the **unit worksheet**.

The **Log Dialog Box** contains the following information starting from the left side of the dialog box:

-- the log types (attributes) to be plotted by depth,
-- a column of radio dials that are manually activated for each log type that is desired to be plotted,
-- the minimum and maximum values for each well log,
-- another column of radio dials that are activated if the desired scale is logarithmic,
-- a right-most column of radio dials to combine two or more adjacent well logs.

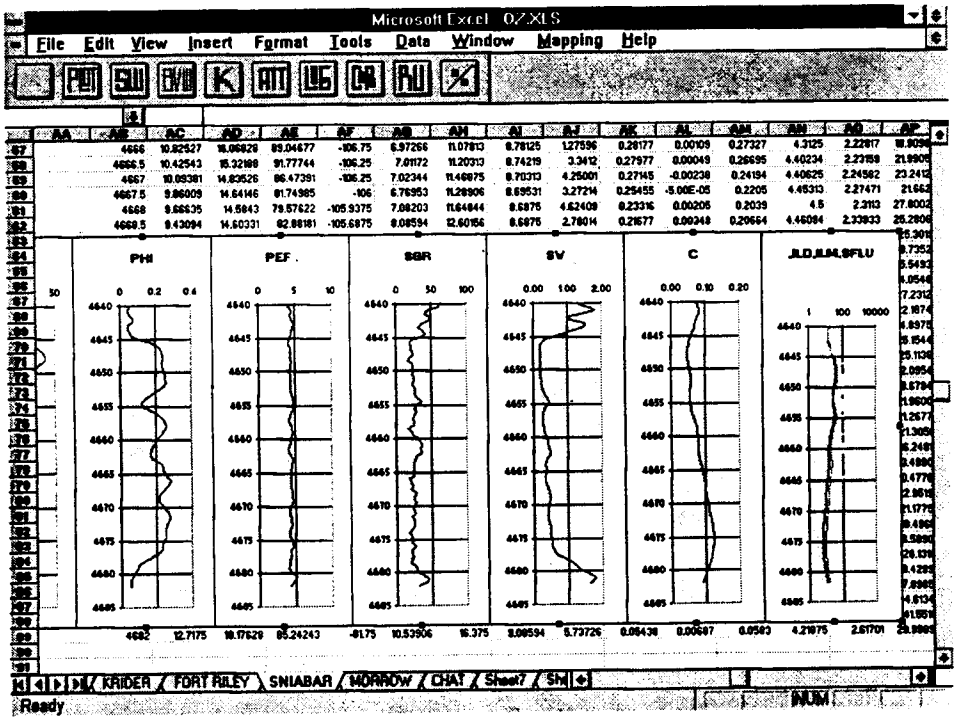


The first step is to select the variables to be displayed using the **Log Dialog Box**. The first column of radio dials is used to select the variables. The box is selected with the click of the mouse. An "X" appears alongside the log title when the log is successfully chosen. Log depth may be one of the variables in the **Attribute Columns** since depth is commonly used in annotate the Super Pickett Crossplot. However, log depth should not be selected since the vertical axis of the plot is depth. If this plot is mistakenly made, it can be simply deleted by selecting it and deleting the chart with the delete key. Resistivity and porosity values used in the Super Pickett crossplot are automatically included in the list of variables from which to make log plots.

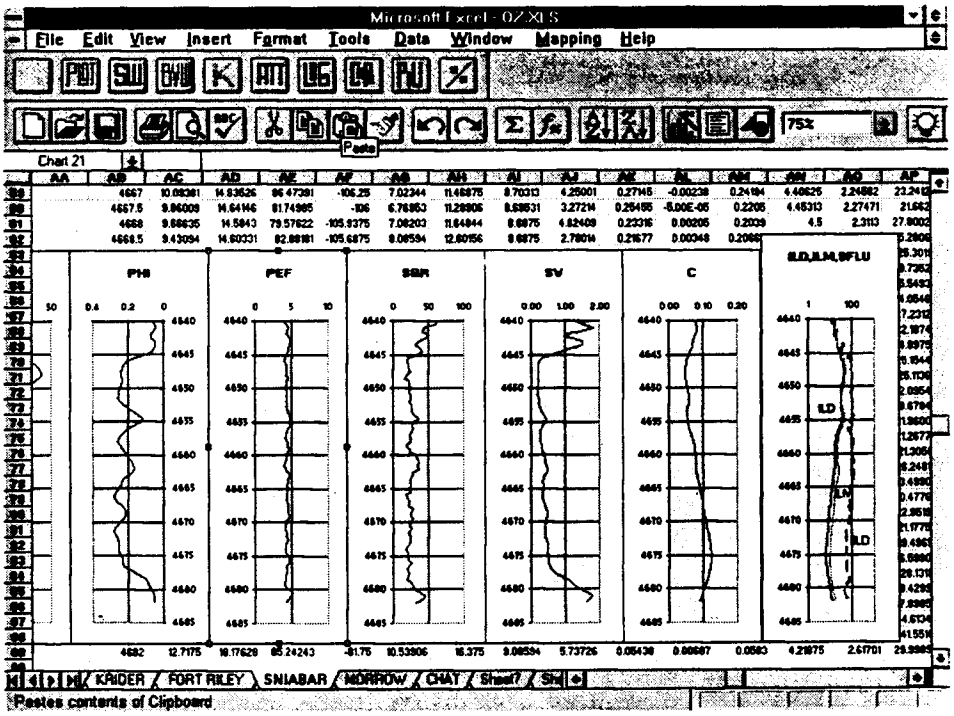
The second (middle) column of radio dials is selected to change the default linear scale to a logarithmic scale. The logarithmic scale is commonly used for resistivity logs or permeability data. Two or more well logs can be combined into one chart by activating the rightmost radio dials. Well logs that are to be combined need to be grouped on the log listing, i.e., included as a set of adjoining attribute columns. The combined logs utilize the maximum range of the selected variables. This is also the case for depth. If data that have contrasting ranges in values are desired to be plotted, perhaps they can be transformed to units that are more similar, e.g., taking the log of one of the variables or adding a constant to one before the variables are plotted together.

The minimum/maximum values provided in the dialog box serves as the default range of the depth plot. This range can be changed to fit the users needs and provide standard logging scale. The scale can also be reversed using EXCEL utilities.

Pressing **OK** on the bottom of the **Log Dialog Box** generates the depth plots. If separate, multiple log plots are chosen, they are displayed as a series of charts, side by side. If depths are the same, these charts will be the same length or the same scale. If not, the charts can be selected with the mouse and stretched or contracted in the vertical dimension to make them the same depth scale. The horizontal size of the chart can also be modified as desired.

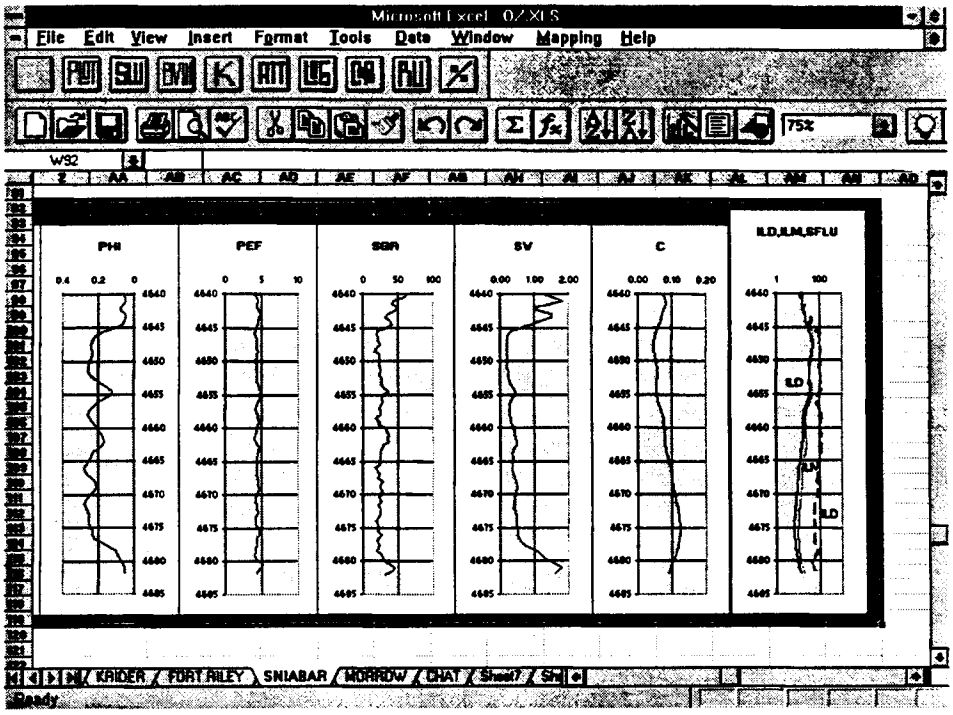


Charts can be re-dimensioned together by first selecting each chart by clicking on them with the mouse with the <shift> key depressed. Then after releasing the <shift> key the mouse can be used to resize all of the charts simultaneously. The logs shown below were resized to facilitate viewing. The range of the scale on the DT log, (the sonic transit time), was changed and the scale was reversed using standard EXCEL formatting of this chart's axis.



Log are combined on one chart using the **Log Dialog Box**. In this example two resistivity logs are combined and presented using a logarithmic scale. Curves can be labeled using the text box found on the **Standard Toolbar** of EXCEL

Charts (depth plots) can be printed together. First, select those charts that are desired to be printed and move them to a blank area of the spreadsheet. Then block (select) the area of the spreadsheet that includes the charts by clicking in the spreadsheet cell just outside the log charts in the upper left hand corner. While holding the left mouse button down, select the spreadsheet through the area covered by the log charts. Go to the **Print Menu** and click on the radio dial next to **Selection** in order to print the spreadsheet area that has been selected.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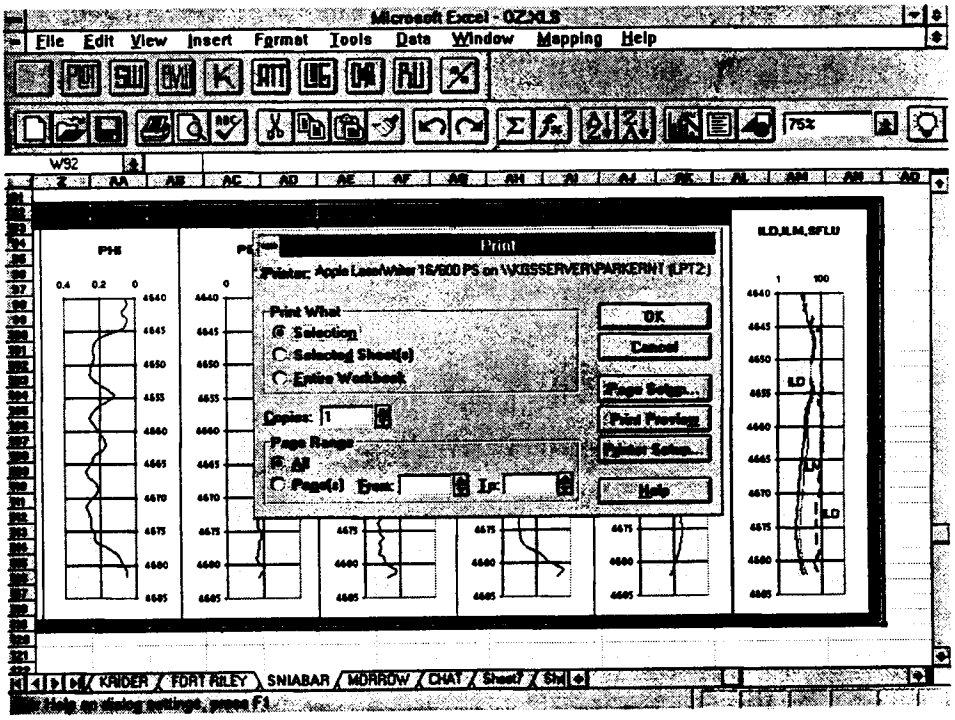
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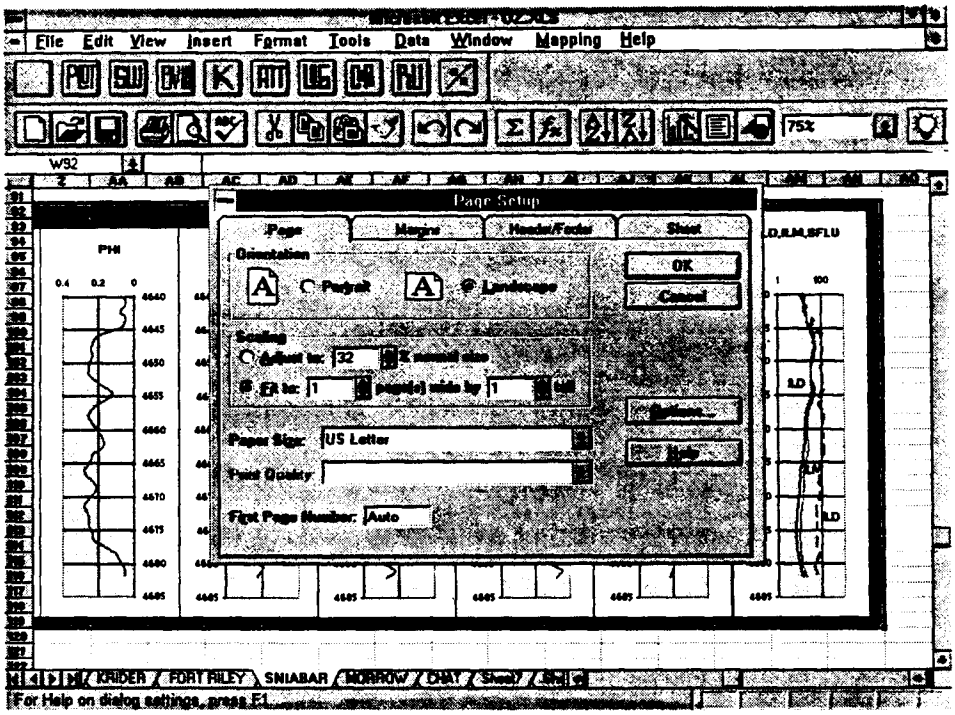
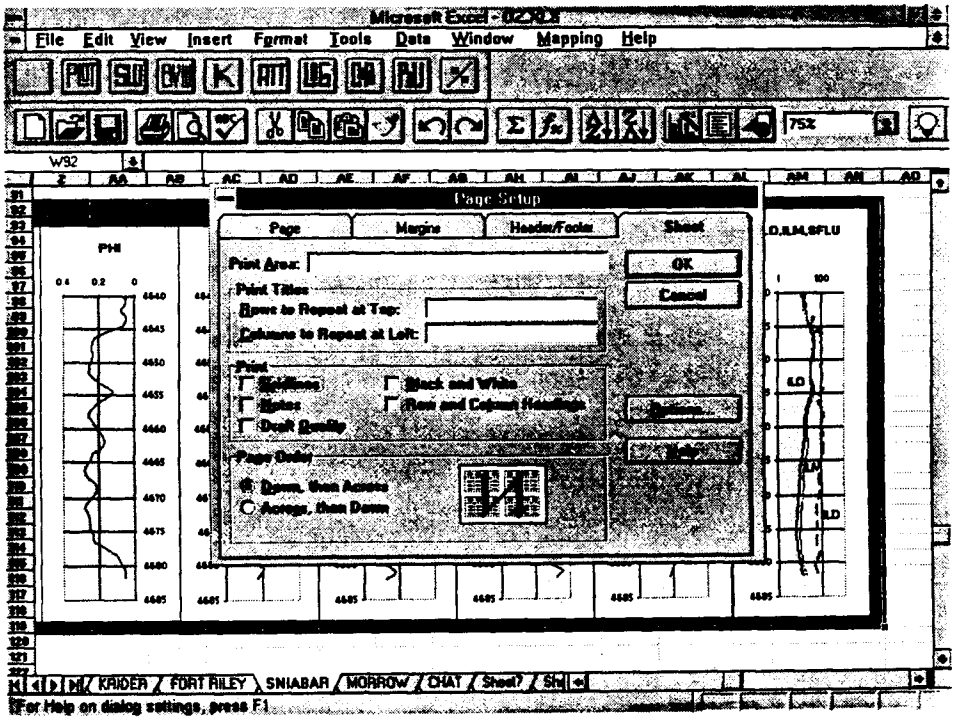
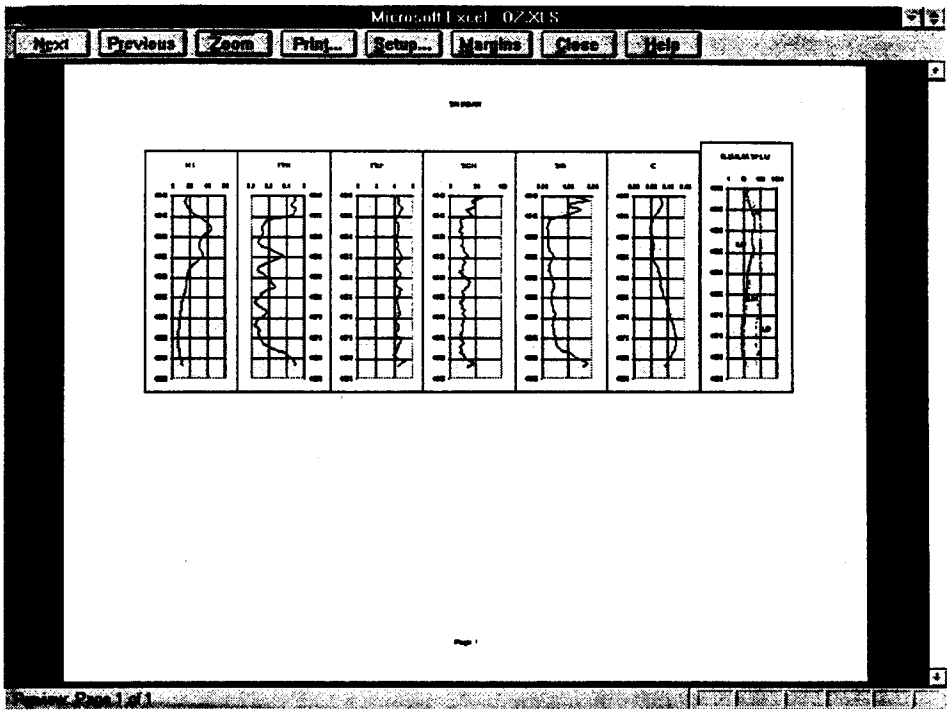
Then go the **Page Setup Dialog Box** to choose the type of orientation and to be able to select the option to fit the selected area to print on one page.



