GEOPHYSICS, VOL. 54, NO. 2 (FEBRUARY 1989); P. 245-253, 11 FIGS.

A new method for the automatic interpretation of Schlumberger and Wenner sounding curves

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ABSTRACT

A fast iterative method for the automatic interpretation of Schlumberger and Wenner sounding curves is based on obtaining interpreted depths and resistivities from shifted electrode spacings and adjusted apparent resistivities, respectively. The method is fully automatic. It does not require an initial guess of the number of layers, their thicknesses, or their resistivities; and it does not require extrapolation of incomplete sounding curves. The number of layers in the interpreted model equals the number of digitized points on the sounding curve. The resulting multilayer model is always well-behaved with no thin layers of unusually high or unusually low resistivities. For noisy data, interpretation is done in two sets of iterations (two passes). Anomalous layers, created because of noise in the first pass, are eliminated in the second pass. Such layers are eliminated by considering the best-fitting curve from the first pass to be a smoothed version of the observed curve and automatically reinterpreting it (second pass). The application of the method is illustrated by several examples.

INTRODUCTION

In the 1970s several methods were developed for computerized interpretation of vertical electrical sounding (VES) curves over horizontally stratified media. These methods may be divided into two groups. The first group relies on the transformation of a VES curve into its corresponding resistivity transform (or kernel function) curve using forward filters such as those developed by Ghosh (1971a), Koefoed (1979), and Strakhov and Karelina (1969). The resistivity transform curve is interpreted using methods based on Pekeris (1940) and Koefoed's (1979) formulas. The drawbacks of this approach were discussed by Zohdy (1975). The second group of interpretation methods relies on inverting the sounding curve itself without first transforming it to its resistivity transform curve (Anderson, 1979a; Kunetz and Rocroi, 1970; Zohdy, 1975).

In this paper, a new iterative procedure is presented in which a layering model is obtained directly from a digitized sounding curve. The method does not require a preliminary guess for the number of layers, their thicknesses, or their resistivities; and it does not require extrapolation of the first and last branches of the sounding curve to their respective asymptotes. The number of layers is equal to the number of digitized points, and layer boundaries are spaced uniformly on a logarithmic depth scale.

For field sounding curves, the present method provides the geophysicist with a theoretical curve that fits the observed curve as closely as possible and produces a corresponding, well-behaved layering model (with no extremely thin layers of unusually high or unusually low resistivities). The geophysicist may accept, simplify, complicate, or modify the resulting solution to satisfy known geologic information using other equivalent layering models (Zohdy, 1974).

OUTLINE OF THE METHOD

The study of Schlumberger and of Wenner theoretical sounding curves for horizontally stratified, laterally homogeneous, and isotropic media shows that regardless of the number of layers or resistivity distribution with depth, the following properties are observed (Figure 1):

(1) Computed apparent resistivities are always positive.

(2) The form of a sounding curve follows the form of the true resistivity-depth curve. As the true resistivities increase (or decrease) with greater depth, the apparent resistivities increase (or decrease) with greater electrode spacings. This is particularly evident for layers whose thickness increases logarithmically with depth.

(3) The maximum change in apparent resistivity always occurs at an electrode spacing that is larger than the depth at which the corresponding change in true resistivity occurs. That is, a sounding curve is "out of phase" with the resistivity-

Manuscript received by the Editor January 18, 1988; revised manuscript received July 29, 1988.
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depth curve and is *always* shifted to the right of the resistivity-depth curve.

(4) The amplitude of a sounding curve is always less than or equal to the amplitude of the true resistivity-depth curve. The apparent resistivity asymptotically approaches the true resistivity at electrode spacings that are very small with respect to the thickness of the first layer or very large with respect to the depth to an infinitely thick last layer.

(5) In a multilayer model, if the true resistivity of a thick layer is changed, the apparent resistivity along a corresponding segment of the sounding curve also changes accordingly. Furthermore, the maximum change in apparent resistivity is approximately equal to the net change in true resistivity (Figure 1).

The above properties also apply to most, but not all, dipole-dipole sounding curves that are computed for horizontally stratified media.

Properties (1) and (2) led early interpreters to assume that electrode spacings are equal to probing depths and that apparent resistivities are nearly equal to true resistivities. In view of properties (3), (4), and (5), however, and as shown in Figure 2, it is evident that:

(i) The electrode spacings do not adequately approximate the depths to various layers (Figure 2a). Therefore, the assumed depths must be shifted to the left in order to bring the assumed layering more or less in phase with the resistivity-depth curve (Figure 2b).

(ii) The apparent resistivities do not adequately approximate the true resistivities; and, therefore, the assumed resistivities must be adjusted to approximate the amplitude of the true resistivities (Figure 2c).

(iii) Property (5) can be used to make the required resistivity adjustments.

Determining the appropriate amount to horizontally shift the depths and vertically adjust the resistivities, without prior knowledge of the true resistivity depth distribution, is the essence of the new iterative method.

EQUIVALENCE AMONG MULTILAYER MODELS

In this iterative method, I take advantage of the property of equivalence among multilayer media. For example, a sounding curve computed for a simple three-layer model is the same, to within 1 or 2 percent, as that computed for an equivalent model composed of many more layers (Figure 3). In practice, the two models are equivalent, and we do not know with certainty which model represents the actual subsurface layering. Thus, when testing the method with theoretical curves to simulate field curves, it is not necessary to recover the exact layering for which the theoretical curve was computed. It is sufficient to obtain a computed curve for a well-behaved model that fits the theoretical test curve to within 1 or 2 percent. Furthermore, whenever an interpretation method is required to fit a field curve with much less than 1 or 2 percent, geologically unrealistic models may result as the method begins to fit the noise in the field data and produces anomalous layers caused by the noise. There is more discussion of this problem in the section on noisy field data.

