Blocking—A New Technique for Well Log Interpretation

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Summary

Almost all well log measurements at a given depth are influenced by formation properties up and down the wellbore. Blocking is a way to eliminate these influences and to restore the original signal, while at the same time performing bed thickness corrections. In addition to obtaining more accurate log values for estimating formation properties, blocking allows zone-by-zone analysis by computer.

Introduction

A very basic fact about well logs is that they all require interpretation. One reason is that the log reading at a given depth does not represent the exact value at this point but is affected by formation characteristics up and down the well. The usual way to deal with this problem is to divide the log into zones corresponding to geological formations of relatively constant character and to work with average values in every zone, applying all possible corrections. The number of intervals that can be picked is limited by the amount of calculations that have to be performed. The values thus obtained are averaged.

Computerized well log data processing allows the log analyst to perform all the calculations at every depth where the measurements were made, thus providing many more data. The point-by-point approach usually taken has its weakness, however, in that the total zones are not considered. Taking the spontaneous potential (SP) log as an example, we see that it measures correct values only in thick beds, and far enough from bed boundaries. Calculations based on E_{SP} close to bed boundaries will be incorrect. If the bed is thin enough, we may not be getting correct calculations anywhere in this bed.

Computed well logs, therefore, do not give absolutely correct answers and must be interpreted. The error in computed logs gets more pronounced as we get closer to bed boundaries. Some of the calculations are completely wasted. The purpose of this work is to show how to do correct bed-by-bed analysis, either manually or with a computer.

Since manual processing already takes bed boundaries into account visually, one can use the algorithm in this paper to obtain better corrections for the log values in cases of complex stratification. For computer-oriented well log processing, this work helps achieve the following goals.

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1. Determine bed boundaries from the logs.
2. Correct for bed boundary effects—i.e., determine the "true" value of the log, without the influence of the nearby layers.
3. Differentiate between meaningful and random features on the logs by use of specially designed filters. This latter technique is used here to help apply blocking to different logs. It also has other applications, described later.

The whole idea that log values should be constant in each bed or, more strictly, "sedimentary facies," is not new. In fact, it follows from the definition of facies. In the case of an SP log, the relationship between a block-form static SP and observed SP is a standard topic.[1,2] These publications also give correction charts for the most simple case of one thin bed surrounded by two identical thick beds—a sandwich.[1] This work extends the previous results for cases of stratification of any complexity.

Another idea related to blocking is the definition of lithofacies from logs[3] by the use of specially defined electrofacies. The concept of electrofacies is indeed similar to blocking. However, there is a very important difference. In Ref. 3, electrofacies are defined with the help of statistical methods such as clustering. The assumption for these methods is that observed log measurements would be constant, if not for statistical variations. The electrofacies are then defined as those depth intervals where the log values fall within variation limits. This assumption is not true close to bed boundaries. Also, since the log values inside electrofacies are defined from statistics, the observed log readings are taken as actual values, and no bed thickness correction is made. The current work takes a different approach. First, the problem is stated and solved for the ideal case where the log is correct and contains no error. Then the algorithm is adjusted to account for noise by use of specially designed filters.

It is best to explain the blocking algorithm with an example. In the following example, the SP log is used. Other logs are considered later.

Example of the Use of the Algorithm

Fig. 1 shows an example of an E_{SP} log (solid line) and a "true" response curve (dashed line), which is called E_{SSP} [static spontaneous potential (SSP)]. It is the values of E_{SSP} and not E_{SP} that must be used in the calculations to arrive at such parameters as the volume of shale. Evidently the E_{SP} did not reach the full value, and must be corrected. Fig. 2 is a correction chart. To apply the chart, bed boundaries must be known. According to many authors (e.g., Refs. 1 and 2), bed boundaries correspond to inflection points of the E_{SP} log. Analysis done in this paper shows that this is never exactly true, but it can be used with a good degree of approximation. Given the bed boundaries and bed thickness, a correction factor can be obtained from the chart of Fig. 2.[4] The corresponding E_{SSP} is shown in Fig. 1. This example shows a thin sand bed inside a thick shaly bed. Correction to the thin-shale bed is a mirror image of the preceding correction and can be done with the same chart.

Fig. 3 depicts a case of a more complex stratification. How should corrections be made to obtain the values of E_{SSP_1}, E_{SSP_2}, and E_{SSP_3}? In trying to apply the simple algorithm just described, we find at least three different approaches.

1. Correct AB and DC first, then correct BC.
2. Correct BC first, then correct AB and CD.
3. Correct AD as one bed, then correct BC, etc.

Within these choices, some questions are still not resolved. For example, if AD is corrected as one bed, should the values of E_{SP} in the interval BC be changed accordingly? And if so, how, or should it be left unchanged until it is later corrected as a single bed?

Evidently, depending on the order in which corrections are applied, the results will be different. This shows that the corrections cannot be dealt with separately but should all be applied at one time. This can be done in the following manner. The E_{SSP} diagram should be broken into three simple diagrams as shown in Fig. 4. Each diagram shows the influence of a single bed on the E_{SP} log. The measured E_{SP} is the sum of responses to each bed. The initial E_{SP} diagram can be obtained as a sum of elementary blocks. At any depth, therefore (Fig. 4), the measured SP can be broken into three components:

$$E_{SP_A}=E_{SP_1}+E_{SP_2}+E_{SP_3}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where E_{SP_A} is the apparent SP at any given depth in the well, and E_{SP_1}, E_{SP_2}, and E_{SP_3} are components from Beds 1, 2, and 3, correspondingly. Eq. 1 reduces a complex E_{SP} response to a sum of simple single-bed responses. Furthermore, it is possible to represent each simple response as a specifically determined "unit" response multiplied times a constant. Fig. 5 shows an SSP log termed E_{SSP} with the amplitude of A_{SSP}, and a unit SSP termed $E_{SSP}{}^1$ with an amplitude of 1 mV. Evidently, the E_{SSP} can be represented as unit static response times the amplitude A_{SSP}:

$$E_{SSP}=E_{SSP}{}^1\times A_{SSP}. \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In the same manner, the apparent E_{SP} curve can be represented as a unit response $E_{SP}{}^1$ (the one corresponding to the SSP with the amplitude of 1 mV) times the amplitude A_{SSP}:

$$E_{SP}=E_{SP}{}^1\times A_{SSP}. \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Later in this article we show how the unit response $E_{SP}{}^1$ can be found from the correction chart (Fig. 2).