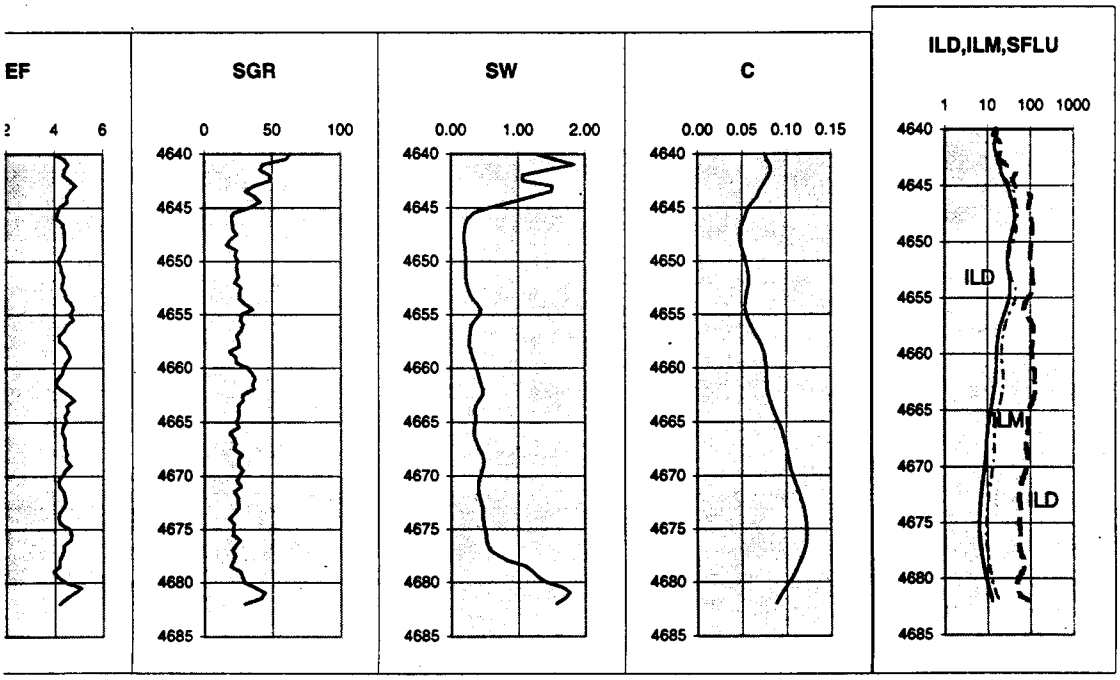
Then go to the **Sheet Dialog Box** by clicking on the tab at the top of the **Page Setup Dialog Box**. Deselect the gridlines by turning off the radio dial in order to remove these lines when the selected area of the spreadsheet is printed. Now press **OK**. This takes you back to the **Page Dialog Box**.



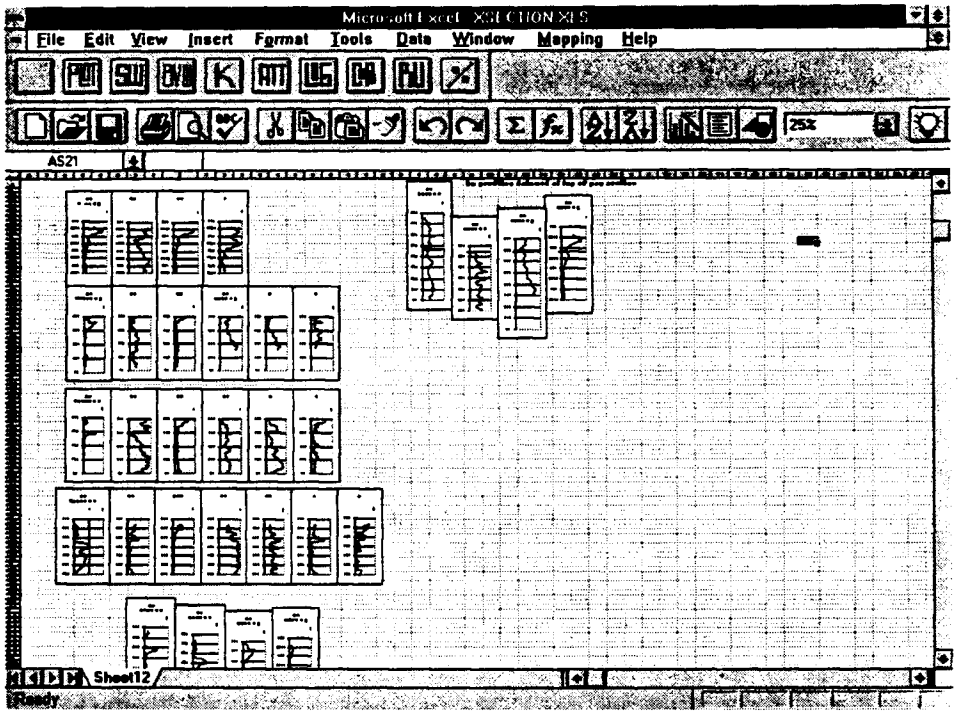
Then click on **Print Preview** to see the page.

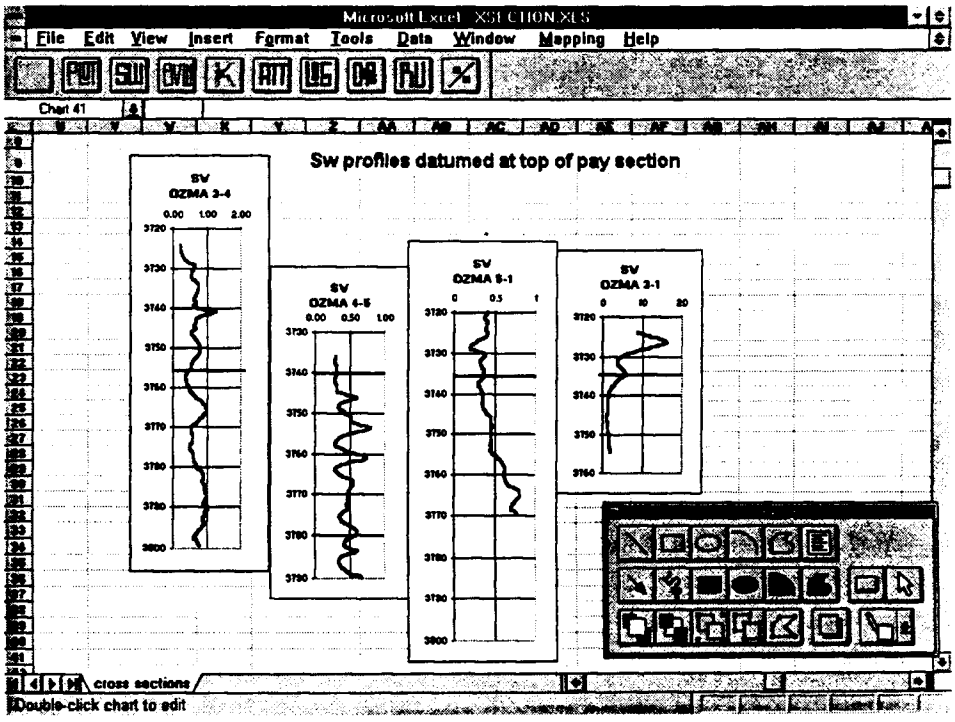


If you are satisfied, print from the **Print Preview** page.



The well log charts can all be written to a separate workbook and used to produce cross sections of well logs. Scales can be easily changed to standardize the presentation and facilitate comparison. Datums can be added to each well to aid in the construction of the cross section.





Mapping capillary pressure contours onto the Pickett plot

The toolbar button **CAPS** launches the procedure that maps either capillary pressure or height of oil or gas column as contours on a Pickett plot. The prerequisites for this procedure are:

(1) capillary pressure data on the **unit worksheet;**

and (2) a Pickett plot produced by **PLOT** (with or without water saturation, BVW, and predicted permeability lines).

For our demonstration, we will use the CHAT worksheet found in the OZ.XLS workbook. The unit is a gas-productive interval of Mississippian microporous chert from southern Kansas. The use of **PLOT** (with the selection of a porosity range of 10 to 100%) and **SW** produces the Pickett plot below:

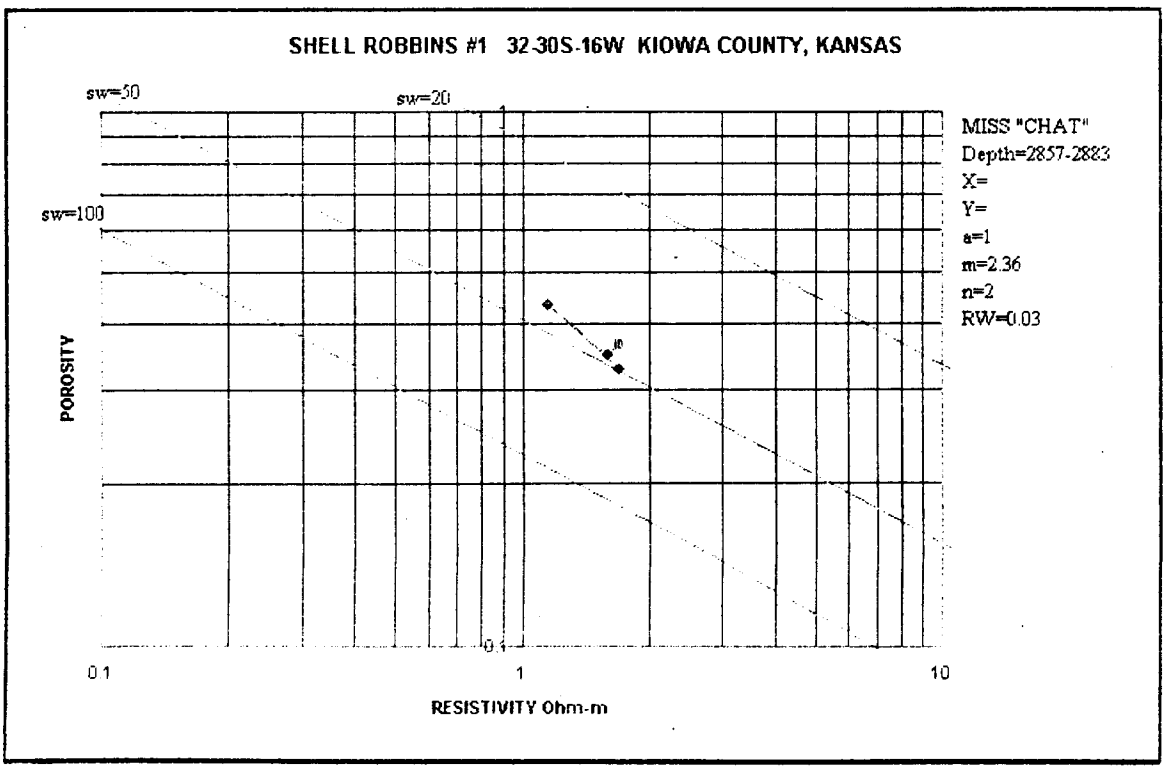
Microsoft Excel

File Edit View Insert Format Tools Data Window Mapping Help

V17

OZ.XLS

	A	B	C	D	E	F	G	H	I	J	K	L
1	SHELL ROBBINS #1 32-30S-16W KIOWA COUNTY, KANSAS											
2	MISS "CHAT"											
3												
4	PARAMETERS		ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C
5	X		1	2857	5	1.7	0.366	0.16	0.32	4.02	0.43	0.16
6	Y		2	2863	10	1.6	0.35	0.13	0.36	3.79	0.47	0.17
7	A	1	3	2873	10	1.15	0.434	0.16	0.22	4.37	0.43	0.19
8	M	2.36	4	2883	10	1.7	0.328	0.12	0.42	3.62	0.49	0.16
9	N	2										
10	RW	0.03										
11	CTHK											
12	AVPHI											
13	FTOIL											
14	KB											
15	P											
16	Q											
17	R											
18												
19												
20												
21	DATA											
22	KIOW											



The capillary pressure data should be entered somewhere in the log columns. The first column contains the capillary pressure levels that will be contoured onto the Pickett plot. In any conversion computation, the defaults of PfEFFER assume that the pressure units are in psi (pounds per square inch) in a mercury/air system. However, other measurement scales can be used, particularly if pressure is to be contoured directly. If the user elects to contour height or gas column, then the user should be prepared to type in an appropriate conversion factor on the **Capillary Pressure panel**. Each of the following columns represents an individual sample in which cell 4 contains a sample identification code chosen by the user and the sample's fractional porosity entered in cell 5. The values below these entries are the fractional water saturations that match the pressure values in the first column. Each column therefore represents a digital vector of a single capillary pressure curve indexed with an identifier and the porosity of the sample. Note that a large set of samples may be entered in the log column area and mapped selectively by the **CAPS** option, because subsets of both samples and pressures may be plotted under user-control of **Capillary Pressure panels**.

Before clicking the **CAPS** button, the user should alert PfEFFER to the location of the capillary pressure values by selecting the cell that contains the first pressure reading.

