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(54) WELL LOGGING CORRELATION TECHNIQUE

(71) We, SCHLUMBERGER INLAND SERVICES INC., a Corporation of Panama, 19 Berkeley Street, London W.C.2., Great Britain, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement: —

This invention relates to methods for correlating well logging data derived from separate logs, and more especially to methods for correlating the relative depth levels of well logging data derived from separate passes through a borehole. In particular, the invention relates to data processing techniques for accomplishing such correlation.

In the logging of an earth borehole, measurements of various formation characteristics are taken at different depth levels throughout the borehole by means of a measuring device which is lowered into the borehole on the end of a supporting cable extending from the surface of the earth. Typically, the measurements taken along the length of the borehole are intended to provide indications of oil or gas bearing strata. It is more and more the practice to combine measurements taken during different runs through a borehole with different investigating device to produce computed measurements of various characteristics or parameters of the earth formations. When combining measurements made during two separate runs through the borehole, it is important that the separately derived measurements be accurately correlated in depth with one another.

In the past, sheave-wheel devices located at the surface of the earth have provided measurements of the length of cable which passes over the sheave-wheel. Unfortunately, such a cable length measuring device does not accurately take cable stretch into account. One cable length measuring system which accounts for cable stretch is shown in U.S. Patent No. 3,497,958, granted to L. H. Gollwitzer on March 3, 1970. This Gollwitzer system measures the tension in the cable at the surface of the earth and at the tool and corrects the cable length measurements derived from the sheave-wheel device for changes in stretch of the cable as reflected by the tension measurements. The Gollwitzer system also corrects for sheave wheel calibration errors and temperature effects on cable stretch.

While the Gollwitzer system has been found to provide extremely accurate depth measurements, there are factors which can cause even the elaborate Gollwitzer system to produce slight errors. For the usual situation, these errors are insignificant and can be ignored. However, when considering the more recent sophisticated and high-powered computational techniques, it becomes desirable to obtain highly accurate depth alignment between data derived from separate runs or passes through the borehole before combining such data for computational purposes.

It is therefore the object of the present invention to provide new and improved methods of determining automatically the depth match between samples of well logging data derived from separate depth levels in a borehole.

In accordance with the present invention a method of determining by machine processing the displacements between a plurality of well logs derived from at least one investigating device passed through a borehole, is characterized in that it comprises the steps of: (a) producing first and second data corresponding to samples of said logs derived at respective depth levels which are referenced to an initial depth level, a sample of said second data corresponding to a sample of said first data and being assumed, as a first assumption, to be displaced with a predetermined

displacement from said selected sample of first data; (b) determining the displacement between a selected sample of said first data and the corresponding sample of said second data; (c) repeating said step of determining the displacement between a number of selected samples of said first data and corresponding samples of second data; and (d) comparing the displacement values determined from a number of said samples for selecting one of said displacement values as a more accurate displacement value for at least one of said samples.

Referring to the drawings:

Figure 1 shows an investigating device in a borehole along with apparatus at the surface of the earth for controlling the investigating apparatus and recording the measurements and processing the data derived therefrom;

Figure 2 is an example of logs produced from separate passes through a borehole;

Figure 3 represents the relationship between several parameters used in accordance with the present invention;

Figure 4 shows two logs obtained from separate passes through a borehole for purposes of defining certain parameters used throughout this specification;

Figure 5 is a table illustrating how depth shifts may be declared; and

Figures 6A and 6B show a computer flow diagram representative of how the techniques of the present invention might be implemented.

Now referring to Figure 1, there is shown an investigating device 10 in a borehole 11 for investigating subsurface earth formations 12. The investigating apparatus 10 is supported in a borehole 11 on an end of a cable 13. The cable 13 passes over a sheave wheel 14 and is secured to a drum and winch mechanism 15. The drum and winch mechanism 15 includes a suitable brush and slip ring arrangement 16 for providing electrical connections between the cable conductors and a control panel 17. The control panel 17 operates to supply power and control signals to the down-hole investigating apparatus and includes suitable electronic circuitry for receiving well logging measurements from the investigating apparatus and readying such measurements for application to a digital tape recorder 18. The tape recorder 18 is stepped as a function of depth by a driving wheel 19 which engages the cable 13 and mechanical linkage 20.

