# DEPARTMENT OF
~~NATIONAL RESOURCES~~
NATIONAL DEVELOPMENT

# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS



Record 1978/85



## INTERPRETATION OF TRANSIENT ELECTROMAGNETIC MEASUREMENTS USING THE APPARENT CONDUCTIVITY CONCEPT

by

B.R. Spies

Record 1978/85

# INTERPRETATION OF TRANSIENT ELECTROMAGNETIC MEASUREMENTS USING THE APPARENT CONDUCTIVITY CONCEPT

by

B.R. Spies

# CONTENTS



FIGURES

PLATES

## SUMMARY

Interpretation of transient electromagnetic (TEM) results usually involves comparing the amplitude of the response at various sample times and rules of thumb to gain semi-quantitative information on the source of an anomaly.

Conversion of TEM results into apparent conductivity curves is possible using graphical or computer techniques. TEM data in this form are more amenable to quantitative interpretation. Apparent conductivity is a function of many factors such as sample time, depth of burial, size and conductivity of the body, and loop size.

TEM methods can be used for depth soundings if measurements are made over a suitable time range. TEM depth soundings promise to be much faster than conventional resistivity sounding methods.

The computation of apparent conductivity curves for various numerical and scale models, supported by field results, shows that this method can assist in discriminating between surficial and bedrock conductors and in estimating the true conductivity of some sources.

# 1. INTRODUCTION

Electromagnetic (EM) methods have been used for over fifty years to search for conductive mineral deposits, assist geological mapping, and make depth soundings.

Most of the EM methods employed to date have operated in the frequency domain. To assist interpretation of frequency domain surveys many papers have been published, particularly in USA and USSR, on the interaction of harmonic electromagnetic fields with conductivity structures. Extensive numerical tables for use in compiling theoretical curves for sounding of horizontally layered structures with frequency domain methods have been published by Frischknecht (1967) and Vanyan et al. (1967).

Although transient EM (TEM) methods were first used in the 1930s, the routine use of TEM in prospecting, mapping, and sounding became common only in the 1970s. Reasons for the delay in the development of TEM methods include problems associated with instrumentation and interpretation. Although TEM fields have been studied since the 1930s, the formulation of the response of TEM systems to even simple conductive structures has proved to be a very difficult problem. However, the advent of cheap and powerful computational techniques such as described in Lee & Lewis (1974) now permits analytical and numerical studies of the response of simple TEM systems to be made. These studies of TEM responses are now leading to the sort of interpretation guidelines that have been available for frequency domain methods for many years.

A particular result of the ability to calculate the response of TEM methods to conductive structures has been the expression of TEM results in the form of an apparent conductivity parameter. Apparent conductivity can provide an insight into the nature of conductivity structures and is therefore a useful aid in the quantitative interpretation of TEMsurveys.

# 2. THE TEM METHOD

The first use of electrical transients in geophysics was in the Eltran method which was based on a patent by Blau (1933). The Eltran method generated transient electromagnetic fields by exciting a grounded dipole with a current pulse. The transient field was detected with an electric dipole in line with the current dipole.

More recent transient systems utilising inductive techniques include the airborne INPUT system and the Russian built MPPO-1 system.

The INPUT system uses a towed receiving coil to detect the transient EM field excited by a large transmitter loop driven by a half-sinusoidal current pulse. The MPPO-1 is a ground prospecting instrument in which a single loop is excited by a square current pulse and is used to detect the transient EM field.

Recently a number of sophisticated TEM systems have become available and offer multiple loop configurations, variable excitation pulses, and, most importantly, very significant noise rejection capabilities (Buselli, 1974; Crone, 1976; Lamontage & West, 1973).

The single-loop method

The single-loop TEM method has been the most common TEM method used in Australia to prospect for subsurface conducting mineral deposits. The method measures the time rate of decay of eddy currents induced in subsurface conductors by the collapse of a magnetic field created by a rectangular current pulse in an insulated loop of wire on the ground. The same loop of wire is used for creating the magnetic field and for measuring the decay of eddy currents between current pulses.

The decaying eddy currents produce in the loop a time-dependent emf e(t) which is measured by the receiver at various sample times (delay times) of from ½ ms to 100 ms. To improve the accuracy of readings, measurements are averaged over several hundred cycles and special filters are used to reduce noise. Loop size is variable, but square loops with side lengths of from 50 to 200 m are commonly used.

The MPPO-1 single-loop TEM system is described by Velikin & Bulgakov (1967), and examples of field and model studies with this system are described by Spies (1976a). A modern single-loop TEM system is described by Buselli & O'Neill (1977).

## 3. CALCULATION OF APPARENT CONDUCTIVITY

The amplitude of a transient decay curve depends on the loop size. Hence analysis of TEM data would be simplified if the results were in a form which is independent of geometry (or loop size). In the resistivity method, measurements are normalised for the array size by utilising a geometric factor to convert V/I readings to apparent resistivity values. An analogous process can be applied to TEM data.

Apparent resistivity ($\rho a$) is defined as the ground resistivity calculated from measurements and a theoretical geometric factor derived for the case where the ground is homogeneous. For the resistivity method, $\rho a$ is a linear ratio of measured voltage V to applied current I, with a proportionality constant (the geometric factor) which depends on the electrode array. In resistivity soundings the dimensions of the array are expanded and apparent resistivity is calculated as a function of distance.

For electromagnetic methods, calculations of apparent conductivity ($\sigma a$) are performed in the same way as in resistivity methods, but the proportionality constant is usually a more complex expression. The main difference is that apparent conductivity is usually calculated as a function of frequency or time.

In 1969 Morrison et al. introduced the concept of apparent conductivity when describing results from numerical computation of TEM fields from a finite loop over a layered half-space for a source/receiver configuration representative of an airborne system. Lee & Lewis (1974) and Lee (1977) derived expressions for calculating the response of a large loop on a layered ground. From these two papers exact values of the TEM response of a homogeneous half-space can be easily calculated for a wide range of loop sizes, conductivity, and time.

The TEM response of a homogeneous half-space of conductivity is given by Lee & Lewis (1974) as

$$\frac{e(t)}{I} = \frac{-2b\mu\sqrt{\pi}}{t} \cdot F\left(\frac{t}{\sigma\mu b^2}\right) \qquad \text{.............................(1)}$$

where b = loop radius

$\mu$ = magnetic permeability

t = time.

when using a square loop of side d, the expression $b = d/\sqrt{\pi}$ is used. Equation (1) cannot be easily calculated for small values of $t/\sigma\mu b^2$ and is valid only for values of $t/\sigma\mu b^2$ between 0.01 and 30.

In a more recent paper, Lee (1977) gives expressions from which the function $F(t/\sigma\mu b^2)$ can be calculated exactly for values of $t/\sigma\mu b^2$ greater than 1.6 and a table from which the response can be interpolated for values between 0.01 and 1.6. For values under 0.01 the expression is undefined. In practice this means that for large loops and extremely conductive ground (e.g. 200 m, 20 S/m) calculations may not be possible over some of the time range normally used in TEM surveys.

The calculation of apparent conductivity from single-loop TEM measurements can be easily made from Lee's paper by the use of a computer. Fortran programs suitable for calculating apparent conductivities on an HP2100 computer are described in Appendix 1. Apparent conductivity calculations can also be made using a program written for a HP-67 calculator described by Spies & Raiche (in prep.).

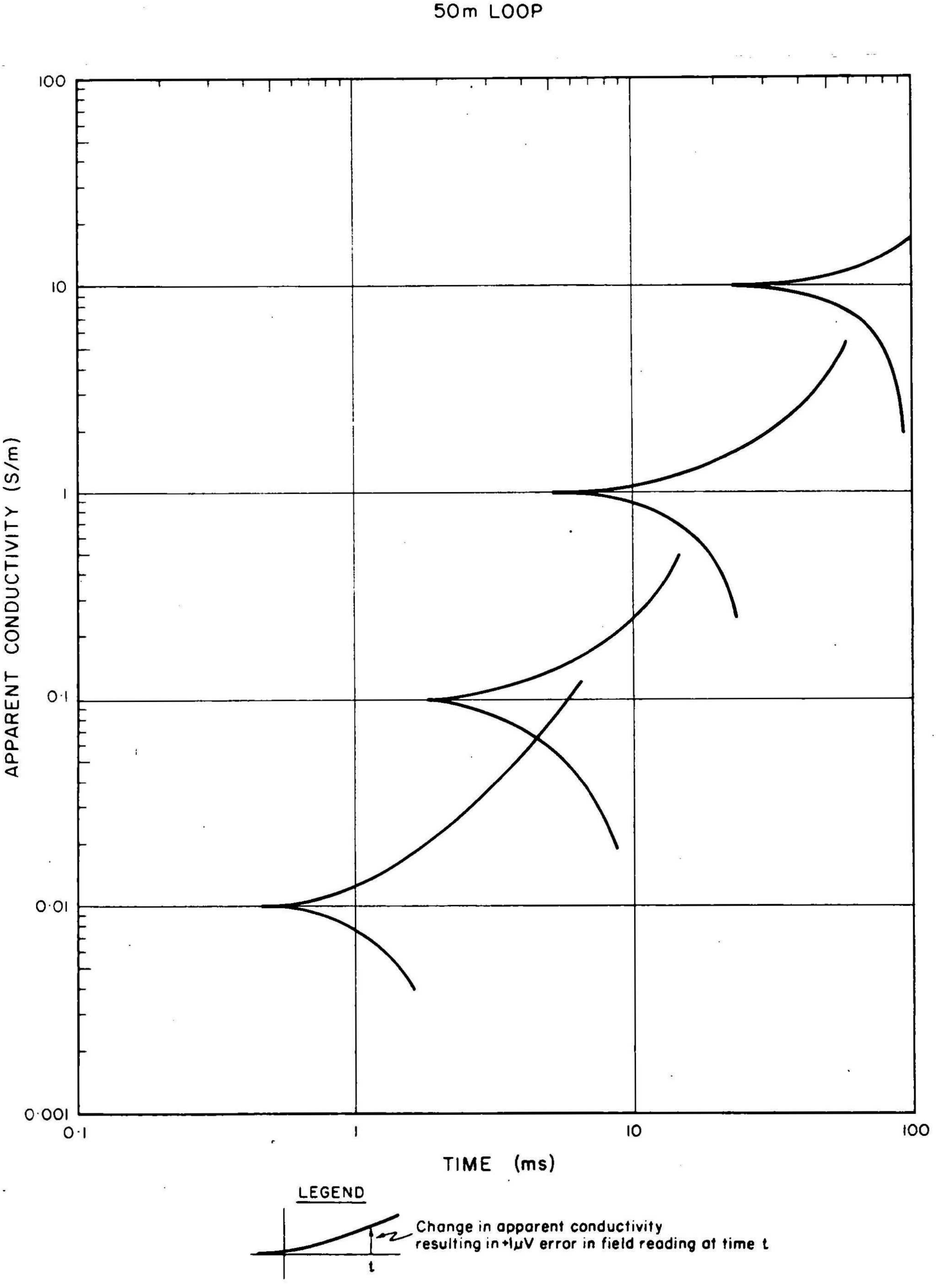
An alternative method of estimating apparent conductivity involves the use of standard curves on which the field decay curve is drawn at an appropriate scale. If the field decay curve follows the shape of a standard curve, the response may be said to be that of a half-space and the apparent conductivity can be estimated. Alternatively, if the field decay curve crosses the standard curve, the time-varying apparent conductivity can be estimated directly from the graph. The Fortran computer program TEMHF described in Appendix 1 can be used to generate standard curves from an HP2100 computer. Standard curves for the TEM response of a homogeneous ground for square loops of size 200, 100, 50, 25, 12.5, 6.25 and 3.12 m are included as Plates 1, 2, 3, 4, 5, 6, and 7 respectively.

## 4. PROPAGATION OF ERRORS IN APPARENT CONDUCTIVITY CALCULATIONS

Apparent conductivity is a function of loop size, time, and response. It can easily be shown that errors in apparent conductivity calculations are likely to be greater at late times or for low conductivities because the measured signal, e(t)/I, will necessarily be smaller. The main difficulty arises in the measurement of the response at small signal strengths, especially in the microvolt and sub-microvolt range. Recent advances in multi-channel signal-averaging techniques (Buselli, 1974) come a long way in alleviating the problem, and increase the signal-to-noise ratio very considerably. Although it is possible to reduce the noise envelope to less than 0.1 $\mu$V it is extremely difficult to measure a voltage accurately in the microvolt range with standard amplifiers (the thermal emf of a resistor, for example, is of the order of several microvolts).

A demonstration of the effect of these errors is shown in Figure 1, in which the effect of a measurement error of $\pm$ 1 $\mu$V/A is shown on the standard apparent conductivity graph. For early times and large conductivities the

Figure 1




Errors in apparent conductivity calculations

Record No. 1978/85

G29-245A

error is negligible. The error increases substantially at later times and for lower conductivities, and can be extremely large at very late times. For example an apparent conductivity calculation with a 50 m loop over a ground of 0.1 S/m is in error by a factor of 2.4 if the response measured at 10 ms is 1 $\mu$V too high.

## 5. INTERPRETATION OF DEPTH SOUNDINGS

There are few references on depth sounding using the TEM method, and very few that can be used for interpreting results from the one-loop method. The quantitative interpretation of TEM data is complicated by interference phenomena and the absence of comprehensive numerical and analogue model studies. However, it is possible to use the apparent conductivity concept to qualitatively interpret TEM soundings. The use of the apparent conductivity concept in the interpretation of TEM depth soundings can be illustrated by analysing the results of theoretical, model, and field studies.

### Theoretical studies

Lee & Lewis (1974) have calculated the TEM response of a horizontal loop over a layered ground, and found that at short times the response is dominated by the term representing a uniform ground of conductivity equal to the top layer. Morrison et al. (1969) have shown that for an airborne type TEM system, the TEM decay curve asymptotically approaches the curve for a half-space with the conductivity of the bottom layer. The same phenomenon would apply to a ground system at late times.

In a recent paper, Lee (1977) suggested that it is possible to estimate the depth to conductors by the use of electrical transients. This is done by utilising the fact that for plane wave excitation of a half-space of conductivity $\sigma$ a maximum in the electric field is found at a depth z and time t when $t = z^2\sigma\mu/2$. Electrical interfaces in the ground will cause reflections of the primary wave which can be observed in apparent conductivity curves, at times depending on the thickness and conductivity of the upper layers. It was shown that, when using a loop with radius 100 m, the true conductivity of the top layer is approached when $\sigma_1\mu d^2/t$ is greater than 0.5, where d is the thickness of the layer.

In calculations of the TEM response of a layered ground, Lee also noted the occurrence of interference effects. In a two-layer case, for instance, these effects can be seen as anomalous apparent conductivity values.

The apparent conductivities are first decreased if the basal layer is a conductor, and are increased if the basal layer is a resistor. These effects have also been observed by Morrison et al. (1969) and Lee & Lewis (1974) when studying more complex sources. Lee & Lewis noted that this may result in the underestimation of the conductivity of the buried layer.

Model studies

The following examples are drawn from scale and numerical model studies of horizontally layered strata, and illustrate the results to be expected when TEM data are converted to apparent conductivity values. Two, three, and four-layer numerical examples are given by Lee & Lewis (1974), and two-layer model study results by Spies (in prep.).

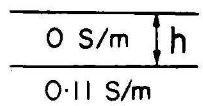
Two-layer cases: The results of scale model studies over two-layered structures are shown in Figures 2 and 3. The scale modelling was carried out using procedures described by Spies (1976b, 1979). The models were constructed of typemetal or graphite, and dimensions were scaled by a factor of 5650.

Figure 2 shows the results over a two-layer case where the top layer has infinite resistivi-ty and the lower layer has a conductivity of 0.11 S/m, for various thicknesses of the top layer. The general trend is for apparent conductivity to increase with time, and to reach the asymptotic value of 0.11 S/m when the top resistive layer is thin. When the layer increases in thickness to 26 m the apparent conductivity at early times has decreased to 0.05 S/m and at late times to 0.1 S/m.

Figure 3 shows the results of several other model studies. Curve 1 is for a 600 m thick bed of 300 ohm-m material underlain by an infinitely resistive layer. The curve departs from the asymptotic value of 0.0033 S/m at early times owing to the effect of the second layer. Curves 2 and 3 are for a 60 m thick layer of 0.11 S/m underlain by a resistive layer (curve 2) and an infinitely resistive layer (curve 3). The effect of the second layer is apparent, and there is almost no difference between the cases of an infinitely resistive and a highly resistive second layer.

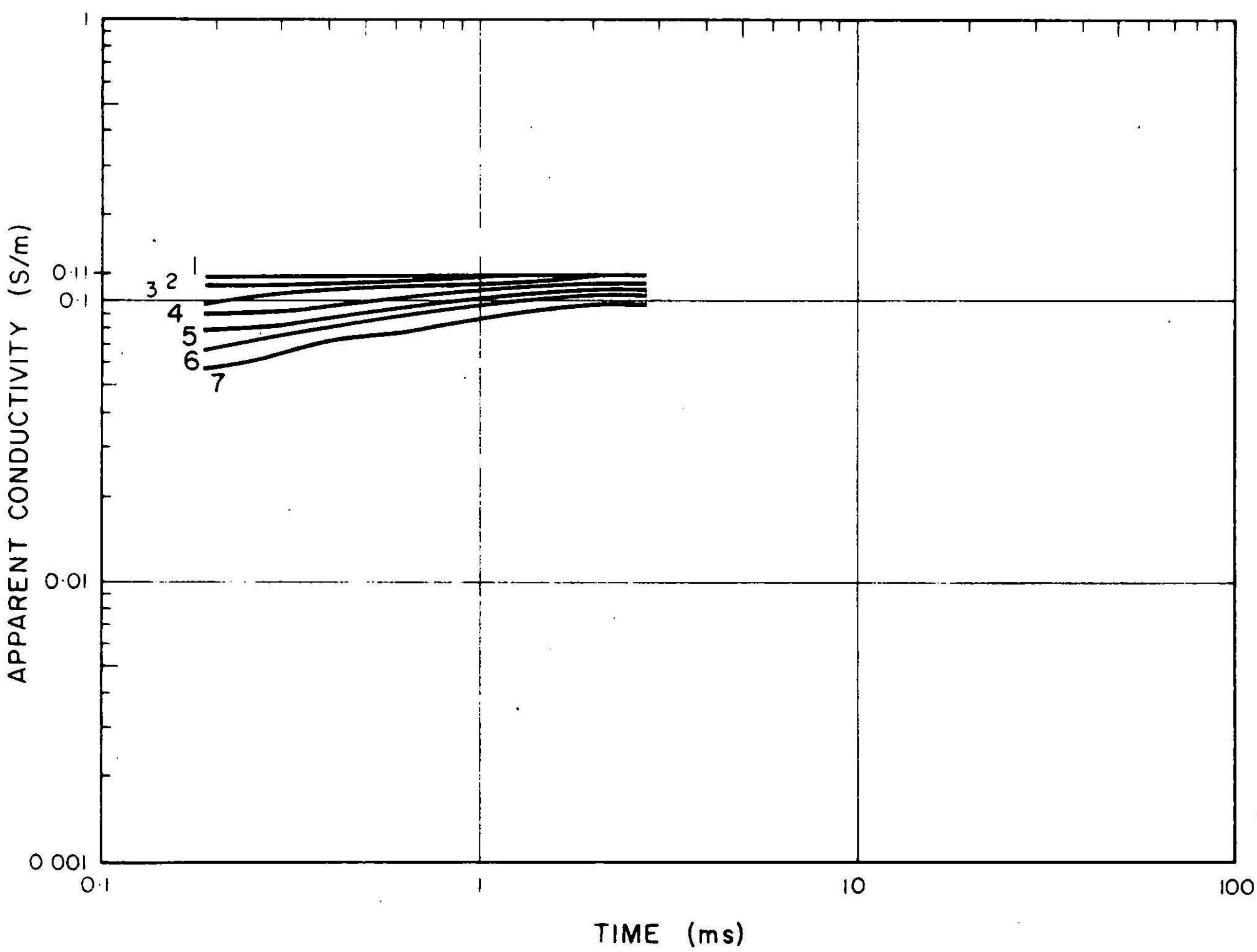
The curves in Figure 4 are taken from numerical results and show the effect of varying the thickness of a layer of conductivity 0.1 S/m overlying a more resistive layer of 0.01 S/m. When the top layer is 200 m thick the curve appears like that from a uniform ground over most of the time range. When the thickness is reduced to 100 m the lower layer is readily visible, and when the thickness is reduced to 10 m the curve almost reaches the true conductivity of the lower layer.