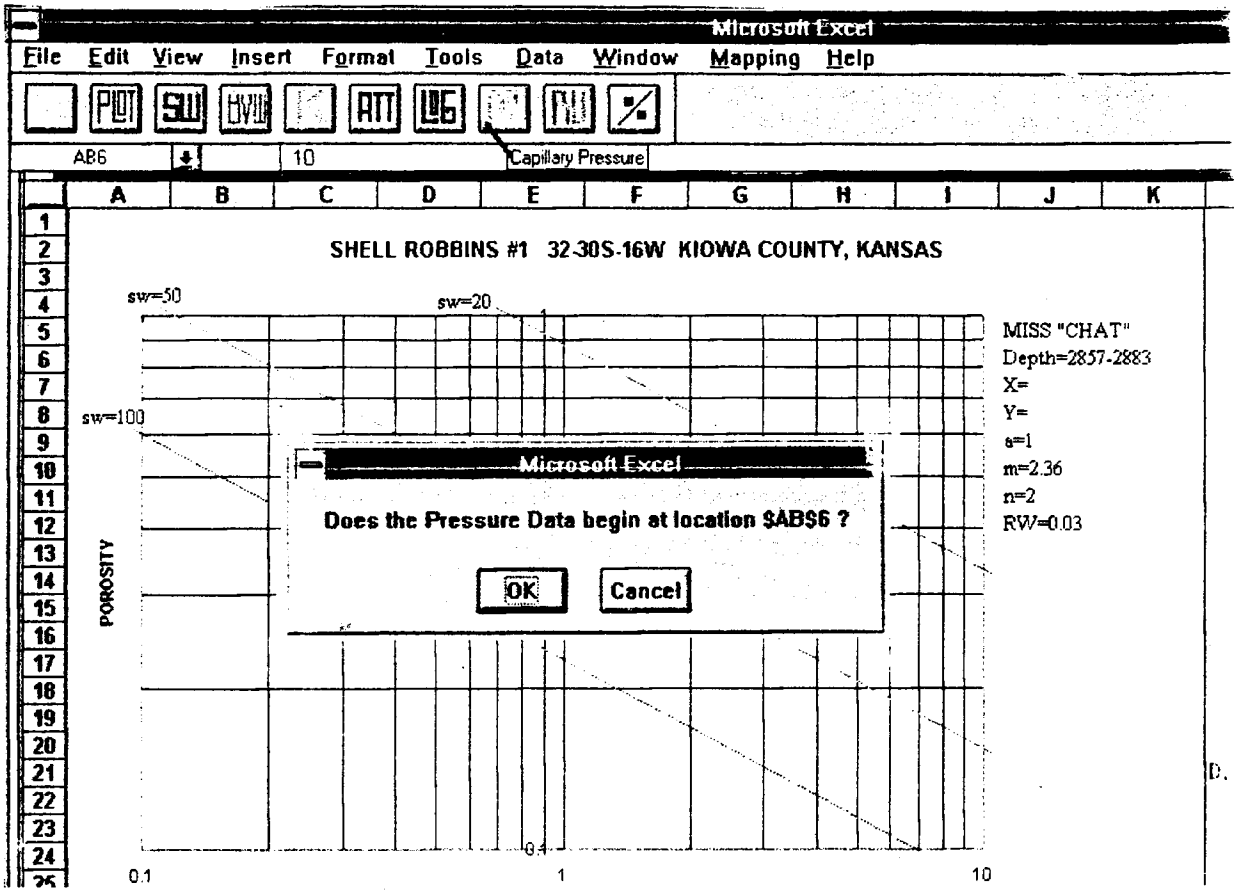
Microsoft Excel

File Edit View Insert Format Tools Data Window Mapping Help

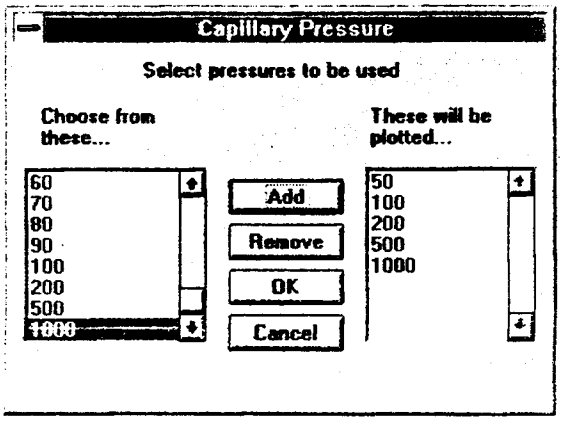
AB6 10

	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
1										
2										
3										
4	ATT#9	ATT#10		PSI	S30	S40	S50			
5					0.3	0.4	0.5			
6				10	0.995	0.99	0.99			
7				20	0.99	0.98	0.98			
8				30	0.98	0.96	0.94			
9				40	0.97	0.945	0.89			
10				50	0.96	0.9	0.82			
11				60	0.94	0.86	0.78			
12				70	0.91	0.805	0.72			
13				80	0.88	0.795	0.705			
14				90	0.825	0.76	0.69			
15				100	0.8	0.725	0.66			
16				200	0.665	0.58	0.5			
17				500	0.505	0.365	0.285			
18				1000	0.42	0.255	0.175			
19										
20										
21										

When the **CAPS** button is clicked, the first panel that appears asks the user to confirm that the selected cell is indeed the cell at which the **Pressure Data** begins. If it is not, then the user should select **Cancel**, find and select the initial pressure cell. If the cell address is correct, then the user selects **OK**.



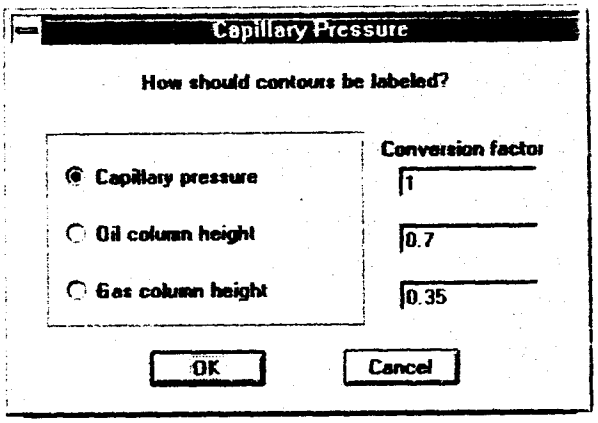
The user is next presented with a **Capillary Pressure panel** from which the user can choose all or a subset of pressure values to be contoured on the Pickett plot.



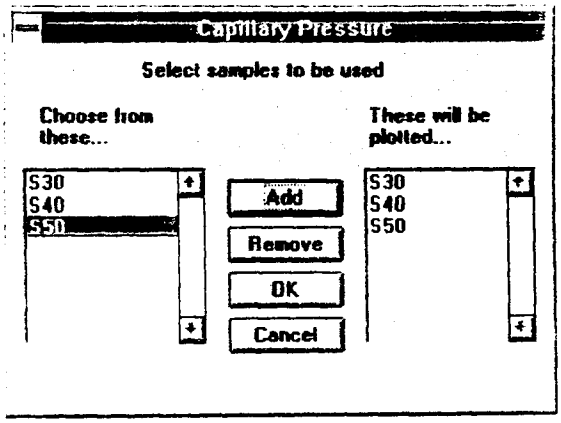
The next panel presents the user with the options to either label the pressure contours with the pressure values found in the first column of the pressure data, or to label them with their equivalent height of oil or gas above free-water level. Default conversion values of 0.7 for oil and 0.35 for gas are offered as reasonable values for an "average" oil and an "average" oil in the computation of label values. The defaults assume that:

(1) the pressure is in units of pounds per square inch (psi);
(2) the measurement system is mercury/air;
(3) the desired output height is in units of feet.

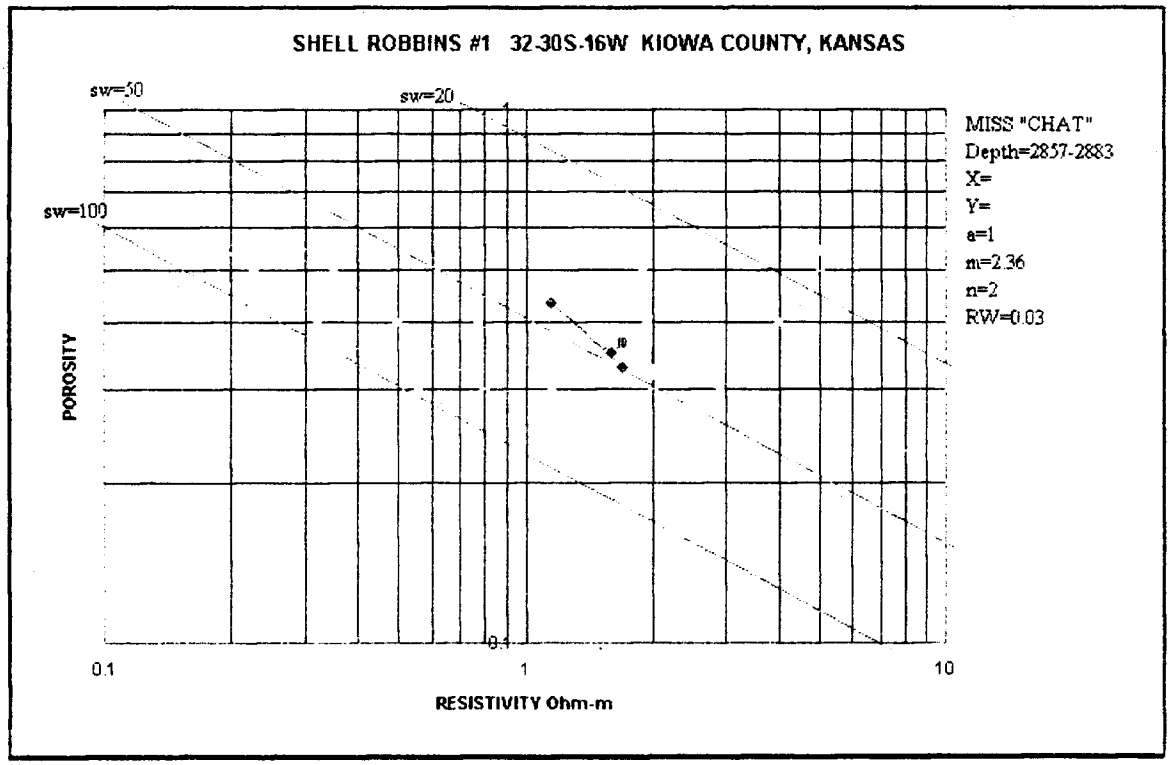
However, other conversions involving metric units, oil/water systems etc. are handled easily, provided that the user knows the appropriate conversion factors and enters it in one of the slots provided.



Finally, the user is presented with a panel that allows the selection of all of the samples or a subset. The ability to choose subsets is valuable as a means to evaluate the data set in terms of a uniform petrofacies or multiple petrofacies. If the samples are a mix, then the interpolation of contours will lead to plots with abrupt breaks and an overall lack in consistent trend. However, samples from a common petrofacies should lead to greater continuity in trend and a general tendency for contours to match BVW lines.



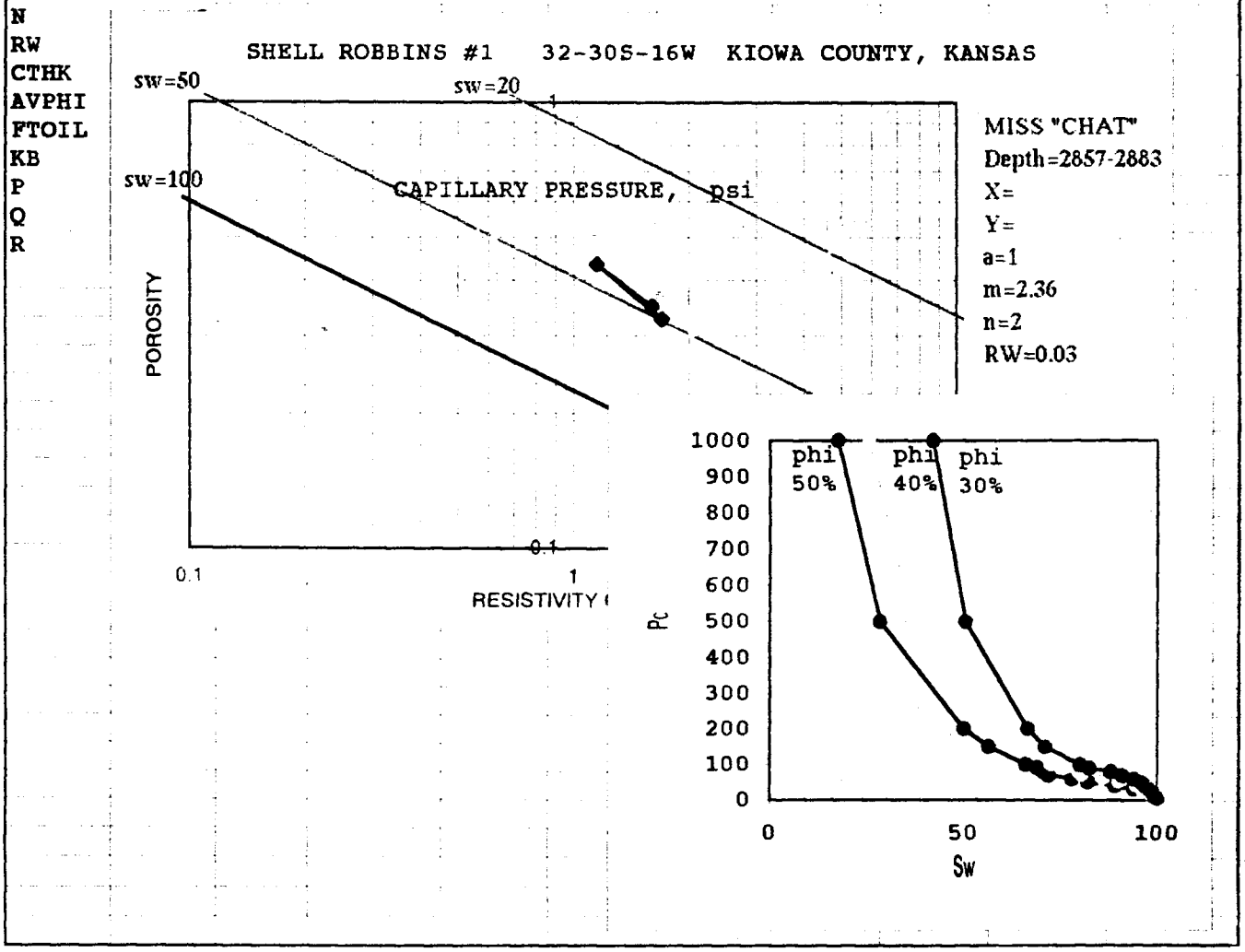
On selecting **OK** for the final panel, the capillary pressures (or equivalent hydrocarbon heights) are contoured onto the Pickett plot as sequences of straight-line segments that link crossplotted pressures located at porosity and water saturation coordinates. The lines appear as purple in color with label values either in pressure or height above free-water level. The location of the unit zones with respect to the contours can be used to deduce their depth position relative to hydrocarbon-water contacts, as well as diagnose productivity, the location and thickness of the transition zone, and other fundamental reservoir descriptors.



The capillary pressure information mapped onto the Pickett plot may also be graphed in a more conventional format using the standard options of ChartWizard within EXCEL. When coupled with the data on the **Home Field** and the contoured Pickett plot, the set facilitates the interpretation of sometimes complex relationships when they are displayed in a single view on a computer screen or on a hard-copy printout.