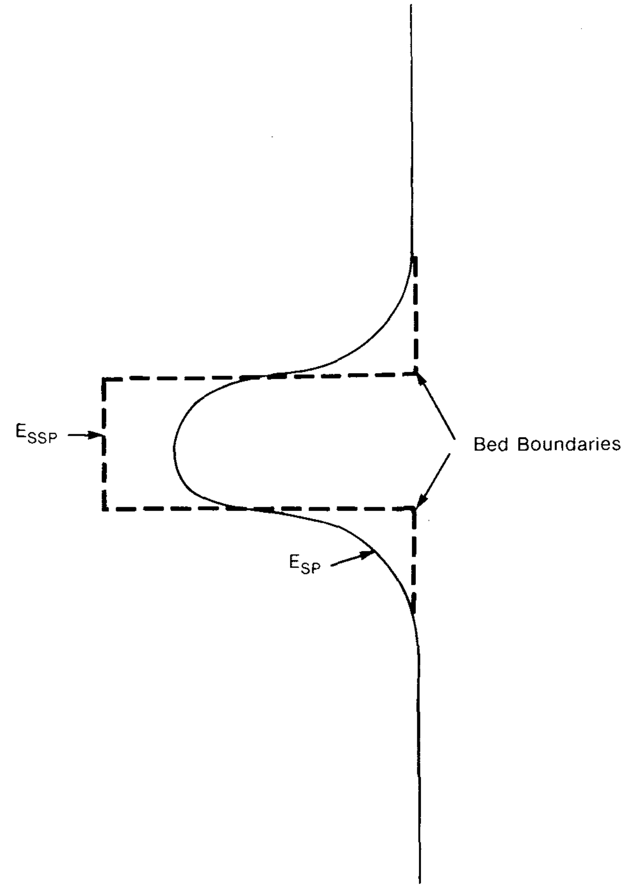


Fig. 1—Correcting SP log in the most simple case.

For now, certain numbers are assumed that are verified later, and the discussion of Fig. 4 continues.

As has been pointed out, at any depth Eq. 1 breaks the E_{SP} into the sum of elementary responses: E_{SP_1}, E_{SP_2}, E_{SP_3}. Combined with Eq. 3, this yields a linear equation with the amplitudes of SSP: A_{SSP_1}, A_{SSP_2}, A_{SSP_3} as unknowns. To solve for three unknowns, three equations are needed. Furthermore, to form these equations, three points on the log corresponding to the centers of the beds on Fig. 4 are used. It is now possible to generate a table for the system of equations (Table 1).

What is the meaning of the numbers in this table? The superscript "1" shows that this is a unit response—i.e., a response that would be observed if the SSP in this bed were 1 mV. The subscript indicates beds (1, 2, 3). E_{SP_1}, therefore, is a measure of influence generated by Bed 1 on the total E_{SP} at different depths.

Using the values in Table 1, we can form a system of simultaneous linear equations, the purpose of which is to determine A_{SSP} in each bed:

$$-0.488\times A_{SSP_1}-0.165\times A_{SSP_2}-0.050\times A_{SSP_3}$$

$$=-50 \text{ mV},$$

$$-0.243\times A_{SSP_1}-0.33\times A_{SSP_2}-0.243\times A_{SSP_3}$$

$$=-45 \text{ mV},$$

and

$$-0.050\times A_{SSP_1} - 0.165\times A_{SSP_2} - 0.488\times A_{SSP_3}$$

$$= -50 \text{ mV}, \qquad \qquad (4)$$

where the units of A_{SSP} are in millivolts.

One may notice a certain symmetry in the system; this is because the geological picture in our example is symmetrical.