The investigating apparatus 10 has a reference point 22 which constitutes the center or recording point of the investigating apparatus 10. Because of the long elastic cable 13, the investigating apparatus 10 is subject to displacement arising from cable stretch thus causing the true depth level to be different from the depth level registered by a depth recorder 21 derived from the driving wheel 19. The depth level registered by the depth recorder 21, which is identical with that registered by the tape recorder 18, is designated "Z". When attempting to depth-match a log produced by the investigating apparatus 10 with the log produced from another investigating apparatus passed through the borehole 11 at a different time, there is a distinct possibility that the logs recorded by the two investigating apparatus at the same depth level will not be referenced at the same depth level.

Referring to Figure 2, there are seen two logs, A and B of the same or similar measurements made during different passes through a borehole. By observation it can be seen that the two logs have similar, though depth shifted details. Considering the log A as the base log, it can be seen that at the depth level Z_1 , log B is depth shifted an amount X from log A. The same holds true at depth level Z_2 . Then at depth level Z_3 , the two logs suddenly are depth matched, i.e., the depth shift is equal to 0. Then at depth level Z_4 , the depth shift becomes 3X. When attempting to combine the associated elements of logs produced and recorded on the separate borehole passes A and B of Figure 2, the results may well be in error because of the lack of depth matching.

The present invention makes it possible to utilize two similar logs made from separate passes through the borehole to correlate the depth levels of all logs produced during one pass with all logs produced during the second pass. Such similar logs are considered to be the same log, such a gamma ray log made on two separate passes, similar logs having similar characteristics such as two porosity logs made with different types of investigating devices, or logs which may be initially dissimilar but which can be made to appear similar as by combining two logs made during one pass to produce a third log for correlation with a log derived from a second pass through the borehole. In any event, this correlation is accomplished by utilizing the log fluctuations of logs A and B to indicate the amount of depth shift of one log relative to the other log.

Turning now to Figure 3 to define certain terms used herein, there are shown the two logs A and B to be correlated. The presently considered depth level, shown

on log A in Figure 3, is designated Z. This depth level Z for both logs A and B is initially the depth level given by the surface depth registering apparatus. Thus, for data recorded on magnetic tape, it is the depth indicia on the magnetic tape. The depth interval over which data is used to produce the correlation function C_K (to be defined below) is designated the correlation interval, $2\Delta Z$. The depth interval which curves A and B are sampled in the correlation process is designated the sample interval, ΔZ_0 , as shown in Figure 3. Thus $2\Delta Z/\Delta Z_0 + 1$ is the number of samples considered in the correlation interval and is designated n. The maximum amount by which curve B is displaced relative to curve A for any given depth level Z is, as shown in Figure 3, designated $2\Delta Z_0$. This interval is called the search interval. After the logs A and B have been depth correlated at the depth level Z, the same process is repeated at a new depth level which is an interval ΔZ_0 from the presently considered level Z.

As a first step in the depth correlation process, one curve (in this case curve B) is effectively depth shifted one search step at a time relative to the other curve (curve A) and a correlation function C_K is computed for each depth level. The search step is for simplicity considered to be ΔZ_0 , the same as the sample interval, but in practice could assume any value. The equation for computing the correlation function C_K could take any desired form. A normalized root mean square equation has been found to give favorable results. This equation is:

$$C_K(Z) = \frac{n \sum_{i=0}^m A_{j-l+i} \cdot B_{j-h+i+K} - \sum_{i=0}^m A_{j-l+i} \cdot \sum_{i=0}^m B_{j-h+i+K}}{\sqrt{[n \sum_{i=0}^m A_{j-l+i}^2 - (\sum_{i=0}^m A_{j-l+i})^2] [n \sum_{i=0}^m B_{j-h+i+K}^2 - (\sum_{i=0}^m B_{j-h+i+K})^2]}} \quad (I)$$

where A and B are the values of the two logs:

i is the sample interval number and increases between 0 and m where m is equal to $2\Delta Z/\Delta Z_0$;

K is the displacement number of log B relative to log A in samples and increases between 0 and K_{MAX} such that $K_{MAX}\Delta Z_0$ is the search interval $2\Delta Z_0$;

z is the correlation step number in samples and corresponds to the depth level Z;

h is a depth offset for the B log in samples and is equal to $(\Delta Z + \Delta Z_0)/\Delta Z_0$;

l is a depth offset for the A log and is equal to $\Delta Z/\Delta Z_0$;

$C_K(Z)$ is the correlation factor for the displacement value of K at a depth level Z, and

n is the number of sample intervals and equals m+1.