Figure 2



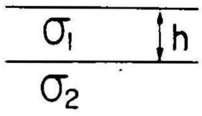

| MODEL | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| h (m) | 0 | 4·5 | 8·2 | 11·7 | 15·3 | 19·8 | 26 |

(56m RADIUS LOOP)



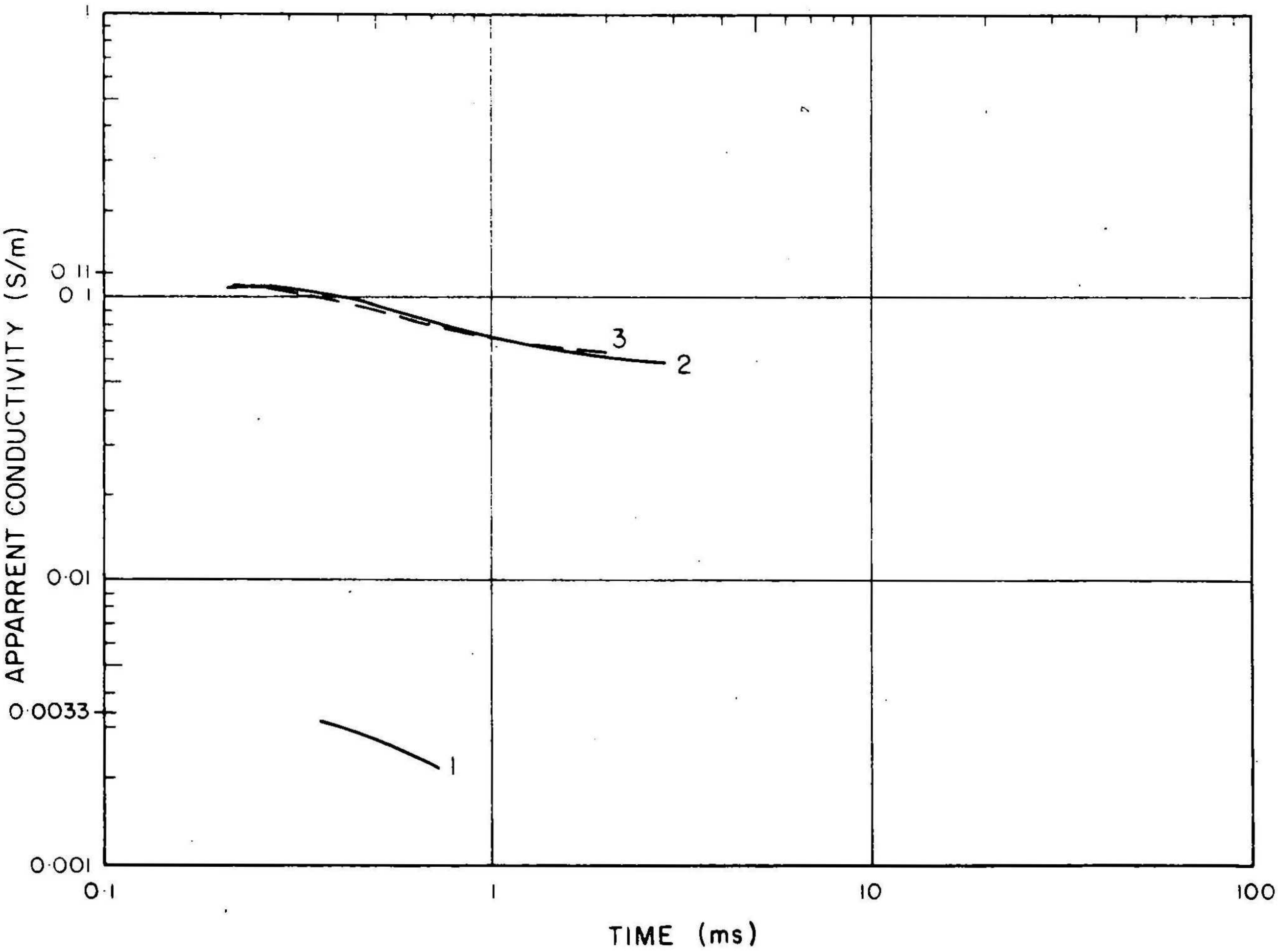

Two-layer case, scale model study

Figure 3



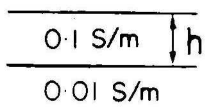

| MODEL | 1 | 2 | 3 |
|---|---|---|---|
| $\sigma_1$ S/m | 0·0033 | 0·11 | 0·11 |
| $\sigma_2$ S/m | 0 | 0·0033 | 0 |
| h (m) | 600 | 60 | 60 |

(100m SQUARE LOOP)



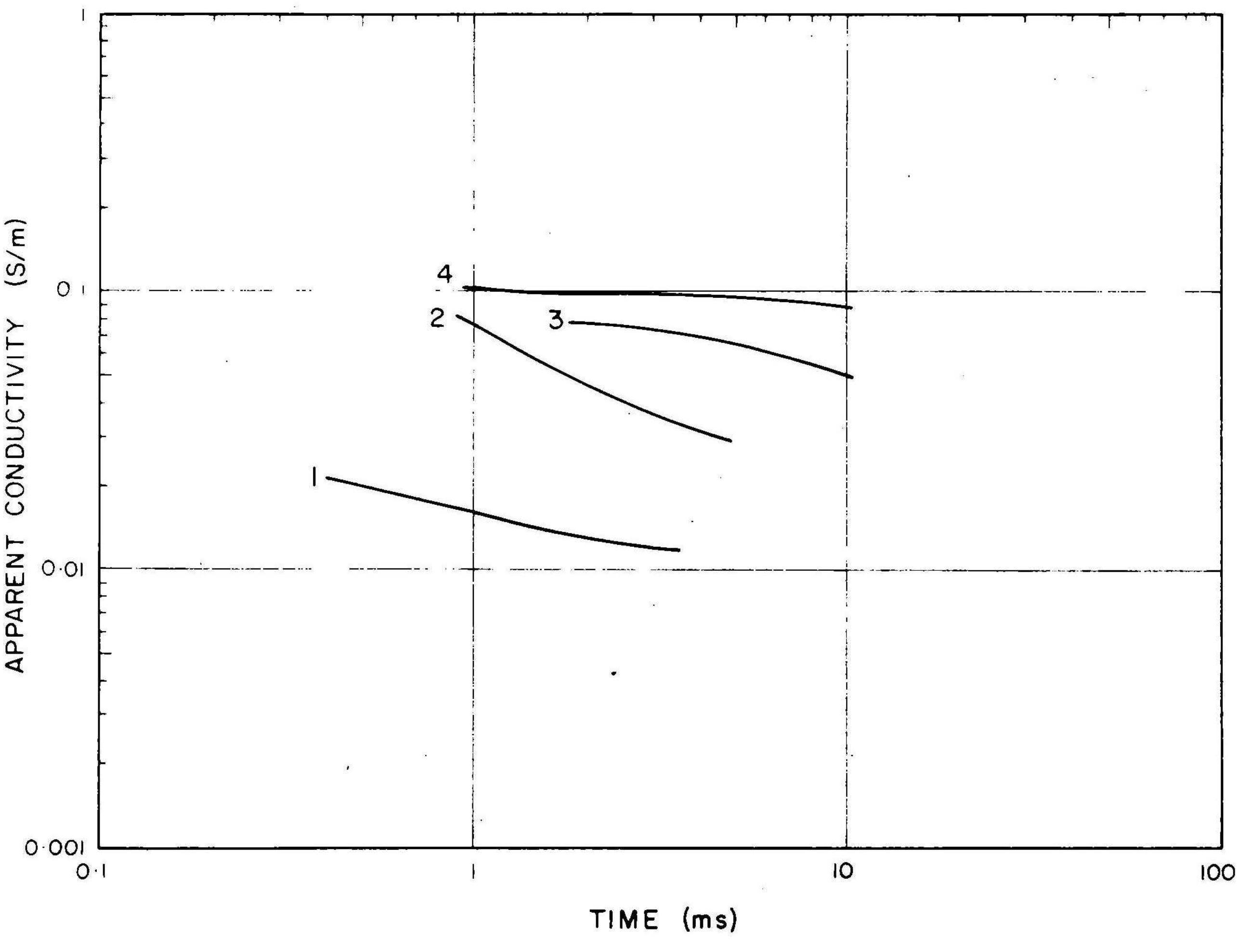

Two-layer case, scale model study

Figure 4




| MODEL | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| h (m) | 10 | 50 | 100 | 200 |

(100m RADIUS LOOP)



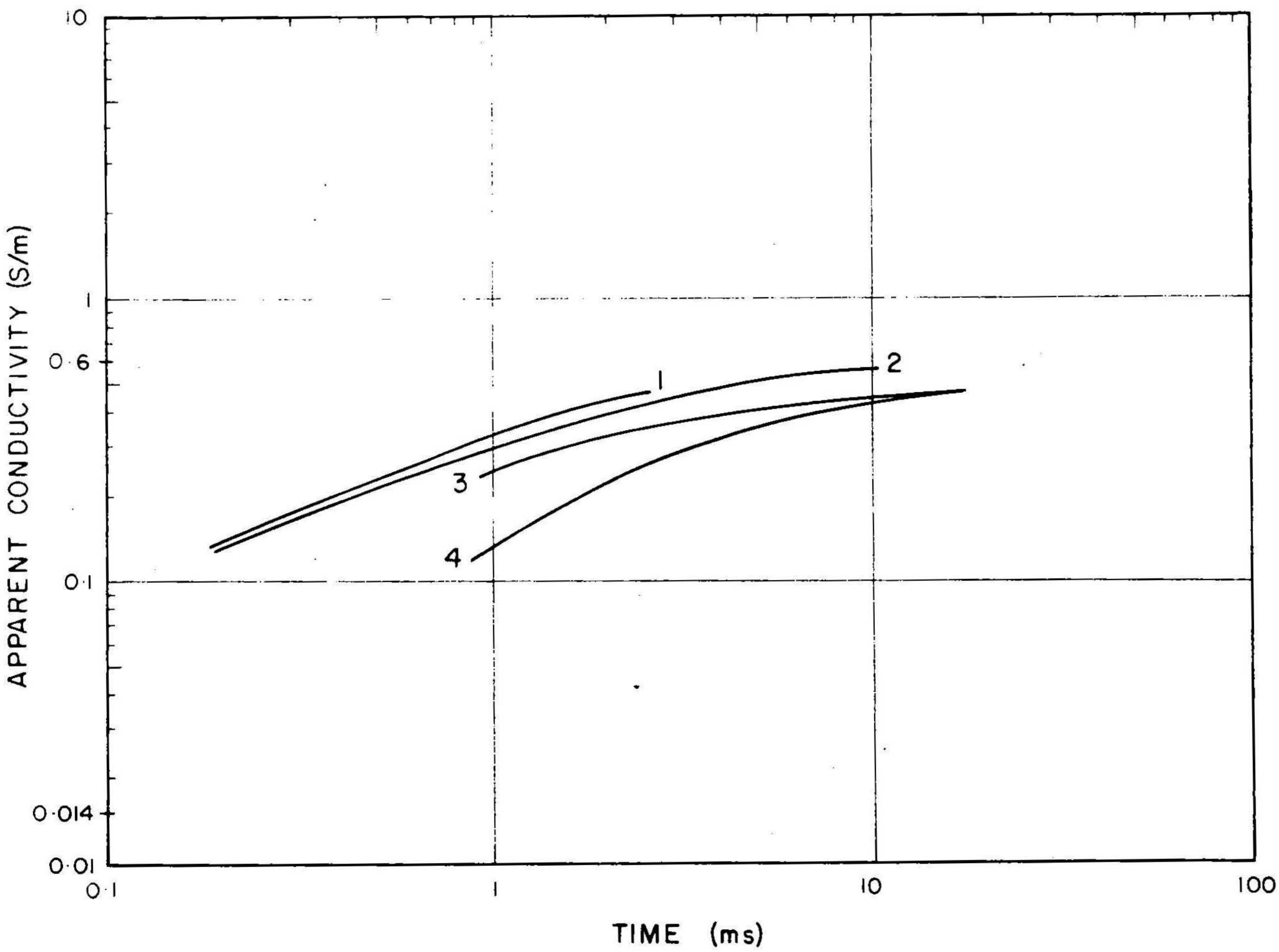

Two-layer case, numerical results

Figure 5

GEO-ELECTRIC SECTION

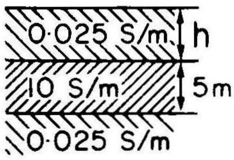
| | |
|---|---|
| | 0 m |
| 0·048 S/m | |
| | 20m |
| 0·60 S/m | |
| | 300m |
| 0·014 S/m | |

| CURVE | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| LOOP RADIUS (m) | 25 | 50 | 100 | 300 |



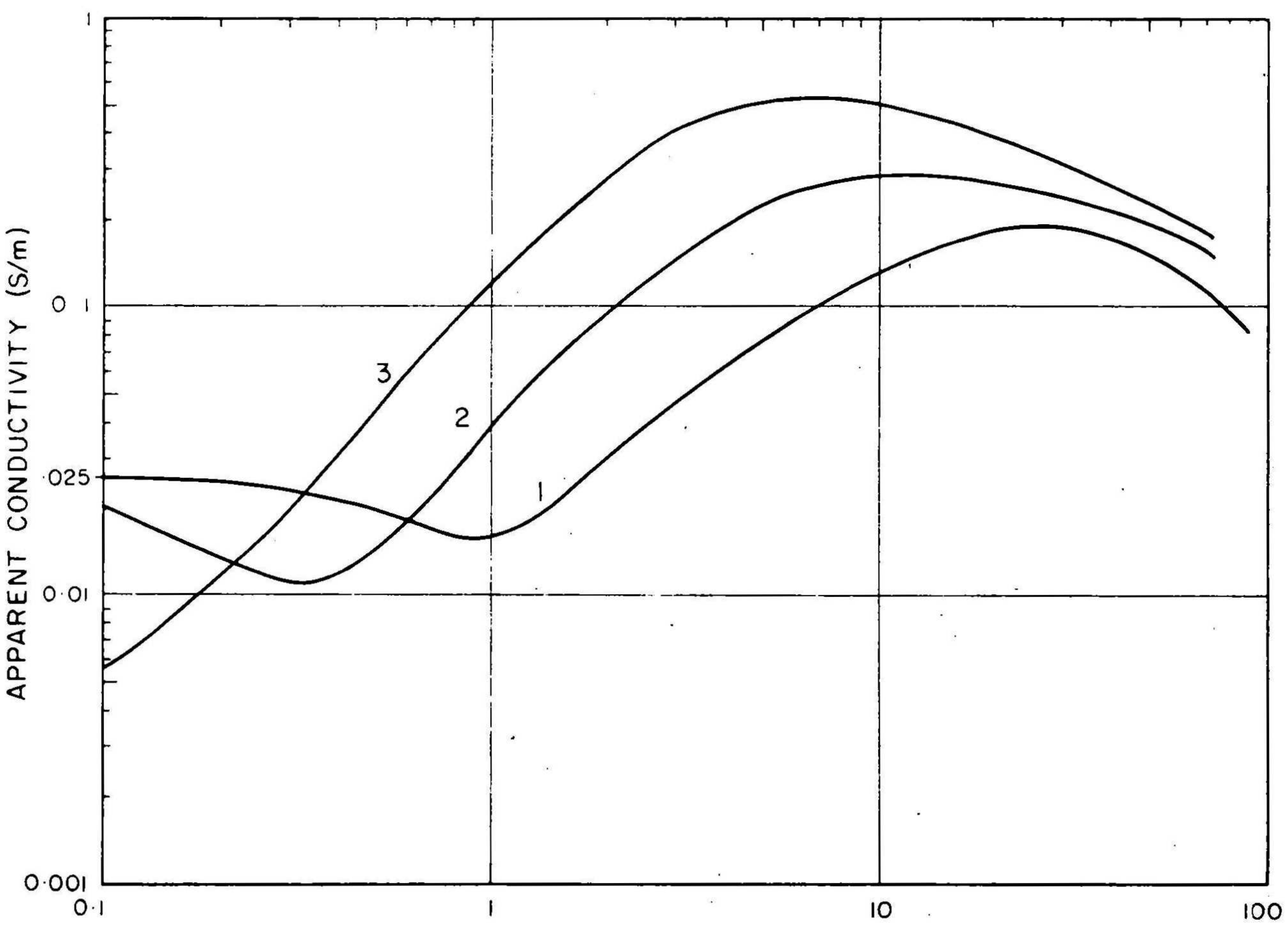

Three-layer case, numerical results

Figure 6




| MODEL | 1 | 2 | 3 |
|---|---|---|---|
| h (m) | 200 | 100 | 50 |

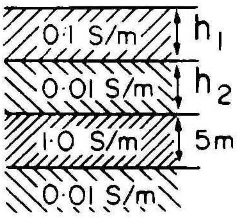
(100m RADIUS LOOP)




FROM LEE & LEWIS (1974) AND LEE (1977)

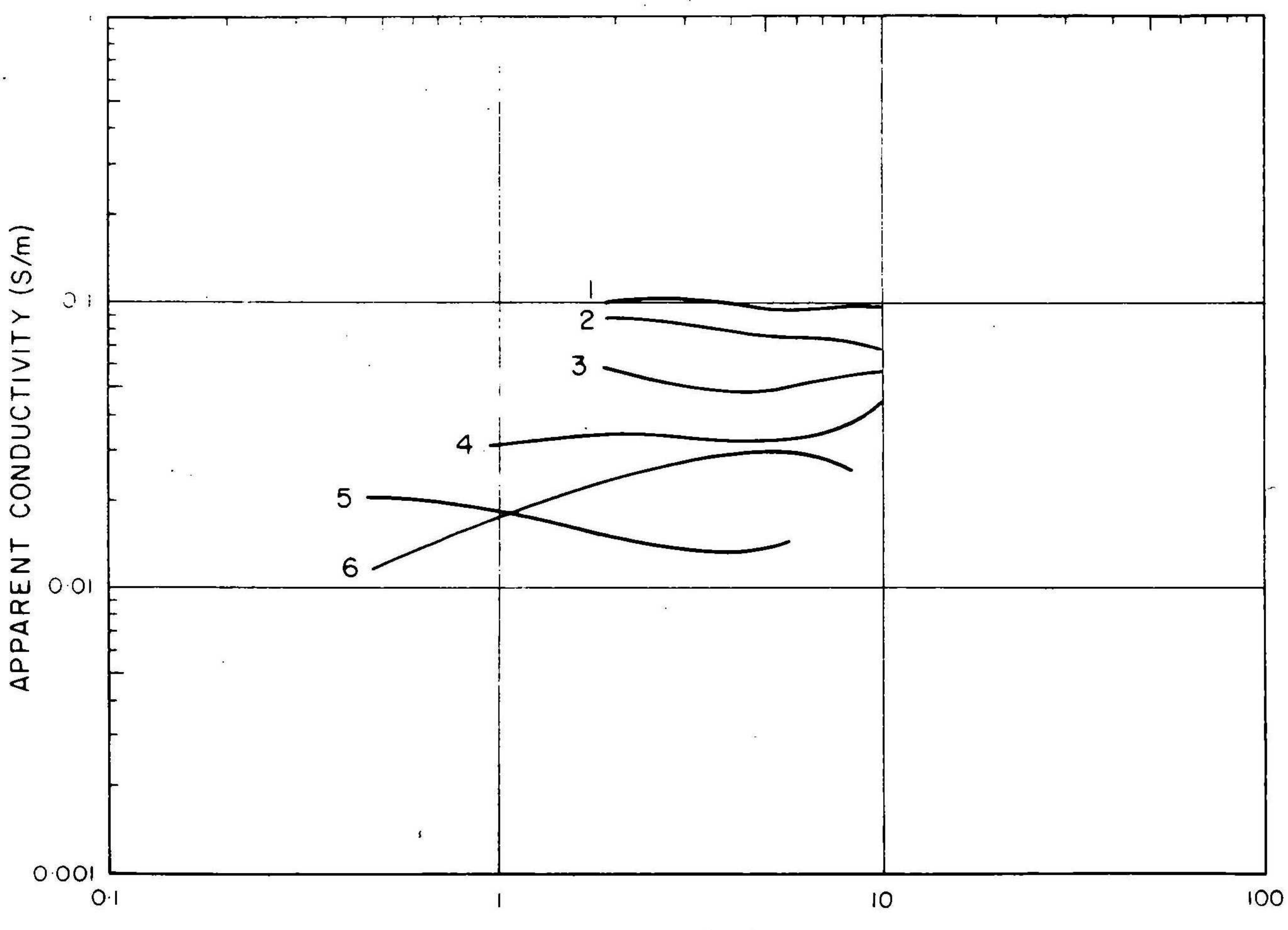
Three-layer case, numerical results

Figure 7




| MODEL | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $h_1$ (m) | 150 | 100 | 50 | 20 | 10 | 0 |
| $h_2$ (m) | 25 | 75 | 125 | 155 | 165 | 175 |

(100m RADIUS LOOP)




Four-layer case, numerical results

The effect of changing loop size over a two-layered resistivity structure is illustrated in the scale model results shown in Figure 18 (sphere absent). In this scale model study curves 1, 3, 5, and 7 illustrate the response obtained with different loop sizes when a 20 m thick conductive layer overlies a resistive half-space. Curves 1 and 3 are for 100 m and 70 m loops respectively and are fairly similar. They appear to be late and early time sections of a composite curve. For the 50 m loop (curve 5) the early time asymptote is nearly reached at 0.5 ms but for other loop sizes, both smaller and larger, the early time asymptote is not reached. The largest loop (100 m, curve 1) appears to be "looking" deepest as it most nearly reaches the 0.01 S/m asymptote.

Three-layer cases: The results shown in Figure 5 were computed from numerical data (Vozoff, pers. comm.) and show the effect of varying loop size. The curves all reach the true conductivity of the thick, 0.6 S/m second layer. The effect of the third layer is not seen because of its depth (300 m).

Numerical results from Lee (1977) and Lee & Lewis (1974) are shown in Figure 6 which shows the response of a conductive layer embedded in a resistive half-space at various depths. The effects of the three layers are clearly evident in the curves, and the times at which the asymptotes due to the layers occur increase with the depth of the layers.

Four-layer case: Figure 7 shows the results of a four-layer case in which a 5 m thick conductive layer (1 S/m) lies in a resistive layer under a cover of medium conductivity (0.1 S/m) overburden. When the surface layer is thicker than 100 m the effects of lower layers are not seen. As the top layer decreases in thickness the apparent conductivity decreases but the effect of the layering is not discernible until the top layer is 10 m thick. Curve 6 reverts to a three-layer case in which the effect of the thin conductive layer can be seen under 175 m of 100 ohm-m material.

## Field studies

The use of the apparent conductivity concept for interpreting TEM depth soundings is illustrated by results of field surveys at Pooncarie (NSW), Pirlta, (Vic.), and Alligator River (NT). The examples show how the apparent conductivity parameter can be used in interpretation and in investigating the accuracy of field measurements. The results at Pooncarie and Pirlta were obtained during a test TEM survey conducted jointly by BMR and Macquarie University with MPPO-1 equipment from 25 to 28 November 1975. The Pooncarie and Pirlta sites were chosen as test areas because geo-electric information (including resistivity depth soundings and magnetotelluric soundings) was available and indicated that the ground was horizontally layered and laterally homogeneous. Drilling and well logs in this area indicate that Quaternary, Tertiary, and Cretaceous sediments in these areas are poorly consolidated, porous and electrically conductive, and overlie more resistive Palaeozoic sediments.

The results of the Alligator River survey were obtained during a geophysical mapping survey by BMR during 1975 (Spies, 1978).

Pooncarie, NSW: A Schlumberger array resistivity depth probe and a magnetotelluric (MT) sounding were carried out on a site near Pooncarie, NSW, by BMR and Macquarie University, Sydney, in 1975. The MT results are given by Vozoff et al. (1975) and the resistivity sounding results by Vozoff (pers. comm.). Supplementary resistivity results for small electrode spacings were obtained during the TEM survey.

The resistivity results were fed into a computer inversion program to derive the geo-electric section (Vozoff, pers. comm.). Possible three-layer and four-layer sections derived in this way are shown in Plate 8, and are compatible with the MT results. Theoretical TEM curves were calculated from these sections using a computer program developed by T. Lee (Macquarie University), and are compared with field results in Plate 8.

The computed TEM results from the four models are fairly similar; the major differences are about 30 percent at early times. It can be seen that for the 300 m loop there is excellent agreement between computed and field results. For loop sizes of 100 and 50 m there are major differences between field and computed results, of about 230 percent at early times and about 160 percent at late times. For smaller loops the differences become much greater. For multi-turn loops of 12.5 m and smaller, discrepancies are very large.

There are several possible explanations for these discrepancies:

(a) Errors in field measurements: Calibration errors in the MPPO-1 equipment may be an explanation. Currents of 2 or 3 amps were used for loops smaller than 300 m, and multi-turn loops for sizes less than 25 m. It is possible that changes in the current or self inductance of the transmitting loop could change the characteristics of the MPPO-1 equipment.

(b) TEM computed curve: Another possibility is that there are errors in the theoretical derivations or computer programs, emphasised at large values of $t/\sigma\mu d^2$. However, these errors would be expected to increase gradually with

$t/\sigma\mu d^2$ and thus would not explain the large difference between the 300 and 100 m loop results.