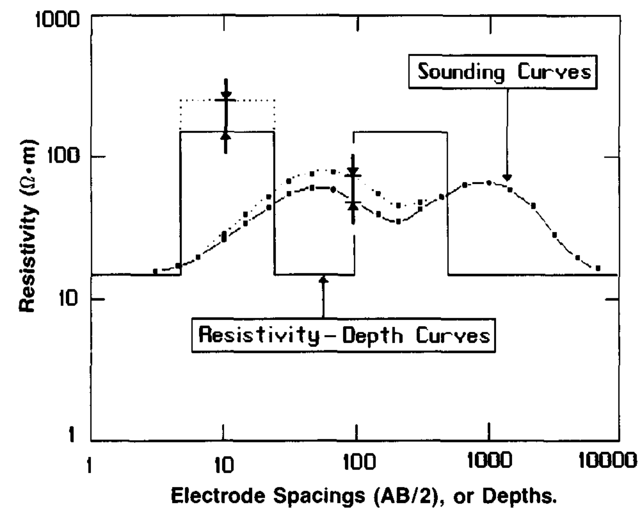

FIG. 1. Two five-layer Schlumberger sounding curves and layerings illustrating the spatial relations among electrode spacings, apparent resistivities, depths, and true resistivities. Graphs also show that the maximum change in apparent resistivity is approximately equal to the change in true resistivity.

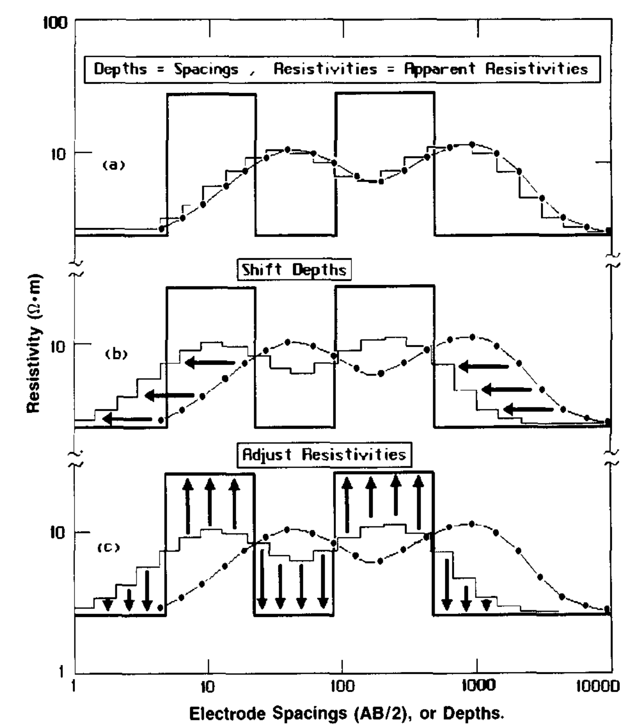

FIG. 2. Basic steps in the automatic interpretation method: (a) assume that layer depths = electrode spacings and that apparent resistivities = true resistivities; (b) shift assumed layer depths to the left to bring them in phase with actual layering; and (c) adjust amplitudes of assumed resistivities to those of actual layering.

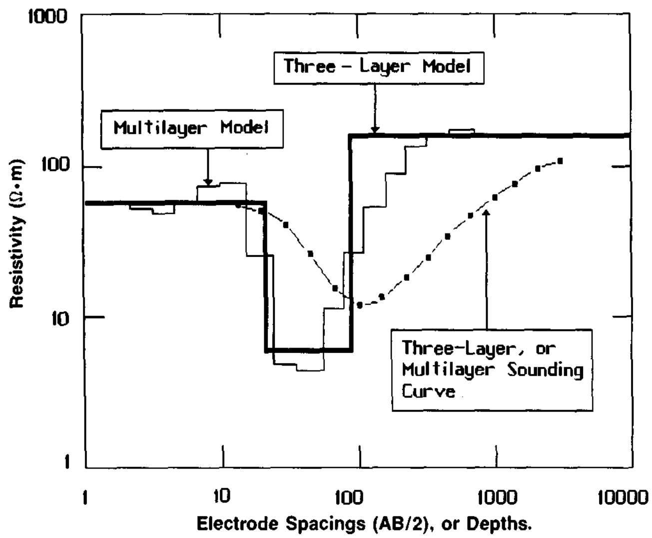

FIG. 3. Example showing equivalence between three-layer model and a multilayer model. Either model produces the same sounding curve to within 2 percent.

INITIAL DATA PREPARATION

Unlike a theoretical curve, a field Schlumberger sounding curve is composed of several overlapping segments. The segmented Schlumberger field curve is processed and reduced to a continuous curve prior to its interpretation in terms of a horizontally stratified model (Deppermann, 1954; Koefoed, 1979; Kunetz, 1966; Mundry, 1980; Zohdy et al., 1973).