These parameters will be described in detail later.

Turning now to Figure 4, it will be described how the computation of the correlation factor C_K takes place. In Figure 4, there are shown the sample points versus depth for two logs A and B. The log values for the successive sample points for the two logs A and B are designated A_1, A_2, A_3 , etc., and B_1, B_2, B_3 , etc. Common subscripts for the logs A and B indicate common initial depth levels as they would be recorded as derived from the exploring devices run through the borehole. For example, the log value A_1 is initially assumed to be on depth with the log value B_1 . Now, assume in Figure 4 that the A and B logs at depth level Z are to be correlated. In this case, assuming the A log to be the base log, that point on the B log which corresponds in depth with the log value A at depth level Z is to be found and shifted, if necessary, to the depth level Z. Desirably, after such shifting, the data sample of the B log which was derived from the same depth level as the A log value at depth Z is now referenced to the depth level Z.

To accomplish this, a plurality of correlation functions $C_K(Z)$ are computed for given values of K between 0 and K_{MAX} for the depth level Z under consideration where, as discussed earlier, K is the displacement number in samples. Since the search step is equal to ΔZ_0 , each increase of K by 1 will correspond to ΔZ_0 depth shift on the log. For each value of K, C_K is computed over the correlation interval $2\Delta Z$ from $i=0$ to $i=m$. Desirably, the correlation interval Z is substantially greater than the search interval $2\Delta Z_0$. Although it is not necessary that the depth interval between each sample used in producing the correlation function C_K be the same

as the search step ΔZ_0 (i.e., that ΔZ_0 be the interval for both i and K), such has been done for this example to simplify the illustration.

To explain how the correlation operation takes place, an example of such an operation will be described using Figure 4. Assume that ΔZ_0 is 6 inches, ΔZ_x is 12 inches, ΔZ_1 is 20 feet, ΔZ_0 is 5 feet and the first depth level to be correlated is that given by sample A_{51} . Furthermore, assume that the interval between successive data samples in Figure 4 is 6 inches, e.g. A_1 to A_2 and B_1 to B_2 is 6 inches. In this situation, z will be initially set to 51 and l will be 40 (i.e. $\Delta Z/\Delta Z_0=40$), h will be 50 (i.e. $(\Delta Z+\Delta Z_0)/\Delta Z_0=50$), m will be 80 (i.e. $2\Delta Z/\Delta Z_0=80$).

The first step is to compute C_K for $K=0$. To accomplish this, in accordance with equation (1), C_K for $K=0$ is computed taking into account all i 's from $i=0$ to $i=m$. Thus, for the A, B term, initially i is set equal to 0 and the A and B values combined in accordance with equation (1); then i is set equal to 1, 2, ... m in turn whereupon the combined A and B values are summed per equation (1) to produce C_K for $K=0$. Taking the values given above for this example, for $K=0$ and $i=0$, $A_{x-i+1}=A_{51-40+0}=A_{11}$ will be combined with $B_{z-h+1+K}=B_{51-50+0+0}=B_1$ for $i=1$, A_{12} with B_2 , ... , and so on until $i=m$ which is equal to 80, $A_{51-40+80}=A_{91}$ with $B_{51-50+80+0}=B_{81}$. The solid lines running between the A and B log values in Figure 4 represent, for a few exemplary cases, how the A and B log values are combined to produce the product terms of equation (1) for summation. For the individual

A and B summation terms (e.g. $\sum_{i=0}^m A_{x-i+1}$), the A and B log values for all i values

between 0 and m are accumulated. Thus, for $K=0$, A_{11} to A_{91} are summed and B_1 to B_{81} are summed. Then, all of the A, B product summation and individual A, B summation terms are combined in accordance with equation (1) to produce C_K for $K=0$. In Figure 4, the B log correlation interval $2\Delta Z$ for $K=0$ at depth level Z is shown. The B log over this depth interval is combined with the A log over its correlation interval A_{11} to A_{91} . This A log correlation interval is the same for all values of K for at depth level Z .