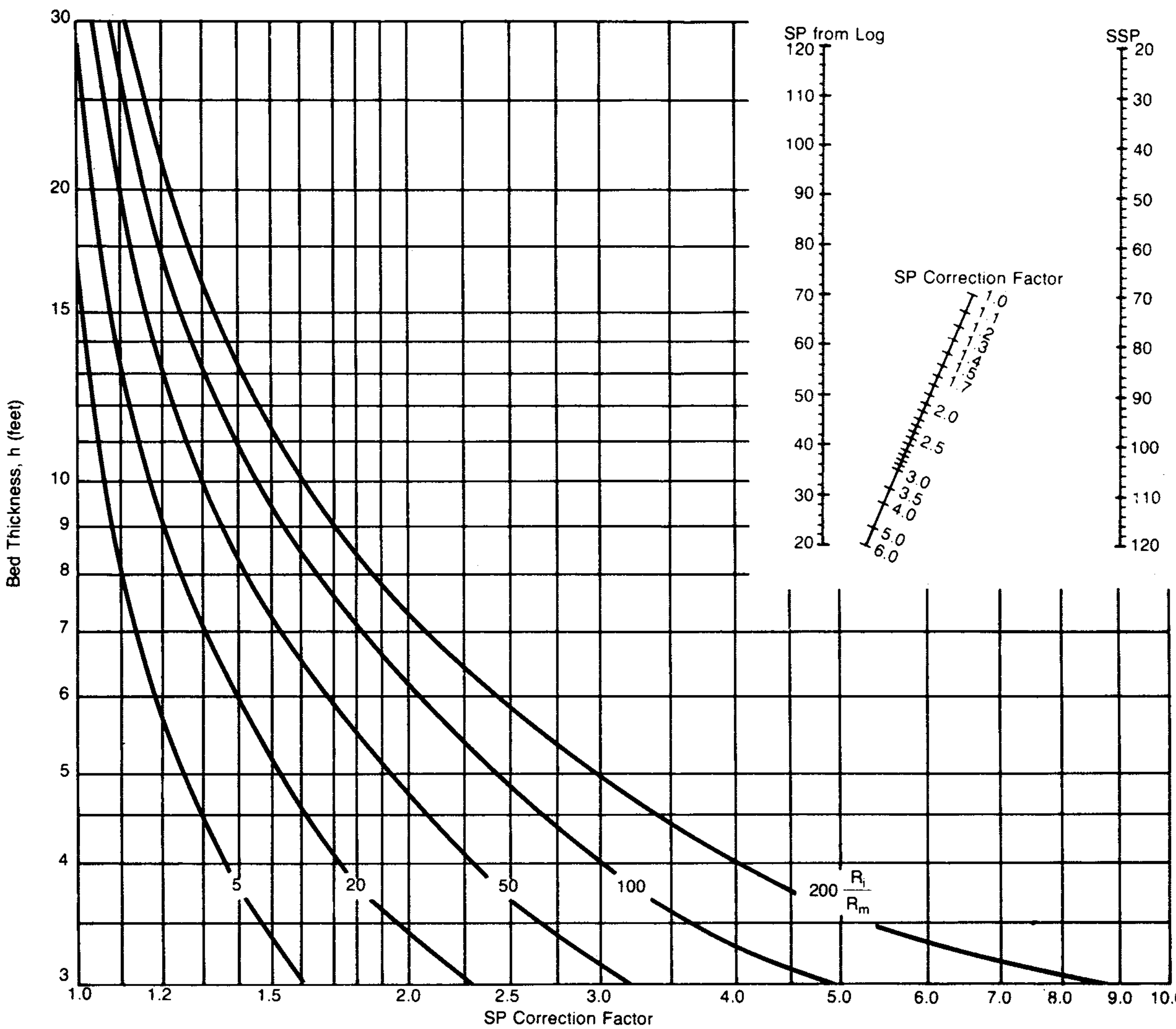
The solution to System 4 is as follows.

$$A_{SSP_1} = -93 \text{ mV},$$

$$A_{SSP_2} = 0 \text{ mV},$$

and

$$A_{SSP_3} = -93 \text{ mV}. \qquad \qquad (5)$$



Equations:(2)

$$\text{SP correction factor} = \frac{\left\{4\left(\frac{R_i}{R_m}+2\right)\right\}^{\frac{1}{3.65}} - 1.5}{h - \left\{\left(\frac{R_i}{R_m}+11\right)/0.65\right\}^{\frac{1}{6.05}} - 0.1} + 0.95 \qquad \text{for } \frac{R_i}{R_m} > 5 \text{ and } 3 < h < 50$$

SSP = SP × SP correction factor

Example:

Given: $SP_{(log)} = -50$ mV ; h = 8 ft ; R_i = 35 Ω-m ; R_m = 0.7 Ω-m

Solution: Bed thickness = 8 ft ; R_i/R_m = 50 ; SP correction factor = 1.42

Nomograph Solution: SP_{log} = 50 mV ; SP correction factor = 1.42 ; SSP = −71 mV

Fig. 2—A chart for correcting E_{SP} for bed thickness.

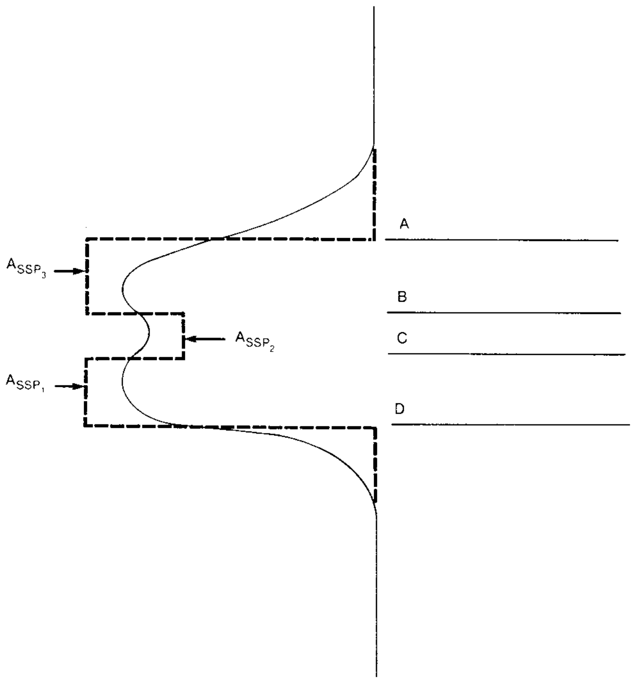


Fig. 3—SP log in the case of a more complex stratification.