SHELL ROBBINS #1 32-30S-16W KIOWA COUNTY, KANSAS
MISS "CHAT"

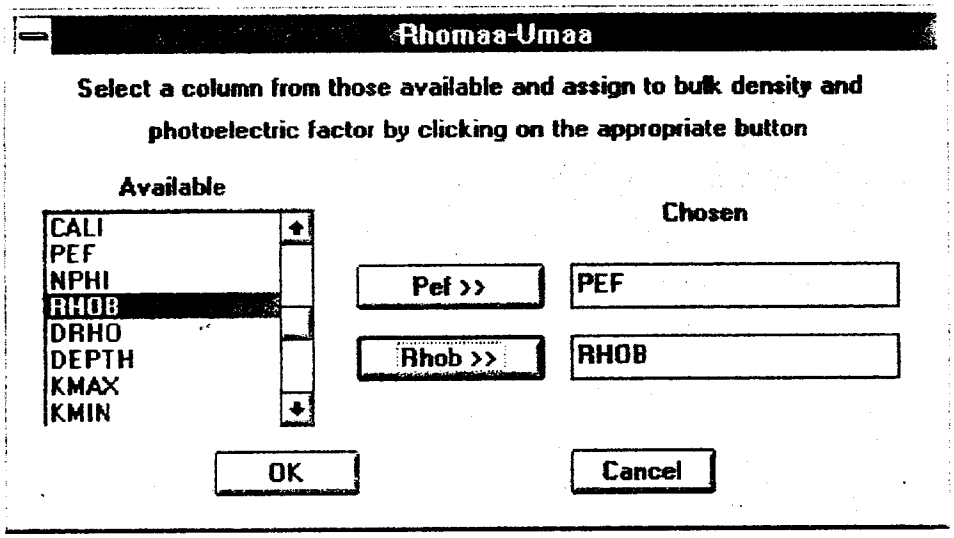
PARAMETERS	ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW
X	1	2857	5	1.7	0.366	0.16	0.32	4.02	0.43
Y	2	2863	10	1.6	0.35	0.13	0.36	3.79	0.47
A 1	3	2873	10	1.15	0.434	0.16	0.22	4.37	0.43
M 2.36	4	2883	10	1.7	0.328	0.12	0.42	3.62	0.49
N									
RW									
CTHK									
AVPHI									
FTOIL									
KB									
P									
Q									
R									



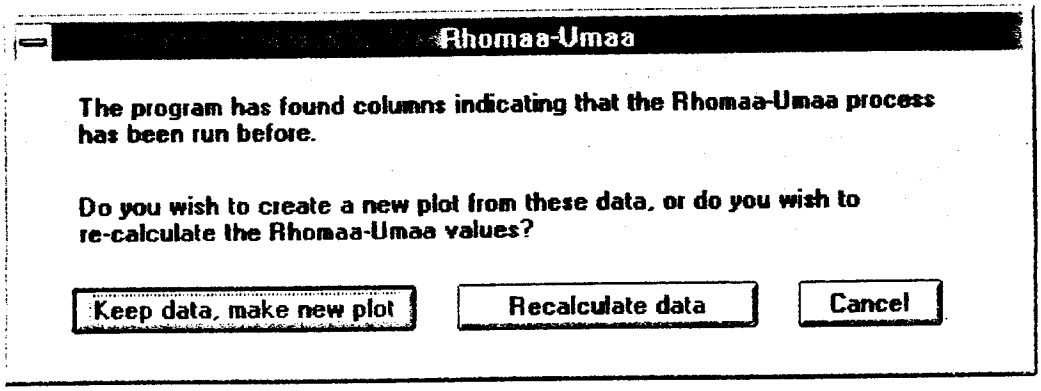
Creating a RHOMAA-UMAA crossplot

A RHOMAA (apparent grain density) - UMAA (apparent matrix photoelectric bulk cross-section) crossplot can be made, providing a photoelectric factor-neutron-density porosity log combination is available in the **unit worksheet**. The procedure computes RHOMAA and UMAA using bulk density (gm/cc), photoelectric factor (barns/electron), and assumes that the values stored in **PHI** in the **Home Field** represents total porosity.

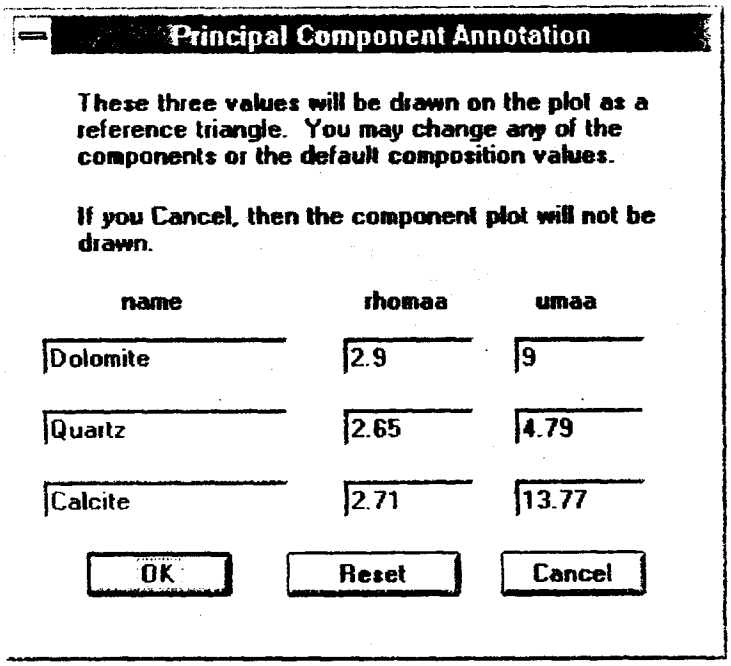
First, the procedure must be notified as to which of the **log columns** contain bulk density (Rhob) and photoelectric factor (Pef). When the **RU** button is selected, the procedure scans all the log titles written in Row 4 of the **log columns** and presents the names to the user in the **Rhomaa-Umaa panel**. The user should identify which of the logs is Rhob and which is Pef.



The **RU** procedure then calculates values for **UTOTAL** (bulk photoelectric cross-section in barns/cc), **UMAA** (apparent matrix photoelectric bulk cross-section), and **RHOMAA** (apparent grain density), and stores these in the first available columns to the right of logs stored in the **log columns**. The **UTOTAL, UMAA,** and **RHOMAA** columns are shaded green to aid recognition. If **RU** is selected at a future time in this **unit worksheet,** these columns will show up on the initial scan and the user will be asked if these values need to be recalculated before processing.



A **Principal Component Annotation panel** is then presented. The user may choose three mineral end member components to be plotted as a mineral triangle on the RHOMAA-UMAA crossplot. **Dolomite, Quartz,** and **Calcite** are offered as default minerals together with their Rhomaa and Umaa values. The user may elect to go with this combination or substitute alternative minerals. However, if other minerals are chosen, the user will be required to enter their Rhomaa and Umaa values, which are available from standard log analysis texts. If the user wishes to revert to the original dolomite-quartz-calcite set, this may be achieved by selecting **Reset**. When the user is satisfied with the three minerals and their values, the **OK** button is selected.

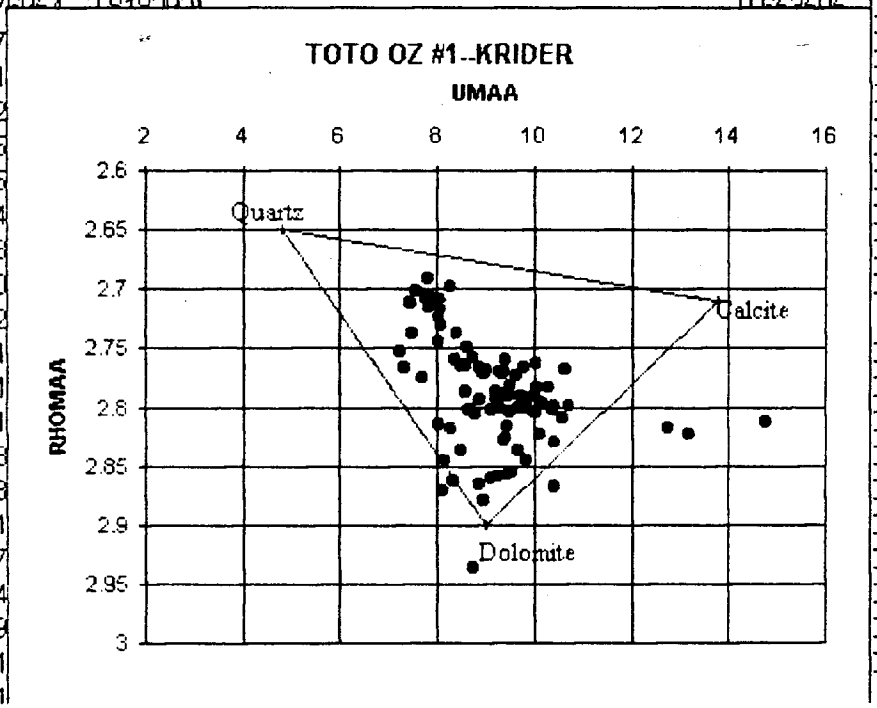


The procedure records the minerals and their RHOMAA and UMAA values on the unit worksheet together with a UNITY vector as a matrix to the right of the UTOTAL, UMAA, and RHOMAA columns. The inverse of this matrix is computed and recorded below. Finally, the inverse matrix is used in conjunction with the UMAA and RHOMAA columns to compute the proportions of the three components in each zone. Note that these proportions will be negative when a zone falls outside the space of the three-component composition triangle.

The RHOMAA-UMAA crossplot is presented with the unit worksheet zones plotted as dots, and the coordinates of the three end members linked as a reference composition triangle. The precise position of each zone in this triangle can be read from the proportions stored in the mineral component columns.

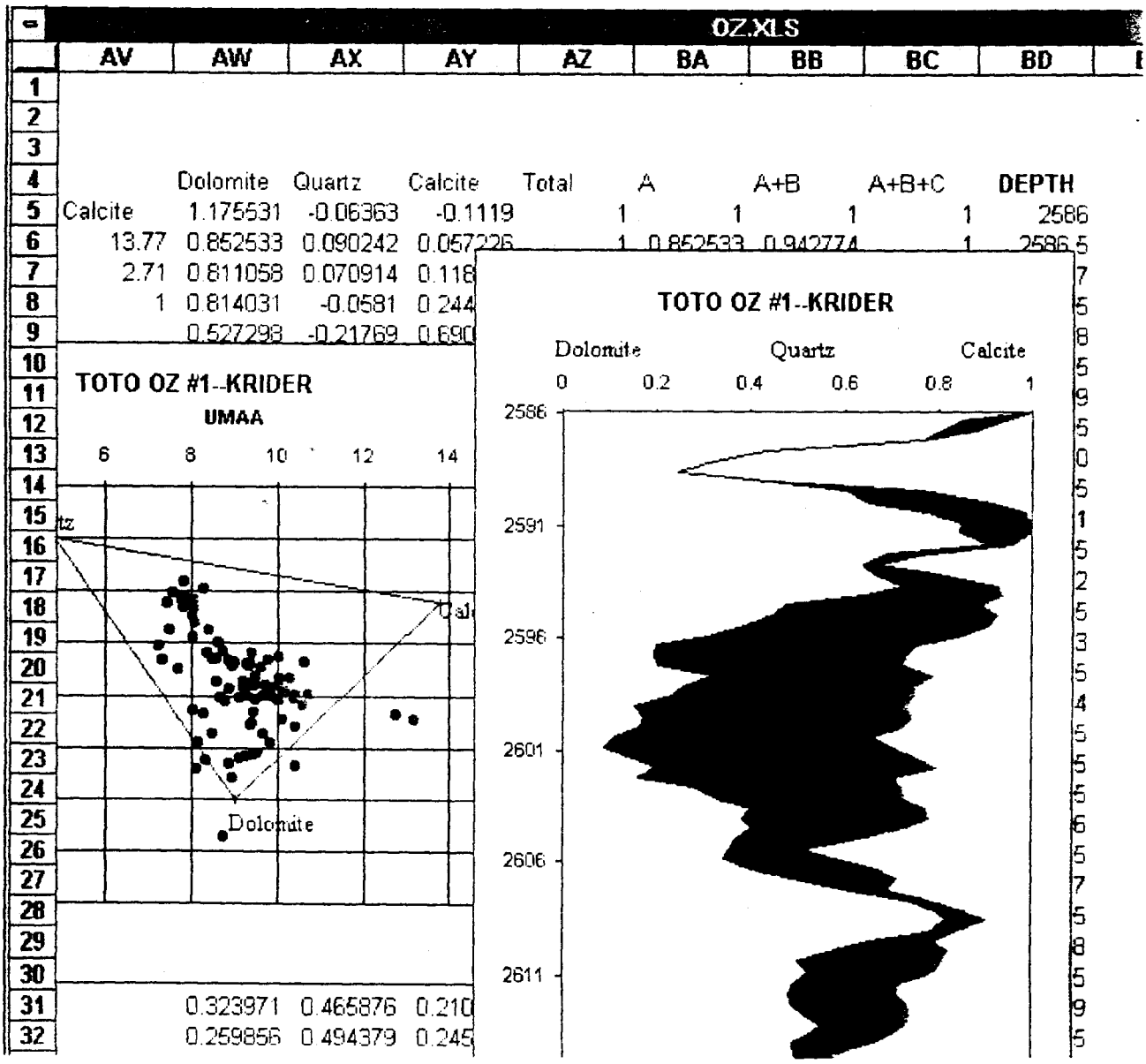
OZ.XLS

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY
1										
2										
3										
4	UTOTAL	UMAA	RHOMAA					Dolomite	Quartz	Calcite
5	6.643391	8.734128	2.937169		Dolomite	Quartz	Calcite	1.175531	-0.06363	-0.1119
6	7.262312	8.893049	2.866567	UMAA	9	4.79	13.77	0.852533	0.090242	0.057226
7	8.065846	9.264441	2.859846	RHOMAA	2.9	2.65	2.71	0.811058	0.070914	0.118027
8	9.616667	10.40884	2.868152	UNITY	1	1	1	0.814031	-0.0581	0.244073
9	12.82174	13.20965	2.823248					0.527298	-0.21769	0.690393
10	15.06071	14.77768	2.813649	INVERSE MATRIX:				0.436811	-0.34424	0.907428
11	17.08349	16.39794	2.808706		-0.03011	4.507127	-11.7996	0.36574	-0.48692	1.121178
12	13.38023	12.75557	2.81756		-0.09536	-2.3941	7.801144	0.515335	-0.16077	0.645435
13	9.527403	9.47663	2.815929		0.125477	-2.11303	4.998494	0.606727	0.155822	0.237451
14	7.809505	8.27							0.264569	0.081926
15	7.3991	8.17							0.208359	0.011797
16	7.089904	8.11							0.154681	-0.04925
17	6.941475	8.32							0.151753	-0.00682
18	7.24125	8.95							0.051779	0.035337
19	7.927801	9.65							0.089853	0.216324
20	8.905762	10.4							0.030011	0.32708
21	8.258479	9.38							0.134827	0.200526
22	7.47385	8.50							0.197829	0.071585
23	6.987237	8.02							0.2979	0.05825
24	6.810604	7.71							0.421324	0.102451
25	6.536398	7.31							0.480383	0.070854
26	6.446637	7.21							0.523871	0.088925
27	6.573417	7.48							0.534468	0.154613
28	6.758975	7.8							0.554523	0.243778
29	6.860419	8.01							0.536809	0.267588
30	6.877406	8.07							0.524995	0.270108
31	6.877656	8.04							0.465876	0.210153
32	6.885819	8.09							0.494379	0.245765
33	6.785383	8.01							0.514655	0.248423
34	6.598099	7.81							0.58119	0.265449



Drawing a composition profile

The component proportions computed by the **RU** procedure can be displayed as a profile of compositional variation with depth by selecting the **%** button. The **%** option recomputes the component proportions, so that all negatives are eliminated as zeroes and the proportions retotalled to sum to unity. Working columns of **Total, A, A+B,** and **A+B+C** are used to store the results. The corrected proportions are then used to generate the depth composition profile.



PfEFFER MAPPING MODULE

Introduction

The **PfEFFER Mapping Module** produces a first-look map to examine spatial variability/continuity among wells. It can be used to quickly assess reservoir heterogeneity or to evaluate the consistency of the variables being mapped. A commercial mapping package is needed if a more complete spatial analysis is desired. The plotfile generated in the **Mapping Workbook** can be easily exported to these mapping packages as a spreadsheet or as delimited text files.