Next, K is incremented by 1 and C_K computed in the same manner. Thus, considering the A, B term of equation (1), for $K=1$, at $i=0$, $A_{x-i+1}=A_{51-40+0}=A_{11}$ is combined with $B_{z-h+1+K}=B_{51-50+0+1}=B_{21}$ for $i=1$, A_{12} with $B_{51-50+1+1}=B_{22}$; and so on until $i=m$, $A_{51-40+80}=A_{91}$ with $B_{51-50+80+1}=B_{82}$. The dashed lines running between the A and B logs shows, for a few illustrative log samples how the A and B log values are combined. The individual A summation terms will be the same for all K 's at any given Z since the A terms are not depth dependent on K . However, for the B terms which are depth dependent on K , B_1 to B_{82} will be summed for $K=1$.

This same process is repeated for all K values to K_{MAX} which, in this example, is 20. Considering the A, B term for $K_{MAX}(K=20)$ at $i=0$, $A_{x-i+1}=A_{51-40+0}=A_{11}$ will be combined with $B_{z-h+1+K}=B_{51-50+0+20}=B_{21}$; at $i=1$, A_{12} with $B_{51-50+1+20}=B_{22}$; and so on until at $i=m=80$, $A_{51-40+80}=A_{91}$ will be combined with $B_{51-50+80+20}=B_{101}$. This is represented in Figure 4 by the dashed lines. For the B summation terms of equation (1), B_{21} to B_{101} will be used. The B log correlation interval for $K=K_{MAX}$ is shown in Figure 4 as extending between B_{21} and B_{101} and is combined with the A log over its correlation interval A_{11} to A_{91} . Also shown in Figure 4 is the B log correlation interval for $K=K_{MAX}/2$. As seen in Figure 4, the depth intervals for the A and B logs exactly coincide for $K=K_{MAX}/2$. In other words, the subscripts for A, B terms used in equation (1) are identical when $K=K_{MAX}/2$ for all i 's between 0 and m .

At this point, the C_K values for K between 0 and K_{MAX} have been computed. The best fit between the two logs at depth level $Z(Z=51)$ occurs at that K where C_K is a maximum. This K is designated K' . The corresponding displacement in samples will be $K'-K_{MAX}/2$ since at $K=K_{MAX}/2$, the A and B log values are referenced to common depth levels as stated above. Taking an example of this using the values given above, if K' is found to be 9, then $K'-K_{MAX}/2$ will be $9-10=-1$, thus indicating that the depth displacement between the two logs is -1 sample or -6 inches. In this case, the B log value B_{50} will be deemed, as a first assumption, to be that sample of the B log which was derived at the same depth level Z as the A log sample A_{51} .

From the foregoing, it can be seen that the B log correlation interval is moved relative to the A log correlation interval for different values of K while computing values of C_K for such different values of K to thereby determine the best correlation

or fit between the two logs. Once the best fit is determined, the corresponding depth displacement can be determined. As will be established later, the depth displacement determined by this process is only a first assumption value which may be improved upon.

To determine the depth displacement at the next depth level which is an interval $\Delta Z = 12$ inches away (for the present example), z is incremented by 2 and the same operation repeated, i.e. C_K for all K 's between 0 and K_{MAX} are computed, etc.

Unfortunately, there are factors which may upset the correlation operation just described and which will give numerically low correlation factors C_K at K . For example, a bad log reading caused by a malfunction in the investigating apparatus, or noise, can cause such a low correlation factor. To prevent an erroneous depth displacement indication upon such an occurrence, $C_{K(MAX)}$ is compared with a number $C_{K(lim)}$ representing the lowest acceptable value of $C_{K(MAX)}$ and if $C_{K(MAX)}$ is lower than $C_{K(lim)}$, the corresponding depth shift is disregarded. In its place, the last acceptable depth displacement is used.

It has been found that the discarding of all depth displacement indications resulting from low correlation factors C_K is not sufficient to prevent occasional errors arising in the depth correlation process. To further improve the accuracy of the depth correlation process, in accordance with an important feature of the present invention, a history file of the depth displacements is produced and utilized to statistically improve the accuracy of the depth correlation process. To accomplish this, a prescribed number of depth displacements of the same magnitude at successive depth levels are required before that depth displacement is declared valid. Once a given depth displacement is declared valid, it takes a prescribed number of occurrences of a different depth displacement quantity before the new depth displacement quantity will be substituted for the old.