Had corrections been applied singularly, the results would be as follows.

$$A_{SSP_1} = -50 \text{ mV} \times 2 = -100 \text{ mV},$$

$$A_{SSP_2} = -45 \text{ mV} + (50 \text{ mV} - 45 \text{ mV}) \times 3 = -30 \text{ mV},$$

and

$$A_{SSP_3} = -50 \text{ mV} \times 2 = -100 \text{ mV}. \quad \ldots\ldots\ldots\ldots (6)$$

The results differ noticeably, especially for the middle bed ($A_{SSP_2} = -30$ mV from the chart, as opposed to the correct value $A_{SSP_2} = 0$ mV). This is exactly what could be expected, since applying the chart directly does not take into account the influence of the nearby beds.

In summary, Eq. 4 provides better estimates of correct log values. This system can be formed and solved for stratification of any complexity, where (apart from getting better values) it may be difficult to determine how to apply the chart at all. Finally, by virtue of its exact formulation, this method can be used in a computer program.

Generalization

In the preceding example, it has been shown how the blocking algorithm can be applied for processing the SP log. The reason why the E_{SP} makes a good example is that it is an important application, a name already exists for the corrected (blocked) log (SSP), and the correction itself has been discussed in literature.[1,2]

To describe formally the algorithm and the class of all logs to which the algorithm is applicable, additional theory must be introduced.

In the general case of n beds, Eq. 1 can be rewritten in the form

$$E_{SP} = \sum_{i=1}^{n} E_{SP_i}. \quad \ldots\ldots\ldots\ldots (7)$$

This equation states the property of additive linearity: the total measured signal is the algebraic sum of signals coming from each bed. For the measurements that are done in one point, this means that there is no interference. This equation holds for the SP log because of linearity of electrical fields. For natural gamma ray logs, it is also true because with the instrument size as it is, gamma rays can be considered as particles, not waves, and added algebraically. This implies an absence of wave interference. Eq. 7 will not hold for resistivity, neutron density, and acoustic logs, because of the way the measurements are averaged on a certain interval and not in one point. For these logs, the blocking algorithm can still be applied, but with a certain degree of approximation discussed later.

A second log property important for blocking was expressed by Eq. 3 and, for our purposes, can be rewritten as follows.

$$E_{SP} = E_{SP}^{\,1} \times A_{SSP}. \quad \ldots\ldots\ldots\ldots (8)$$

To clarify the meaning of this equation, we must rewrite it in the following form.

$$\frac{E_{SP}}{E_{SP}^{\,1}} = \frac{A_{SSP}}{1}. \quad \ldots\ldots\ldots\ldots (9)$$

Eq. 8 states that in a given bed, the ratio of apparent E_{SP} signals is equal to the ratio of corresponding SSP signals (E_{SSP}). In Eq. 9, this fact is expressed in relation to the unit response: E_{SSP} is equal to 1 mV, and $E_{SP}^{\,1}$ is the response corresponding to this unit E_{SSP}. However, it is easy to show that a more general relation is true. Let E^*_{SP} be another log response in the same bed, corresponding to a static signal, E^*_{SSP}. (Physically, this can be modeled by water or mud filtrate salinity being changed, without changing bed boundaries). Then according to Eq. 9:

$$\frac{E^*_{SP}}{E_{SP_1}} = \frac{E_{SSP}}{1}. \quad \ldots\ldots\ldots\ldots (10)$$

From Eqs. 9 and 10 it follows that

$$\frac{E_{SP}}{E^*_{SP}} = \frac{E_{SSP}}{E^*_{SSP}}. \quad \ldots\ldots\ldots\ldots (11)$$

Eq. 11 is assumed in the chart on Fig. 2, where the correction factor does not depend on the actual E_{SP} amplitude but only on bed thickness. For the E_{SP} log, Eqs. 7 and 11 are theoretically true because of linearity of electrical fields. For the natural gamma ray log, Eq. 11 follows from the fact that this log may be represented by a convolution integral and from linearity of such an integral. For resistivity logs, Eq. 11 does not hold, because changes in formation resistivity affect the

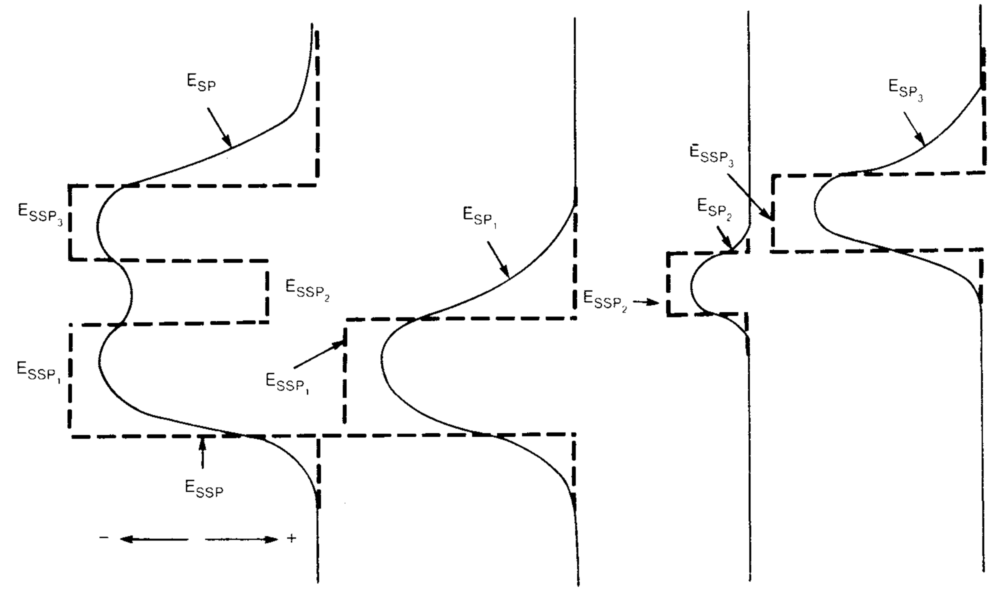


Fig. 4—Breaking an SP log into a sum of elementary responses.

distribution of the power lines in the electrical fields, which makes the response nonlinear. A certain degree of approximation is required here, and it is discussed together with approximations to Eq. 7.