The processed Schlumberger sounding curve or the Wenner field curve is digitized at a logarithmic interval equal to (or equal to a multiple of) the sampling interval of the filter to be used in calculating the theoretical sounding curve. The purpose of digitizing the sounding curve is to speed up the computations of the succession of theoretical sounding curves used in the iterative process. A sampling interval of six points per logarithmic cycle (O'Neill, 1975) is considered commensurate with the electrode spacing intervals used in the field and is considered optimal for defining the form of a sounding curve. For Schlumberger sounding curves with steeply descending branches, Anderson's filter coefficients (Anderson, 1975, 1979b) provide greater computation accuracy at very large resistivity contrasts. Steeply descending branches are defined as those on which, within one logarithmic cycle of electrode spacings, the apparent resistivity drops more than three logarithmic cycles. Ghosh's inverse filter coefficients for the Wenner array (Ghosh, 1971b) are used for interpreting Wenner sounding curves. However, since Ghosh's inverse filter for Wenner curves is based on a sampling interval of three points per logarithmic cycle, it is used twice to produce better defined curves at the rate of six points per decade.

When a processed field Schlumberger sounding curve or a field Wenner curve is digitized, it is ready for interpretation by the iterative method. In the following discussion, the processed and digitized Schlumberger, or the digitized Wenner, field curve is referred to as the "observed" curve for brevity.

ITERATIVE PROCEDURE

The iterative procedure relies on the following initial assumptions:

(i) The number of layers in the model equals the number of digitized points on the observed curve. This assumption remains unchanged throughout the iterative process.

(ii) The depths of the model layers are equal to the digitized electrode spacings which are equally spaced on a logarithmic depth scale.

(iii) The true resistivities of the model equal the apparent resistivities.

Depth determination

In practice, the true resistivity-depth curve is unknown. Therefore, in order to determine the amount of shift to the left to bring the assumed and unknown layering to the nearest "in-phase" condition, do the following iterative calculation:

(a) Assume that the digitized electrode spacings are equal to the depths and that the apparent resistivities are equal to the true resistivities at those depths (Figure 4a).

(b) Compute a theoretical sounding curve for this multilayer model by convolution (Figure 4b).

(c) Compute the root-mean-square (rms) percent from the equation

$$\text{rms\%} = \sqrt{\frac{\sum_{j=1}^{N}\left(\frac{\bar{\rho}_{0j} - \bar{\rho}_{cj}}{\bar{\rho}_{0j}}\right)^2}{N}} \times 100, \tag{1}$$

where

$\bar{\rho}_{0j}$ = jth "observed" apparent resistivity,
$\bar{\rho}_{cj}$ = jth calculated apparent resistivity, and
N = number of digitized apparent resistivity points (with $j = 1$ to N).

(d) Multiply all the depths by 0.9 to decrease all the layer depths by 10 percent (small arbitrary amount).

(e) Repeat steps (b) and (c) and compute a new rms percent.

(f) Compare the new rms percent with the previous one. If the new rms percent is less than the previous one (which it will be for the first few iterations), then the newly computed shallower depths are now more in phase and are closer in position with respect to the true, but unknown, depths than the previously assumed depths.

(g) Repeat steps (d), (b), (c), and (f) until the rms percent is minimum. A minimum is detected when the rms percent increases as the depths are shifted too far to the left (are made too shallow). Figure 4c shows the shifted layering and the corresponding calculated sounding curve for a minimum rms percent between observed and calculated sounding curves.

In order to speed up the iterative process, the initial depths may be started at a value that is already smaller than the electrode spacings. For example, multiply all the electrode spacings by 0.8 and then successively reduce the depths by 10 percent until a minimum rms percent is found.

Resistivity determination

Having calculated a theoretical sounding curve using shifted depths and apparent resistivities, we must adjust the amplitudes of those resistivities to obtain a better fit between observed and calculated sounding curves. This is done iteratively as follows:

(a) At each digitized electrode spacing on the observed and calculated curves, if the computed apparent resistivity, at the jth spacing, is less (or greater) than the corresponding observed apparent resistivity, the corresponding true resistivity of the jth layer should be increased (or decreased) so that the calculated apparent resistivity will rise (or fall) and approach the observed resistivity (Figure 4d). The amplitude of a layer resistivity is iteratively adjusted as:

$$\rho_{i+1}(j) = \rho_i(j) \times \bar{\rho}_0(j)/\bar{\rho}_{ci}(j), \tag{2}$$

where

i = number of iteration,
j = jth layer and jth spacing,
$\rho_i(j)$ = jth layer resistivity at the ith iteration,
$\bar{\rho}_{ci}(j)$ = calculated apparent resistivity at the jth spacing for the ith iteration, and
$\bar{\rho}_0(j)$ = observed apparent resistivity at the jth spacing.

The ratio of observed to calculated apparent resistivity is multiplied by the corresponding layer resistivity to adjust it to a higher or lower value.

(b) Calculate a new sounding curve using the adjusted layer resistivities.

(c) Compute a new rms percent and compare it to the previously obtained rms percent.

(d) Repeat steps (a), (b), and (c) until a match is found to the observed curve (Figure 4e) or until another condition is met to terminate the iterative process.

The iterative process is terminated when one of the following conditions is met: a prescribed minimum rms percent (less than 2 percent for field data) is obtained; a slowness in further improvement in fit is detected (less than 5 percent reduction in successive rms percent); a maximum number (30) of iterations is reached; or the rms percent increases instead of decreases. The average number of iterations is about 10.

OPTIONS AND CHARACTERISTICS

The iterative process as described above is complete for almost all practical purposes. However, the options below may be used to generate equivalent models, to impose constraints, and to illustrate some characteristics of the method.