Before considering this statistical analysis in detail, it would first be desirable to consider some definitions. The computed depth displacement or depth shift at any given level Z is designated $SH(Z)$, the declared depth displacement is designated SH_D , and the stored depth displacement is designated SH . The number of occurrences of any given depth displacement is designated HC (for history counter). Prior to the time depth displacement is declared, the number of consecutive (depthwise) occurrences of such a depth displacement is designated UDC (for undeclared displacement counter). The prescribed number of consecutive occurrences of a given displacement shift which are necessary to cause that displacement to be declared, is designated UDC_{MIN} . The number of depth levels Z considered for each declared displacement is designated $LEVEL$.

Turning now to Figure 5, there is shown a table giving representative values of an illustrative example of how depth displacements may be declared. Each row in Figure 5 is considered to be a separate depth level Z_N . Assume that UDC_{MIN} is equal to 2. Furthermore, assume that the last declared displacement SH is 1 at Z_0 . At the beginning of any history all shifts are set to zero. At the first depth level Z_1 , the computed displacement $SH(Z)$ is 0. As shown in Figure 5 the computed displacement $SH(Z)$ at the next depth level Z_2 is also 0, and since UDC_{MIN} is equal to 2, the value of $SH_D = 0$ is declared and UDC reset to 0. SH_D is set equal to 0. In addition, each of the continuous $SH(Z)$ values making up this history is then used to redefine corresponding SH_D values. Thus SH_D at Z_1 , which was 1, is re-defined as its $SH(Z)$, 0. Then at the depth level Z_3 , $SH(Z)$ is found to be 1 and UDC incremented. However UDC at this time is only equal to 1 and thus SH_D remains at 0. Then at the next depth level Z_4 , an $SH(Z)$ of 2 is computed. Since a different displacement value was computed at the last depth level Z_3 , the declared displacement remains at 0 and UDC remains at 1. Then at depth level Z_5 , $SH(Z) = 1$ is again computed. However, to declare a new displacement, two consecutive values of the same displacement must be computed. Thus the declared displacement remains at 0. The same is true for depth level Z_6 , Z_7 , and Z_8 where computed displacements of 3, 1, and 0 are computed. Since each displacement is different from the last, UDC remains at 1. Then at depth level Z_9 and Z_{10} two consecutive $SH(Z)$ displacement values of 1 are computed such that UDC equals UDC_{MIN} and $SH(Z) (=1)$ is declared as SH_D at both Z_9 and Z_{10} . At depth levels Z_{11} and Z_{12} the declared shift of 1 remains.

Now turning to Figures 6A and 6B, there is shown a flow diagram depicting a representative implementation of the techniques of the present invention. First, refer to Figure 6A. After the depth correlation routine is entered (element 30), the various parameters used by the program are read as represented by element 31. This includes the designation of the logs A and B which are to be used in the correlation

parameters are equal, the presently declared depth shift SH_D is retained and the history counter HC is incremented by 1, as represented by element 52. The program proceeds to output SH_D at the appropriate depth level, or if the entire interval has been processed, go to another interval or exit the routine (see elements 42, 43 and 44). On the other hand, if the presently computed depth shift $SH(Z)$ is not equal to the declared depth shift SH_D , the program determines if a new depth shift should be declared. This operation is represented by the elements 53 through 58 of Figure 6B.

Considering this new depth shift determination operation in detail, first, it is determined if the depth shift for the present level Z , i.e. $SH(Z)$, is equal to the stored depth shift SH_S , as represented by decision element 53. (The step depicted by element 36 sets SH_S to 0 initially). If they are not equal, SH_S is set equal to $SH(Z)$ as represented by element 54 and the undeclared displacement counter is set equal to 1 as represented by element 55. The reason for this is evident from the discussion of Figure 5 where it was set forth that the prescribed consecutive number of identical depth shifts (UDC_{MIN}) must be computed before a new depth shift is declared. It is the undeclared shift counter UDC which keeps track of the consecutive number of shifts. Since $SH(Z)$ and SH_S were not of the same magnitude, when the program goes to elements 54 and 55, a new shift was not declared, the program outputs the presently declared shift value SH_D at depth level $Z - (UDC_{MIN} - 1)$ and proceeds to consider the next depth level. (See elements 41 through 44).