Note that Eq. 7 defines the relation between E_{SSP} and E_{SP} when only one E_{SSP} is present in one bed. It is possible to combine Eqs. 7 and 11 into one statement that will not have such a limitation. Let E_{SSP_1} be an arbitrary SSP signal at a certain depth interval, and E_{SP_1} be the corresponding observed signal. The relationship of correspondence between the theoretical and observed log response will be denoted by an arrow ($\to$), so for E_{SSP_1} and E_{SP_1} this can be expressed as

$$E_{SSP_1} \to E_{SP_1} . \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Also let, E_{SSP_2} be another signal, so that

$$E_{SSP_2} \to E_{SP_2} . \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

From Eqs. 7 and 11 and because Eq. 7 is true for any combination of bed boundaries, it follows that an algebraic sum, $E_{SSP_1} + E_{SSP_2}$, will produce an observed signal $E_{SP_1} + E_{SP_2}$. In symbolic notation, this can be stated as

$$E_{SSP_1} \to E_{SP_1} ,\ E_{SSP_1} \to E_{SP_2} => E_{SSP}$$

$$+ E_{SSP_2} \to E_{SP_1} + E_{SP_2} , \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where => denotes "implies."

Eq. 11 can be rewritten with this notation in the following form.

$$E_{SSP_1} \to E_{SP} => K \times E_{SSP_1} \to K \times E_{SP_1} , \quad \ldots\ldots \quad (15)$$

where K is any real number.

Eqs. 14 and 15 represent a more familiar expression of the property of linearity, where linearity is attributed to the relation denoted by an arrow and representing a relation between actual and observed signal.

For the purpose of convenience, Eqs. 14 and 15 have been formulated in terms of the SP log. Evidently, E_{SP} can be substituted for any other appropriate log. Eq. 14 is more useful than Eq. 7 and is now used to find a relation between observed signals and correction charts.

Relation Between Observed Log Response and Bed-Thickness Corrections Chart

In the formulation of the blocking algorithm, a complex log response was reduced to a sum of elementary responses (Fig. 4), which in turn were represented as unit responses times a constant (Fig. 5). The question of finding the values of a unit response at any depth was not answered there. It is now possible to resolve this question and show how one can find values for Table 1—in other words, how to form the system of linear equations for the true log responses. (The term "log response" should not be confused with the instrument response. Log response is affected primarily by formation properties up and down the well, not by characteristics of the logging instrument.)

The unit response was defined as E_{SP} corresponding to the E_{SSP} with the amplitude of 1 mV. Given the bed thickness, how can this unit response be found?

The unit log, $E_{SSP}{}^1$ (1), can be broken even further into the sum of two steps (2 and 3) as represented in Fig. 6. According to (Eq. 14), log response (4) will be broken into a sum of two responses to a step (5 and 6), each representing an observed log at a boundary separating one infinitely thick bed from another. This is a purely mathematical representation. For the E_{SP} log, one can think of changing mud filtrate salinity and thus inverting the polarity of a signal. For other logs (such as natural gamma ray), it may not have any physical meaning. The two responses to a step on Fig. 6 (5 and 6) are symmetrical and, in fact, represent one universal response function, f, in two different positions. A unit response

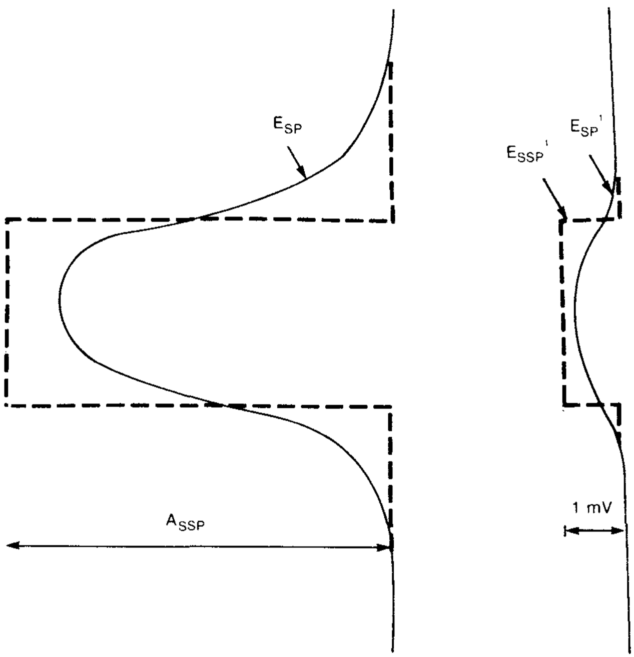


Fig. 5—Representing elementary log response as unit responses times a constant.

for any bed thickness can be calculated as a sum of the two (f) functions, with their zeros being at two respective bed boundaries. The value of f for any argument can be determined from a simple consideration.