(c) The presence of a near-surface, thin, horizontal, conductive layer: Such a layer would have a large effect on small loops and a small effect on large loops. It is possible that such a layer would have minor influence on the resistivity results. However this again would not explain the large differences between the 50 and 100 m loop results.

The discrepancies in field results from different loop sizes can also be seen in Figure 8, where the TEM field results have been converted to apparent conductivity curves. The 300 m loop curve changes from 0.2 S/m at early times to 0.46 S/m at late times, i.e. the early times are influenced by the first 20-m thick layer and the curve reaches the asymptotic value for the underlying layer at about 10 ms.

The 50, 25, and 12.5 m loop fieldresults are fairly similar in that apparent conductivities are in the 0.5-1.0 S/m range, significantly higher than that of any layer in the computed resistivity section. With smaller loops the apparent conductivities increase to such an extent that the most probable explanation is errors in the field data as described in (a).

Figure 9 shows apparent conductivity curves obtained from the numerically computed TEM results. There is a fairly smooth transition from the 300 m loop results to the 25 m loop results. For smaller loops the curves appear to show too low an apparent conductivity and suggest inaccuracies in the numerical modelling for small loops.

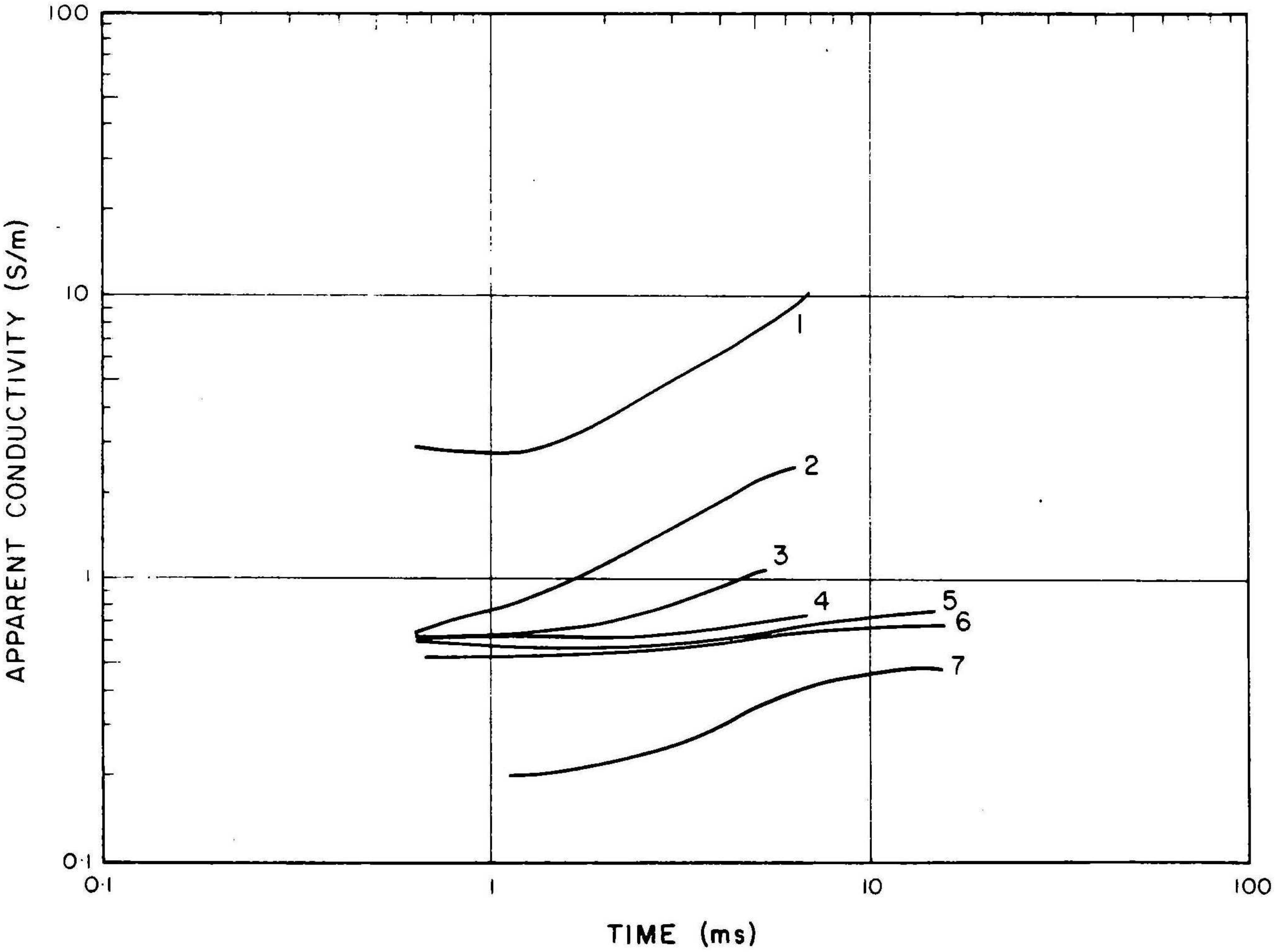
Pirlta, Victoria: This area is located 30 kmsouthwest of Mildura, Victoria, and was chosen as a test area because an earlier BMR resistivity survey had shown that the geo-electric section consists of simple horizontally layered sediments (also supported by MT results, Vozoff, pers. comm.). The inferred section, taken from Dolan et al. (1975), is shownin Plate 9. No computed TEM curves are available.

The TEM field results and geo-electric section obtained from inversion of the resistivity data are presented in Plate 9. A thin surface resistive layer overlies 25 m of 0.2-0.3 S/m sediments, which in turn overlies a 135 m section of 2 S/m material. The TEM fields would probably not penetrate beneath this relatively thick layer.

The apparent conductivity results (Fig. 10) show reasonably consistent results for the 100, 50, and 25 m loops, and appear to be influenced by the 0.2-0.3 S/m and the 2.0 S/m layers over the measured time range. Note that

Figure 8

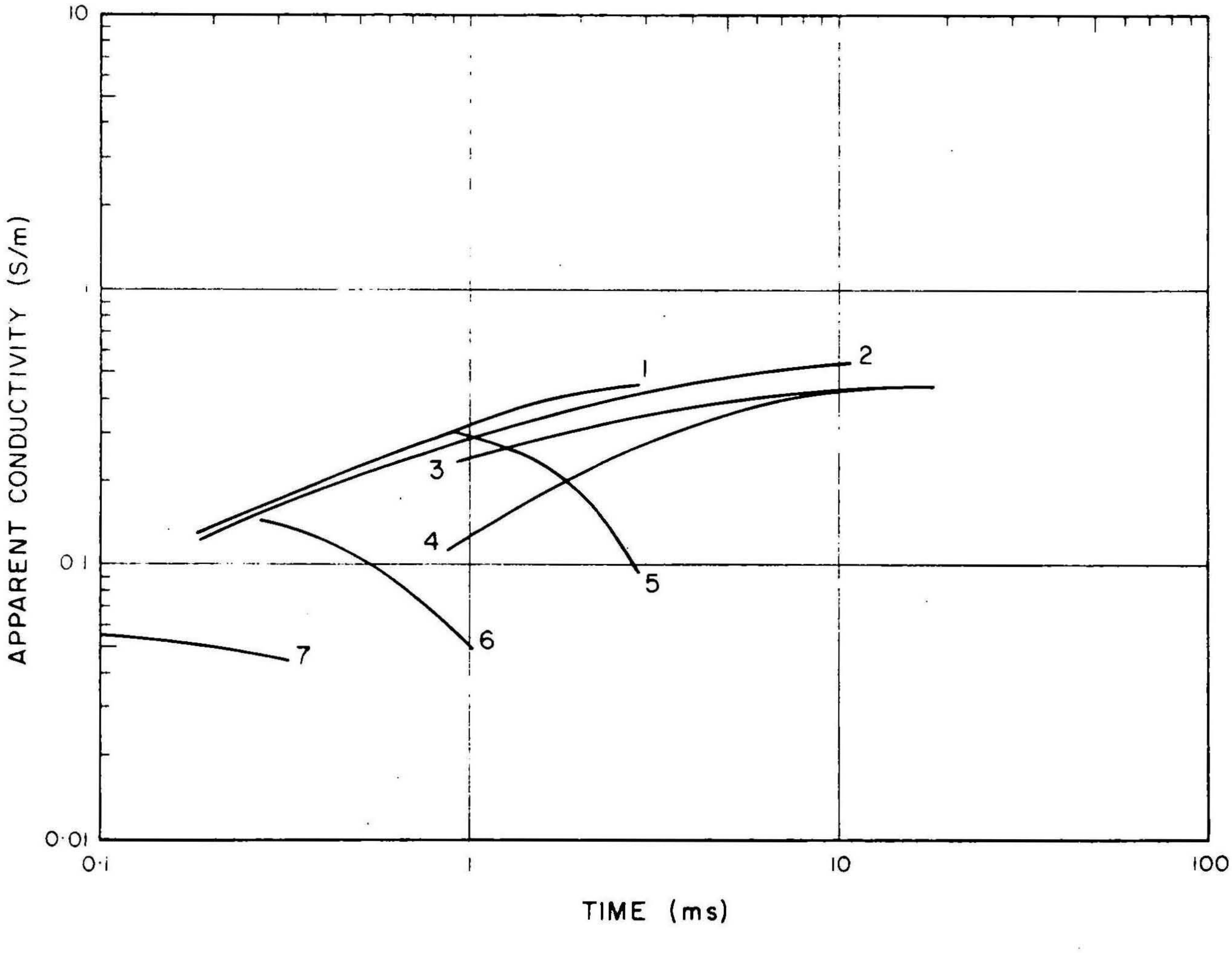
| CURVE | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| LOOP SIZE (m) | 3·12 | 6·25 | 12·5 | 25 | 50 | 100 | 300 |




Pooncarie, NSW: Field results

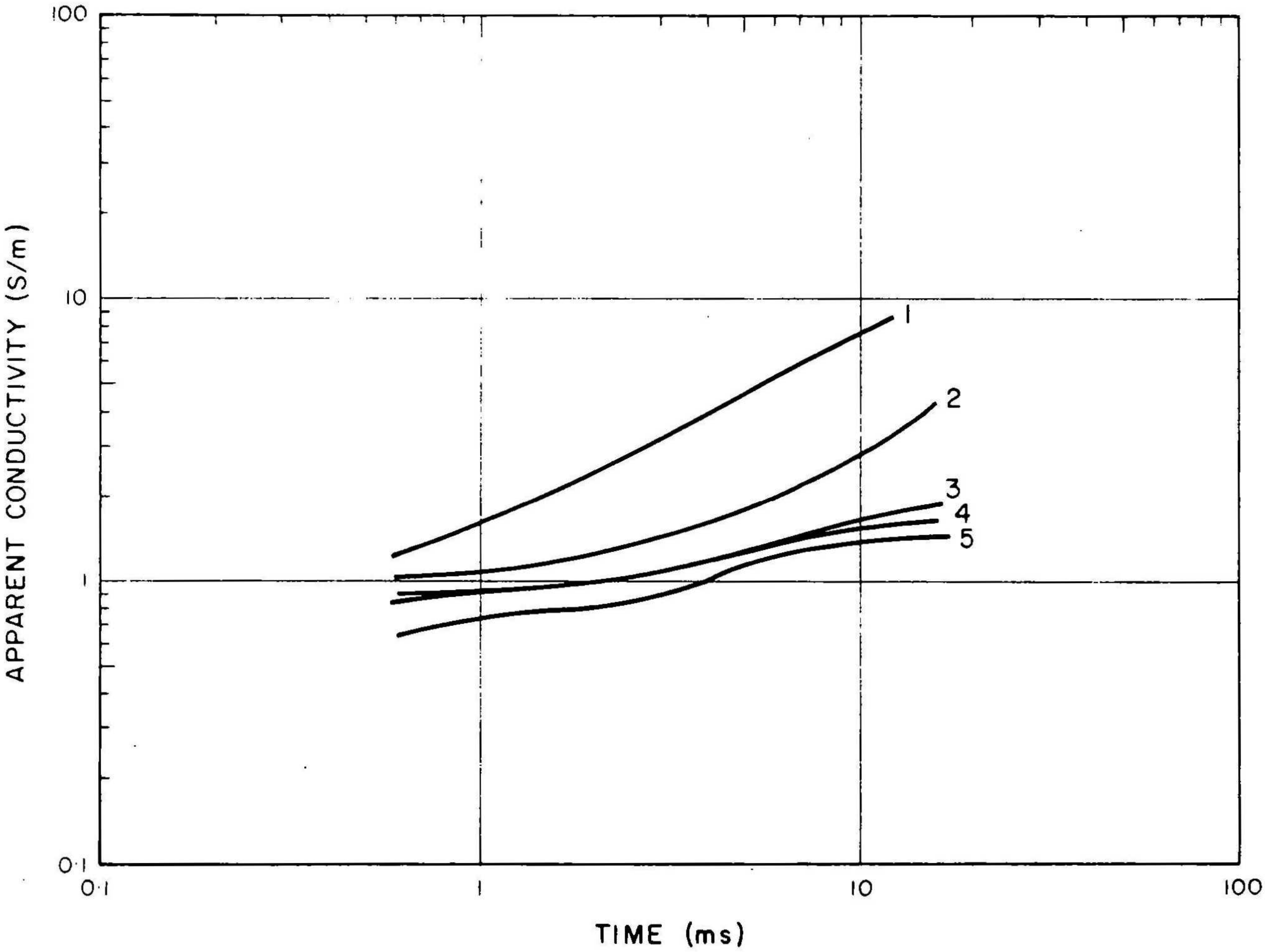
Figure 9

| CURVE | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| LOOP SIZE (m) | 25 | 50 | 100 | 300 | 12·5 | 6·25 | 3·12 |




Pooncarie, NSW: Field results

| CURVE | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| LOOP SIZE (m) | 6·25 | 12·5 | 25 | 50 | 100 |




Pirlta , Vic.: Field results

the curves do not reach the actual conductivity of the 2.0 S/m layer. As expected, the thin, highly resistive surface layer does not affect the TEM curve.

The results for the smaller multi-turn loops are again higher than expected, and similar reasons are proposed to those in the Pooncarie example.

It appears that further work is desirable to explain or interpret results with the small loops, because the use of small, multi-turn loops has many applications in TEM surveys.

Alligator River, NT

In the 1975 Alligator River survey TEM was used to assist geological mapping by tracing carbonaceous shales beneath alluvial cover. It was observed that TEM anomaliescaused by carbonaceous shale could be distinguished from surficial conductors by using apparent conductivity curves.

A detailed traverse along the Arnhem Highway revealed two main anomalies, which have been referred to as anomalies A and B. Geo-electrical control on the anomaly sources was obtained from Schlumberger array resistivity depth probes and holes drilled as part of BMR's geological program. A hole drilled at anomaly A intersected quartzite, clay, and weathered phyllite after passing through 40 m of sandy clay. The resistivity results indicate that a section of the sandy clay from 20-30 m has high conductivity (0.5 S/m) and is bounded by more resistive sediments. This geo-electric section is reflected in the apparent conductivity curves (Fig. 11) which show a decrease in apparent conductivity with time. Anomaly B was found to be caused by conductive (0.02-1.0 S/m) carbonaceous siltstone under a resistive (0.004-0.0012 S/m) weathered cover. The apparent conductivity curve over this type of anomaly shows an increase with time, which indicates there is a continuous depth extent of conductive material.

Similar responses to those obtained along the Arnhem Highway were observed in the Red Lily area (Fig. 12), where exploration drillholes had intersected graphitic, pyritic schists at a depth of about 50 m beneath weathered or partly weathered siltstone and phyllite. A resistivity sounding showed that the surface layers (0.08-0.04 S/m) were more resistive than the unweathered graphitic pyritic schist (0.14 S/m). Curve 1 is taken over the site of the resistivity depth sounding. The other curves are arbitrarily chosen from extensions of the Red Lily anomaly. It was also noted that in areas of less conductive carbonaceous shale or thinly interbedded carbonaceous shale/siltstone the apparent conductivity curve sometimes remained constant

GEO - ELECTRIC SECTIONS

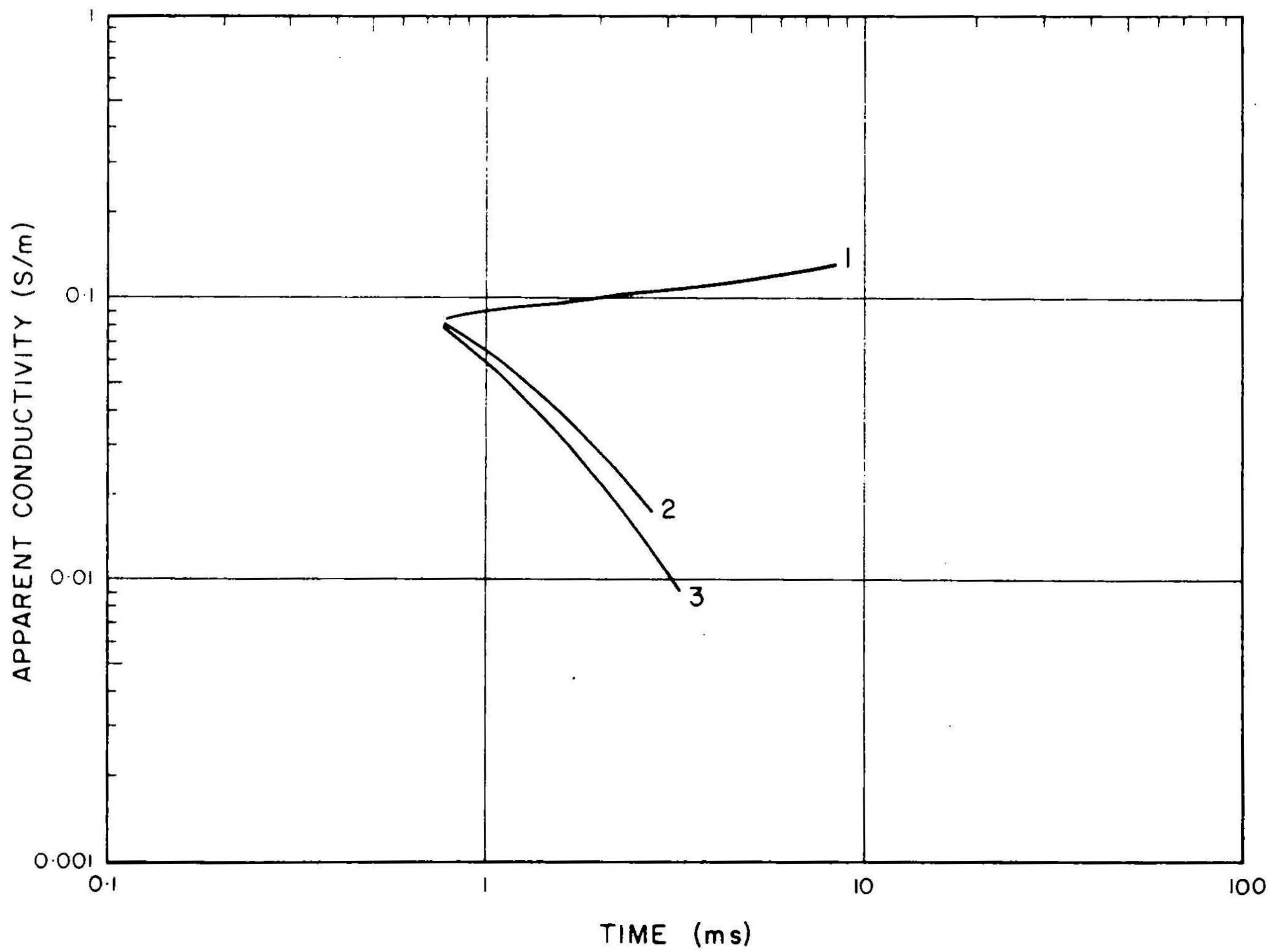
ANOMALY A

0m
0·001 S/m
10m
0·03 S/m
20m
0·5 S/m
30m
0·004 S/m

ANOMALY B

0m
0·0004 S/m
10m
0·0012 S/m
20m
0·02–1·0 S/m

| CURVE | 1 | 2 | 3 |
|---|---|---|---|
| ANOMALY | B | A | A |
| LOOP SIZE (m) | 100 | 50 | 100 |



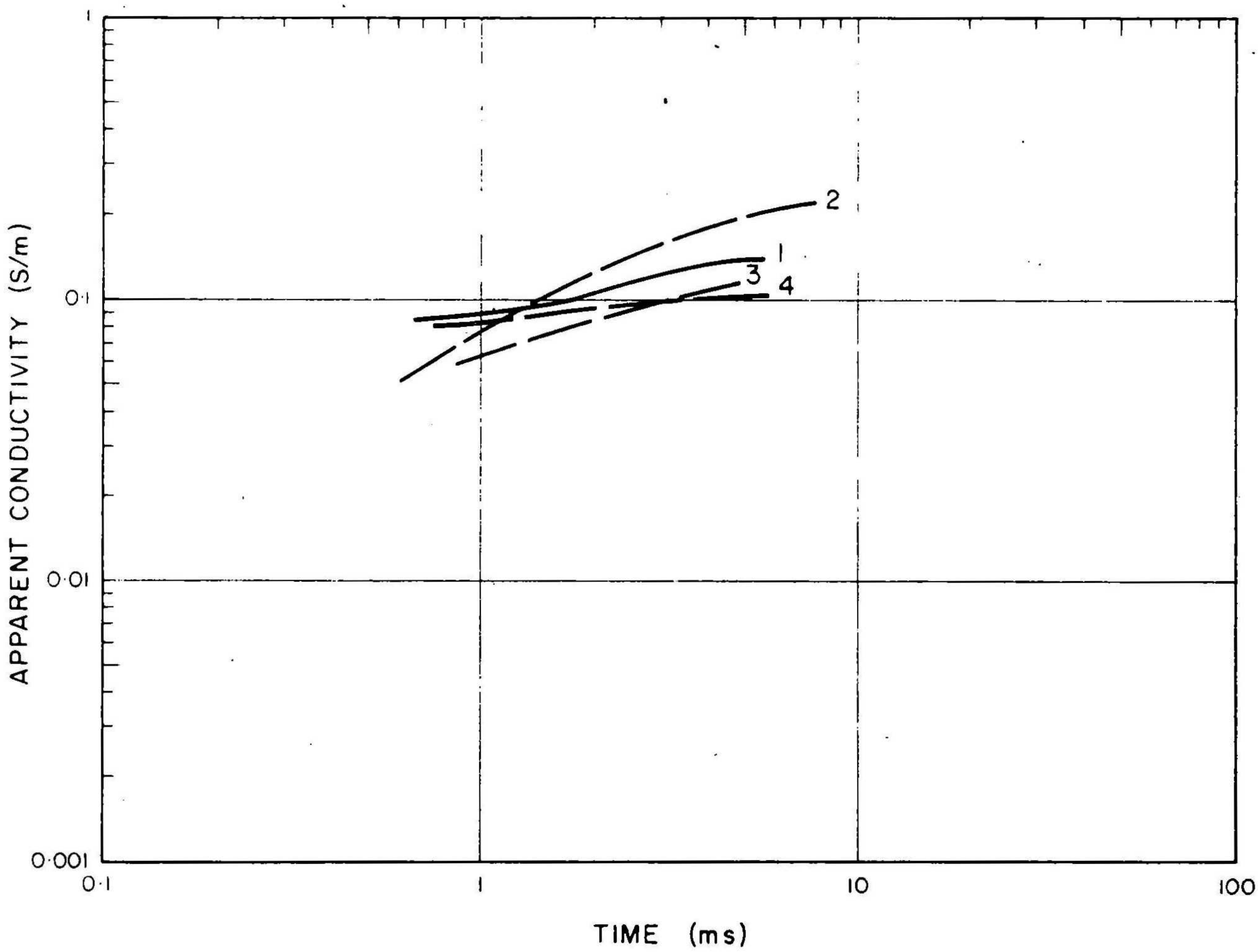

Alligator River area, NT: Arnhem Highway traverse results

Figure 12

GEOLOGICAL AND ELECTRIC SECTION
L9/300 SE

0m
0·087 S/m laterite, clay
10m
0·043 S/m siltstone, phyllite
50m
0·143 S/m graphitic pyritic schist

| CURVE | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| LINE (SE) | 9/300 | 8·5/425 | 14/1275 | 9/250 |
| LOOP SIZE (m) | 50 | 50 | 50 | 50 |