The **Mapping Module** assembles, grids, and maps a set of variables representing a common set of reservoir units from a number of different wells. The module extracts selected information from the **Well Workbooks** and creates a new **Mapping Workbook**. The **Mapping Workbook** is also a project summary file for the assembled wells. The **Mapping Workbook** can be re-assembled as wells and zones are added or deleted. The gridding is based on the inverse distance method. The gridding parameters are presented in a dialog box and can be changed. A **Gridding Worksheet** is created showing the values of the gridded nodes to be mapped. This step in gridding can be repeated to produce the optimum grid. The grid values are operated on by **Map** or **Surface Options** in the **Mapping Menu** to produce a 2-D or 3-D presentation of the data. Also, a posting of the well locations may be created directly from a **Reservoir Unit Worksheet** using the **Posting Option**. A shaded contour map or three-dimensional surface representation of the data are standard EXCEL charts that can be edited with standard EXCEL utilities. The contour interval can be easily changed with EXCEL utilities.

The user initiates mapping via a pull-down menu under the **MAP Option** located in the primary **EXCEL Menu**. Options include setting up a new **Mapping Workbook** or editing an existing one. Grid and map options are initiated only after the **Mapping Workbook** is established.

Demonstration example

In the following text, we will demonstrate the PfEFFER mapping options with real data from a Mississippi Chat field in Kansas that has been given Oz nomentclature to preserve confidentiality. The example uses seven wells drilled by TOTO Petroleum Inc. with the names OZMA 3-1, 3-4, 4-5, 5-1, 5-3, 5-4, and 5-5 in the Emerald Field. The well files are available on the PfEFFER distribution disc.

Generating a Mapping Workbook

The file created by PfEFFER for mapping is the **Mapping Workbook**. It also serves as the **Project Workbook**, where information is compiled for a selected set of **Well Workbooks**. In establishing an new **Mapping Workbook** the user selects the **Well Workbooks** through a file list. The software then opens these **Well Workbooks** extracting the map parameters from each **Reservoir Unit Worksheet**. In order to perform these extractions successfully, the reservoir unit names must be spelled identically in all the **Well Workbooks**. Otherwise, separate **Reservoir Unit Worksheets** will be created even though they are part of another worksheet. The order of the **Reservoir Unit Worksheets** included in each **Well Workbook** must also be the same. The sequence of the **Reservoir Unit Worksheets** in the **Well Workbook** can be easily changed by dragging the tab labels located on the bottom of the sheet with the mouse over to the new position.

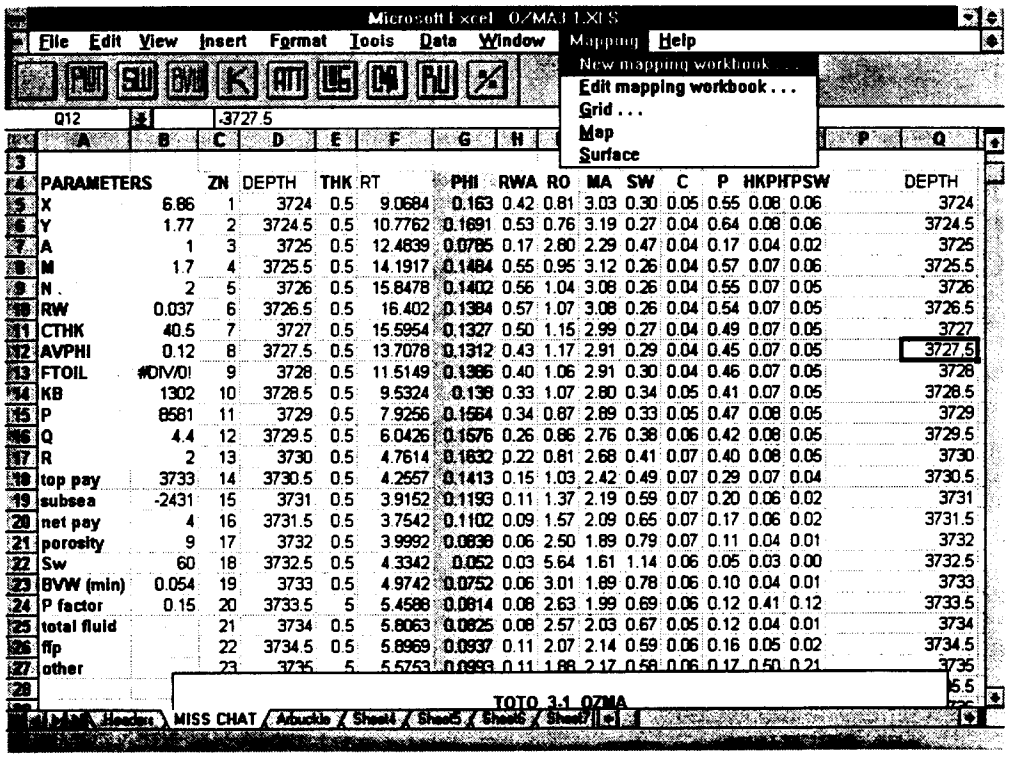
The data that are transferred from the **Reservoir Unit Worksheet** into a **Well Workbook** to the **Mapping Workbook** consists of those parameters listed in column B and their names in column A of the worksheet.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	NAME OF WELL																		
2	NAME OF FORMATION																		
3																			
4	PARAMETERS	ZN	DEPTH	THK	RT	PHI	RWA	RO	MA	SW	C	P	HKPH	PSW		ATT#1	ATT#2	ATT#3	
5	X	1					0.00	#####	#####	#####	#####	#####	0.00	#####					
6	Y	2					0.00	#####	#####	#####	#####	#####	0.00	#####					
7	A	1	3				0.00	#####	#####	#####	#####	#####	0.00	#####					
8	M	2	4				0.00	#####	#####	#####	#####	#####	0.00	#####					
9	N	2	5				0.00	#####	#####	#####	#####	#####	0.00	#####					
10	RW	0.1	6				0.00	#####	#####	#####	#####	#####	0.00	#####					
11	CTHK	0	7				0.00	#####	#####	#####	#####	#####	0.00	#####					
12	AVPHI	#####	8				0.00	#####	#####	#####	#####	#####	0.00	#####					
13	FTOIL	#####	9				0.00	#####	#####	#####	#####	#####	0.00	#####					
14	KB		10				0.00	#####	#####	#####	#####	#####	0.00	#####					
15	P	8581	11				0.00	#####	#####	#####	#####	#####	0.00	#####					
16	Q	4.4	12				0.00	#####	#####	#####	#####	#####	0.00	#####					
17	R	2	13				0.00	#####	#####	#####	#####	#####	0.00	#####					
18			14				0.00	#####	#####	#####	#####	#####	0.00	#####					
19			15				0.00	#####	#####	#####	#####	#####	0.00	#####					

Rows 4-17 in column B of each **Reservoir Unit Worksheet** are populated automatically by the PfEFFER software. These are preset variables used by the software. The user adds additional entries to this column (below those calculated by PfEFFER) with parameter labels in column A found immediately to the left of the corresponding parameter values. The software matches parameter labels in order to put parameter values in the appropriate **Reservoir Unit Worksheet** of the **Map Workbook**. The parameter label match is not case sensitive. However, parameter labels must be *spelled identically* in all of the **Well Workbooks** in order to be recognized as the same parameter. The *order* of the parameters must also be the same for each unit in each well.

Using the Mapping Menu

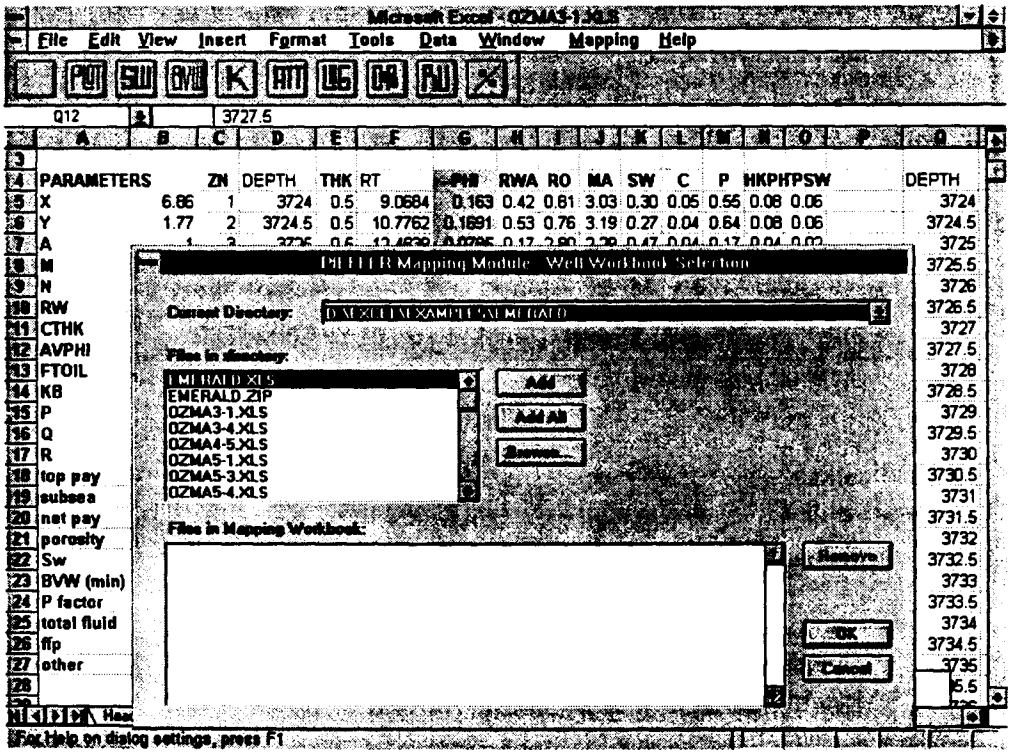
Care must be taken in using the current version of Pfeffmap because all items are available at all times in the **Map Menu** even when they are not appropriate.



Specifically, the **Edit mapping workbook... Option** should be selected only when the **Summary Sheet** is active, the **Post Data...** and **Grid... Options** should be selected only when a **Reservoir Unit Worksheet** is active. Originally, the software was set up such that only the appropriate menu items were available when a given worksheet was active. This was accomplished by setting the 'OnSheetActivate' and 'OnSheetDeactivate' properties of the

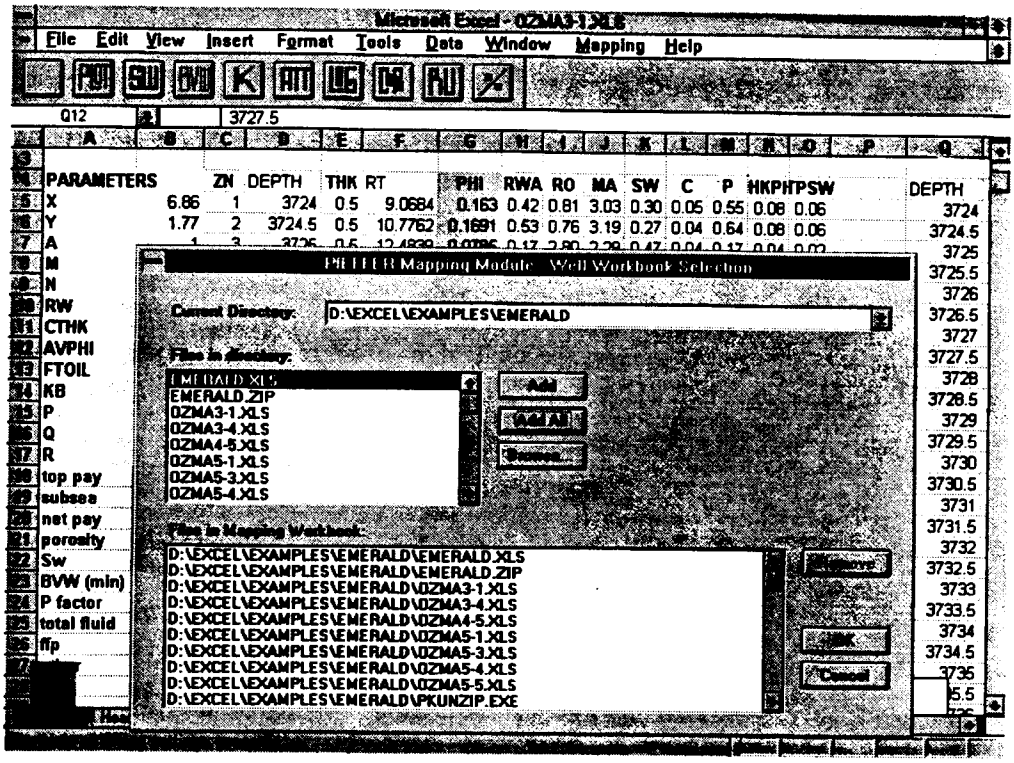
setting the 'OnSheetActivate' and 'OnSheetDeactivate' properties of the worksheets to point to routines that turned on and off the appropriate menu items. It was discovered that EXCEL does not preserve these properties between sessions, meaning that menu items did not behave properly upon opening a **Mapping Workbook** that had been created in an earlier EXCEL session. Therefore the code was altered so that all the items in the **Mapping Menu** are available at all times, even though only one or two of them will result in valid operations on any given worksheet.

The first mapping menu item in the **Map Menu, New mapping workbook...** allows the user to create a **Mapping Workbook** from a collection of **Well Workbooks**. Once this item is selected the code will create a **Summary Worksheet** of the new **Mapping Workbook**. The user is then presented with the **Well Workbook Selection Dialog Box**.

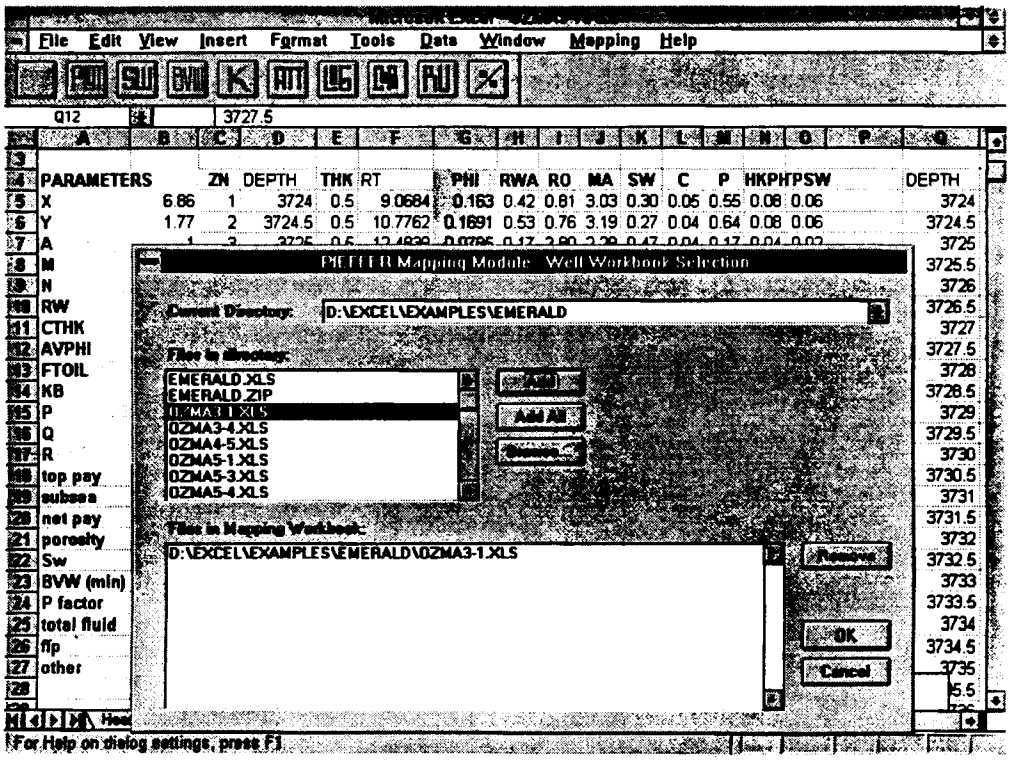


The upper box contains a list of the files in the current directory. The lower dialog box contains the list of the files to be included in the **Mapping Workbook**. Files are transferred from the **Files in Directory** list to the **Files in Mapping Workbook** using the **Add** and **Add All** buttons.