Fixed shift factor

Each sounding curve has its unique depth shift factor that yields a minimum rms percent. The value of this shift factor depends on (a) the curve type; that is, H, K, A, Q, HK, KH, etc. (Zohdy et al., 1974); (b) the completeness of the left and right branches of the field curve; and (c) the amount of noise present. It was found, however, that because of equivalence, determining the optimum shift factor is not critical for the final fitting of the curve. Thus, a fixed shift factor may be selected from the range between 0.3 and 0.6 (approximately) and used for almost all Schlumberger curve types; and the observed curve will probably be matched when the resistivity

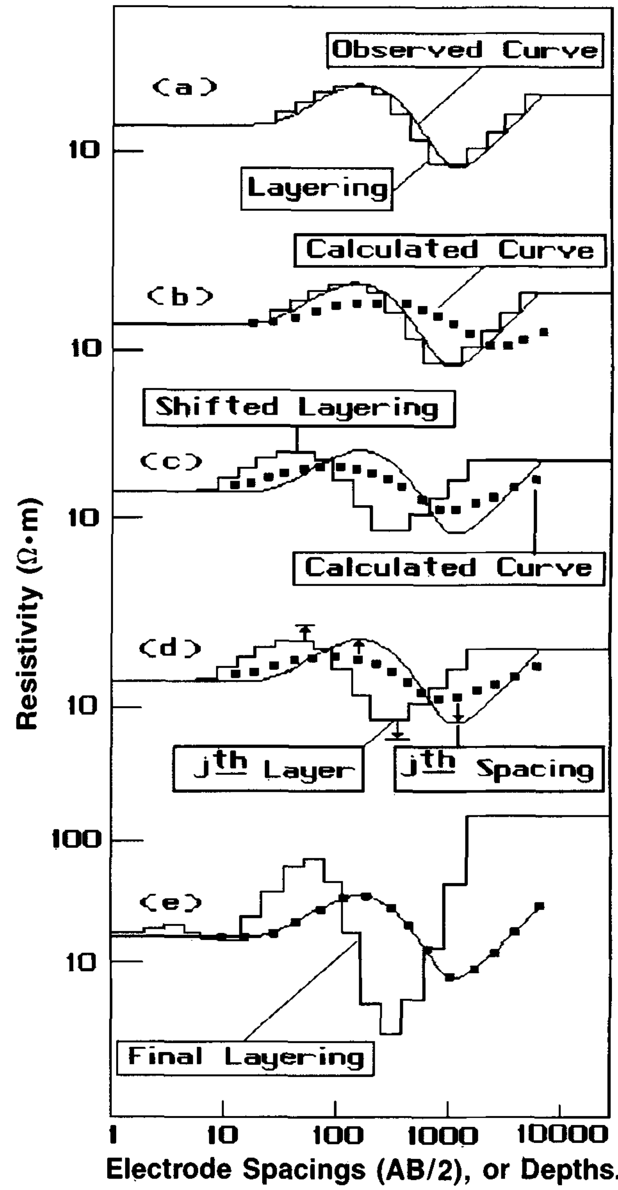

FIG. 4. Graphs showing iterative process of interpreting a sounding curve of unknown layering: (a) layering derived from sounding curve, (b) calculated sounding curve, corresponding to (a), (c) optimally shifted layering and corresponding sounding curve for minimum rms percent between calculated and observed curve, (d) adjustment of each layer resistivity using logarithmic differences between calculated and observed sounding curves, and (e) final layering after several iterations, with calculated curve fitting observed curve.

amplitude adjustments are applied. For Wenner soundings, the corresponding fixed shift factor may be selected from the range between 0.4 and 0.9 (approximately).

The use of a fixed shift factor eliminates a few iterations that would have been necessary to find the optimum shift factor for each curve type. It can also be used to fix the depth to the last layer in the interpreted model. However, the number of iterations saved in using a fixed shift factor may result in a larger number of amplitude adjustment iterations. Furthermore, if the selected fixed shift factor is too small (layering is shifted too far to the left), overshoots or undershoots will develop at shallow depths; and the depth to the last layer will be defined by an abrupt change in resistivity. Conversely, if the selected fixed shift factor is too large (layering shifted too far to the right), then overshoots and undershoots will develop at large depths; and the depth to the shallow layers will be defined by abrupt changes in resistivity.

Layer compression

Severe K-type curves ($\rho_1 \ll \rho_2 \gg \rho_3$) are sometimes encountered when working in permafrost areas (Cagniard, 1959; Kalenov, 1958) or over dry lava flows covered by a thin layer of conductive soil (Zohdy and Stanley, 1973). A severe K-type curve is a curve that rises steeply at an angle of nearly 45 degrees, continues to rise for nearly two logarithmic cycles, forms a somewhat sharp maximum, and then falls to low resistivity values. The sharp maximum on a severe K-type curve should not be confused with the generally sharper maximum, of shorter wavelength, which is caused by the limited lateral extent of a moderately resistive second layer (Alfano, 1959, Figure 19, p. 362).

Interpreting theoretical test curves of the severe K type results in rms percent values in the range of 5 to 10 percent. Such curves cannot be fit within 2 percent because the distribution of layer depths, obtained from digitized electrode spacings, extends over a much larger depth profile than does the true (or any equivalent) layer-depth profile. Therefore, the layer depths must be compressed so that the resistivity adjustment procedure may succeed in yielding a good fit. Layer compression is another means of bringing the assumed layering in phase with the unknown layering, as well as reducing the wavelength of the assumed layering so that it is closer to the wavelength of the unknown layering.

Layer compression is done by fixing the depth to the first layer and successively multiplying that depth ($N - 1$) times by $10^{(1/C)}$, where N equals the total number of layers and C equals the number of layers per logarithmic cycle. Thus, using $C = 6$ and O'Neill's filter coefficients, which are based on a sampling interval of six points per decade, there is no compression. For $C > 6$, the number of layers per decade is increased, hence greater compression. Note that the total number of layers N is still the same as the number of digitized points and that the thicknesses of all layers beneath the first layer still increase at a uniform logarithmic rate, but now the depth interval is less than the electrode spacing interval from which it was originally derived.