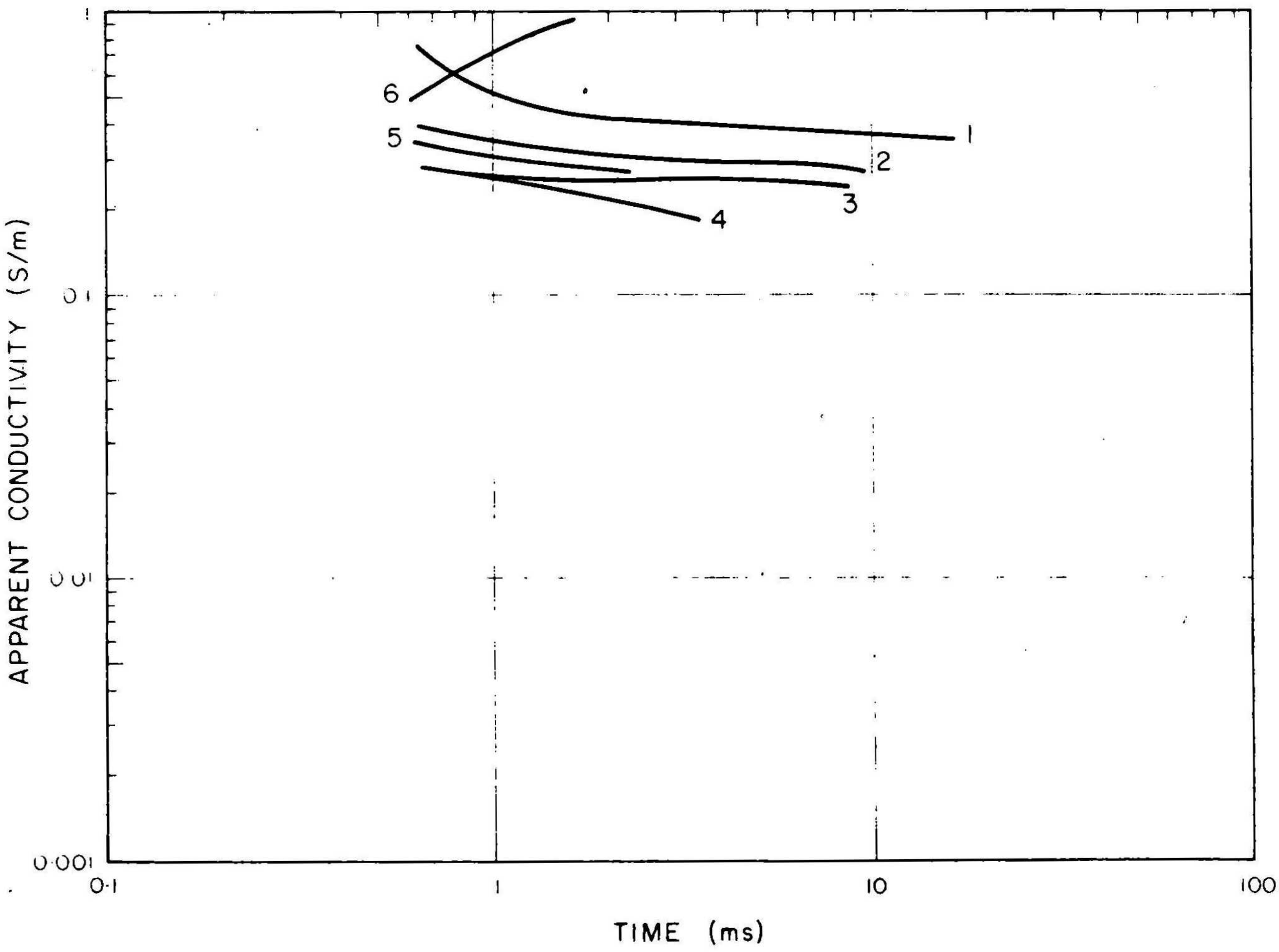

Alligator River area, NT: Red Lilly area results

Figure 13

GEO-ELECTRIC SECTIONS

| FOUR-LAYER CASE | Depth | THREE-LAYER CASE | Depth |
|---|---|---|---|
| | 0m | | 0m |
| 0·5 S/m | | 0·9 S/m | |
| | 10m | | 6m |
| 0·12 S/m | | 0·08 S/m | |
| | 50m | | 95m |
| 0·03 S/m | | 0·0007 S/m | |
| | 120m | | |
| 0·003 S/m | | | |

| CURVE | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| LOOP SIZE (m) | 100 | 50 | 25 | 12·5 | 6 | 3 |
| No. TURNS | 1 | 1 | 2 | 4 | 8 | 17 |




Alligator River area, NT: Flood plain results



D53/B7-97A

with time or even decreased slightly. However, it was easy to distinguish these responses from surficial conductor responses, which decreased rapidly with time.

Very large TEM responses were obtained during this survey when traverses entered the floodplain of the South Alligator River. A geo-electric section obtained from a resistivity depth sounding indicates that the source of these anomalies is conductive surficial sediments as shown in Figure 13. Also shown in Figure 13 are TEM responses obtained with different loop sizes. Referring first to curve 1 it can be seen that at early times (0.6 ms) the curve is asymptotic to the conductivity of the top layer of the three-layer case. At late times the apparent conductivity decreases to a near half-space response of about 0.3 S/m which is higher than that inferred in the resistivity section. However, lateral inhomogeneities are probably the cause of the discrepancy in this case. The lower resistive layer is probably bedrock underlying the floodplain. The responses with the small loops differ from those with the larger loops, but this discrepancy may be explained by inaccuracies in the computation of apparent conductivity for small loops or errors in the field results for small loops.

## 6. INTERPRETATION OF FINITE RESISTIVITY STRUCTURES

Interpretation of TEM surveys over finite structures is commonly based on analyses of the shape and amplitude of transient decay curves. In the single-loop system, results are normally plotted as profiles or contours of the emf e(t) induced in the loop at sample time t, normalised by dividing by the primary current I. Results are compared at early times (e.g. 1 ms) and late times (e.g. 15 ms) to compare responses from different sources. In general the early-time response is influenced by near-surface conductors and the late-time response by deeper and/or more conductive bodies. The results are usually interpreted by visual or graphical inspection of the results at different times to determine the position and strength of anomalies, and several "rules-of-thumb" based on decay curve shape (Spies, 1976a) have been developed to assist in the identification of buried conductors. A more thorough interpretation of TEM responses over finite structures is very complex, but some further assistance in interpretation can be provided by the use of the apparent conductivity concept. The use of the apparent conductivity concept in interpreting TEM results over finite structures can be illustrated by analysing the results of model and field studies.

Model studies

Sphere in a layered ground: Figures 14 to 18 show the response for a one-loop system to a conductive sphere buried in a uniform ground or layered earth. The responses have been calculated from numerical TEMdata provided by Lee (1975). In Figure 14, a sphere (2 S/m) is buried at different depths. Although the effect of the sphere is evident in the change of apparent conductivity, the time range of measurements (0.4-3 ms) is not great enough to distinguish the sphere from the background. However, a series of profiles over the body would give a circular anomaly pattern and enable the shape of the conductor to be inferred. A smaller loop of 50 m radius is used in Figure 15. In this case the sphere is clearly discernible, even for depths up to 100 m. The effect of varying loop size is demonstrated in Figure 16. This shows that the most distinctive response is obtained if the radii of the loop and the sphere are the same. When the radius of the loop is smaller than that of the sphere, the curve shape is difficult to explain intuitively.

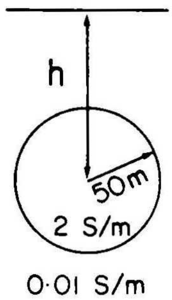
The sphere is placed under a conductive overburden in Figure 17, and is discernible only in the case where the top of the sphere is 25 m from the surface (curve 1). When the top of the sphere is at a depth of 60 m the response is similar to that of a half-space, and for greater depths the effect of the sphere is not discernible. The results shown in Figure 18 are for a case similar to that of Figure 17 except the loop size is varied and the conductivity of the sphere has been reduced. For a 100 m loop a sphere of radius 50 m is not discernible. When the loop is 70 m or smaller, however, the effect of the sphere is readily seen in the curves.

Dipping dyke: This example indicates the result to be expected over a dipping dyke-like structure. The results, presented in Figure 18, are taken from a scale model study by Spies (in prep.) and show the peak response of a profile over a dyke 18 m thick dipping at 45 degrees. The loop radius is 25 m and dyke conductivity is 0.22 S/m.

From t = 0.1 ms to t = 0.5 ms the apparent conductivity increases to approach the true conductivity of the dyke. However, for times greater than 0.5 ms the response falls off very quickly towards the conductivity of the surrounding medium.

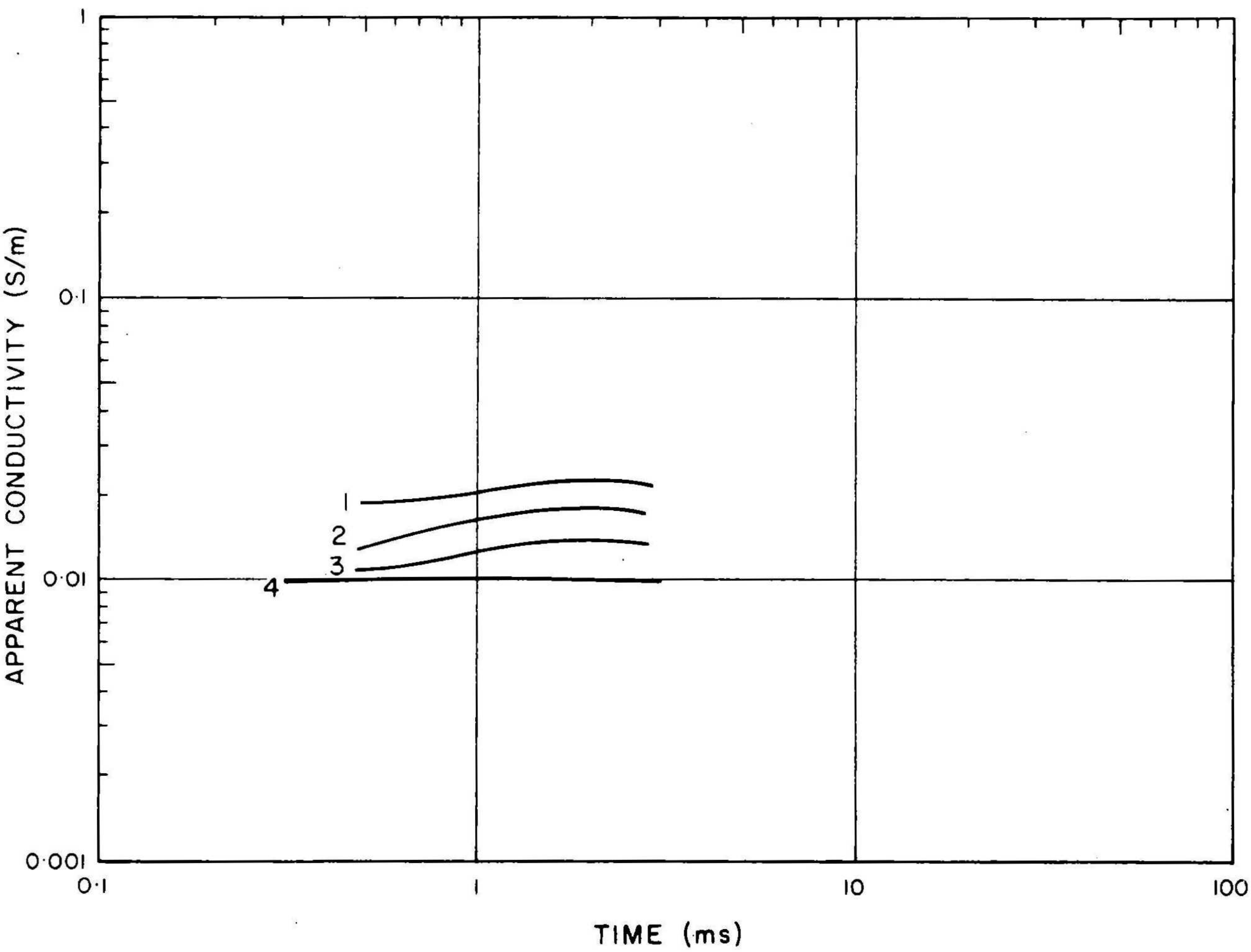
Field study

Woodlawn, NSW: The Woodlawn copper-lead-zinc orebody is near Tarago, NSW, and has been studied with a large range of geophysical methods. Both BMR (Young 1976) and CSIRO (G. Buselli, CSIRO, pers. comm.) have conducted experimental



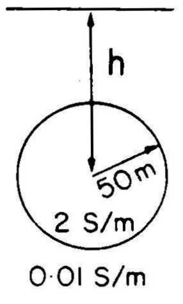

| MODEL | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| h (m) | 75 | 100 | 150 | ∞ |

(100m RADIUS LOOP)



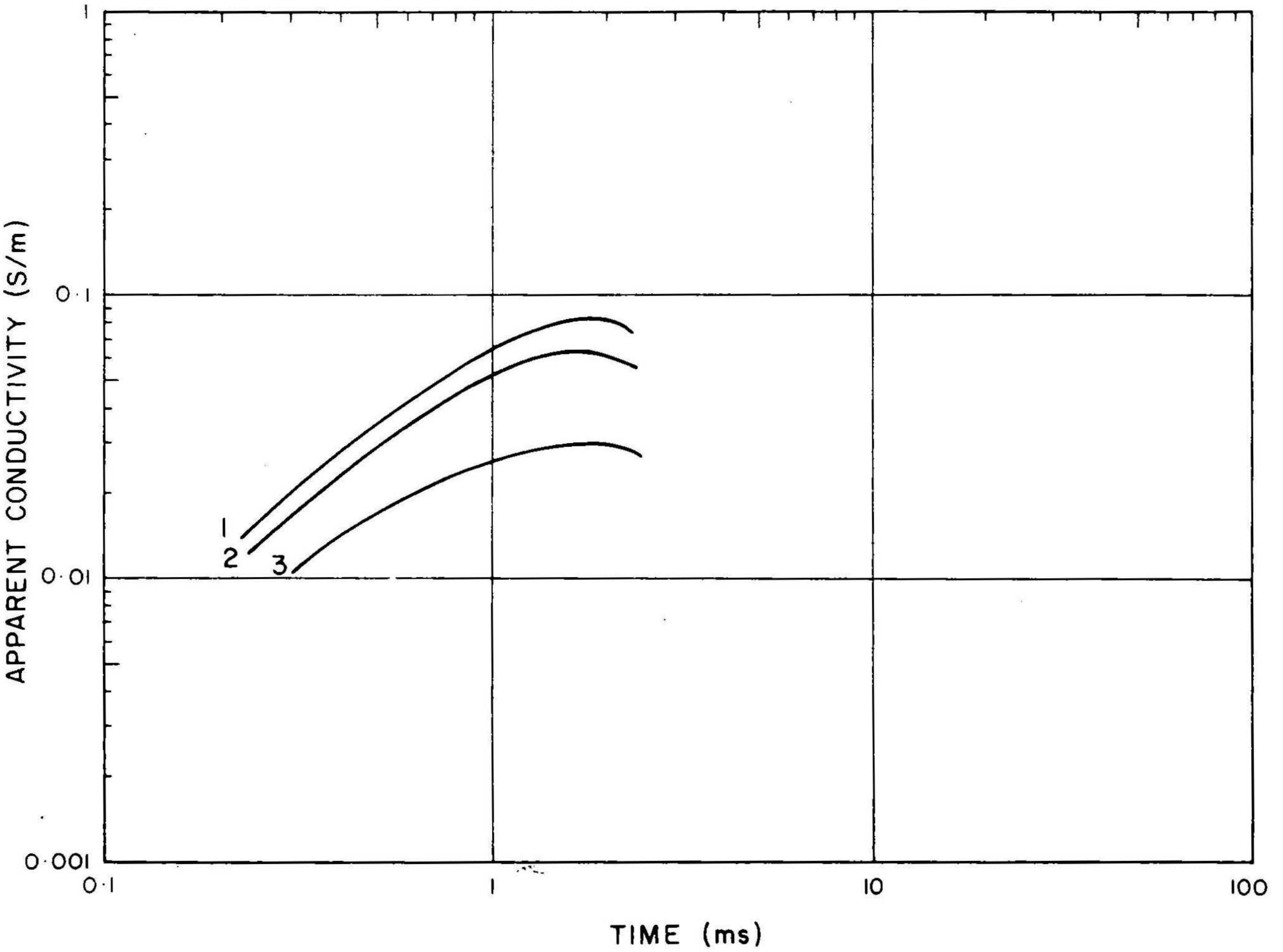

Sphere in uniform ground, varying depth of burial

Figure 15




| MODEL | 1 | 2 | 3 |
|---|---|---|---|
| h | 70 | 75 | 100 |

(50m RADIUS LOOP)