If $SH(Z)$ is equal to SH_S , then the undeclared shift counter UDC is incremented by 1 as represented by element 56 and it is determined if UDC is equal to UDC_{MIN} as represented by element 57. If $UDC \neq UDC_{MIN}$, a new shift cannot be declared yet, and the program outputs the present declared shift value SH_D and proceeds to the next depth level. (See elements 41-44.) If UDC is equal to UDC_{MIN} the value of SH computed at the presently considered depth level Z , $SH(Z)$, is used to reset SH_D , i.e. a new shift is declared, as is represented by element 58.

After a new SH_D is declared, the $LEVEL$ and HC counters are set to UDC_{MIN} and UDC is set to 1, as represented by elements 59, 60 and 61 in readiness for the determination of a new declared shift. Then the program proceeds to output the newly declared shift value SH_D for the appropriate depth level Z , i.e. depth level Z at the beginning of the accepted history. It then proceeds to the next depth level, etc.

If desired a quality factor Q could be computed representing the percentage of depth levels for which each declared shift occurred, as represented by element 62. This quality factor Q can be computed with the expression:

$$Q = \frac{HC}{LEVEL} \times 100 \quad (2)$$

With equation (2), $Q=100\%$ represents perfect correlation. Referring to Figure 5 to give an illustrative example of how Q is derived a depth shift of 0 was declared at depth level Z_2 and this depth shift was computed three times throughout the interval when 0 was the declared depth shift, i.e. Z_1 through Z_8 . Thus, the quality factor Q for example would be 38% since HC would be equal to 3 (depth level Z_1 , Z_2 , and Z_8) and $LEVEL$ would be equal to 8.

The above-described operation has produced numerical outputs giving the depth shift between the two logs A and B at each depth level. (See element 41.) A log analyst could then shift the log B relative to log A by the indicated amount by a suitable technique. Alternatively, the program could automatically shift the log B by the declared shift interval SH_D to match the log A at the appropriate depth level. This operation is depicted by the element 65 in Figure 6. This operation would take the form of assigning the log value of B at the depth level $Z - (UDC_{MIN} - 1) - SH_D$ to the depth level $Z - (UDC_{MIN} - 1)$. The same thing will apply to all logs derived from investigating devices on the same investigating apparatus which produced log B. Such a shift operation is straightforward and well known and need not be discussed further here.

Summarizing the depth correlation operation depicted in Figures 4, 5 and 6, the two logs to be correlated are initially considered to be depth matched in accordance with the depth indicia on the magnetic tape on which the log data is recorded. Beginning at the initial depth level Z_a , a first assumption value of the depth displacement is computed between the B log and the A log at each selected depth level from Z_a to Z_b in increments of ΔZ_T . Thus, the A log is considered to be in the

base log and the displacement for the B log relative to the A log is computed. Of course, the A log may not be accurately depth referenced itself but when combining logs for computational purposes to achieve better well log interpretation data, the depth correlation between the combined logs is the most important item. If "absolute" depth accuracy is desired, the methods disclosed in the aforementioned Gollwitzer patent could be utilized in conjunction with the techniques of the present invention.

Concerning the depth correlation process at one depth level, the B log is effectively shifted one step ΔZ_0 at a time and a correlation function C_K is computed at each such step with equation (1). Once the C_K 's over the entire search interval $2\Delta Z_0$ are computed, that K which produced the maximum value of C_K , designated K' , is determined. The corresponding depth displacement will be $(K' - K_{MAX}/2)\Delta Z_0$. Thus, for example, if ΔZ_0 is 1 inch and $(K' - K_{MAX}/2)$ is -6, the computed depth displacement for log B at the presently considered depth level Z will be -6 inches. However, this depth displacement is not computed unless $C_{K(MAX)}$ is equal to or greater than $C_{K(11m)}$. This prevents weak correlation quantities from causing depth displacements. If $C_{K(MAX)}$ is greater than $C_{K(11m)}$, the displacement $SH(Z)$ is computed and entered into the history file for statistical analysis. This computed value $SH(Z)$ is only a first assumption of the depth displacement which may be changed by the statistical analysis.

This statistical analysis takes the form of declaring a depth displacement only when a consecutive number of identical depth displacements have been computed. (Consecutive meaning consecutive depth levels.) By so doing, an occasional erroneous depth displacement caused by noise, for example, will not cause log B to be depth displaced.