Since the two curves on Fig. 6 (5 and 6) are symmetrical, their values at 0 are identical, both being equal to f (h/2), where h is bed thickness. Being added in Fig. 6, (4) they give the value of $2 \times$f (h/2) at 0. On the other hand, if we were to correct E_{SP} using the bed-thickness correction chart (Fig. 2) we would use the bed thickness to obtain a correction factor $F(h)$, and multiplied by the maximum log deflection to obtain the value of 1 mV. Therefore, with the maximum deflection being denoted as δ, the equation for δ is

$$\delta \cdot F(h) = 1, \quad \ldots\ldots (16)$$

and

$$\delta = \frac{1}{F(h)}. \quad \ldots\ldots (17)$$

At the same time, the maximum deflection on Fig. 6 (4) occurs at zero, and the value there has already been found to be $2 \times$f (h/2). Therefore,

$$\frac{1}{F(h)} = 2 \times \mathrm{f}\left(\frac{h}{2}\right). \quad \ldots\ldots (18)$$

This equation relates the observed log response on the boundary of two infinitely thick beds, and a bed-thickness correction chart. Eq. 18 can be used in three different ways. If the correction chart is given, it can be used in the blocking algorithm to produce the correct (blocked) signal. If the chart is not given, Eq. 18 can be used to build such a chart. The only condition is to use a log with two adjacent beds that are thick enough for the log response to level off. Finally, Eq. 18 can be used to construct a self-correcting blocking algorithm. One part of the log would be used to find the response, f, equivalent to the correction chart, and then apply that response in another part of the log to produce the corrected log values. For computational purposes, Eq. 18 can be rewritten, substituting h/2 for D. The final expression now takes the form

$$\mathrm{f}(D) = \frac{1}{2F(h)}, \quad \ldots\ldots (19)$$

where f(d) is a log response to a step in the true log value at the depth D counted from the bed boundary; $F(h)$ is a correction factor from the bed-thickness correction chart; and h is the bed thickness that is entered on the chart, $h = 2 \times D$. Of course, the chart may also require other parameters, such as R_i/R_m, which should be determined from the log or the log heading.

Determining Bed Boundaries From Logs

In Refs. 1 and 2, bed boundaries are said to be found at the inflection points of the E_{SP} log. Fig. 6 explains why this is not always true. In Secs. 5 and 6, bed boundaries occur where the log crosses the horizontal axis. The logs do have an inflection point in these places, because the boundary separates two infinitely thick beds and is symmetrical, with the bed boundary being a plane of symmetry. In Sec. 4, however, the log is a sum of two logs from Secs. 5 and 6. The bed boundary has not moved, but the log does not have an inflection point at this depth.

Indeed, the second derivative of a curve at an inflection point must be equal to zero. However, the second derivative of a log in Sec. 4 at the bed boundaries is not zero, since it can be represented by the sum of two derivatives from logs in Secs. 5 and 6, one of which is zero (inflection point), and the other is not.

Eq. 19 opens a way to check what the degree of approximation is in assuming the bed boundary to be at the inflection point of the log, by investigating the behavior of the second derivative of f. For the E_{SP} log, it has been found that this assumption is accurate within the sampling interval (usually 0.5 ft [0.15 m]) and the chart limits (bed thickness not less than 3 ft [0.9 m], R_i/R_m not greater than 200). Therefore, within certain limits, bed boundaries can be taken at the log inflection points. It is also possible to suggest an iterative algorithm, where the boundaries are first assumed at inflection points, and then iteratively shifted to reduce the difference between observed and calculated log responses. Since the initial approximation is within the expected range of values, the process will most likely converge.

The question now arises of how to find the curve inflection points. Since these points occur at zeros of the second derivative, it would seem reasonable to take a second derivative of a log and find its zeros. This approach is prone to error, however, because of noises of different kinds that are always present on the logs. It is natural, therefore, to think of filtering the data in some way. The method by which filtering is done in this work

TABLE 1—COEFFICIENTS FOR THE SYSTEM OF EQUATIONS (after Ref. 4)

Depth	Measured SP (mV)	$E_{SP_1}{}^1$	$E_{SP_2}{}^1$	$E_{SP_3}{}^1$
Center of Bed 1	−50	−0.488	−0.165	−0.050
Center of Bed 2	−45	−0.243	−0.333	−0.243
Center of Bed 3	−50	−0.050	−0.165	−0.488

is through use of an activity function. This function was originally developed for determining bed boundaries from the microresistivity logs used in dip computations.[5] The analytical expression for this function is as follows.

$$A(D)=\int_{D-x}^{D+x}[E_{\log}(t)-\bar{E}_{\log}(D)]^2 dt, \quad \text{..........(20)}$$

where

A = curve activity at depth D,
$E_{\log}$ = log signal,
$\bar{E}_{\log}$ = an average of the log, taken at a filtering window, and
x = half of that window.

Ref. 5 shows that the extent of the window controls the filtering properties of activity function. Furthermore, it is possible to set up a noise level cutoff determined analytically from the log. It has also been shown that the activity measurement can be made standard for all logs, by using its discrete normalized and linearized form:

$$A'=\arctan\left[\frac{A}{\dfrac{n_{\log}(n_{\log}+1)(2n_{\log}+1)}{3}}\cdot\frac{b}{r_s\cdot L_{\log}\cdot S/100}\right], \quad \text{..................(21)}$$

where

A = a discrete analog of Eq. 20,
$n_{\log}$ = number of log measurements in half of the filtering window,
b = the track width in inches,
r_s = the engineering scale ranges,
$L_{\log}$ = the distance between two consecutive log measurements in feet, and
S = the plot scale in inches per 100 ft.