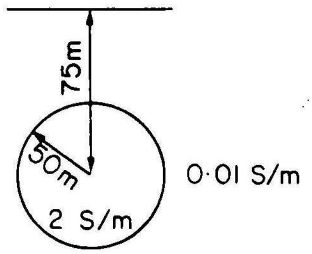



Sphere in uniform ground, varying depth of burial

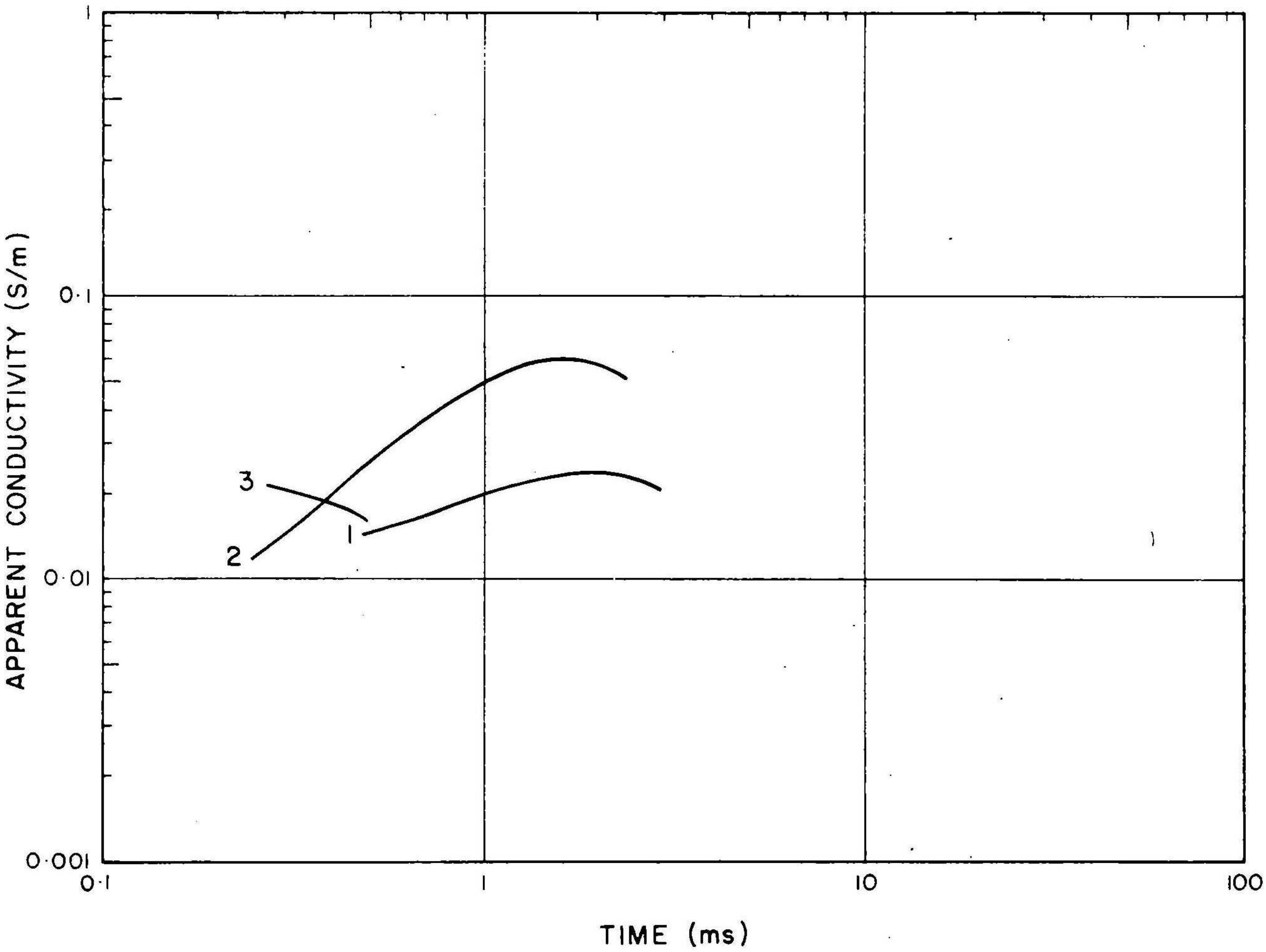


G29-240A

Figure 16

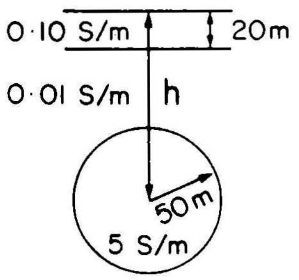



| MODEL | 1 | 2 | 3 |
|---|---|---|---|
| LOOP RADIUS (m) | 100 | 50 | 30 |



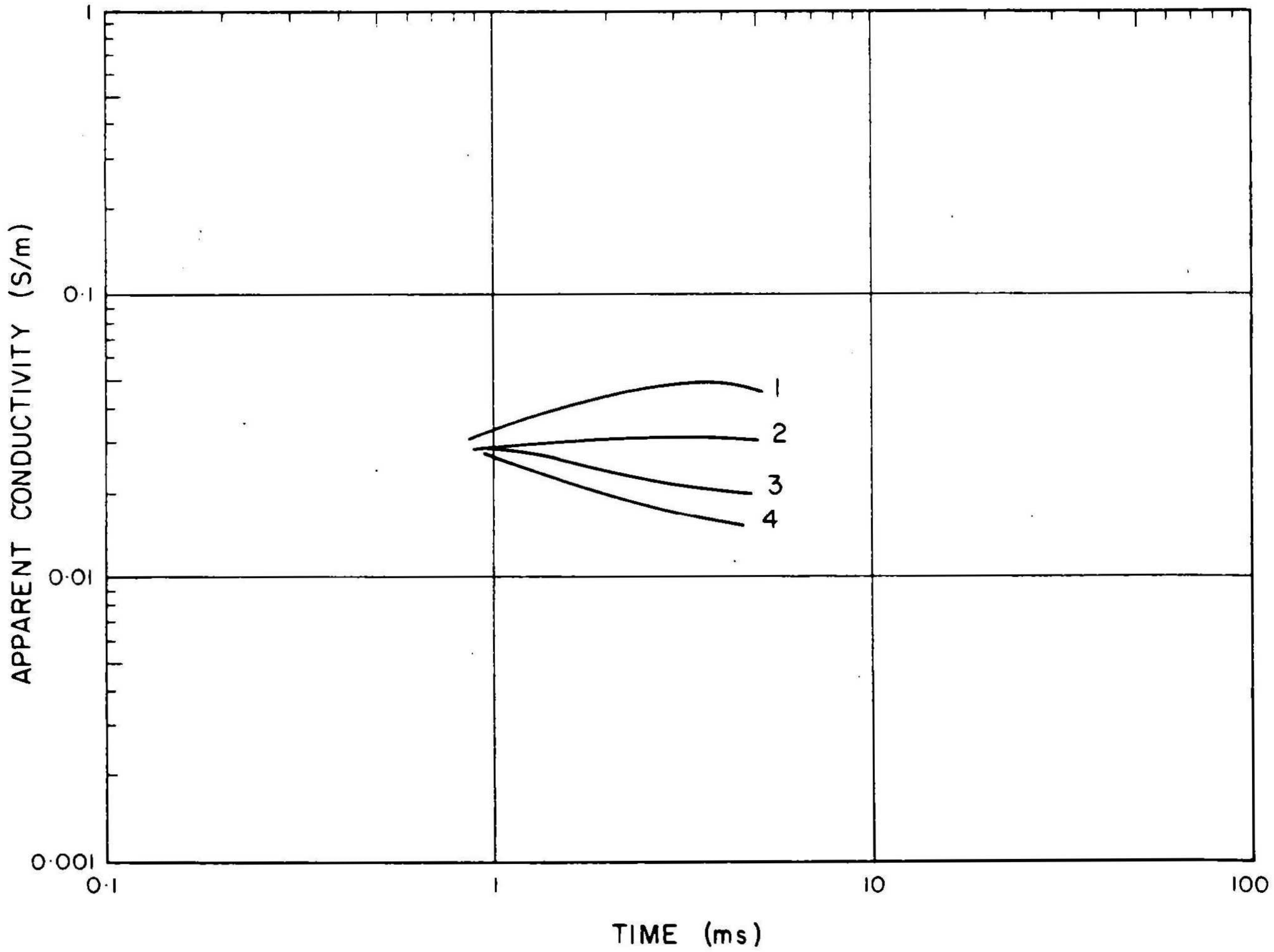

Sphere in uniform ground, varying loop size

Figure 17

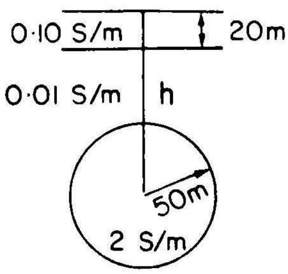



| MODEL | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| h (m) | 75 | 110 | 150 | ∞ |

(100m RADIUS LOOP)

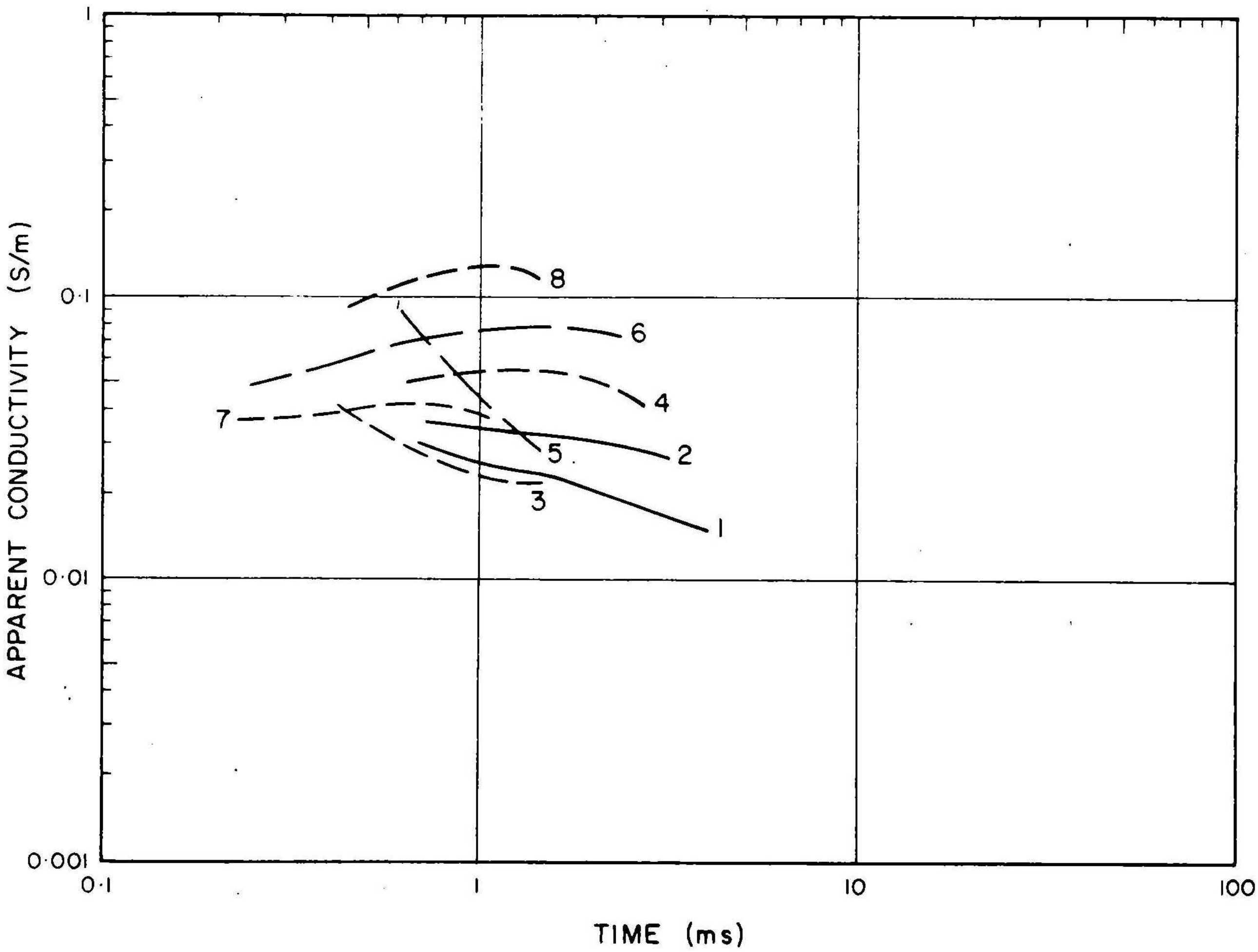



Sphere in layered ground, varying depth of burial



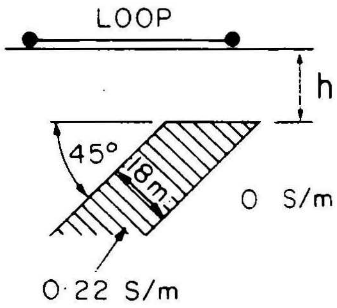

| MODEL | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| LOOP RADIUS (m) | 100 | 100 | 70 | 70 | 50 | 50 | 30 | 30 |
| WITH SPHERE ? | NO | YES | NO | YES | NO | YES | NO | YES |

h = 75m



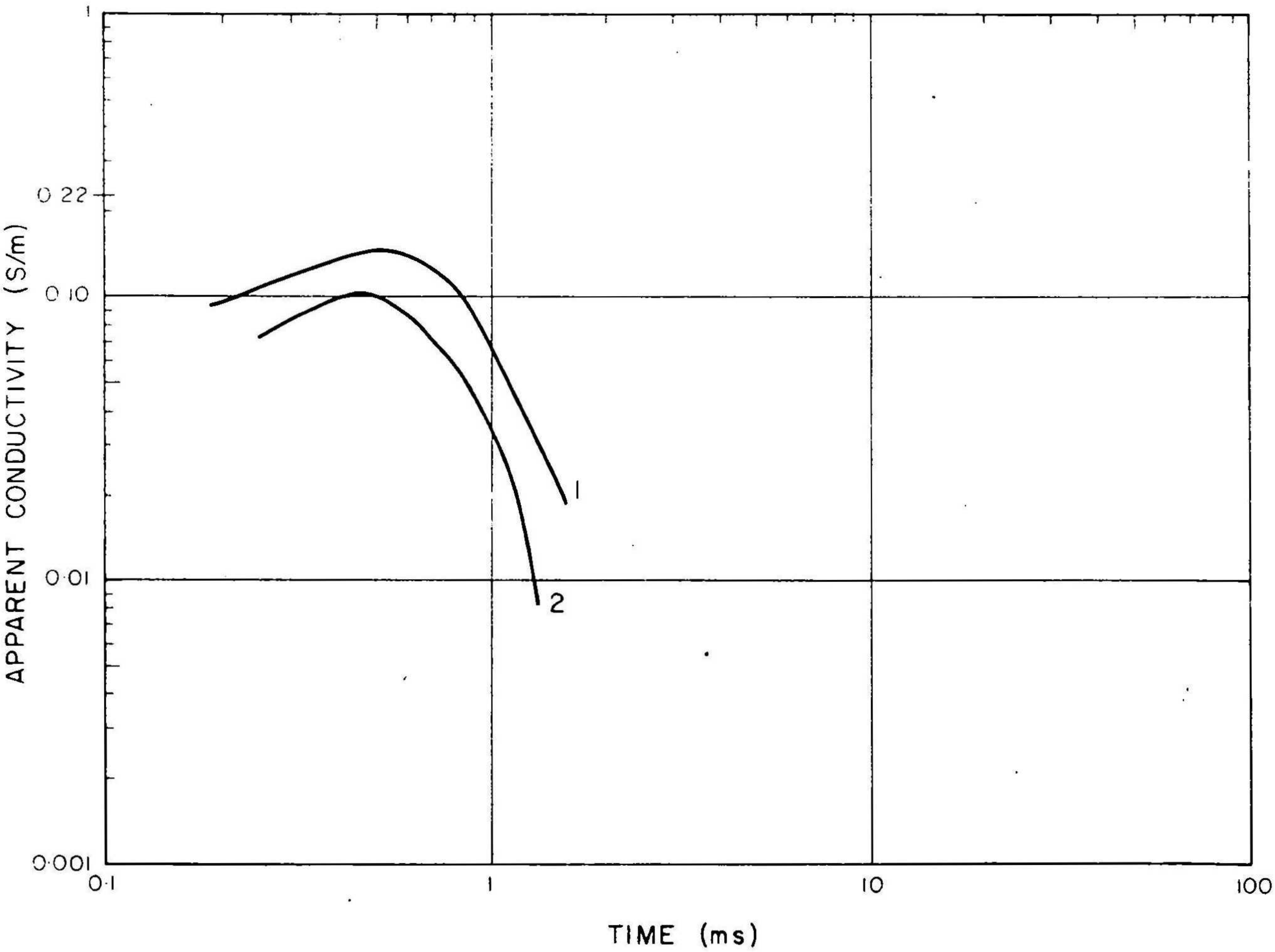

Sphere in layered ground, varying loop size

Figure 19




| MODEL | 1 | 2 |
|---|---|---|
| h (m) | 1·3 | 6 |

(25m RADIUS LOOP)




Dipping dyke, scale model study

TEM surveys over the deposit. CSIRO's results are of greater accuracy and cover a wider time range than BMR's results and provide a good field example from which to study the TEM response of finite structures.

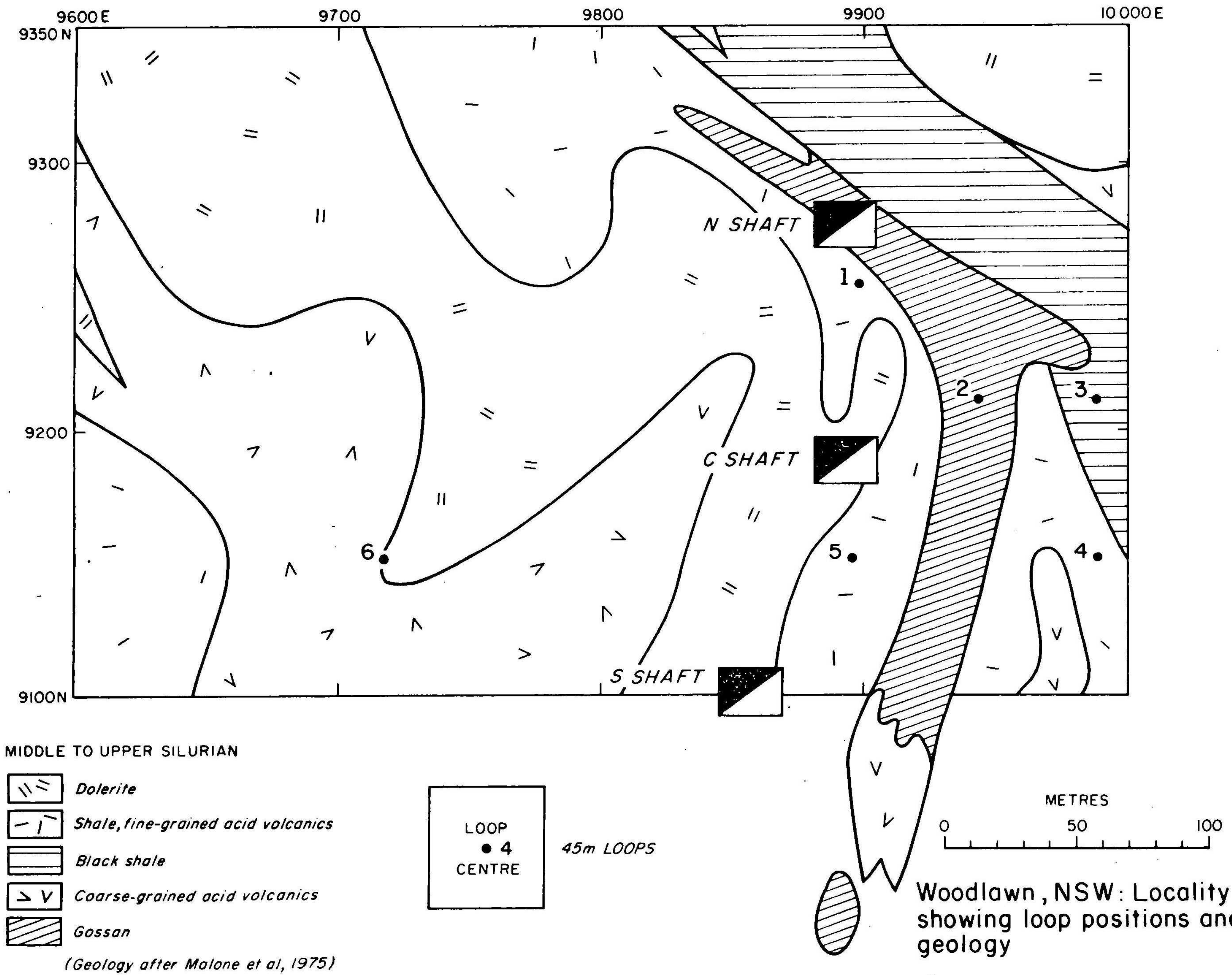
The Woodlawn orebody is a concordant lens of bedded, high-grade Cu-Pb-Zn sulphides, 20 m thick, and dips to the west at about $45^{o}$. The near-surface oxidised zone is about 12 m thick, consists mainly of ferruginous clay, and has a sharp contact with the sulphides. A locality plan and surface geological map (taken from Malone et al., 1975) is shown in Figure 20.

The apparent conductivity results shown in Figure 21 were computed from CSIRO data obtained in the loop positions shown in Figure 20. Curves 1 and 2 are measured over the top of the orebody while curve 5 is down-dip. Curves 3 and 4 are up-dip from the orebody, and the response is much less than 1 and 2. Curve 6 is located about 200 m down-dip.

In curves 1 and 2, the apparent conductivity increases steeply from 0.4 S/m at 0.5 ms to between 15 and 20 S/m at 50 ms. This latter figure agrees with results from Spies (1977) who determined bulk conductivity measurements of 5-20 S/m from scale model studies of the orebody. However, other curves do not indicate the conductivity of the orebody as well as curves 1 and 2.

Curve 5 is similar to 1 and 2 at early times but departs significantly for times greater than 8 ms. This departure is difficult to explain, but as explained in Chapter 4 it is possible that errors in field measurements occur at late times.

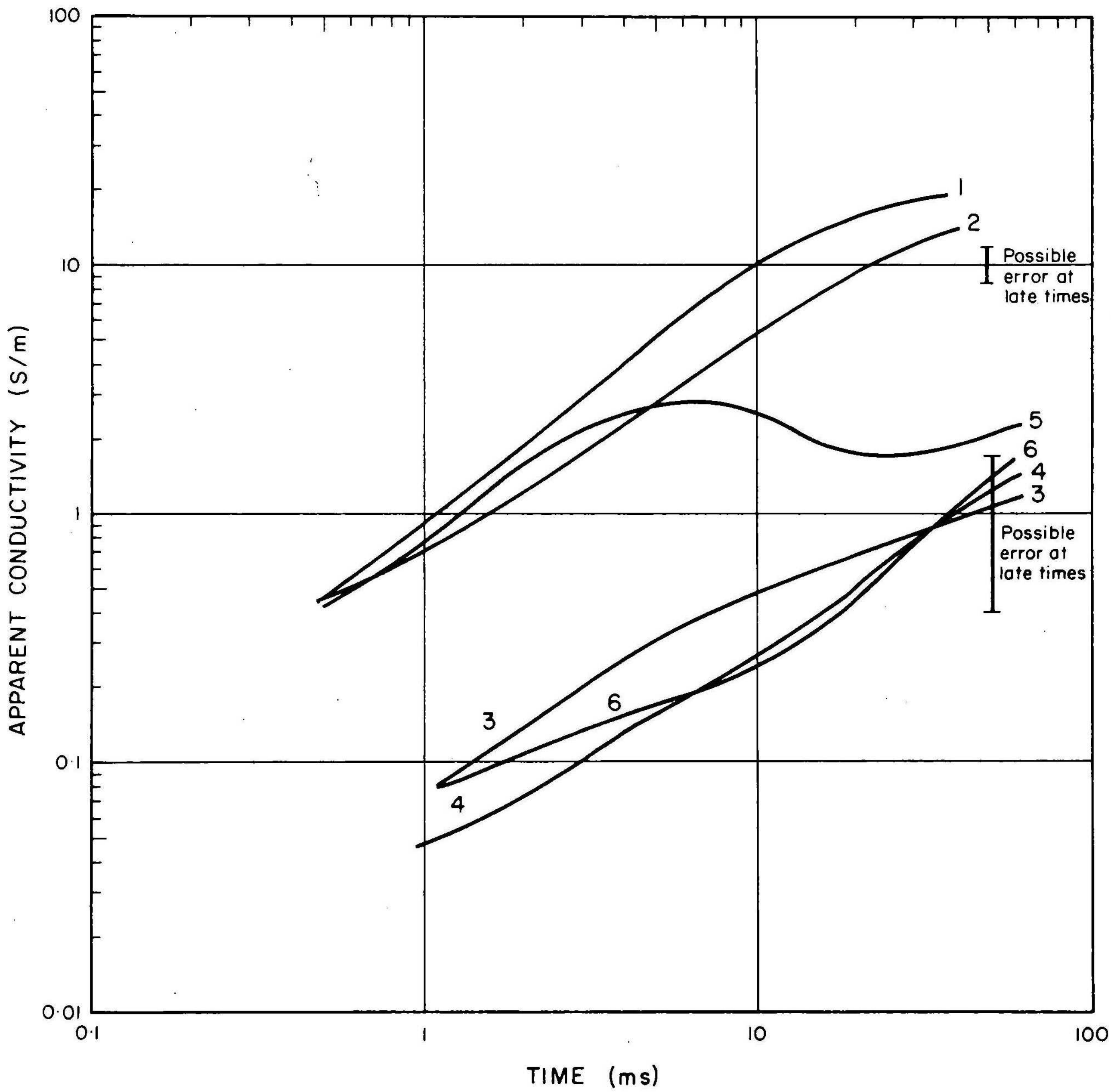
Curves 3, 4, and 6 are similar; apparent conductivities are less than 0.1 S/m at 1 ms and increase steadily with time. It is likely that the orebody influences the response at late times even at distances equal to several loop sizes. However, it would appear unlikely that at very late times (60 ms) the apparent conductivity would be as high as 2 S/m, which is of the order of the true conductivity of the orebody. Again, the high values of apparent conductivity at very late times in curves 3, 4, and 6 could easily be explained by errors in field measurement. Note that a reading error of 1 $\mu$v/A would lower these apparent conductivities to about 0.3 S/m.




Woodlawn, NSW: Locality map showing loop positions and geology

Figure 20

45m LOOP




(DATA SUPPLIED BY CSIRO)

Woodlawn, NSW: Field results

## 7. DISCUSSION AND CONCLUSIONS

Transient electromagnetic decay curves can be easily converted into apparent conductivity curves using graphical or computer techniques described in Chapters 3 and 4. Interpretation of field results is much easier with the data in this form. However, the continued development of methods to interpret TEM apparent conductivity curves is currently hampered by lack of precision in field measurements and the difficulty of theoretically calculating TEM responses.

It has been shown that the TEM method can be used as a depth sounding technique if measurements are made over a suitable time range and high precision measurements are available at late times. Such a technique has advantages over conventional resistivity sounding methods in that TEM soundings are faster and it is not necessary to expand electrodes over a great distance.

The computation of apparent conductivity curves for various numerical and scale models shows that with suitable field techniques it may be possible to estimate the true conductivity of conductors. The apparent conductivity is a function of many factors such as sample time, depth of burial, size and conductivity of the body, and loop size. In some cases, for example a thick conductive sequence, the apparent conductivity equals the true conductivity. A unit such as a thin resistive bed will have a negligible effect on the apparent conductivity curve.