There has been described a technique for accurately depth correlating logs produced from independent passes through a borehole. This has been accomplished by taking two similar logs from separate passes through the borehole and matching them through a correlation technique. The validity of this correlation technique has been strengthened by a statistical analysis of the results to prevent occasional errors from upsetting the operation. In Figures 6A and 6B, this statistical analysis has taken the form of delaying the declaration of a new depth displacement until a designated number of computed depth displacements of a given value have been produced. Knowing the delay, since it is accounted for, the displacement can be applied to the appropriate depth, i.e. where the delay began. Of course, there are more elaborate techniques which could be utilized and which are encompassed within the present invention. For example, the threshold level for declaring a new displacement SH_D could be functionally dependent on the quality factor Q. Thus as Q decreases, UDC_{MIN} could correspondingly increase to make it more difficult to declare a new displacement.

While there has been described what is at present considered to be a preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, intended to cover all such changes and modifications as fall within the scope of the invention.

WHAT WE CLAIM IS:—

1. A method of determining by machine processing the displacements between a plurality of well logs derived from at least one investigating device passed through a borehole, characterized in that it comprises the steps of:

(a) producing first and second data corresponding to samples of said logs derived at respective depth levels which are referenced to an initial depth level, a sample of said second data corresponding to a sample of said first data and being assumed, as a first assumption, to be displaced with a predetermined displacement from said selected sample of first data;

(b) determining the displacement between a selected sample of said first data and the corresponding sample of said second data;

(c) repeating said step of determining the displacement between a number of selected samples of said first data and corresponding samples of second data; and

(d) comparing the displacement values determined from a number of said samples for selecting one of said displacement values as a more accurate displacement value for at least one of said samples.

2. A method according to claim 1 characterized in that said at least one sample is a sample of said number.

3. A method according to claim 1 or 2 characterized in that said compared



base log and the displacement for the B log relative to the A log is computed. Of course, the A log may not be accurately depth referenced itself but when combining logs for computational purposes to achieve better well log interpretation data, the depth correlation between the combined logs is the most important item. If "absolute" depth accuracy is desired, the methods disclosed in the aforementioned Gollwitzer patent could be utilized in conjunction with the techniques of the present invention.

Concerning the depth correlation process at one depth level, the B log is effectively shifted one step ΔZ_0 at a time and a correlation function C_K is computed at each such step with equation (1). Once the C_K 's over the entire search interval $2\Delta Z_0$ are computed, that K which produced the maximum value of C_K , designated K' , is determined. The corresponding depth displacement will be $(K' - K_{MAX}/2)\Delta Z_0$. Thus, for example, if ΔZ_0 is 1 inch and $(K' - K_{MAX}/2)$ is -6, the computed depth displacement for log B at the presently considered depth level Z will be -6 inches. However, this depth displacement is not computed unless $C_{K(MAX)}$ is equal to or greater than $C_{K(11m)}$. This prevents weak correlation quantities from causing depth displacements. If $C_{K(MAX)}$ is greater than $C_{K(11m)}$, the displacement $SH(Z)$ is computed and entered into the history file for statistical analysis. This computed value $SH(Z)$ is only a first assumption of the depth displacement which may be changed by the statistical analysis.

This statistical analysis takes the form of declaring a depth displacement only when a consecutive number of identical depth displacements have been computed. (Consecutive meaning consecutive depth levels.) By so doing, an occasional erroneous depth displacement caused by noise, for example, will not cause log B to be depth displaced.

There has been described a technique for accurately depth correlating logs produced from independent passes through a borehole. This has been accomplished by taking two similar logs from separate passes through the borehole and matching them through a correlation technique. The validity of this correlation technique has been strengthened by a statistical analysis of the results to prevent occasional errors from upsetting the operation. In Figures 6A and 6B, this statistical analysis has taken the form of delaying the declaration of a new depth displacement until a designated number of computed depth displacements of a given value have been produced. Knowing the delay, since it is accounted for, the displacement can be applied to the appropriate depth, i.e. where the delay began. Of course, there are more elaborate techniques which could be utilized and which are encompassed within the present invention. For example, the threshold level for declaring a new displacement SH_D could be functionally dependent on the quality factor Q. Thus as Q decreases, UDC_{MIN} could correspondingly increase to make it more difficult to declare a new displacement.

While there has been described what is at present considered to be a preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, intended to cover all such changes and modifications as fall within the scope of the invention.