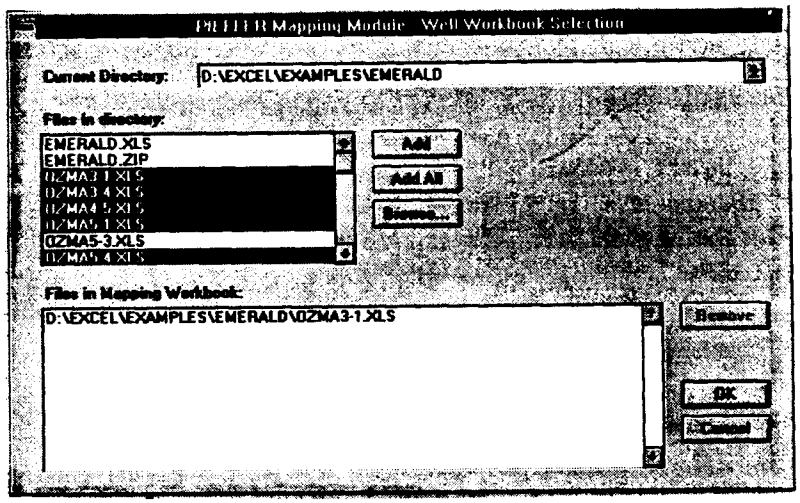
The **Add All** button will transfer the entire list of files in the directory to the list of files in the mapping workbook.



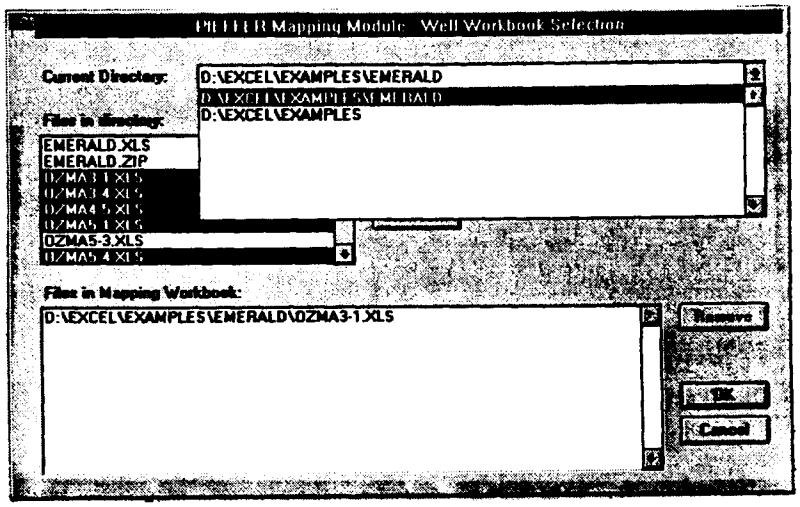
One or more files may be transferred by selecting them in the **Files in Directory** list and clicking the **Add** button.



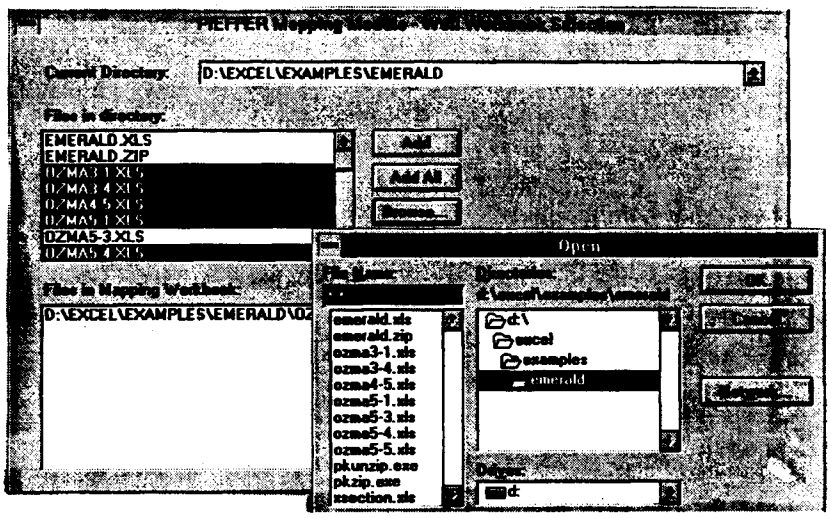
The **Files in Directory** list allows multiple selection: a contiguous list of files may be selected by dragging or by clicking (once) on the first one and then shift-clicking on the last one in the list. Non-contiguous selections may be made by ctrl-clicking on the desired files.



Files may be removed from the **Files in Mapping Workbook** list by selecting them and then clicking on the **Remove** button. The **Files in Mapping Workbook** list also allows multiple selection. **Well Workbooks** from different subdirectories may be included in the **Mapping Workbook**. The drop down list box at the top of the dialog box displays the current directory and allows navigation among subdirectories.



Clicking on the down arrow will result in the display of a list of the current subdirectories of the current directory. Clicking on a subdirectory name will result in a change of current directory to that directory. The **Files in Directory** list will then display the files in the new directory, which can then be added to the **Files in Mapping Workbook** list. The **Browse** button permits the user to obtain a standard file dialog box to easily negotiate other directories to obtain files.



You should add only PfEFFER well workbooks to the **Files in Mapping Workbook** list. Inclusion of any other files (including LAS files) will result in errors. It is the user's responsibility to remember which files represent PfEFFER well workbooks. There is no way for the code to detect this prior to opening the files.
Filenames will be transferred to the **Files in Mapping Workbook** list with their full pathnames included.

The **Edit Mapping Workbook...** menu item should be selected only when the **Summary Sheet** in a **Mapping Workbook** is active. This option will result in the creation of a new mapping workbook, with the **Files in Mapping Workbook** list initially populated by the files contained in the current workbook. Otherwise, the operation of this option is identical to that described for the '**New Mapping Workbook**.

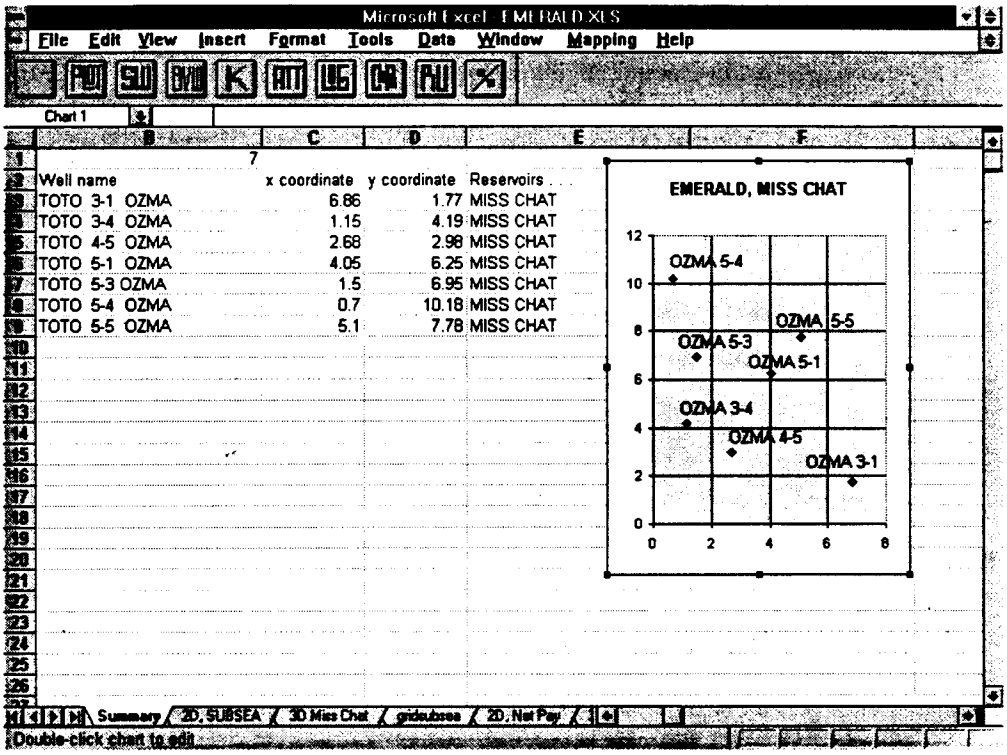
Creating a Mapping Workbook

Once you are satisfied with the list of selected files, click on 'OK'. The software will then open each of the selected **Well Workbooks** and transfer information from those workbooks to **Reservoir Unit Worksheets** in the **Mapping Workbook**, as described above. Depending on the computer, this operation may take a minute or two. Again, the names of unit worksheets in different **Well Workbooks** must be spelled identically (apart from capitalization) in order to be identified as the same unit. Otherwise, you will find separate sheets created for each unique spelling.

Most of the cells in the **Reservoir Unit Worksheets** of the **Mapping Workbook** are populated by linking them to the corresponding cells in the appropriate **Well Workbooks**; that is, the code sets their formulas rather than transferring actual numerical values to them. Thus, the **Reservoir Unit Worksheets** in the **Mapping Workbook** are dynamically linked to the **Reservoir Unit Worksheets** in the **Well Workbooks**. The one exception to this rule is that the 'X coordinate' and 'Y coordinate' values on the **Reservoir Unit Worksheets** in the **Mapping Workbook** are linked to the 'X coordinate' and 'Y coordinate' values for the corresponding wells listed on the **Summary Worksheet** of the **Mapping Workbook** itself, rather than to the values in the corresponding **Well Workbooks**. The coordinate values in the **Summary Worksheet** are linked (initially) to the 'X' and 'Y' parameters listed in the first **Reservoir Unit Worksheet** of the corresponding **Well Workbook**. Thus, the coordinate data in the **Summary Worksheet** represents the master copy of this information; editing coordinate data for a given well on the **Summary Sheet** results in changes to the coordinates for that well for all **Reservoir Unit Worksheets** in the **Mapping Workbook**. Numerical values entered in the X and Y cells on the **Summary Worksheet** will overwrite the formulas for those cells, breaking the link to the X and Y cells in the well workbooks. It is more than likely that the coordinate data cells in the **Well Workbooks** will not be populated with any meaningful information, anyway, since the **OpenLAS add-in** does not attempt to tackle the vast problem of extracting such information from the original LAS files. In other words, it is probably most reasonable to just use the X and Y coordinate cells in the **Summary Worksheet** as the central repository for coordinate information for a mapping project. The burden of finding location information for the wells and converting locations to consistent mapping coordinates rests entirely on you.

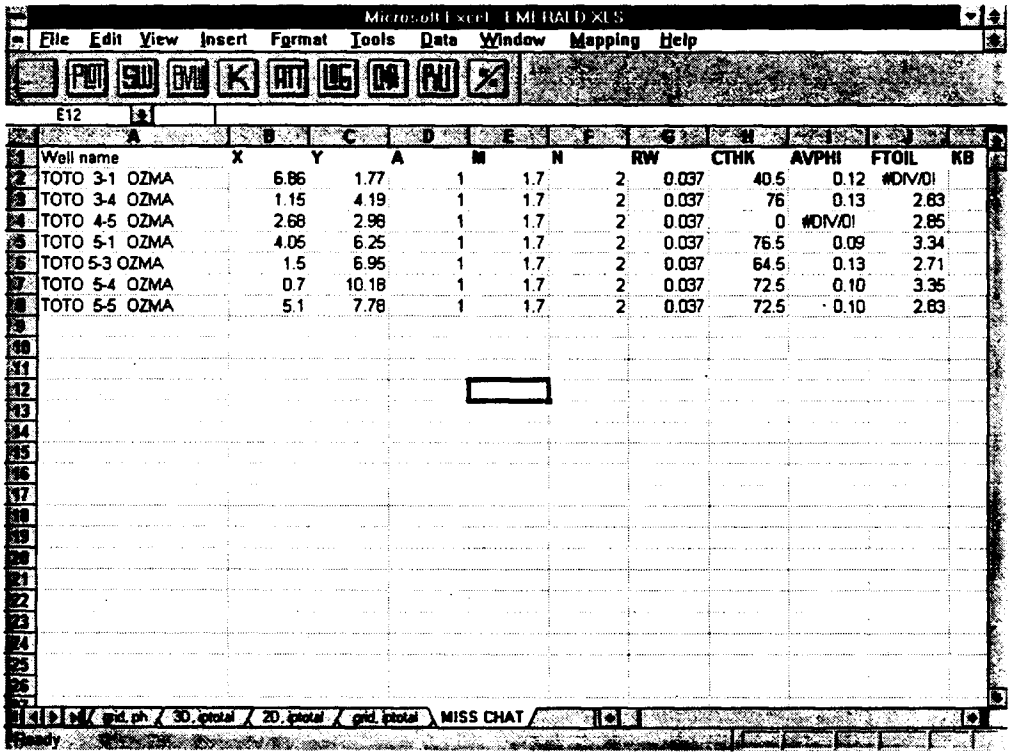
Summary Worksheet of the Mapping Workbook

The **Summary Worksheet** contains the file name, well name, X and Y coordinates, and reservoir names for each **Well Workbook** represented in the **Mapping Workbook.**



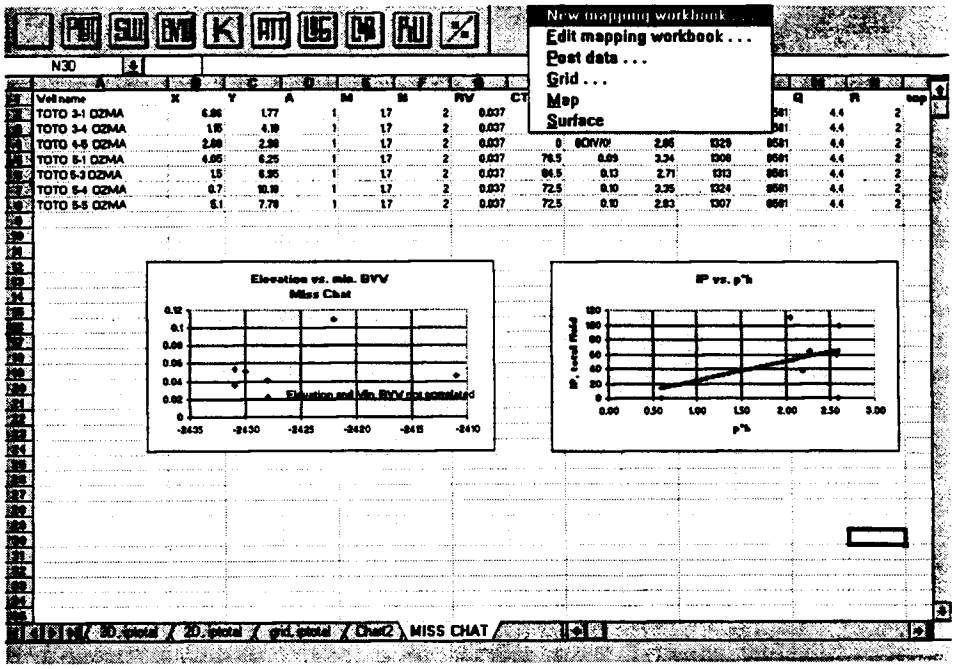
Reservoir Unit Worksheet of the Mapping Workbook

The **Reservoir Unit Worksheet** is accessed by clicking the mouse on the appropriate tab labeled with the reservoir unit name carried from the well workbooks. The worksheets contain well names, x, y, and the parameters that are common to the wells. The parameters are linked back to the original **Reservoir Unit Worksheets** of each **Well Workbook.** New parameters can also be added to the **Reservoir Unit Worksheet** in the **Mapping Workbook.** Graphs can also be made of any of the parameters to examine possible correlations.