In the case of field surveys apparent conductivity calculations have been shown to assist in distinguishing surficial conductors from bedrock conductors, and to disclose the true conductivity of some sources.

In summary, the conversion of TEM data to apparent conductivity curves has many applications in interpretation of TEM results. More quantitative interpretation may be possible once further numerical or model study results are available and better field measurements are possible.

## 8. ACKNOWLEDGEMENTS

The assistance of Mr R.F. Moore in preparing the plotting programs, and Jododex Australia Pty Ltd for supplying data on the Woodlawn deposit is gratefully acknowledged. The permission of CSIRO to use the Woodlawn TEM results shown in Figure 21 is also gratefully acknowledged.

## 9. REFERENCES


BLAU, L.W., 1933 - Method and apparatus for geophysical exploration. US Patent, 1, 911, 137, Issued May 23, 1933.

BUSELLI, G., 1974 - Multichannel transient electromagnetic measurements near Cloncurry. CSIRO Mineral Research Laboratory, Investigation Report, 103.

BUSELLI, G., & O'NEILL, B., 1977 - SIROTEM: A new portable instrument for multichannel transient electromagnetic measurements. Bulletin of the Australian Society of Exploration Geophysicists, v. 8(3), p. 82-87.

CRONE, J.D., 1976 - Ground exploration with pulse electromagnetics for sulphide deposits. 25th International Geological Congress, Sydney, Australia. Abstracts Volume 2, Section 9B, p. 385.

DOLAN, B.H., POLAK, E.J., & RAMSAY, D.C., 1975 - Mildura resistivity depth probe, Victoria 1973. Bureau of Mineral Resources, Australia, Record 1975/25.

FRISCHKNECHT, F.C., 1967 - Fields about an oscillating magnetic dipole over a two layer earth, and application to ground and airborne electromagnetic surveys. Quarterly of the Colorado School of Mines, v. 62, (1): 370.

LAMONTAGNE, Y., & WEST, G.F., 1973 - A wide-band, time-domain, ground EM system. Symposium on Electromagnetic Exploration Methods. Dept. Physics., University of Toronto.

LEE, T., & LEWIS, R., 1974 - Transient EM response of a large loop on a layered ground. Geophysical Prospecting, v. 22, (3), p. 430-444.

LEE, T., 1975 - Transient electromagnetic response of a sphere in a layered medium. Geophysical Prospecting, v. 23(3), p. 492-512.

LEE, T., 1977 - Estimation of depth to conductorsby the use of electromagnetic transients. Geophysical Prospecting, v. 25(1), p. 61-75.

MALONE, E.J., OLGERS, F., CUCCHI, F.G., NICHOLAS, T., & McKAY, W.J., 1975 - Woodlawn copper-lead-zinc deposit. In Economic Geology of Australia and Papua New Guinea. 1. Metals, A.I.M.M. Monograph No. 5, Parkville, Australia.

MORRISON, H.F., PHILLIPS, R.J., & O'BRIEN, D.P., 1969 - Quantitative interpretation of transient electromagnetic fields over a layered half space. Geophysical Prospecting, v. 17, (1), p. 82-101.

SPIES, B.R., 1976a - The transient electromagnetic method in Australia. BMR Journal of Australian Geology & Geophysics, v. 1(1), p. 23-32.

SPIES, B.R., 1976b - The derivation of absolute units in electromagnetic scale modelling. Geophysics, v. 41(5), p. 1042-1047.

SPIES, B.R., 1977 - Absolute electromagnetic scale modelling and its use in interpretation of TEM response. BMR Journal of Australian Geology & Geophysics, v. 2(2), p. 89-95.

SPIES, B.R., 1978 - Alligator River area geophysical survey, Northern Territory, 1975. Bureau of Mineral Resources, Australia, Report 205.

SPIES, B.R., 1979 - Scale model studies of a transient electromagnetic prospecting system using an interactive minicomputer. Institute of Electrical and Electronic Engineers Transactions on Geoscience Electronics, v. GE-17, (2).

SPIES, B.R., - The transient electromagnetic method in Australian conditions: Field examples and model studies. Ph.D. Thesis, Macquarie University, Sydney (unpubl.), (in prep.).

SPIES, B.R., & RAICHE, A.P. - Apparent conductivity calculations for the TEM (coincident loop) method using a HP-67 calculator. (in prep.).

VANYAN, L.L., BOBROVNIKOV, L.Z., KUNETSOV, A.N., LOSHENITZINA, V.L., MOROZOVA, G.M., & SHTIMMER, A.I., 1967. Electromagnetic Depth Sounding. Translated from Russian by G.V. Keller. Consultants Bureau, New York.

VELIKIN, A.B., & BULGAKOV, Yu.I., 1967 - Transient method of electrical prospecting (one loop version). U.N.O. Conference, Moscow, 1967. Ministry of Geology of the USSR, Moscow.

VOZOFF, K., KERR, D., MOORE, R.F., JUPP, D.L., & LEWIS, R.G., 1975 - Murray Basin magnetotelluric study. Journal of the Geological Society of Australia. p. 361-375.

YOUNG, G.A., 1976 - Drill-hole logging and transient electromagnetic test surveys, Woodlawn deposit, New South Wales, 1973. Bureau of Mineral Resources, Australia, Record 1976/52.

# APPENDIX 1

## DESCRIPTION OF COMPUTER PROGRAMS TO CALCULATE APPARENT CONDUCTIVITY

Fortran program TERRY which is included as Appendix 1a is designed for use with an HP2100 computer and Gould 5000 plotter. TERRY computes the value of apparent conductivities directly from the TEM response. Input data are title, loop size, number of readings, number of loop turns, loop current, sample times, and response. The time array may be stored for consecutive runs. Output is in the form of a table and an apparent conductivity plot on the Gould 5000. This program calls subroutines EXEC and TERRZ (executive system subroutines to enable rerunning of main program), AKIMI and plotting subroutines PLOT, LOGAX, SYMB. TERRZ, AKIMI, and LOGAX are included as Appendixes 1b, 1c, and 1d respectively. A sample output from program TERRY is included as Appendix 1e.

Fortran programs HOMOG and TEMHF which areincluded as Appendixes 1f and 1g are also designed for use with an HP2100 computer and Gould 5000 plotter. TEMHF is used to produce plots for the construction of standard curves for various loop sizes and half-space conductivities. HOMOG is used to produce tables of the response for various loop sizes and half-space conductivities.

Input parameters for HOMOG are conductivy, loop size, and loop shape (square or circle). The TEM response is calculated for 55 sample times between 0.1 and 100 ms. ITEST is a parameter which shows which part of the theoretical TEM response was used in the calculation. If the exact expression was used ITEST = 0, if the interpolation formula was used ITEST = 1 and if the value is outside the possible range of calculations ITEST = -1. HOMOG calls subroutines HALF and AKIMI. Subroutine HALF, which is included as Appendix 1h, computes the TEM response of a homogeneous ground having a specified conductivity and loop size, for sample times from 0.1 to 100 ms. Output data from this subroutine are given in two arrays containing successive values of time and voltage. Subroutine AKIMI is an interpolation routine and is used for calculating the expression for values of t between $7.9 \times 10^{-7}\ \sigma b^2$ and $1.2 \times 10^{-4}\ \sigma b^2$. An example of the output from HOMOG is included as Appendix 1i.

Program TEMHF is an extension of program HOMOG and produces standard curves for various loop sizes and a range of conductivities. As well as calling AKIMI and HALF this program calls the plotting subroutines LCOMP, INTPL, and LOGAX which are included as Appendixes 1j, 1k, and 1d. Examples of the output from TEMHF have been included as Plates 1 to 7.

```
FTN4
      PROGRAM TERRY
C
C  COMPUTES APPARENT CONDUCTIVITY FROM TEM VALUES
C   INPUT DATA IS
C         NAME=TITLE OR LOCATION
C         SIZE=LOOP SIDE,M
C         N=NUMBER OF POINTS ON CURVE
C         IOPT=1     READS NO  OF TURNS & CURRENT
C               0    ASSUMES 1 TURN , 1 AMP
C         T(I)=TIME,MS
C         V(I)=RESPONSE,UV
C
      INTEGER TERRZ(3)
      DIMENSION LBLX(15),LBLY(15),NAME(30),IO(5)
      DIMENSION V(80),T(30),SIGMA(80),ITEST(80),A(12),B(12)
      EQUIVALENCE (IO(1),IO1)
      DATA LBLX/2HTI,2HME,2H, ,2HMS,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2H  ,2
     1H  ,2H  ,2H  ,2H  /
      DATA LBLY/2HAP,2HPA,2HRE,2HNT,2H C,2HON,2HDU,2HCT,2HIV,2HIT,2HY ,2
     1H, ,2HS/,2HM ,2H  /
      DATA TERRZ/2HTE,2HRR,2HZ /
      DATA A/.39716,.5,.62946,.79245,.99763,1.25594,
     *1.58114,1.99054,2.5059,3.15478,3.9717,5./
      DATA B/.01005,.017897,.029896,.046262,.06535,.084001
     *.099678,.111711,.120534,.126866,.131320,.134419/
      ALOGT(Q)=ALOG(Q)/2.302585
      CALL RMPAR(IO)
      IF(IO(2).EQ.1)GO TO 1
      CALL EXEC(4,1,ISTRK,IDISC,ISECT)
      IO(3)=ISTRK
      IO(4)=IDISC
    1 WRITE(IO1,4)
    4 FORMAT("TYPE NAME")
      READ(IO1,2)NAME
    2 FORMAT(30A2)
      WRITE(IO1,5)
    5 FORMAT("TYPE SIZE, NO.PTS, IOPT(NORMALLY 0)")
      READ(IO1,*)SIZE,N,IOPT
      IF(IOPT.EQ.0)GO TO 3
      WRITE(IO1,6)
    6 FORMAT("TYPE NTURNS & CURRENT")
      READ(IO1,*)NTURNS,AMPS
    3 WRITE(IO1,9)
    9 FORMAT("IF NEW TIMES ARE REQUIRED TYPE 1")
      READ(IO1,*)IQ
      IF(IQ.NE.1)GO TO 10
      WRITE(IO1,7)
    7 FORMAT("TYPE IN TIMES (MS)")
      READ(IO1,*)(T(I),I=1,N)
      CALL EXEC(2,IO(4),T,N,IO(3),0)
   10 M=2*N
```

## Program TERRY

```
      IF(IQ.NE.1)CALL EXEC(1,IO(4),T,M,IO(3),0)
      WRITE(IO1,8)
    8 FORMAT("TYPE IN RESPONSE (UV)")
      READ(IO1,*)(V(I),I=1,N)
C  THIS SECTION IS IN CASE THE HP HAS TIMED YOU OUT
      WRITE(IO1,11)
   11 FORMAT(" TYPE 1 IF YOU WISH TO START AGAIN")
      READ(IO1,*)IR
      IF(IR.EQ.1)GO TO 1
C
C   THIS LOOP COMPUTES SIGMA FOR X LESS THAN  39
C
      NUM=0
      DO 20 I=1,N
      IF(IOPT.EQ.0)GO TO 17
      VALUE=AMPS*NTURNS**2
      V(I)=V(I)/VALUE
   17 Y=.00039789*V(I)*T(I)/SIZE
      IF(Y.GT. 134)GO TO 19
      IF(Y.LT. .01)GO TO 23
C   CALL THE INTERPOLATION FORMULA.
      CALL AKIMI(B,-1.,A,12,Y,-1.,X,1)
      ITEST(I)=1
      GO TO 22
C   THIS SECTION USED FOR RANGE WHERE LEE'S EQN VALID
   23 ITEST(I)=0
      YPOW=Y**.666667
      X=(((+20.8835)*YPOW  6.49229)*YPOW+2.38095 )*YPOW+1.70998)*SQRT(YPOW
     1)
   22 SIGMA(I)=T(I)*10000 *((X/SIZE)**2)
      WRITE(46,18)Y,YPOW,X,SIGMA(I)
   18 FORMAT(" Y=",F14.7," YPOW=",F14.7," X=",F14.7," SIGMA=",F14.7)
C
C     ITEST=0 IF VALUE HAS BEEN CALCULATED FROM FORMULA
C          =-1 IF VALUE IS OUTSIDE RANGE
C          =1 IF VALUE HAS COME FROM INTERPOLATION
C
      GO TO 20
   19 ITEST(I)=-1
      WRITE(46,16)Y
   16 FORMAT(" Y= ",F14.7," IS OUTSIDE RANGE")
   20 CONTINUE
C
C
      WRITE(46,34)NAME
   34 FORMAT(2X,30A2,//)
      WRITE(46,35)
   35 FORMAT(" TIME(MS)  RESPONSE(UV/A)  APP COND(S/M)   APP RES(OHM.M)
     1    ITEST")
C
      DO 40 I=1,N
      IF(ITEST(I).EQ.-1)SIGMA(I)=.00012
      RO=1./SIGMA(I)
      WRITE(46,41)T(I),V(I),SIGMA(I),RO,ITEST(I)
   41 FORMAT(F8.2,4X,F10.4,3X,F10.6,5X,F10.4,6X,I8)
```

## Program TERRY

```
   40 CONTINUE
C
C   THIS SECTION PLOTS THE CURVES
      CALL PLOTS(14.,12.,0,-5.,-5.)
      CALL PLOT(1.,1.,-3)
      CALL LOGAX(-2,-4,5,6,2.,1.5,LBLX,LBLY,NAME)
C
      DO 50 I=1,N
      XX=ALOGT(T(I))
      YY=ALOGT(SIGMA(I))
      XX=(XX+2.)*2
      YY=(YY+4.)*1.5
      CALL SYMB(XX,YY,.03,1,0.,-1)
   50 CONTINUE
      IO(2)=1
C
      CALL PLOT(0.,0.,999)
      CALL EXEC(10,TERRZ,IO(1),IO(2),IO(3),IO(4),IO(5))
      CALL GOPLT
C
      STOP
      END
      END$
```

Program TERRY

```
FTN4
      PROGRAM TERRZ
      INTEGER TERRY(3)
      DIMENSION IO(5)
      DATA TERRY/2HTE,2HRR,2HY /
      CALL RMPAR(IO)
      CALL EXEC(10,TERRY,IO(1),IO(2),IO(3),IO(4),IO(5))
      STOP
      END
      END$
```

Subroutine TERRZ

```
FTN4
      SUBROUTINE AKIMI(X,DX,Y,N,Z,DZ,V,M)
      DIMENSION X(1),Y(1),Z(1),V(1)
C
C    INTERPOLATION ROUTINE BY AKIMA
C    INPUT DATA
C       (X(I),Y(I)),I=1,N
C       DX=SPACING, =-VE IF DIFFERENT
C       Z=ABSCISSAE FOR POINTS FOR INTERPOLATION
C       DZ=SPACING. =-VE IF DIFFERENT
C       V= ORDINATES INTERPOLATED
C       M= NO  OF INTERPOLATIONS
C       DZ=SPACING, =-VE IF DIFFERENT
C
      T=Z(1)
      IT=1
      XN=X(1)+(N-1)*DX
      IF(DX.LE.0.) XN=X(N)
C *** GET DIFFS BETWEEN ABSCISSA OF 1ST 3 POINTS
      D21=DX
      IF(DX.LE.0.)D21=X(2)-X(1)
C *** GET FIRST 4  CHORDAL SLOPES
      C3=(Y(2)-Y(1))/D21
      D32=DX
      IF(DX.LE.0.)D32=X(3)-X(2)
      C4=(Y(3)-Y(2))/D32
      C2=C3+C3-C4
      C1=C2+C2-C3
C *** GET 1ST SLOPE
      C=(ABS(C4-C3)*C2+ABS(C2-C1)*C3)
      D=ABS(C4-C3)+ABS(C2-C1)
C *** SET SLOPE AT POINT
      S1=(C2+C3)/2
      IF(D.GT.1.E-10)S1=C/D
C *** SET SECTION COUNT
      I=2
C *** SHIFT CHORDAL SLOPES
    1 C1=C2
      C2=C3
      C3=C4
      C4=C3+C3-C2
      IF(I.GE.N-1)GO TO 2
      DIF=DX
      IF(DX.LE.0.) DIF=X(I+2)-X(I+1)
C *** GET NEW CHORDAL SLOPE
      C4=(Y(I+2)-Y(I+1))/DIF
    2 C=(ABS(C4-C3)*C2+ABS(C2-C1)*C3)
      D=ABS(C4-C3)+ABS(C2-C1)
C *** GET SLOPE AT NEXT POINT
      S2=(C2+C3)/2.
      IF(D.GT.1.E-10)S2=C/D
      DIF=DX
```

## Subroutine AKIMI

```
      IF(DX.LT.0.)DIF=X(I)-X(I-1)
C *** CALCULATE POLYNOMIAL COEFFS
      P1=S1
      P2=(3.*C2-S1-S1-S2)/DIF
      P0=Y(I-1)
      P3=(S1+S2-C2-C2)/(DIF*DIF)
C *** SET XA AND AB AS ABSCISSAE OF 2 EXTREEMS OF POLYNOMIAL
      XA=X(1)+(I-2)*DX
      XB=XA+DX
      IF(DX.GT.1.E-10)T=Z(IT)
      XA=X(I-1)
      XB=X(I)
    3 IF(T.LE.XB.OR.T.GT.XN) GO TO 4
C *** ADVANCE TO NEXT PAIR OF POINTS
      S1=S2
      I=I+1
      GO TO 1
C *** CALCULATE POLYNOMIAL BETWEEN POINTS
    4 A=T-XA
      V(IT)=P0+A*(P1+A*(P2+A*P3))
      IT=IT+1
      IF(IT.GT.M) RETURN
      T=T+DZ
      IF(DZ.LE.0.)T=Z(IT)
      GO TO 3
      END
      END#
```

## Subroutine AKIMI

```
FTN4,B
C
C *** "LOGAX"
C
C      DRAWS AND ANNOTATES LOG-LOG PLOT AXES
C
       SUBROUTINE LOGAX(LX0,LY0,NXC,NYC,SCX,SCY,LBLX,LBLY,NAME)
       INTEGER FPN(4)
       DIMENSION LBLX(15),LBLY(15),NAME(30)
       DATA ALG10/2.302585/
       ALOGT(X)=ALOG(X)/ALG10
C
C *** DRAW PLOT AXES
C
       CALL PLOT(FLOAT(NXC)*SCX,0.,2)
       CALL PLOT(FLOAT(NXC)*SCX,FLOAT(NYC)*SCY,2)
       CALL PLOT(0.,FLOAT(NYC)*SCY,2)
       CALL PLOT(0.,0.,2)
C
C *** SCALE OFF 'X' AXIS
C
       Y0=0
       Y1=SCY*.05
       DO 115 K=1,2
       DO 110 J=1,NXC
       XC=FLOAT(J-1)*SCX
       DO 105 I=1,10
       X=XC+ALOGT(FLOAT(I))*SCX
       CALL PLOT(X,Y0,3)
       CALL PLOT(X,Y1,2)
   105 CONTINUE
   110 CONTINUE
       Y0=FLOAT(NYC)*SCY
       Y1=Y0-SCY*.05
   115 CONTINUE
C
C *** SCALE OFF 'Y' AXIS
C
       X0=0
       X1=SCX*.05
       DO 130 K=1,2
       DO 125 J=1,NYC
       YC=FLOAT(J-1)*SCY
       DO 120 I=1,10
       Y=YC+ALOGT(FLOAT(I))*SCY
       CALL PLOT(X0,Y,3)
       CALL PLOT(X1,Y,2)
   120 CONTINUE
   125 CONTINUE
       X0=FLOAT(NXC)*SCX
       X1=X0-SCX*0.05
   130 CONTINUE
```

## Subroutine LOGAX

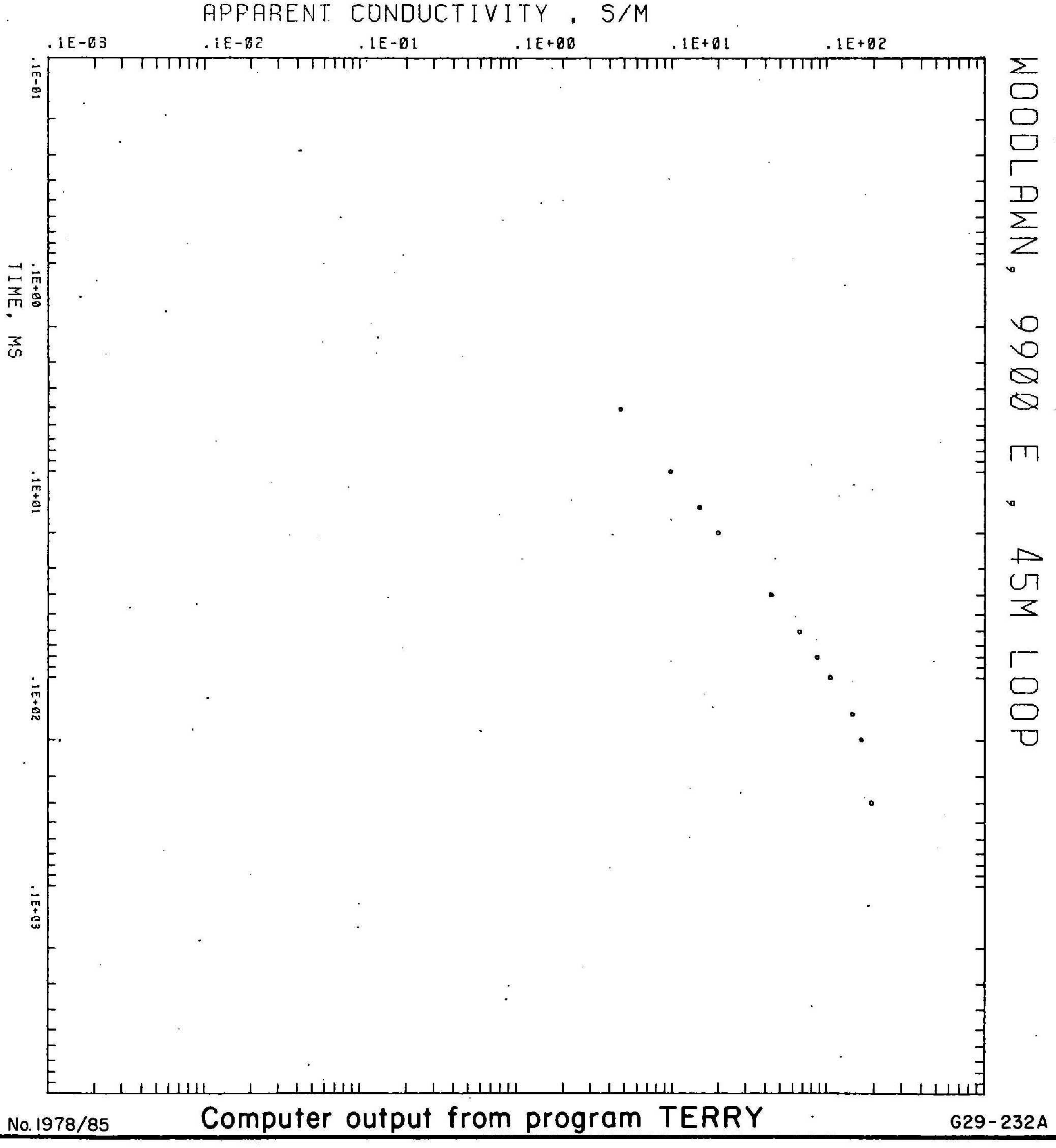
```
C
C *** ANNOTATE 'X' AXIS
C
      LOG=LX0
      Y=-SCY* 1
      HT= 05*SCY
      DO 135 I=1,NXC
      X=FLOAT(I-1)*SCX-2 *HT
      Z=10 **LOG+ 1E-4
      CALL CODE
      WRITE(FPN,310) Z
  310 FORMAT(E8 1)
      CALL SYMB(X,Y,HT,FPN,0.,8)
      LOG=LOG+1
  135 CONTINUE
C
C *** ANNOTATE 'Y' AXIS
C
      LOG=LY0
      X=-SCX* 05
      HT= 05*SCX
      DO 140 I=1,NYC
      Y=FLOAT(I-1)*SCY-2 *HT
      Z=10.**LOG+.1E-4
      CALL CODE
      WRITE(FPN,310) Z
      CALL SYMB(X,Y,HT,FPN,90.,8)
      LOG=LOG+1
  140 CONTINUE
C
C *** LABEL PLOT
C
      HT=(FLOAT(NXC)*SCX)/40
      X=2 *HT
      Y=(FLOAT(NYC))*SCY+HT
      CALL SYMB(X,Y,HT,NAME,0.,40)
C
C *** LABEL X,Y AXES
C
      X=SCX
      Y=- 25*SCY
      CALL SYMB(X,Y, 08*SCY,LBLX,0.,30)
      X=-.18*SCX
      Y=SCY*.5
      CALL SYMB(X,Y,.08*SCX,LBLY,90.,30)
      RETURN
      END
      END$
```