Figure 5 shows the results of interpreting a theoretical test curve of the severe K type. Using layer compression resulted in the excellent fit shown. In this example, the final value of C

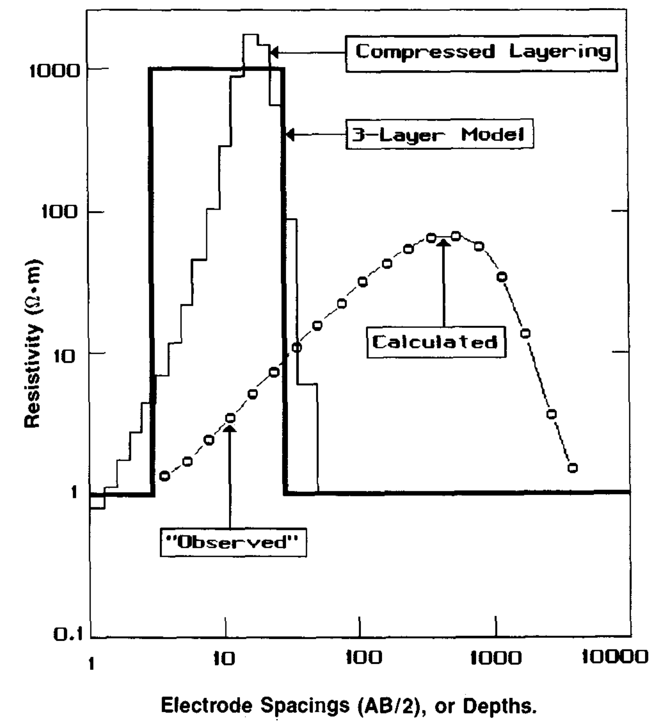

FIG. 5. Example of automatic interpretation of a theoretical test curve of the severe K type using layer compression.

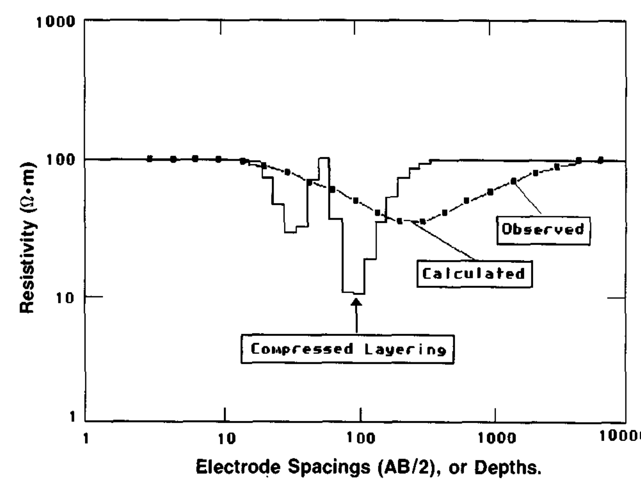

FIG. 6. Example of applying extreme layer compression to interpret an H-type curve with a flat left branch. The shift factor is 3 and the compression factor is 12. The result is equivalent to a five-layer model of HKH-type.

is 10, which corresponds to 10 layers per decade instead of the initial value of $C = 6$.

Compression of layer thicknesses is unnecessary for most resistivity contrasts and layer thicknesses in K-type curves and is never required for other types of curves. Furthermore, in practice. K-type curves are often more readily distorted by the limited lateral extent and irregular thickness of the first conductive layer and of the buried resistive beds (buried stream channels, ice lenses, lava flows, etc.) than are other types of curves. For such distorted curves, layer compression is generally ineffective in bringing about a better fit to the observed curve.

Layer compression can be used advantageously in areas where electrical anisotropy is present or where the interpreted depths are required to be shallower than those obtained without compression. Whenever layer compression is used, high-resistivity layers (in a K portion of the layering) have higher resistivities than those obtained without compression; similarly, low-resistivity layers (in an H portion of the layering) have lower resistivities. This is a direct result of the principle of equivalence.

Experimentation with layer compression showed that compression works best with shift factors close to unity. In fact, with sounding curves whose left branch is flat, compression can be used in conjunction with a fixed shift factor that is greater than unity. Figure 6 shows an H-type curve interpreted using a shift factor of 3, a compression factor $C = 12$, and O'Neill's filter. Here. the calculated model is not necessarily obvious from the shape of the curve.

Layer expansion

Just as layer compression results from increasing the value of C (to increase the number of layers per decade), layer expansion results from decreasing the value of C (to decrease the number of layers per decade.)

Fixed last layer resistivity

The resistivity of the last layer may be fixed by the interpreter so that, for example, all sounding curves that show a rising right branch (S line) would be interpreted in terms of a constant resistivity value for the geoelectric basement and thus produce geoelectric cross-sections that have a common basement resistivity. An easy way to obtain a common basement resistivity is to set the last layer's resistivity equal to the required value instead of letting it equal the apparent resistivity of the last point on the curve; the last layer's resistivity would not change during the iterative process.

INTERPRETATION OF INCOMPLETE CURVES

An incomplete sounding curve is one in which the left and (or) right asymptotes to the resistivity of the first and (or) last layer, respectively, are not measured. Most field sounding curves are incomplete. A field sounding curve whose last right branch rises at an angle of 45 degrees for at least three or four points (sampled at the rate of about six points per decade) is considered to have a complete right-hand branch (S line).