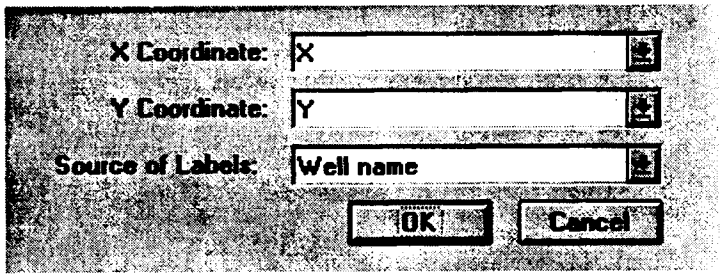


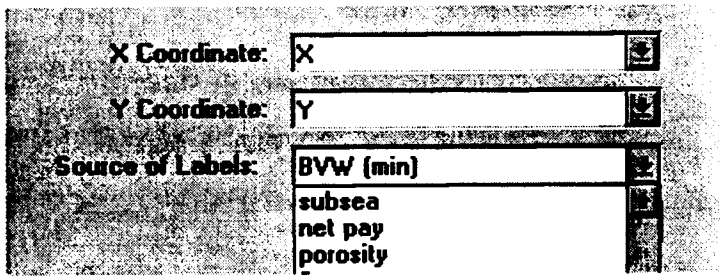
In addition, when a unit worksheet is active, the **Post Data... Option** can be used to create a posting of the well locations, or more generally an x-y scatterplot of any two variables in the sheet. After you select **Post Data...** you will be presented with a **Select Variables Dialog Box** like that for the **Grid... Option**, except that the third variable now represents the variable used to label the data points. By default this is set to the well name, but could be set to any other variable. For example, well locations could be posted labeled with the values of cumulative thickness. The title of the posting will indicate the name of the unit worksheet from which the data came and also the name of the variable used for labeling. It is likely that you will want to change the dimensions of the plot area and possibly the limits on the x- and y-axes in order to obtain a map with approximately the same scale on each axis.

post option

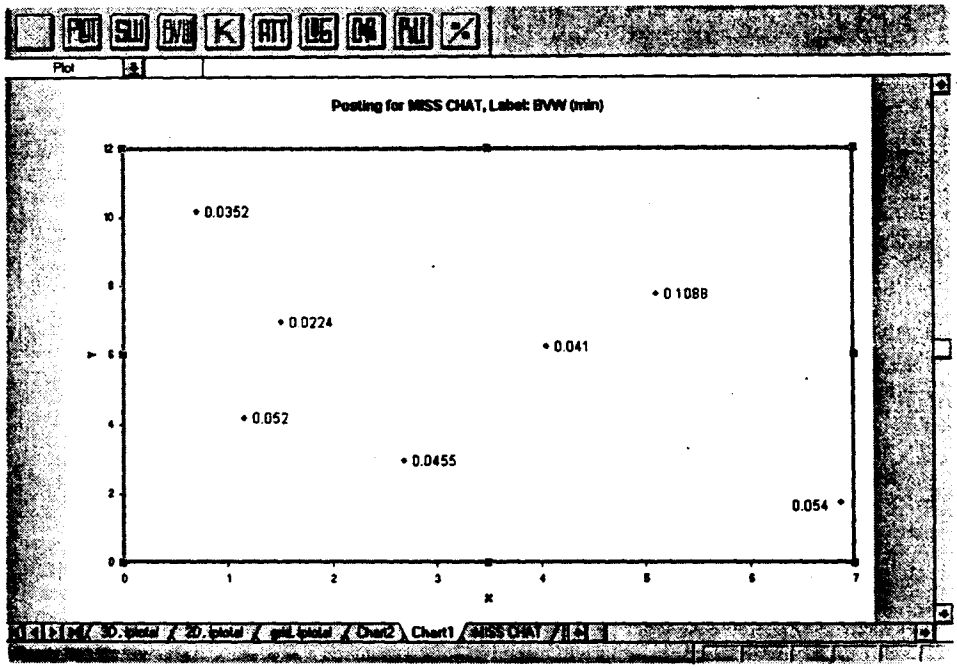


Select variables dialog box

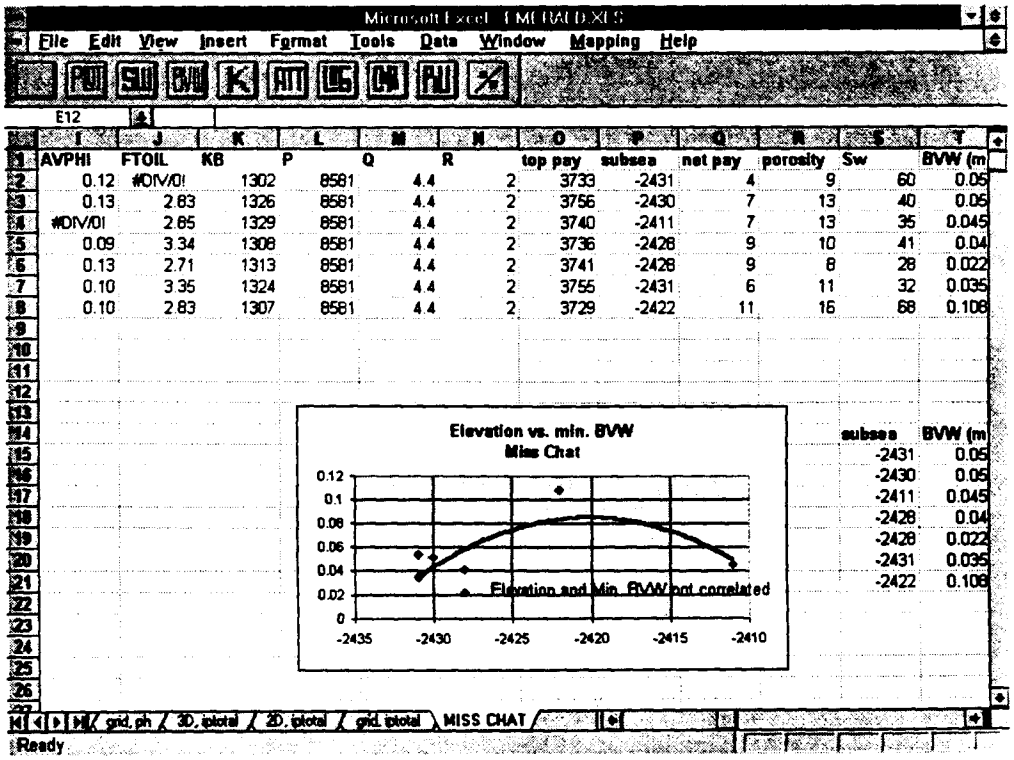




posting



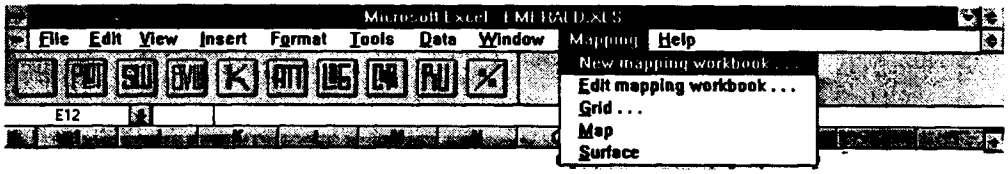
graphing in the reservoir worksheet



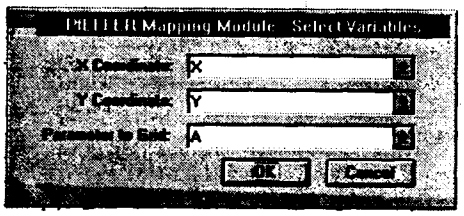
AVPHI	FTOIL	KB	P	Q	R	top pay	subsea	net pay	porosity	Sw	BVW (m
0.12	#DIV/0!	1302	8581	4.4	2	3733	-2431	4	9	60	0.05
0.13	2.83	1326	8581	4.4	2	3756	-2430	7	13	40	0.05
#DIV/0!	2.85	1329	8581	4.4	2	3740	-2411	7	13	35	0.045
0.09	3.34	1308	8581	4.4	2	3736	-2428	9	10	41	0.04
0.13	2.71	1313	8581	4.4	2	3741	-2428	9	8	28	0.022
0.10	3.35	1324	8581	4.4	2	3755	-2431	6	11	32	0.035
0.10	2.83	1307	8581	4.4	2	3729	-2422	11	16	68	0.108

subsea	BVW (m
-2431	0.05
-2430	0.05
-2411	0.045
-2428	0.04
-2428	0.022
-2431	0.035
-2422	0.108

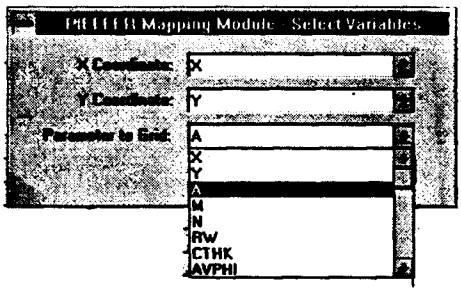
Once the X and Y coordinate values on the **Summary Worksheet** are filled with meaningful information, a map or three-dimensional surface representation of any parameter for a given unit may be created in a two-step process. First, the **Grid... Option** is used to interpolate the parameter values from the scattered locations of the wells to a regular grid. Then the **Map** or **Surface Options** is used to create a shaded contour or three-dimensional surface representation of this grid. To interpolate a parameter to a regular grid, first select the desired unit worksheet then select **Grid...** from the **Mapping Menu**. Selecting '**Grid . . .**' when the active sheet is something other than a **Reservoir Unit Worksheet** in a **Mapping Workbook** will result in unpredictable behavior.



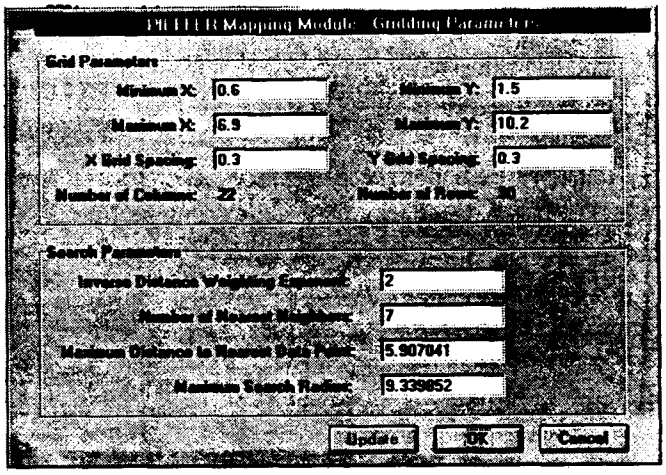
Once the grid option is chosen, you will then be presented with the **Select X, Y, Z Variables Dialog Box.**



This dialog box contains three drop down list boxes allowing you to select which parameters to use as the X and Y coordinates and as the parameter to grid.



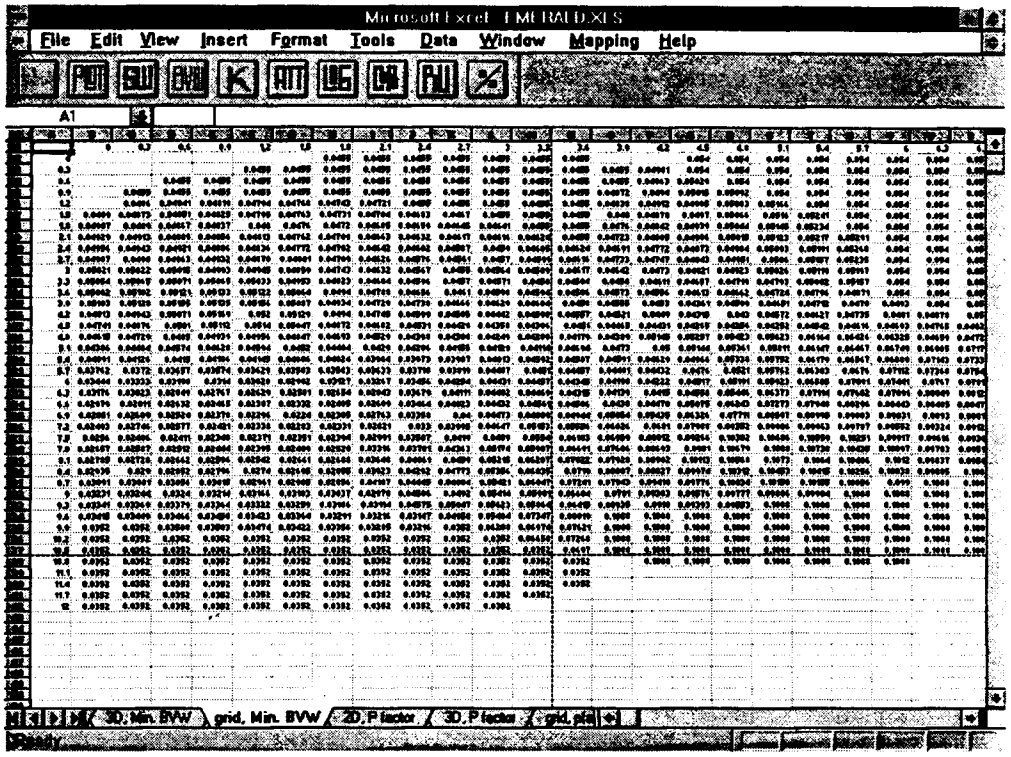
By default these will be set to the first three parameter columns, X, Y, and A. You will want to change the Z parameter to a mappable parameter, like CTHK (cumulative thickness) or other user defined variable. You can do this by clicking on the down arrow for the drop down list box and selecting the appropriate parameter from the drop down list. Click '**OK**' once the appropriate parameter values are selected and you will then be presented with the **Gridding Parameters Dialog Box.**



The upper portion of the box allows you to set the minimum and maximum X and Y values in the grid, as well as the grid node spacing. You may want to make sure that the X and Y values are the same between maps so that the maps show the same area. If data are missing from some of the wells, the minimum or maximum values of the grid may change and dimensions of he the generated maps will be different.

The lower portion of the menu allows the user to set several parameters controlling the search and interpolation processes described below. If any of these values are changed, the '**OK**' button will be disabled and the **Update** button will be enabled. The **Update** button triggers code that checks the consistency of some of the values and recomputes the number of columns and rows in the grid. Once '**Update**' is selected, '**OK**' is reactivated. This process can be repeated until you are satisfied with the parameter values. At this point, click '**OK**'.

The software then inserts a new worksheet in the workbook to contain the gridded parameter values.

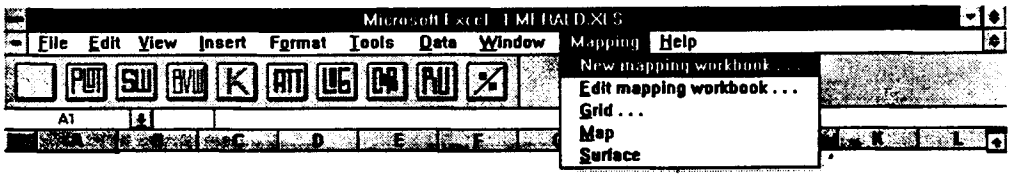


The grid node X coordinates will be listed in the first row of the **Grid Worksheet**. The grid node Y coordinate values will be listed in the first column. The gridded parameter value for a given node will be listed in the cell at the intersection of the column and row for the corresponding X and Y values. Certain cells may be empty due to a search failure, described below. Unfortunately, when a map or 3D surface of this grid is created, the empty cells will be represented as if they contained zeros. The user can increase the search radius or maximum distance to nearest data point, if desired.