In this form, the activity function can be used to find bed boundaries. The number $n_{\log}$ and the noise level are

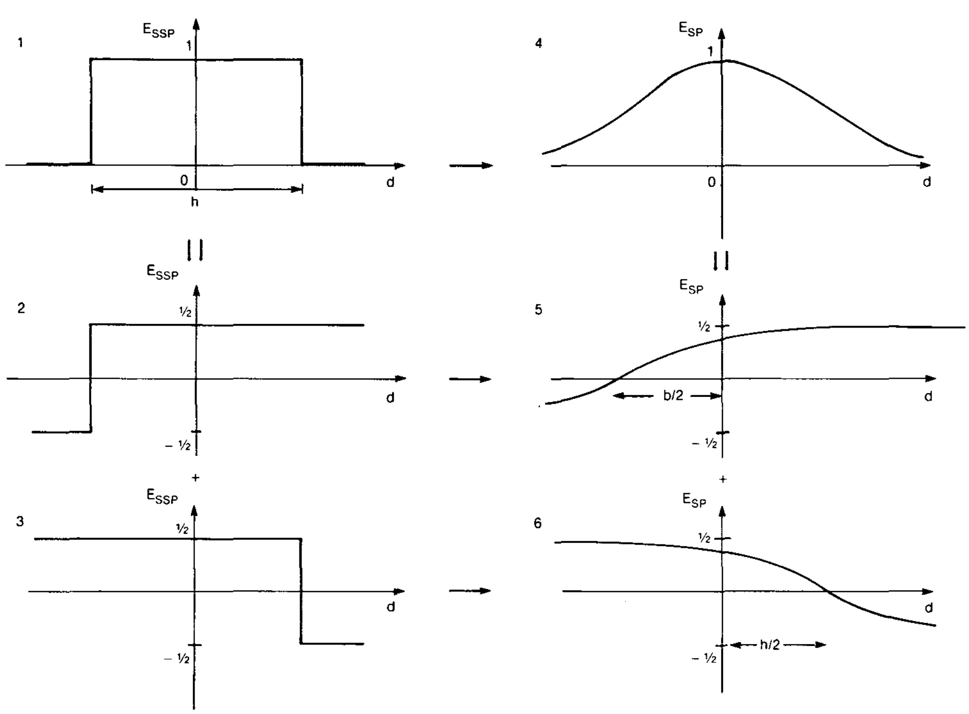


Fig. 6—Breaking a unit response into a sum of two steps.

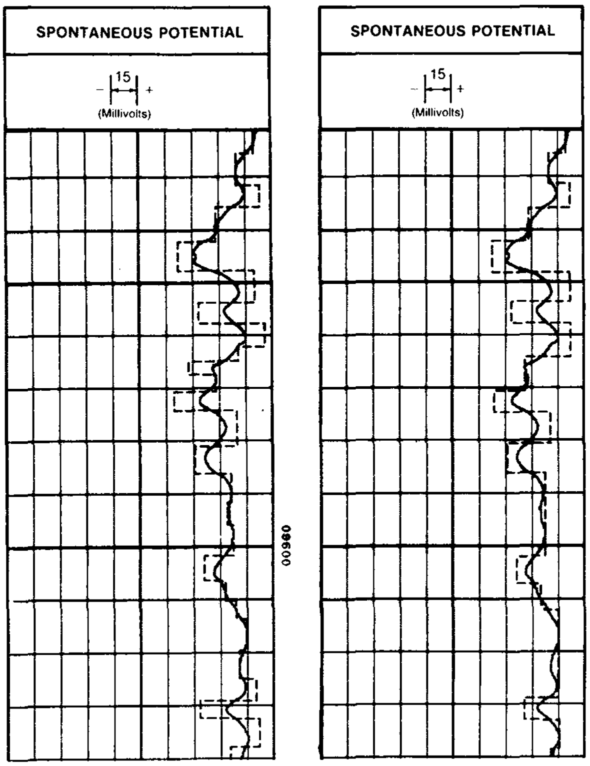


Fig. 7—Blocking the SP log.

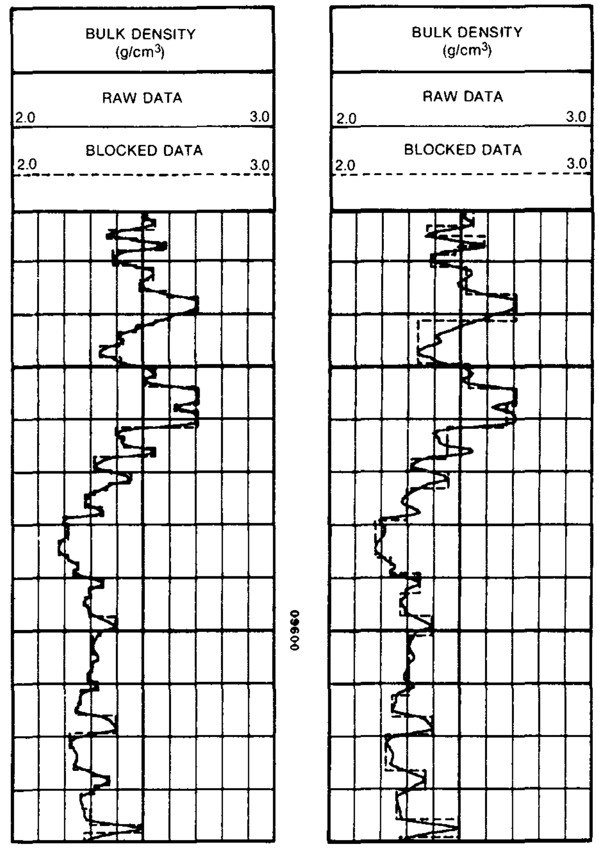


Fig. 8—Blocking the density log.

adjusted for different logs. For a log that is fairly smooth, the activity function is equal to an absolute value of the gradient in degrees. For logs with statistical and/or other variations, the activity function provides smoothing. The bed boundaries correspond to the maximums of the activity function.

