GL00626

INTERPRETATION OF SCHLUMBERGER DATA IN THE VICINITY OF ZUNIL I

SUMMARY

Soundings in the vicinity of Zunil I indicate a broad conductive zone at depth, which correlates qualitatively with surface geothermal manifestations and hydrothermal alteration of ash flows as indicated in wells. This conductive zone is underlain by a more resistive zone, which could represent a different alteration grade of the ash flows or could represent unaltered granitic basement.

Statistical analysis indicates that the parameters of the layered models which fit the sounding data can change over a wide range without affecting the data fit by a statistically significant amount.

The data also include features which cannot be fit by layered earth models. Finally, the soundings are very widely spaced, making correlation from one sounding to the next difficult. The way to overcome these obstacles to quantitative interpretation is to interpret an expanded data set with a multidimensional interpretation algorithm with geologic constraints placed on the model.

INTRODUCTION

The Schlumberger method of direct current resistivity sounding measures the potential drop across a short receiver wire, which is attached to the earth at its two end points M and N, for a direct current transmitter. The distance MN is increased as needed to maintain the level of the received signal. The transmitter wire is collinear with the receiver wire and straddles it symmetrically. The transmitter wire in turn is attached to the earth at its two endpoints. The transmitted current has a waveform which has a repetition frequency low enough to minimize inductive effects but high enough to avoid geomagnetic noise, which is inversely proportional to frequency. The measured potential is transformed to an apparent resistivity, which is the resistivity of a uniform earth which would give the same potential as that measured for the particular transmitter spacing. A complete sounding consists of the measured apparent resistivities for a number of different transmitter wire lengths. It is important to use a number of different transmitter wire lengths because the depth of investigation on a layered earth is dependent on the length of the transmitter wire. The longer the transmitter wire, the greater the depth of investigation.

The Schlumberger method is well suited for groundwater investigations where the geologic strata are layered with gradual lateral variations in the thickness and the resistivity of the layers. In this application, the data can be interpreted using graphical techniques or with computer inversion techniques. Computerized inversion is generally preferred to graphic techniques because of their greater accuracy and versatility. Regardless of the interpretational procedure, however, the fact that the interpretation is based on a limited amount of data containing some noise can lead to large standard deviations in the interpreted model parameters of layer resistivities and thicknesses.

When the geologic units are not layered, interpreting the Schlumberger method can be difficult. This is because quantitative interpretation then requires a two- or three-dimensional modelling algorithm and data from a large number of soundings with various orientations. In this case, quantitative interpretation is often not practical and qualitative interpretation is all that is possible in a timely fashion.

Approximately 30 Schlumberger soundings were taken in the vicinity of Zunil I. These data were provided to us in the form of field notes and as plotted apparent resistivity curves. In general, the soundings were located in zones of radical lateral inhomogeneities, which can be expected to complicate the interpretations. The sounding curves were oriented in only one direction and were widely spaced.

GENERAL RESISTIVITY STRUCTURE

The soundings provided to us are located in the colored regions of Figure 1. The soundings can be divided into groups A and B, as shown in Figure 1. The soundings in group A indicate high resistivity terrain, underlain in some cases by a lower resistivity rock. A representative sounding from group A, Q.C. Sounding number 114, is contained in Appendix 1. For these soundings the resistivity and the total thickness of the lower resistivity rock cannot be determined from the data. Because of the absence of deep drillholes in this area, it is unclear whether the lower resistivities could represent intense hydrothermal clay alteration of ash-flows at depth. Interpretation is complicated in many cases by the jagged nature of the plotted data curves, which could indicate poor data quality or the effects of lateral inhomogeneities. Since the soundings are widely spaced, it is difficult to assess the influence of lateral inhomogeneities on these soundings.

The soundings of group B indicate a high resistivity layer, underlain by a low resistivity layer, which in turn is underlain by a layer of high resistivity. The geographic coincidence of the soundings in Group B with the area of surface geothermal manifestations and high thermal gradients suggests that the low resistivity layer is rock which has been hydrothermally altered to conductive clay. The bottom high resistivity zone could be rock which is either unaltered or altered to a less conductive state.

Since the soundings in group B lie in the area of most active exploration interest we have concentrated on these data.

GROUP B SOUNDINGS - GENERAL CONSIDERATIONS

Figure 2 shows the location of a subset of Group B soundings in the immediate vicinity of the deep, production wells in Zunil I. Appendix 1 contains the data for these soundings together with one-dimensional interpretations of some of the soundings. Those soundings not interpreted contained unusually noisy or erratic data.

The data has been plotted for all MN values, as is indicated by the multiple data points at single AB/2 spacings. We do this because we do not want to bias an interpretation by adjusting the curve up or down to make the curves for various MN values coincident, as has been done traditionally. The apparent resistivity curves for the various MN values should parallel one another if the data is accurate. When the curves are not parallel then data quality is suspect. Any offset in the apparent resistivity curves for different values of MN reflects effects of lateral inhomogeneity on the MN electrodes. Traditionally, Schlumberger soundings have been interpreted by fitting them to the responses of layered earths. Some layered earth interpretations are contained in Appendix 1 for individual soundings. The interpretations were done using a ridge regression least-squares inversion computer program developed at ESL/UURI. The basic technique is discussed by Inman (1975). Computer modeling is important in this application because it rapidly finds the solution which fits noisy or inadequate data in a least-squares sense and because it gives a statistical appraisal of the uniqueness of the final solution. Appendix 1 also includes the percent parameter standard deviations and the parameter correlation matrix for selected soundings.