Subroutine LOGAX

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Y= | 0123788 | YPOW= | 0000000 | X= | 4454002 | SIGMA= | .9796E11 |
| Y= | .0128651 | YPOW= | .0000000 | X= | .4532643 | SIGMA= | 1.5218410 |
| Y= | .0126087 | YPOW= | .0000000 | X= | .4492165 | SIGMA= | 1.9930410 |
| Y= | .0139704 | YPOW= | .0000000 | X= | .4683104 | SIGMA= | 4.3321400 |
| Y= | .0144301 | YPOW= | 0000000 | X= | 4735245 | SIGMA= | 6.6437168 |
| Y= | .0140057 | YPOW= | .0000000 | X= | .4687335 | SIGMA= | 8.6799469 |
| Y= | .0135283 | YPOW= | .0000000 | X= | .4627439 | SIGMA= | 10.5744171 |
| Y= | .0123081 | YPOW= | .0000000 | X= | .4441876 | SIGMA= | 14.6150074 |
| Y= | 0106104 | YPOW= | 0000000 | X= | 4102144 | SIGMA= | 16.6198349 |
| Y= | 0053759 | YPOW= | .0306880 | X= | .3132842 | SIGMA= | 19.3870621 |

WOODLAWN, 9900 E , 45M LOOP

| TIME(MS) | RESPONSE(UV/A) | APP COND(S/M) | APP RES(OHM.M) | ITEST |
|---|---|---|---|---|
| 50 | 2700 0000 | 472736 | 2.1153 | 1 |
| 1.00 | 1400 0000 | 979661 | 1 0208 | 1 |
| 1 50 | 970 0000 | 1 521841 | .6571 | 1 |
| 2.00 | 713 0000 | 1 993041 | .5017 | 1 |
| 4.00 | 395 0000 | 4 332140 | .2308 | 1 |
| 6.00 | 272 0000 | 6 643717 | 1505 | 1 |
| 8.00 | 198 0000 | 8 679947 | 1152 | 1 |
| 10.00 | 153 0000 | 10.574417 | 0946 | 1 |
| 15 00 | 92 8000 | 14 615007 | .0684 | 1 |
| 20.00 | 60.0000 | 16.619835 | 0602 | 1 |
| 40.00 | 15.2000 | 19 387062 | 0516 | 0 |






Computer output from program TERRY

```
FTN4
      PROGRAM HOMOG
C   COMPUTES THE TEM RESPONSE OF A HOMOGENEOUS HALFSPACE
C   INPUT DATA IS
C                    COND=CONDUCTIVITY
C                    SHAPE=SQUARE OR CIRCLE
C                    SIZE=SIDE LENGTH OR RADIUS
C   SI UNITS USED THROUGHOUT
C
      INTEGER SHAPE(3)
      REAL COND
      DIMENSION V(60),T(60),ITEST(60),IO(5)
      EQUIVALENCE(IO(1),IO1)
      CALL RMPAR(IO)
    1 WRITE(IO1,2)
    2 FORMAT(" TYPE IN CONDUCTIVITY AND SIZE")
      READ(IO1,*)COND,SIZE
      IF(COND.LE.0 )STOP
      WRITE(IO1,3)
    3 FORMAT(" SQUARE OR CIRCLE?")
      READ(IO1,4)SHAPE
    4 FORMAT(3A2)
      RES=1./COND
      WRITE(IO1,5)SIZE,SHAPE,COND,RES
      WRITE(6,5)SIZE,SHAPE,COND,RES
    5 FORMAT(" HOMOGENEOUS HALFSPACE  ",F9.2," M  ",3A2,"  LOOP",/," CON
     1DUCTIVITY= ",F8.4," S/M, RESISTIVITY = ",F8.4," OHM-M")
      CALL HALF(SIZE,SHAPE,COND,T,V,ITEST)
C
C   NOW PRINT ANSWERS
      WRITE(6,6)
    6 FORMAT(" TIME(MS)  RESPONSE(UV/A)   ITEST")
      DO 10 I=1,55
      IF(ITEST(I).EQ.-1)GO TO 8
C   NOW FORMAT FOR MS AND UV
      TMS=T(I)*1000.
      VUV=V(I)*1.E6
      WRITE(6,7)TMS,VUV,ITEST(I)
    7 FORMAT(F8.2,4X,F10.4,3X,I6)
      GO TO 10
    8 TMS=T(I)*1000
      WRITE(6,9)TMS,ITEST(I)
    9 FORMAT(F8.2,4X,"     -        ",I8)
   10 CONTINUE
      GO TO 1
      END
      END$
```

## Program HOMOG

```
FTN4,B
      PROGRAM TEMHF
C THIS PROGRAM PRODUCES AND PROVIDES DATA TO PRODUCE STANDARD CURVES
C FOR TEM RESPONSE OF HOMOGENEOUS HALFSPACES
C    INPUT DATA IS
C                        COND=CONDUCTIVITY
C                        SIZE=SIDE LENGTH OR RADIUS
C                        SMIN=LOWER SIZE LIMIT FOR LOOP
C    SI UNITS USED THROUGHOUT
C
      INTEGER SHAPE(3)
      REAL COND,COND1,CONDIV
      DIMENSION LABLX(4),LABLY(6),ISIZE(4),T(60),V(60),ITEST(60),IO(5)
      EQUIVALENCE(IO(1),IO1)
      DATA LABLX/2HTI,2HME,2H(M,2HS)/
      DATA LABLY/2HRE,2HSP,2HON,2HSE,2H(M,2HV)/
      ALOGT(Q)=ALOG(Q)/2.302585
      THOU(Q)=1000.*Q
      CALL EMPAR(IO)
[illegible]
      WRITE(IO1,2)
    2 FORMAT(" TYPE IN COND1,SIZE AND SMIN")
      READ(IO1,*)COND1,SIZE,SMIN
      WRITE(IO1,3)
    3 FORMAT(" TYPE IN SHAPE")
      READ(IO1,4)SHAPE
    4 FORMAT(3A2)
      WRITE(IO1,5)
    5 FORMAT(" TYPE IN SIZE & CONDUCTIVITY DIVISION FACTORS")
      READ(IO1,*)SIZED,CONDIV
      WRITE(IO1,6)
    6 FORMAT(" TYPE IN LXO,LYO,NXC,NYC,SCX,SCY")
      READ(IO1,*)LXO,LYO,NXC,NYC,SCX,SCY
C
C    THIS LOOP IS FOR CHANGE IN LOOP SIZE
   10 DO 90 L=1,30
      COND=COND1
      IF(SIZE.LT.SMIN)GO TO 100
      CALL CODE
      WRITE(ISIZE,11)SIZE
   11 FORMAT(F8.2)
      WRITE(13,12)ISIZE,SHAPE
      WRITE(13,13)LABLX
      WRITE(13,14)LABLY
      WRITE(13,15)LXO,LYO,NXC,NYC,SCX,SCY
   12 FORMAT(8A2)
   13 FORMAT(4A2)
   14 FORMAT(6A2)
   15 FORMAT(4(I3,1H,),F6.2,1H,,F7.2)
C
C    THIS LOOP IS FOR CHANGE IN CONDUCTIVITY
      DO 70 K=1,100
      IF(COND.LT..0001)GO TO 80
      WRITE(6,21)COND,SIZE,SHAPE
```

## Program TEMHF

```
   21 FORMAT(" TRANSIENT DECAY CURVE FOR HALFSPACE , CONDUCTIVITY=",F8.4
     1" S/M" /.F9.2 " METRES",2X,3A2,2X," LOOP.")
      WRITE(6,22)
   22 FORMAT(/ " TIME(MS)     RESPONSE(MV)   ITEST")
      NCOUNT=0
C     NOW CALCULATE VALUES FOR ONE DECAY CURVE
      CALL HALF(SIZE,SHAPE,COND,T,V,ITEST)
      DO 24 I=1,55
      TMS=THOU(T(I))
      IF(ITEST(I).LT.0)V(I)=0
      VMV=THOU(V(I))
      WRITE(6,23)TMS,VMV,ITEST(I)
   23 FORMAT(F9.4,F15.6,I6)
      IF(VMV.LT..0001.OR.VMV.GT.100.)GO TO 24
      NCOUNT=NCOUNT+1
   24 CONTINUE
      IF(NCOUNT.EQ.0)GO TO 60
      WRITE(13,25)NCOUNT
   25 FORMAT(I2)
      DO 26 I=1,55
      TMS=THOU(T(I))
      VMV=THOU(V(I))
      IF(VMV.LT..0001.OR.VMV.GT.100.)GO TO 26
      WRITE(13,27)TMS,VMV
   27 FORMAT(E12.5,1H,,E12.5)
   26 CONTINUE
   60 COND=COND/CONDIV
   70 CONTINUE
   80 SIZE=SIZE/SIZED
      WRITE(13,15)NN
   90 CONTINUE
  100 ENDFILE 13
      ENDFILE 13
      STOP
      END
      END$
```

# Program TEMHF

```
FTN4
      SUBROUTINE HALF(SIZE,SHAPE,COND,T,V,ITEST)
C     COMPUTES THE TEM RESPONSE OF A HOMOGENEOUS HALFSPACE
C     INPUT DATA IS
C                    COND=CONDUCTIVITY
C                    SHAPE=SQUARE OR CIRCLE
C                    SIZE=SIDE LENGTH OR RADIUS
C     OUTPUT TIMES RANGE FROM 0.1 TO 100 MS.
C     SI UNITS USED THROUGHOUT.
C
      INTEGER SHAPE(3)
      REAL COND
      DIMENSION V(60),T(60),ITEST(60),IO(5),A(12),B(12)
      EQUIVALENCE(IO(1),IO1)
      DATA A/.39716,.5,.62946,.79245,.99763,1.25594,
     *1.58114,1.99054,2.5059,3.15478,3.9717,5./
      DATA B/.01005,.017897,.029896,.046262,.06535,.084001,
     *.099678,.111711,.120534,.126866,.131320,.134419/
      FACTR=1
      IF(SHAPE(1).EQ.2HSQ) FACTR=.56419
C
      IFLAG=0
      TIME=.00005
      DO 20 I=1,3
      II=10**I
      TINC=.000005*II
      DO 20 J=1,19
      IF(I.NE.1.AND.J.EQ.1)GO TO 20
      TIME=TIME+TINC
C     NOW CALCULATE THE RESPONSE
C       ITEST=0  IF VALUE IS CALCULATED FROM FORMULA
C            =-1 IF VALUE IS OUTSIDE RANGE
C            =1  IF VALUE COMES FROM INTERPOLATION
      IFLAG=IFLAG+1
      X=5.605E-4*SIZE*FACTR*SQRT(COND/TIME)
      IF(X.LT..4)GO TO 15
      IF(X.GT.5.)GO TO 18
C     CALL THE INTERPOLATION FORMULA
      CALL AKIMI(A,-1.,B,12,X,-1.,Y,1)
      ITEST(IFLAG)=1
      GO TO 16
C     THIS SECTION USED WHEN LEE'S EQN VALID
   15 Y=(X*(.584803-.27848*X**2+.13813*X**4-.05414*X**6))**3
      ITEST(IFLAG)=0
   16 V(IFLAG)=4.454E-6*SIZE*FACTR*Y/TIME
      GO TO 19
   18 ITEST(IFLAG)=-1
   19 T(IFLAG)=TIME
   20 CONTINUE
      RETURN
      END
      END$
```

## Subroutine HALF

HOMOGENEOUS HALFSPACE 45.00 M SQUARE LOOP
CONDUCTIVITY= 5000 S/M, RESISTIVITY = 2.0000 OHM-M

| TIME(MS) | RESPONSE(UV/A) | ITEST |
|---|---|---|
| 10 | 74749.3437 | 1 |
| 15 | 37019 1094 | 1 |
| 20 | 21557 4414 | 1 |
| 25 | 13831.0762 | 1 |
| 30 | 9513 4883 | 1 |
| 35 | 6870.2246 | 1 |
| 40 | 5136 6475 | 1 |
| 45 | 3955 0664 | 1 |
| 50 | 3128 4136 | 1 |
| 55 | 2525.5391 | 1 |
| 60 | 2071 0239 | 1 |
| 65 | 1727.2839 | 0 |
| 70 | 1456.4397 | 0 |
| 75 | 1241 5156 | 0 |
| 80 | 1068 4985 | 0 |
| 85 | 927 4431 | 0 |
| 90 | 811 1405 | 0 |
| 95 | 714 2744 | 0 |
| 1 00 | 632 8608 | 0 |
| 1 50 | 240.5064 | 0 |
| 2 00 | 119 9321 | 0 |
| 2 50 | 69.6300 | 0 |
| 3 00 | 44 5606 | 0 |
| 3 50 | 30.5160 | 0 |
| 4 00 | 21 9665 | 0 |
| 4.50 | 16 4227 | 0 |
| 5 00 | 12 6645 | 0 |
| 5 50 | 10 0055 | 0 |
| 6 00 | 8.0670 | 0 |
| 6.50 | 6.6181 | 0 |
| 7 00 | 5.5059 | 0 |
| 7 50 | 4 6399 | 0 |
| 8 00 | 3 9533 | 0 |
| 8.50 | 3 4009 | 0 |
| 9 00 | 2 9503 | 0 |
| 9.50 | 2 5799 | 0 |
| 10 00 | 2.2712 | 0 |
| 15 00 | .8281 | 0 |
| 20 00 | .4044 | 0 |
| 25 00 | .2318 | 0 |
| 30 00 | .1471 | 0 |
| 35 00 | 1001 | 0 |
| 40.00 | .0717 | 0 |
| 45 00 | .0535 | 0 |
| 50 00 | .0411 | 0 |
| 55 00 | 0324 | 0 |
| 60 00 | 0261 | 0 |
| 65 00 | 0213 | 0 |
| 70 00 | 0177 | 0 |
| 75 00 | 0149 | 0 |
| 80 00 | .0127 | 0 |
| 85 00 | .0109 | 0 |
| 90 00 | .0095 | 0 |
| 95 00 | .0083 | 0 |
| 100 00 | .0073 | 0 |

Computer output from program HOMOG

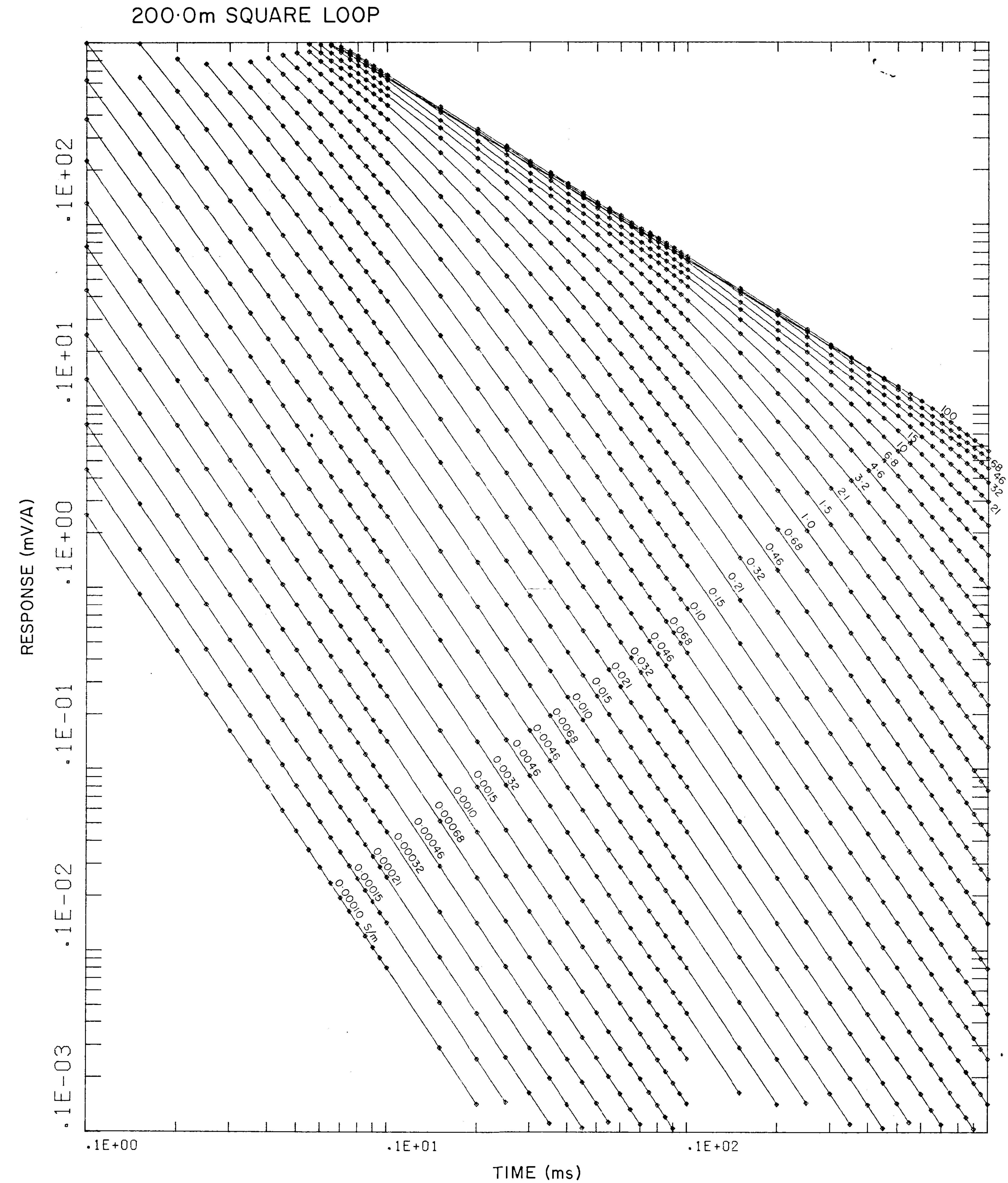
```
FTN4,B
C
C       'LCOMP' WILL PLOT A CONTINUOUS LOG-LOG CURVE
C       ON THE CALCOMP FROM A DISCRETE SET OF DATA
C       POINTS WHERE   X(I+1) > X(I)
C     THIS HAS THE SAME FUNCTION AS LGRPH.
C
        PROGRAM LCOMP
        DIMENSION LBLX(15),LBLY(15),NAME(30),IO(5),X(99),Y(99)
        COMMON IOP(5)
        DATA M1/2H-1/
        CALL RMPAR(IO)
        IO1=IO(1)
        DO 105 I=1,5
        IOP(I)=IO(1)
    105 CONTINUE
        CALL PLOTS(0,0,7)
C *** READ PLOT TITLE, AXIS LABELS
      5 READ(IO1,201)NAME
        IF(NAME(1).EQ.M1)GO TO 30
        READ(IO1,201)LBLX
        READ(IO1,201)LBLY
    201 FORMAT(30A2)
C *** READ PLOT BOUNDS INFORMATION
        READ(IO1,*)LXO,LYO,NXC,NYC,SCX,SCY
        CALL PLOT(SCX,.5*SCY,-3)
        CALL LOGAX(LXO,LYO,NXC,NYC,SCX,SCY,LBLX,LBLY,NAME)
        NPLTS=0
C *** READ NO. POINTS FOR PLOTTING
     10 READ(IO1,*)N
        IF(N.LE.0)GO TO 20
        DO 110 I=1,N
C *** READ DISCRETE X,Y POINTS
        READ(IO1,*)X(I),Y(I)
        X(I)=ALOG(X(I))/2.302585
        Y(I)=ALOG(Y(I))/2.302585
    110 CONTINUE
        CALL INTPL(N,X,Y,LXO,LYO,NXC NYC,SCX,SCY)
        NPLTS=NPLTS+1
        FLXO=FLOAT(LXO)
        FLYO=FLOAT(LYO)
        DO 120 I=1,N
        CALL SYMB((X(I)-FLXO)*SCX,(Y(I)-FLYO)*SCY,
       *.05,5,0.,-1)
    120 CONTINUE
        GO TO 10
     20 CALL PLOT(FLOAT(NXC+2)*SCX,0.,-3)
        GO TO 5
     30 CALL PLOT(0.,0.,999)
        STOP
        END
        END$
```

## Subroutine LCOMP

```
FTN4,B
      SUBROUTINE INTPL(N,X,Y,LX0,LY0,NXC,NYC,SCX,SCY)
      DIMENSION X(51),Y(51),Z(2),V(51)
      COMMON IOP(5)
      IO2=IOP(2)
      NOPI=50
      FNOPI=FLOAT(NOPI)
      NPTS=IFIX((X(N)-X(1))*SCX*FNOPI)+1
      SINT=1./(SCX*FNOPI)
      S=X(1)
      IP=3
      DO 150 I=1,NPTS
      Z(1)=S
      CALL AKIMA(X,0.,Y,N,Z,0.,V,1)
      CALL LOGGR(10.**S,10.**V(1),
     *LX0,LY0,NXC,NYC,SCX,SCY,IP)
      IP=2
      S=S+SINT
  150 CONTINUE
      RETURN
      END
      END$
```