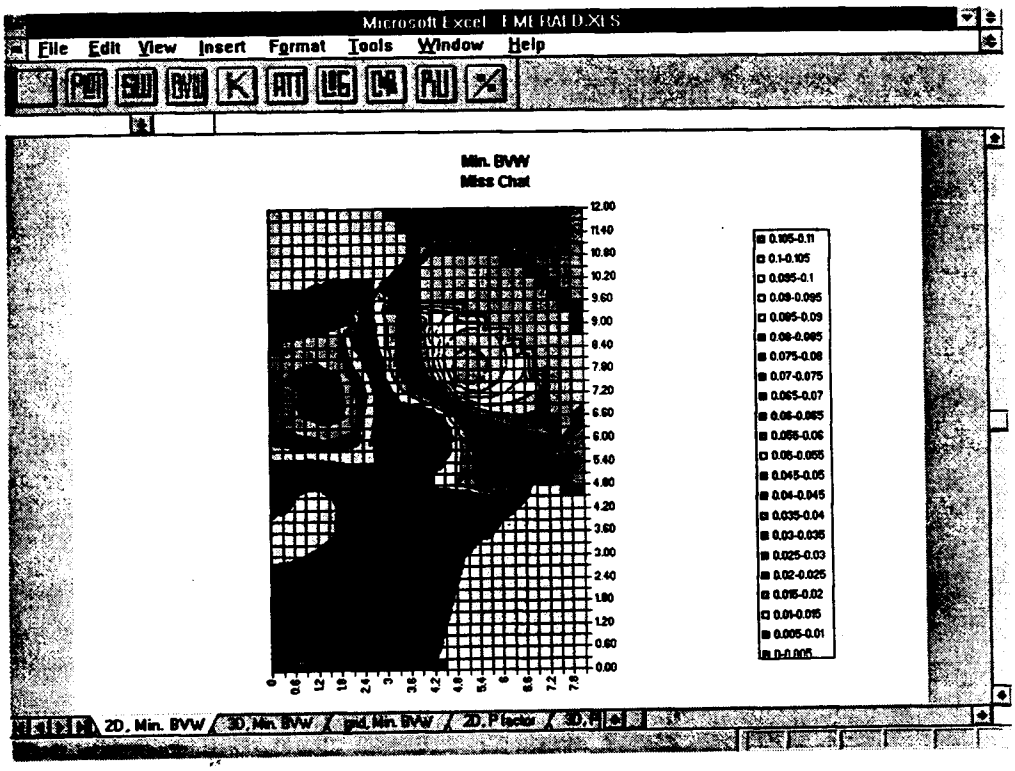
The interpolation algorithm is a simple inverse distance weighted averaging algorithm as described in Davis (1986). By default an inverse distance-squared weighting is used, but you have the option of changing the exponent (Inverse Distance Weighting Exponent on the **Gridding Parameters Dialog Box**) so that, for example, you could use inverse distance (exponent = 1) or inverse distance-cubed (exponent = 3) weighting. The effects of varying

the exponent are described in Davis (1986). A simple nearest neighbor search is employed. The maximum number of nearest data points to use in estimating the parameter value at a grid node is specified as **Number of Nearest Neighbors** in the **Gridding Parameters Dialog Box**. By default, eight nearest neighbors are used. Two additional parameters that control the search algorithm are the maximum allowable distance from the estimation point (grid node) to the nearest data point (**Maximum Distance to Nearest Data Point** on the **Gridding Parameters Dialog Box**) and the maximum search radius (**Maximum Search Radius**). If no data points are found within the maximum allowable distance to the nearest data point, then the search fails for that grid node and the corresponding cell is left empty. If the search does not fail, then the algorithm will search for data points until either the number of data points specified in the **Number of Nearest Neighbors Box** is found or until there are no points left within the specified maximum search radius, whichever happens first. The default value for the maximum allowable distance to the nearest data point is set so that, on average, twice the number of data points specified as 'Number of Nearest Neighbors' would fall within this radius assuming a uniform distribution of data points across the map area. The default maximum search radius would contain, on average, five times the specified number of nearest neighbors under the same assumption. These are the same criteria used to set the default search neighborhood values for the nearest neighbor search in Surface III (Sampson, 1988).

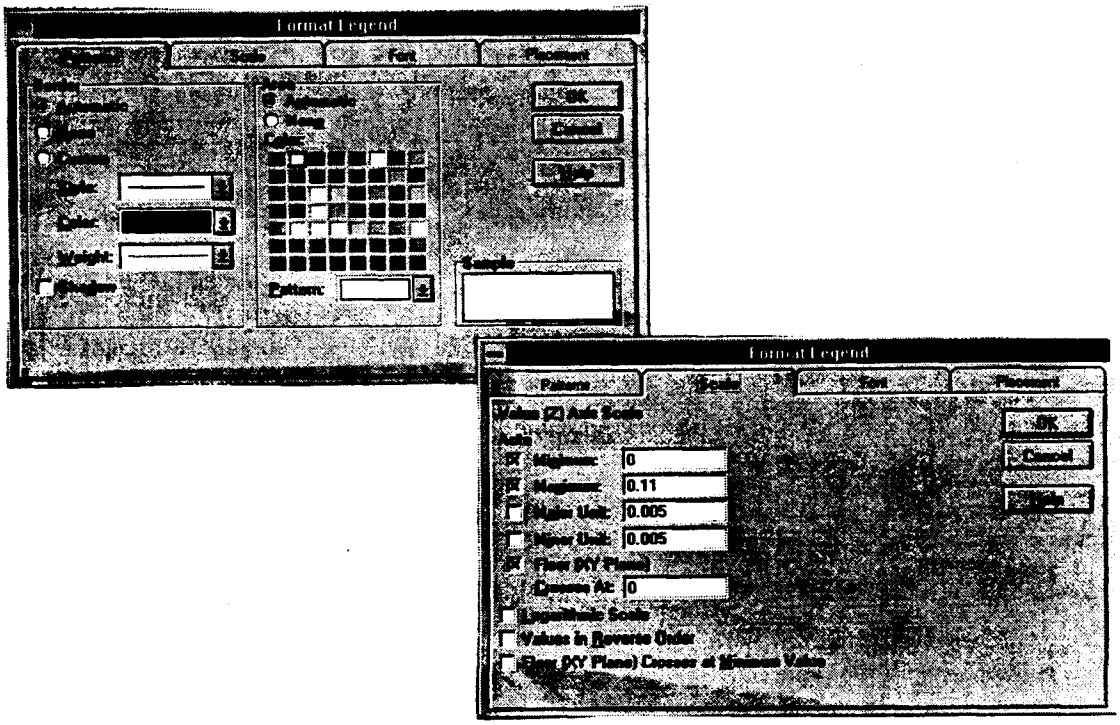
When a **Grid Worksheet** containing a grid is active, you may select the **Map Option** from the **Mapping Menu** to create a shaded contour map of the gridded values or the **Surface...** option to create a 3D shaded surface representation.



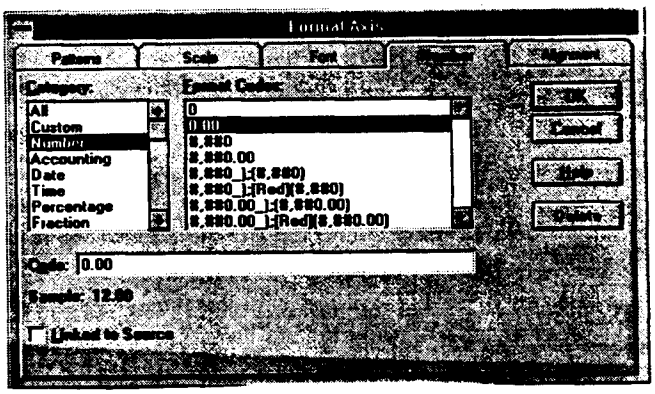
The map or shaded surface will be created on a separate chart sheet.



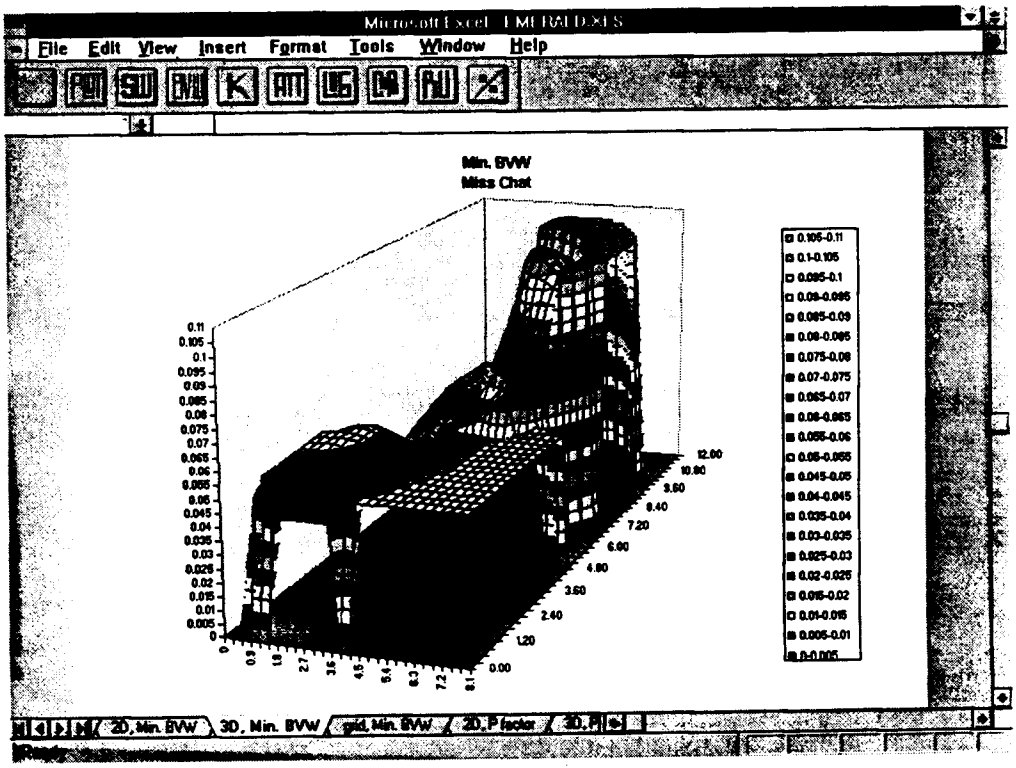
Standard EXCEL operations may then be used to annotate the chart or modify its appearance. For example, double-clicking on the legend allows you to modify the scale. Legend placement and size can also be made.

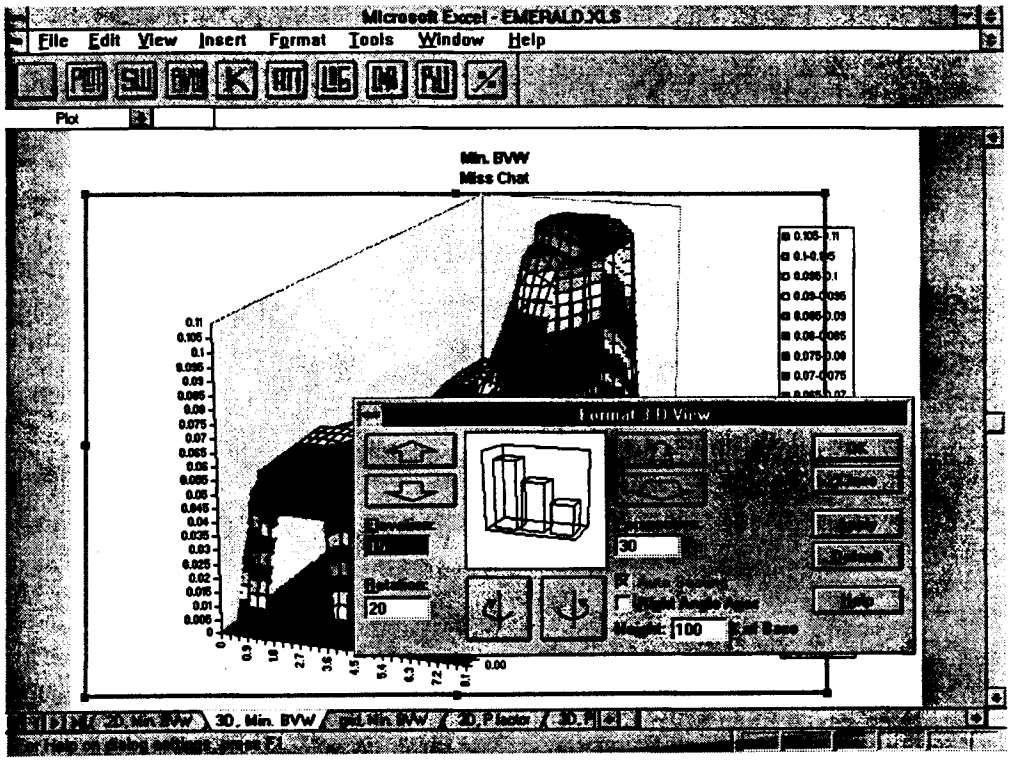


Clicking on a labeled axis of the map can permit you to re-format the grid labels, e.g., changing the significant figures to two beyond the decimal point using the **Number Menu** in the **Format Axis Dialog Box.**

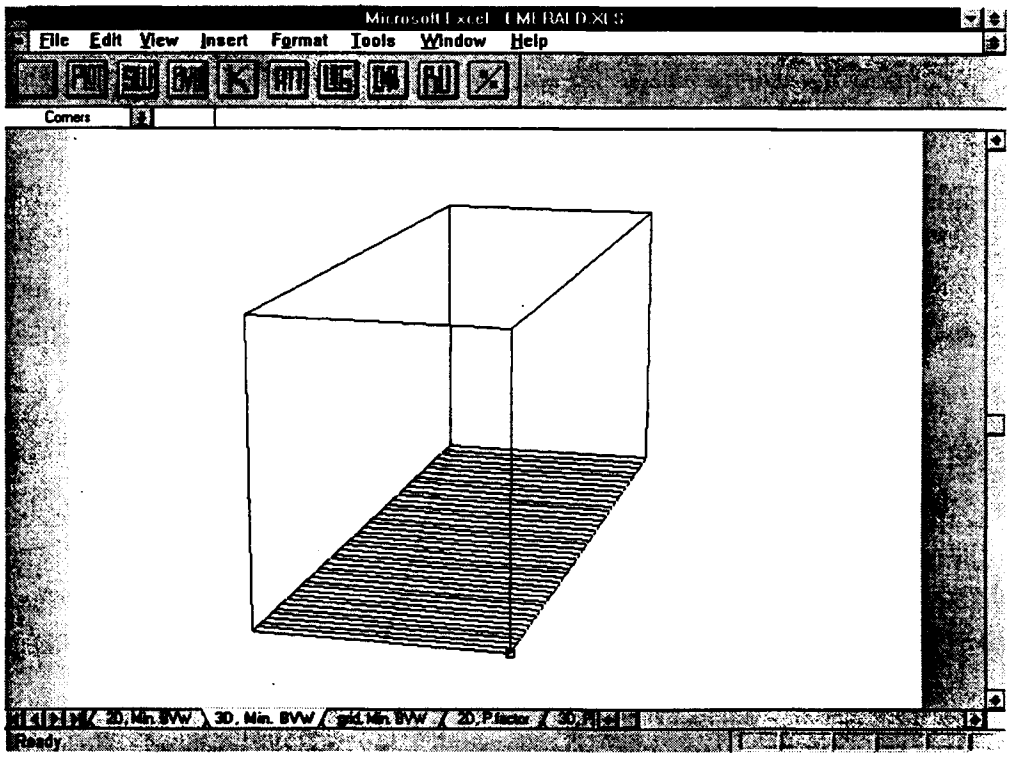


A three-dimensional chart can also be generated from the grid sheet. The 3-D chart works well to make B&W copies since the "topography" is clearly illustrated. Clicking on a 3-D chart will permit you to reformat and change the perspective of the 3-D view.





3-D edit dialog box



wireframe

A wireframe box can be generated by clicking the mouse on a lower corner of the 3-D diagram and holding down on the mouse until the wireframe appears. The box can be moved at will as long as the mouse button remains depressed.

Select the **Titles Option** from the **Insert Menu** to add axis labels and a chart title. For contour maps, the horizontal axis represents the X coordinate (increasing column number in the **Grid Worksheet**) and the vertical axis represents the Y coordinate (increasing row number in the **Grid worksheet**). For 3D representations, the near axis is the X axis and the receding axis is the Y axis.

If grids need to be modified and new maps generated, the user can easily delete the unwanted charts and sheets by clicking on the tab labels located at the bottom of the screen. The right mouse button can be used to delete the chart or sheet. The mouse can also be used to move the highlighted tab to another location. Also the re-naming of the sheets and charts can be accomplished through the same procedure to facilitate preparing your electronic report.

Charts can be written to other sheets or workbooks and aggregate sets of diagrams can be compiled.

References

Davis, J. C., 1986, Statistics and Data Analysis in Geology, Second Edition, John Wiley & Sons, New York, 646 pp.

Sampson, R. J., 1988, Surface III User's Manual, Kansas Geological Survey, 277 pp.