Another important use of this function is to find whether the curve behavior has leveled off. If the log has been stable on a depth interval that is of sufficient length, this separates the part of the log that is self-contained. It can be processed without checking other parts of the same log because the readings are not influenced by other bed. The condition is simple; interval ΔD separates the part of the log from all other influences if, on the whole interval,

$$\Delta D \geqslant \Delta D_{\max} \text{ and } A \leqslant N_e, \qquad (22)$$

where

$\Delta D_{\max}$ = the maximum depth interval needed for the log to level off,
A = activity from Formula 21, and
N_e = noise level.

Parameter $\Delta D_{\max}$ is usually determined from the charts. If it is increased, the system of linear equations (Eq. 4) increases in size, and the larger portion of the log is processed at one time, with the final results usually being the same. If $\Delta D_{\max}$ is set to zero, no bed-thickness correction is made, but correct bed boundaries are determined. Log values in the beds are taken by maximum log deflection to the left and to the right. This option is very useful in blocking logs that cannot or do not have to be bed-thickness corrected.

For example, according to modeling done in Ref. 6, natural gamma ray logs do not require corrections for the bed thickness less than two hole diameters. It is a good approximation therefore to smooth and block this log without any bed thickness correction by use of Eqs. 21 and 22 where ΔD is set equal to 0.

There is an interesting parallel between blocking of the natural gamma ray logs and statistical data processing. According to an intuitive algorithm in Ref. 6, natural gamma ray logs can be processed by using a mean square deviation of the log. In the depth interval on which the log does not differ from its average by more than 2 to 3 mean square deviation, the log is considered constant. Using its mean value will produce a more correct interpretation than exact values in more than 96% of the cases. In this work, Eqs. 20 and 21 play exactly the same role as statistical processing in Ref. 6. As pointed out in Ref. 5, the activity function represented by Eqs. 20 and 21 has three interpretations: physical (energy), information theory (information contents), and statistical (signal dispersion). Since dispersion is directly related to the mean square deviation, it is easy to see that for natural gamma ray logs the blocking algorithm, in fact, performs statistical processing.

Description of the Algorithm

It is now possible to give a full description of the blocking algorithm that can be used to write a computer program.

1. Start with the starting depth of the log.
2. Find an interval to be processed, separated from other intervals according to Eq. 22.
3. Find bed boundaries in this interval, as maximums of Eq. 21.
4. Form the system of linear equations (Eq. 4). To find the coefficients, use Eq. 19. To determine the right part of the system of linear equations, use measurements and depths at maximum log deflections to the left and to the right in each bed. Such a choice of points will produce the most stable results with minimum effect from noise.
5. Solve the system of linear equations and record the log responses in each bed.
6. Repeat Steps 2 through 5 until the entire log is processed.

Examples

Fig. 7 represents an example of blocking the SP log using different filtering windows and different noise levels. The larger the filtering windows and the higher the noise level, the more that variation on the log is considered random; hence, the more general is the blocked picture. Note in particular the interval between 9,586 and 9,602 ft [2922 and 2927 m]. While on the left plot, the blocked E_{SP} indicates several beds, the picture on the right shows this interval as one homogeneous bed, because the noise level cutoff has been raised, and the variations of the log in this interval are considered random. The same point is illustrated by the interval 9,612 to 9,629 ft [2930 to 2935 m]. This example shows how the noise level cutoff parameter controls the amount of detail in the analysis. Fig. 8 shows blocking of the density log. Parameter ΔD_{max} is set to 0, so no bed-thickness correction is applied. This is also an example of how blocking can be applied to logs that are not linear and do not satisfy Eqs. 14 and 15. Calipers can be blocked in the same way.

Conclusions

The blocking algorithm can be used in computerized well log analysis to determine bed boundaries from the logs, perform the bed-thickness correction, eliminate random errors, and break the log into homogeneous zones. The result is a more accurate log interpretation. In addition, blocking opens the way to a zone-by-zone analysis on the computer, or automatic zoning, which will be discussed in another paper.

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Nomenclature

A = activity of a log
A' = normalized activity
A_{SSP} = amplitude of SSP log, mV
$A_{SSP_{1,2,3}}$ = amplitude of SSP log in various beds, mV
b = plot track width, in. [cm]
D = depth of the log measurement, ft [m]
ΔD = depth interval checked for separation, ft [m]
ΔD_{max} = maximum depth interval needed for the log to level off, ft [m]
E_{log} = any log response
$\bar{E}_{log}$ = average log value
E_{SP} = SP log, mV
$E_{SP_{1,2,3}}$ = SP log components from various beds, mV
$E_{SP}{}^{1}$ = unit log response, mV
$E_{SP}{}^{1}_{1,2,3}$ = relative influences on SP log generated by a unit response from various beds
E_{SSP} = SSP log, mV
$E_{SSP_{1,2,3}}$ = SSP log components from various beds, mV
E_{SSP_1} = unit SSP, mV
E^*_{SP} = another possible SP log, mV
E^*_{SSP} = another possible SSP log, mV
f = response function, representing log response to a step in value
F = correction factor for SP log
k = bed thickness, ft [m]
K = coefficient in the log linearity equation
L_{log} = distance between two consecutive log measurements, ft [m]
n_{log} = number of log measurements in half a filtering window
N_L = noise level
r_s = engineering scale range
R_i = resistivity of invaded zone, $\Omega \cdot m$
R_m = mud resistivity, $\Omega \cdot m$
S = flat depth scale, in./100 ft [cm/100 m]
X = half the filtering window
δ = maximum log deflection

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SI Metric Conversion Factor

ft × 3.048* E−01 = m³

*Conversion factor is exact.

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