WHAT WE CLAIM IS:—

1. A method of determining by machine processing the displacements between a plurality of well logs derived from at least one investigating device passed through a borehole, characterized in that it comprises the steps of:

(a) producing first and second data corresponding to samples of said logs derived at respective depth levels which are referenced to an initial depth level, a sample of said second data corresponding to a sample of said first data and being assumed, as a first assumption, to be displaced with a predetermined displacement from said selected sample of first data;

(b) determining the displacement between a selected sample of said first data and the corresponding sample of said second data;

(c) repeating said step of determining the displacement between a number of selected samples of said first data and corresponding samples of second data; and

(d) comparing the displacement values determined from a number of said samples for selecting one of said displacement values as a more accurate displacement value for at least one of said samples.

2. A method according to claim 1 characterized in that said at least one sample is a sample of said number.

3. A method according to claim 1 or 2 characterized in that said compared



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displacement values are determined from a number of successive samples with reference to depth.

4. A method according to claim 3 characterized in that said one displacement value is selected as the final displacement value for said at least one sample upon said final value occurring in a predetermined successive relationship.

5. A method according to any of claims 1 to 4 characterized in that said one displacement value is selected as the final displacement value for said at least one sample upon such value occurring for a selected number of samples.

6. A method according to claim 5 further characterized in that said steps of comparing and selecting includes comparing the determined displacement values for at least two consecutive samples of said first data from at least two consecutive levels and declaring the displacement value for such consecutive samples as the final displacement value for at least some of said samples if such displacement values for such consecutive samples are identical.

7. A method according to claims 1 to 4 further characterized in that said step of comparing and selecting includes the steps of comparing the determined displacement value for each of a number of successive samples with that value from at least one previously considered sample and producing a coincidence output for each successive sample if such compared displacement values are identical, counting the occurrences of such coincidence outputs to produce an accumulated count of such coincidence outputs, comparing the accumulated count with a predetermined number and declaring such identical displacement value as the final displacement value of at least one of said considered samples if such accumulated count is at least as great as the predetermined number.

8. A method according to claim 7 characterized in that said at least one considered sample includes the first of said considered samples for which a coincidence output has been produced.

9. A method according to claim 7 or 8 characterized by further declaring such identical displacement value as the final displacement value for any of said selected samples for which a coincidence output has been produced.

10. A method according to any of claims 7 to 9 further characterized by declaring the displacement value declared for the last of said previously considered samples with reference to depth as the final displacement value for those of said number of successive samples for which no coincidence output or a number of successive coincidence outputs smaller than said predetermined number has been produced when said compared displacement values are not identical.

11. A method according to any of claims 7 to 10 characterized by further including the steps of counting the number of successive samples for which a given final displacement value is declared to produce a first count, counting among said successive samples the total number for which a determined displacement value identical to said given final declared displacement value occurs to produce a second count, and combining said first and second counts to produce an indication of the quality of a final declared displacement over a given interval.

12. A method according to any of claims 1 to 11 further characterized in that said step of determining the displacement between selected samples of first data and a corresponding sample of said second data comprises the step of combining samples of said first data over a first interval including said selected sample with samples of said second data over a second interval including said corresponding sample while varying the relative positioning of said second interval to determine the best correlation or likeness of said first and second intervals and the corresponding displacement between said selected samples of said first data and said corresponding sample of said second data.

13. A method according to claim 12 characterized in that said step of combining further includes computing a correlation function for each position of said second interval relative to said first interval, determining which one of said correlation functions has the highest value and determining whether this highest value exceeds a given limit, and said step of comparing includes comparing the displacements corresponding to said correlation functions having the highest values only if said values exceed said given limit.

14. A method according to any of the preceding claims further comprising the step of displacing the reference origin of said second data by an amount determined by the final displacement value declared for such samples.

15. A method according to any of claims 1 to 14 wherein said well logs are derived from separate passes of the investigating devices through the borehole.

16. A method according to any of the preceding claims wherein said displace-



ment is a depth displacement, wherein said displacement value is a depth displacement value, wherein said consecutive levels are consecutive depth levels and wherein said interval is a depth interval.

- 5 17. A method of determining by machine processing the displacements between a plurality of well logs derived from at least one investigating device passed through a borehole, substantially as described hereinbefore with reference to and as illustrated in the accompanying drawings.

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