Since the data contains apparent multi-dimensional effects, which we will discuss later, the data match obtained is in many cases rather poor. If we assume for a moment that the non-layered earth behavior of the data curves is simply noise, then we can view the layered models as being layered earth models which fit the noisy data in a least squares sense. The parameter standard deviations give an estimate of the degree to which each model parameter can be perturbed and still give a model which will fit the data to within one estimated standard deviation. Since these statistics are based on a linearized approximation to the geoelectric response, they are accurate only in a local sense. In particular, standard deviations which are higher than 100% only indicate that the parameter is poorly resolved, not that there is a possibility that the parameter can assume a negative value. As can be seen from the percent parameter standard deviations calculated for each sounding, the individual resistivities and thicknesses of the conductive layers are poorly resolved. Thus, although we are certain that a conductive zone exists at depth, its thickness is largely unresolved from the soundings themselves. At most, a conductivity-thickness product can be determined for this conductive layer. In this light, predicting the depth of granodiorite from the layered earth interpretations could well be inexact.

The data itself indicates multi-dimensional structure. For example, no layered earth can produce the greater than 45° slopes for the ascending branches for large AB/2 values for soundings 1, 3, 4, 5, 6, 8, 10, 11, 115, and 116. This behavior is consistent with the existence of lateral contacts, such as are shown in Figure 3 (Kunetz, 1966), whose distance from the expander center is equal to the AB/2 value of the cusp. The application of layered earth interpretation schemes in such cases for the determination of depth to granodiorite is suspect.

GROUP B SOUNDINGS - SPECIFICS

To illustrate these remarks, we will now briefly discuss in detail some of the soundings from group B and their layered earth interpretations, as contained in Appendix 1.

Sounding no. 4 gives an example of an apparently radical effect of lateral inhomogeneity on the apparent resistivities for two different MN spacings for the receiver electrodes. The effect occurs at an AB/2 of 40 meters, where the apparent resistivity curves are offset by almost one order of magnitude. Unfortunately, the data collector did not gather data at the old MN spacing for two consecutive AB/2 values, and hence we cannot assess the possible role of data collection noise in producing such an offset. Another apparent discontinuity occurs between an AB/2 of 60 meters and an AB/2 of 100 meters, indicating poor data quality, lateral discontinuities, or extremely large resistivity contrasts between adjacent layers. The poor data fit achieved with the layered model is not surprising given the multi-dimensional or noisy character of the data. Adding more layers with realistic resistivities might improve the match somewhat, but given the character of the data, no layered model would be able to achieve a statistically significant match.

Soundings number 6 and 12 also contain multidimensional effects, most notably the slopes of the sounding curves for large AB/2 are greater than 45°. This behavior cannot be produced by layered earths. In these cases, the depth and resistivity of the basement as indicated by the layered earth models cannot be trusted.

Sounding number 115 is more amenable to layered earth interpretation than the previous soundings which we have discussed. Essentially, the layered earth model whose parameters are given provides an acceptable fit to the data. We have also plotted the matches obtained by maintaining the conductivity-thickness product of the third layer while changing the conductivity up or down by a factor of 2. Although these matches are not as good as the optimal match, they do not seem to be significantly worse in a statistical sense. This example illustrates the poor model parameter resolution which ~~might be achievable~~ ~~is obtained~~ can occur through unconstrained inversion of Schlumberger soundings.

The remaining six soundings which we have quantitatively interpreted all contain data points which are affected by lateral inhomogeneities or error in data collection. Sounding number 38, for example, has an apparent cusp at AB/2 = 1000 m, which may well be the effect of a lateral inhomogeneity. On the other hand, the soundings number 1, 3, 28, 8, and 116 all have several data points which seem to be erratic.

DISCUSSION AND CONCLUSIONS

Group B soundings all indicate a resistivity structure consisting of a high resistivity layer overlaying a very conductive layer, which in turn overlays a resistive layer. A thorough quantitative interpretation of these soundings using layered earth models is difficult for two reasons. First, several of the data curves are very ragged, which could be due to lateral inhomogeneities or to poor data quality. Second, many of the data curves exhibit ascending branches with slopes greater than 45°. This behavior is impossible with layered earths and suggests that layered earth modelling may well be inappropriate in this region.

Unfortunately, the soundings are so sparsely placed that multidimensional modeling is not very useful either.

If we assume, on the other hand, that the multi-dimensional features in the data are just noise, the layered earth interpretations are applicable. Computer modeling suggests that in this case, the geo-electric section cannot be uniquely determined from unconstrained interpretations. However, constraining the interpretations with an 'a-priori' estimate of one or more parameters can lead to increased resolution of other parameters in the model. This is because many of the layered earth parameters are correlated, as can be seen by inspecting the correlation matrices contained in Appendix 1.

Figure 2 gives the depths to the resistive basement for the layered earth interpretations. Of course, the validity of this map is subject to the reservations already mentioned. However, certain features of this map are suggestive.

Joe: Do your thing.

REFERENCES

1) Inman, J. R., 1975, Resistivity inversion with ridge regression: Geophysics, v. 40, p. 798-817.

2) Kunetz, G., 1966, Principles of direct current resistivity prospecting: Berlin, Gebruder Borntraeger.

FIGURE 2:

Location map for soundings
in the vicinity of ZCQ-I.

Map also gives best estimates to the ~~Lowest~~ resistiv~~e~~ity ~~layer~~ basement
as given by layered earth modeling.

make unified caption here.