The automatic interpretation method presented here treats incomplete sounding curves very effectively and naturally. An

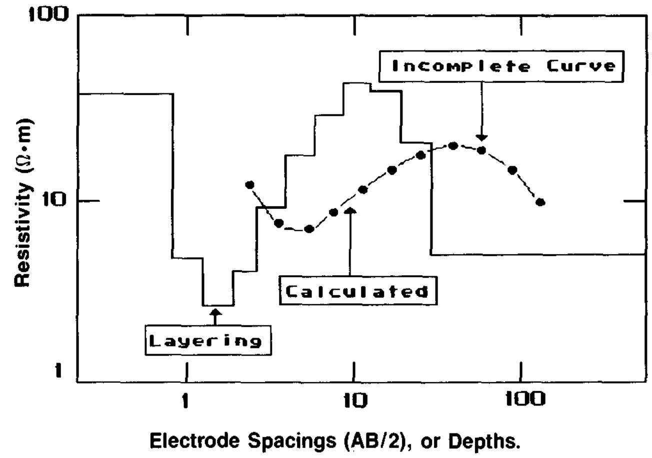

FIG. 7. Example of automatic interpretation of an incomplete Schlumberger sounding curve.

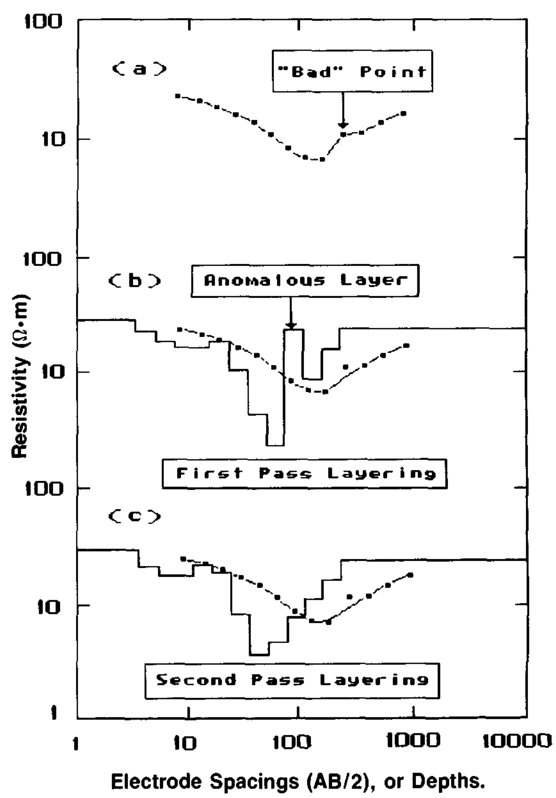

FIG. 8. Example of automatic interpretation of a moderately distorted sounding curve: (a) observed curve, (b) first-pass results showing calculated sounding curve and layering with anomalous layers, and (c) second-pass results showing calculated curve with anomalous layers eliminated.

incomplete left branch presents no convergence problem for the standard iterative process because the depth to the bottom of the first layer is always less than the first electrode spacing. Uncertainty in the value of the resistivity of the first layer(s) always exists, but the first point on the observed sounding curve will be fit, provided the curve is not distorted. Similarly, an incomplete right branch merely presents an uncertainty in the resistivity value of the last layer (same as with curve matching procedures). Figure 7 shows an example of the interpretation of an incomplete sounding curve, in which both the left and right branches are incomplete.

INTERPRETATION OF DISTORTED SOUNDING CURVES

Sounding curves are considered to be distorted when their form departs from the theoretical forms computed for horizontally stratified media. Distortions are caused by errors in measurements, by current leakage (Zohdy, 1968), by manmade structures (fences with grounded metal posts, metallic pipe lines, buried telephone cables with lead sheaths, etc.), or by lateral geologic inhomogeneities. Since distortions affect the resulting model, the automatic interpretation is made in two passes.

First pass

Figure 8a shows a moderately distorted sounding curve. Inasmuch as each digitized point on a sounding curve represents a layer, a bad point (or points) on a sounding curve causes the automatic interpretation process to generate a somewhat anomalous layer(s) starting with the very first iteration. As the resistivity adjustment procedure continues, the anomalous layer(s) increase in amplitude and are present in the final model (Figure 8b). A bad point is defined as a point which cannot be fit with a curve computed for horizontally stratified media. An anomalous layer is a layer with an anomalously high or low resistivity that the computer program generates in an attempt to fit the bad point(s) on the sounding curve, and in spite of which, the bad point(s) cannot be fit perfectly. The result is a theoretical sounding curve that may fit the observed sounding with an acceptable rms percent but the layering obtained contains an unacceptable anomalous layer(s) within it (see Figure 8b).

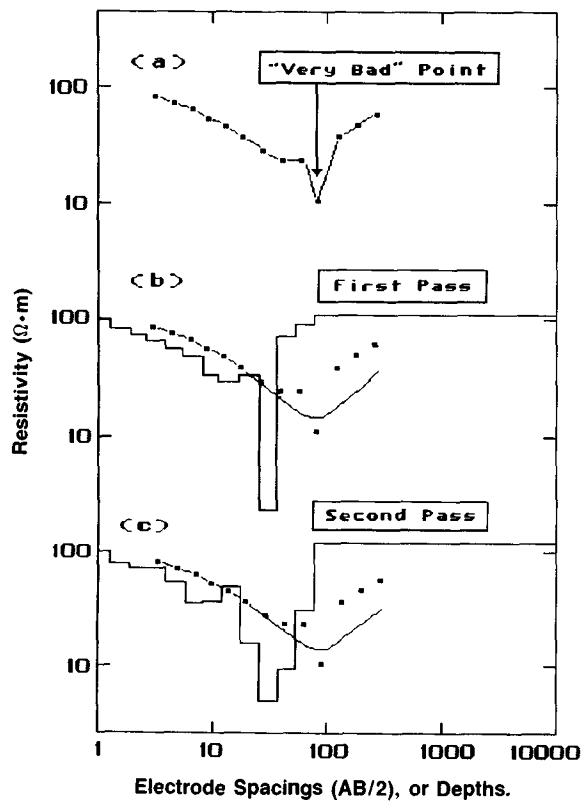

FIG. 9. Example of automatic interpretation of severely distorted sounding curve: (a) observed curve, (b) first-pass results with anomalous layer and calculated curve not fitting data too well, and (c) second-pass results with anomalous layer eliminated and calculated curve still not fitting data too well.

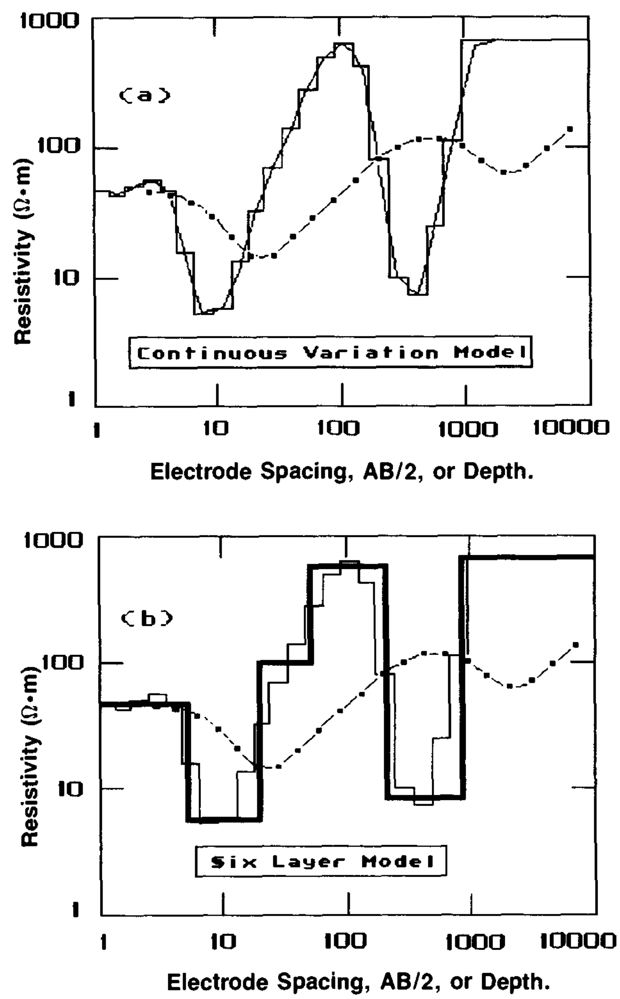

FIG. 10. Results of automatic interpretation and two methods of generating equivalent layerings to interpreted multilayer model: (a) creating continuous variation of resistivity with depth and (b) reducing multilayer model to a six-layer model.

Second pass

To eliminate the anomalous layer, the best-fitting theoretical curve obtained from the first pass is considered to be a smoothed version of the observed curve and is automatically reinterpreted (second pass), the logic being that, since the best-fitting theoretical curve (resulting from the first pass) is smooth and noise-free, the iterative automatic interpretation process is not steered into creating anomalous layer(s) in the early set of iterations. Anomalous layer(s) are not recreated, provided the fitting tolerance is not set to an unnecessarily small rms percent value (such as 0.1 percent). For the second pass, the fitting tolerance is set at 1 percent; and the smoothed version of the observed curve is fit using a layering model that does not contain anomalous layers (Figure 8c).

Note, however, that with a very bad point (or points) on a sounding curve (Figure 9a), the best-fitting curve resulting from the first pass may not be the logical smoothed version for that sounding. In fact, the best-fitting curve will miss fitting perfectly good points that are adjacent to the very bad point (Figure 9b). Good points are here defined as those that should have been fit with a curve for horizontally layered media had the bad point not been there. Reinterpretation of the best-fitting curve (second pass) eliminates the anomalous layer(s), but, of course, the resulting curve still does not fit the observed curve (Figure 9c). Such a sounding curve must be smoothed manually before entering the data into the computer program. Manual smoothing is much faster and more efficient than assigning fitting tolerances to each point.

Single pass

If the original observed sounding curve is fit with an rms percent of less than 2 percent in the first pass, the iterative procedure is terminated, and the best-fitting theoretical sounding curve is not reinterpreted. Indeed, with a very good fit of less than 2 percent, the observed curve must have been a smooth field curve with no bad points.

APPLICATION OF THE METHOD

The multilayer step-function model resulting from the iterative procedure is seldom used, without modification, in the construction of geoelectric cross-sections. There are too many

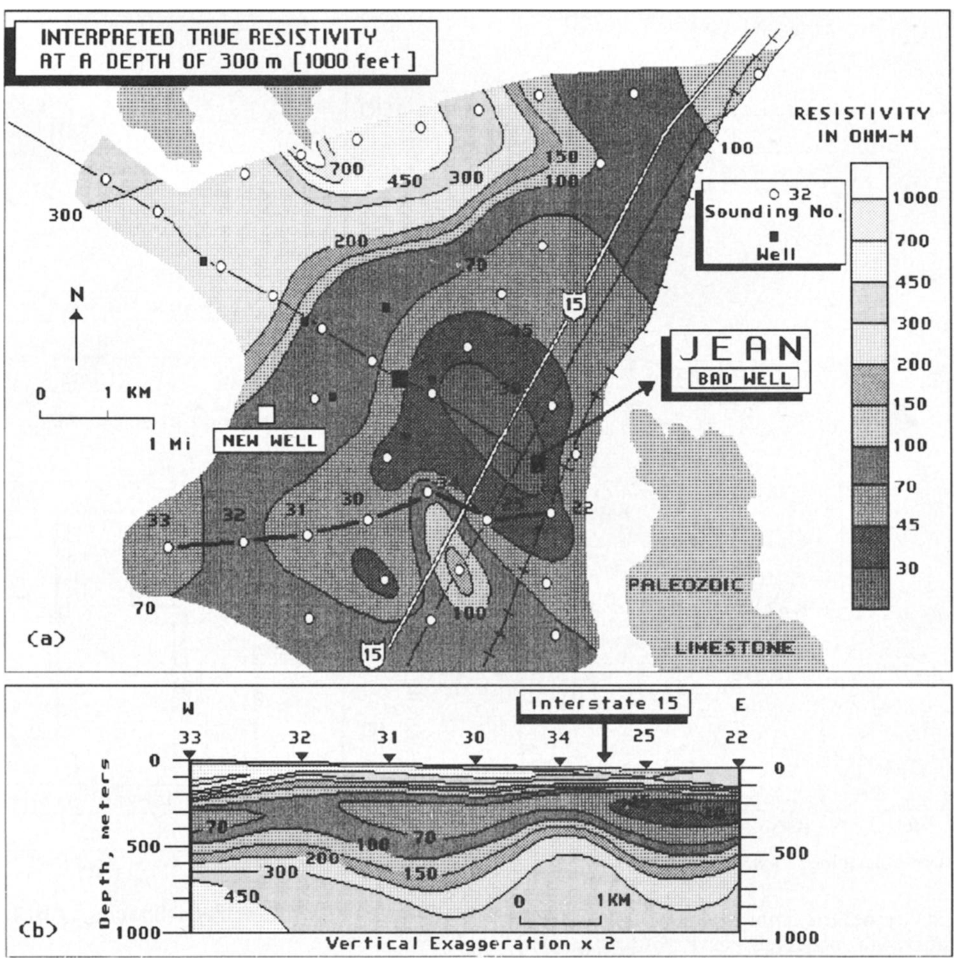

FIG. 11. Interpreted true resistivity map at a depth of 300 m (approximately 1000 ft) and geoelectric cross-section near Jean, Nevada. Map and cross-section were obtained using the continuous variation of resistivity with depth method. Contours are in ohm-meters. Soundings were made using Schlumberger arrays (after Zohdy, 1988).

layers to plot and too many layers to correlate and modify across a cross-section, using manual and traditional methods that are based on fixing the resistivity of each layer and adjusting the thickness in accordance with the principle of equivalence. Furthermore, if the multilayer step-function models are used in a computer contouring program to generate contours of interpreted resistivity, the result will be a blocky looking cross-section (steps in, blocks out). Therefore, for each multilayer step-function model, either an equivalent continuous variation of resistivity with depth model is created (Figure 10a), or a simpler and equivalent step-function model with fewer layers is constructed (Figure 10b).

Continuous variation of resistivity with depth

A continuous variation of resistivity with depth curve is easily derived from the multilayer step-function curve by calculating or drawing a curve that passes through the logarithmic midpoint of each vertical and horizontal line on the multilayer step-function model. In view of the fact that the layer depths are logarithmically closely spaced, the derived continuous variation of resistivity with depth model is equivalent to the original model. This approach makes it easy to construct maps of contoured resistivity at different depths and to construct contoured geoelectric cross-sections. Figure 11 shows a map and a cross-section constructed with the continuous variation of resistivity with depth method. All soundings were interpreted using the automatic interpretation method described here. The results of the interpretations provided new information that was later supported by drilling (Zohdy, 1988).

Simplified layering

The multilayer step-function model may be reduced to a fewer number of layers either by using a computer routine (Zohdy, 1973; Zohdy and Bisdorf, 1975) based on Dar Zarrouk functions (Maillet, 1947; Orellana, 1963; Zohdy, 1973, 1974), or by simply drawing bold horizontal and vertical lines through the multilayer model. The computerized or manual use of Dar Zarrouk curves is preferred when the layering is to be modified significantly to incorporate constraints on layer resistivities or thicknesses. The simplified layering must be tested for equivalence to the original model by computing a theoretical sounding curve and comparing the theoretical curve to the original sounding curve. A reduction in the number of layers is often necessary when two-dimensional or three-dimensional analysis is applied to a set of sounding curves.

SUMMARY AND CONCLUSIONS

A basically simple but powerful method is presented for the fully automatic interpretation of Schlumberger and Wenner VES curves. The method is fast, involves a short computer code, results in layering models that are pleasing to the eye, and virtually eliminates the generation of anomalous layers caused by noise in the data. The method provides the geophysicist with a geologically reasonable layering model that he/she may accept or may wish to modify to satisfy geologic information. Some modifications and constraints can be made using options (fixed shift factor, layer compression, layer expansion, or fixing the resistivity of the last layer) to generate other equivalent models. Testing the method with numerous theoretical curves and using it to interpret nearly 200 field curves resulted in models that not only agreed with known geology and hydrology, but also provided valuable new information that was proved to be correct by test drilling.

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