## Subroutine INTPL

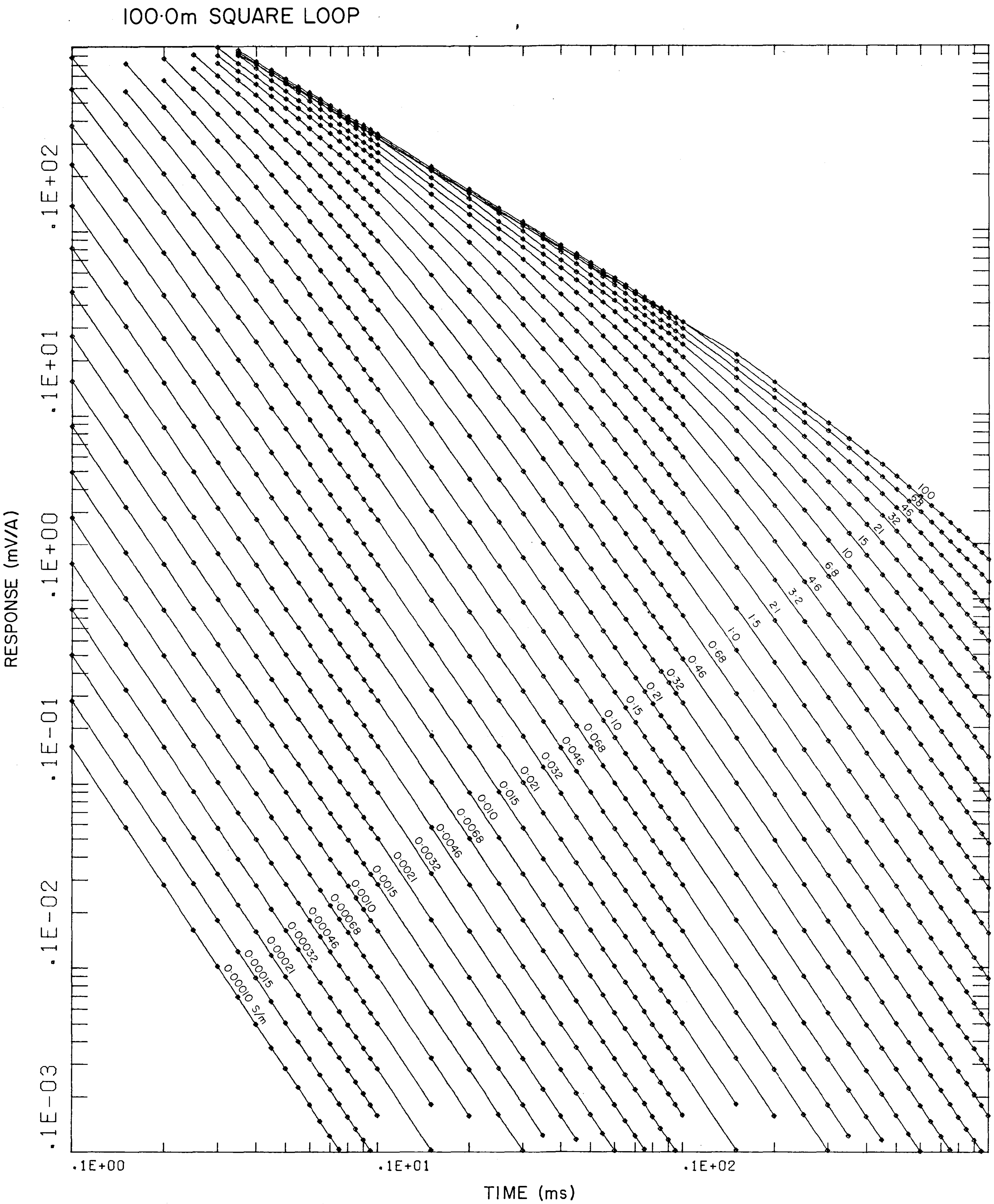
PLATE I




Standard curves for TEM response of homogeneous half-space (200m loop)

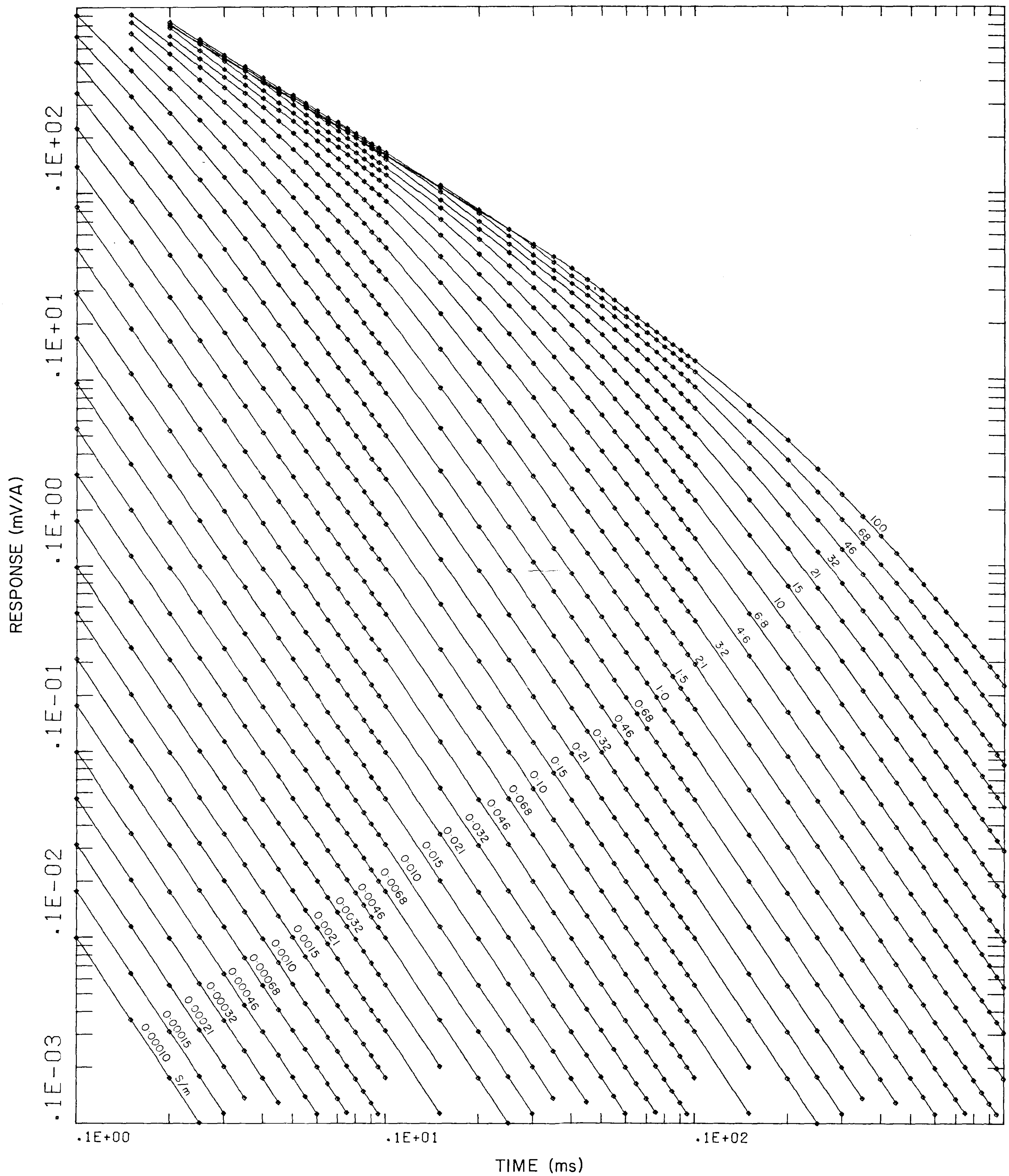


G29-246



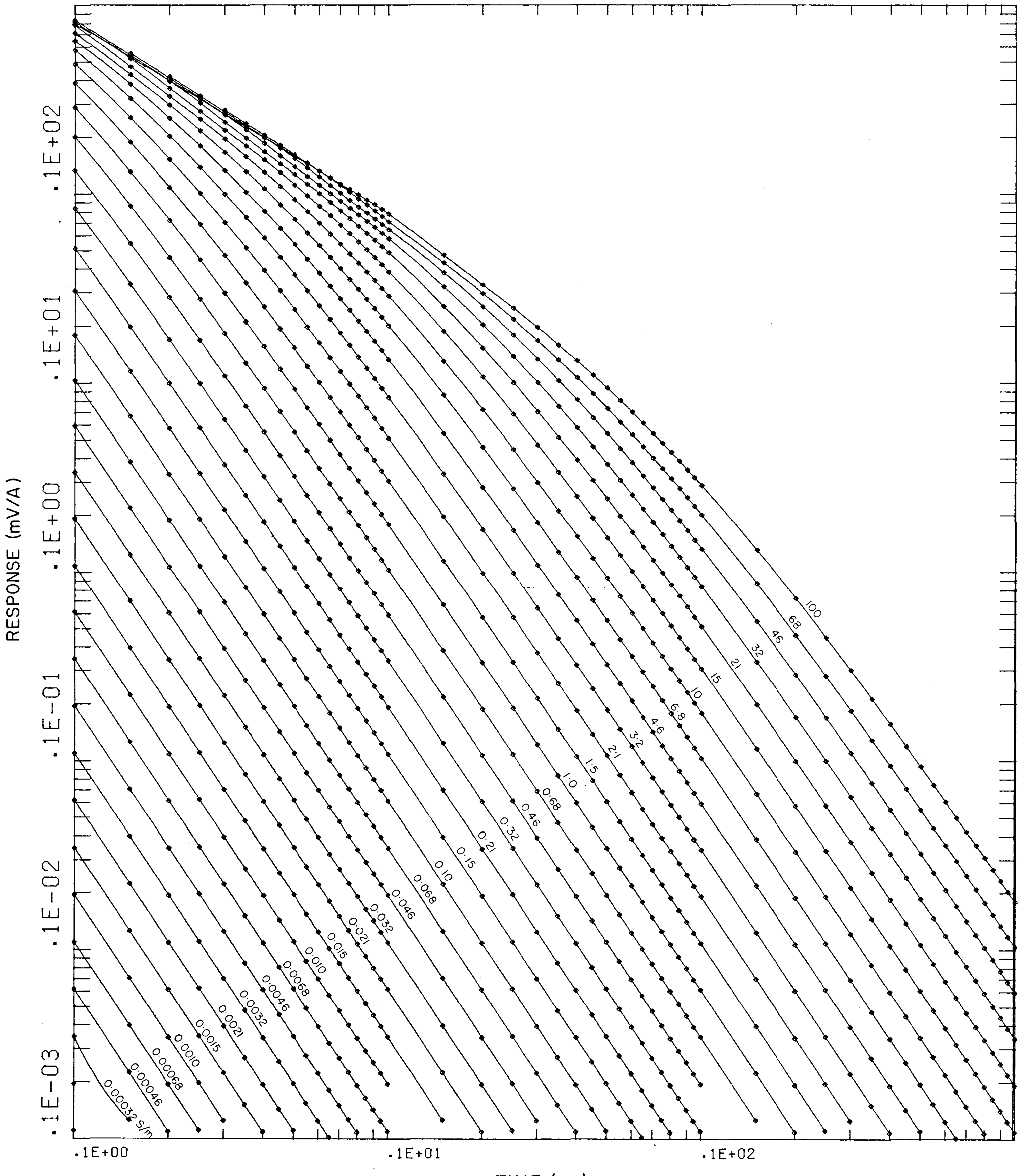

Standard curves for TEM response of homogeneous half-space (100m loop)

## 50·0m SQUARE LOOP




Standard curves for TEM response of homogeneous half-space (50m loop)

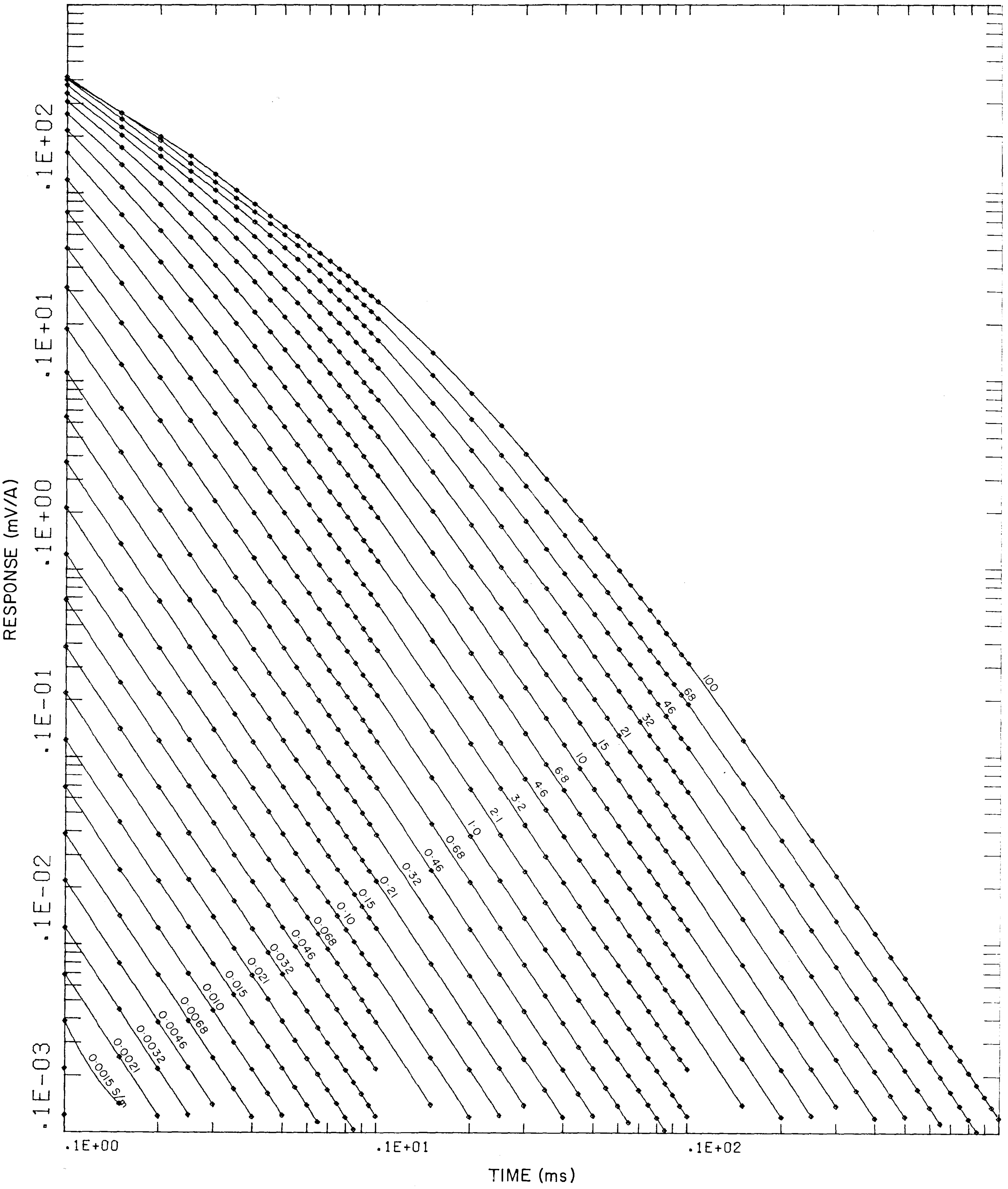
25·0m SQUARE LOOP




Standard curves for TEM response of homogeneous half-space (25m loop)

PLATE 5

12·5m SQUARE LOOP

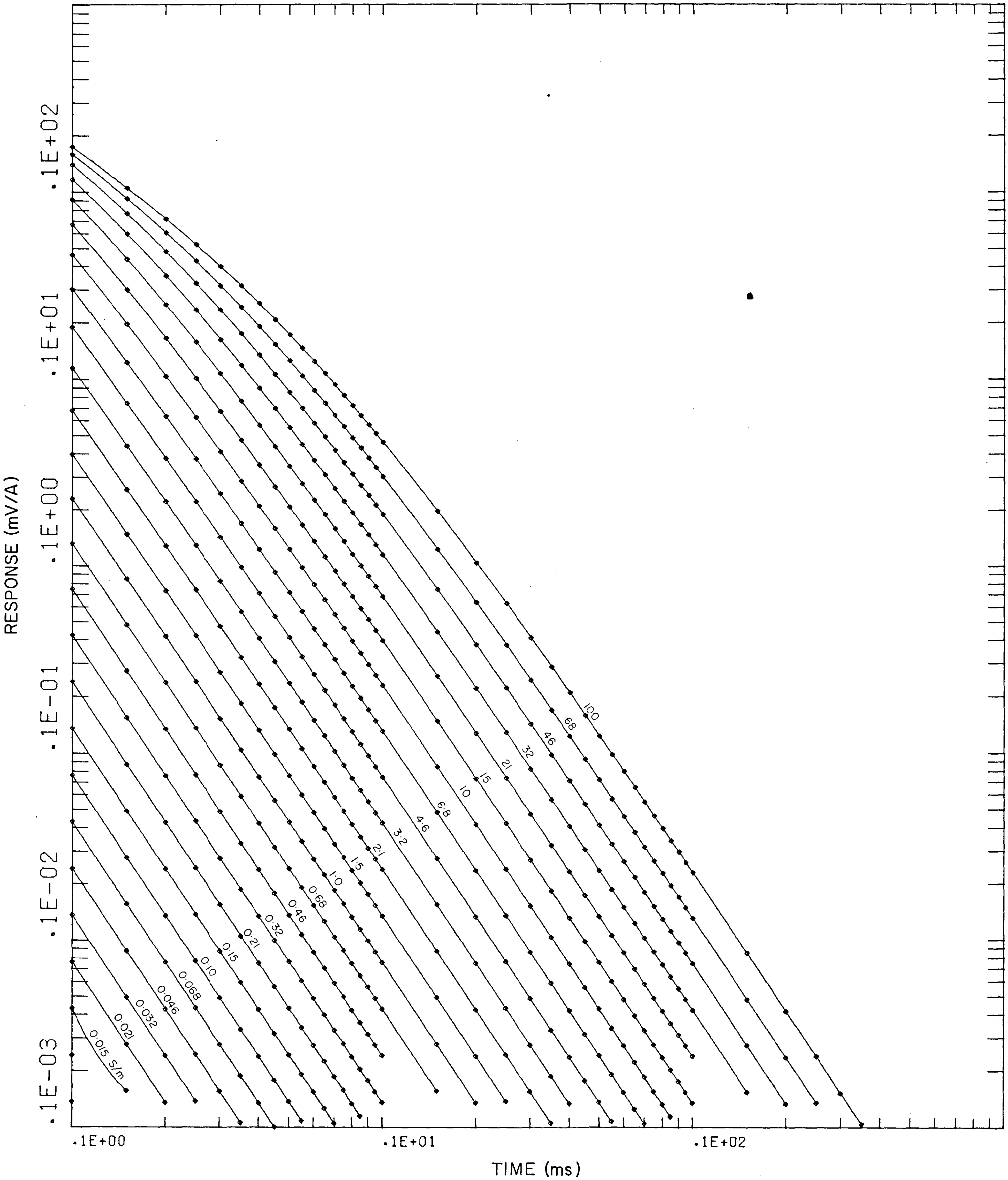



Standard curves for TEM response of homogeneous half-space (12·5m loop)

Record No. 1978/85

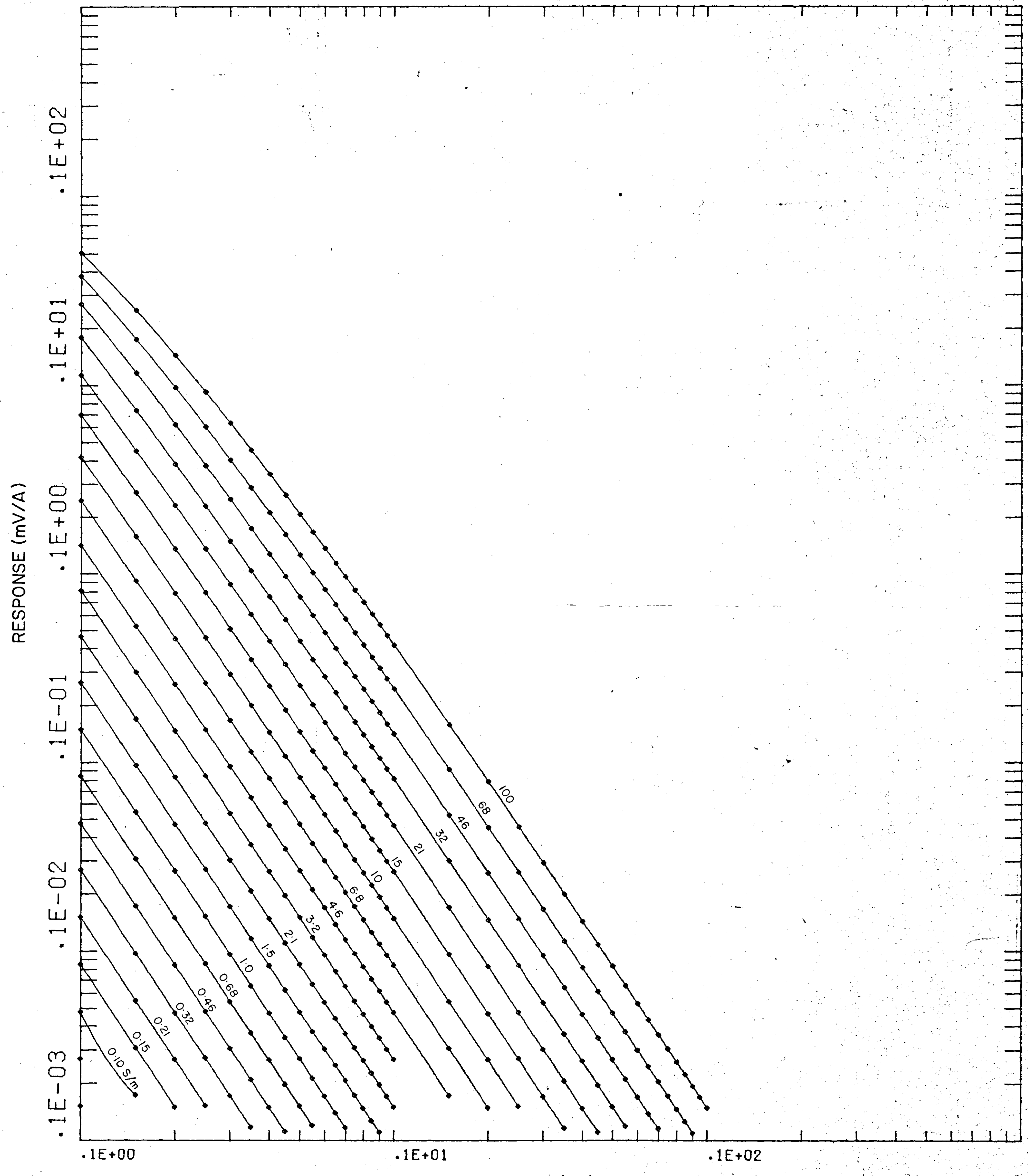
G29-250

6·25m SQUARE LOOP



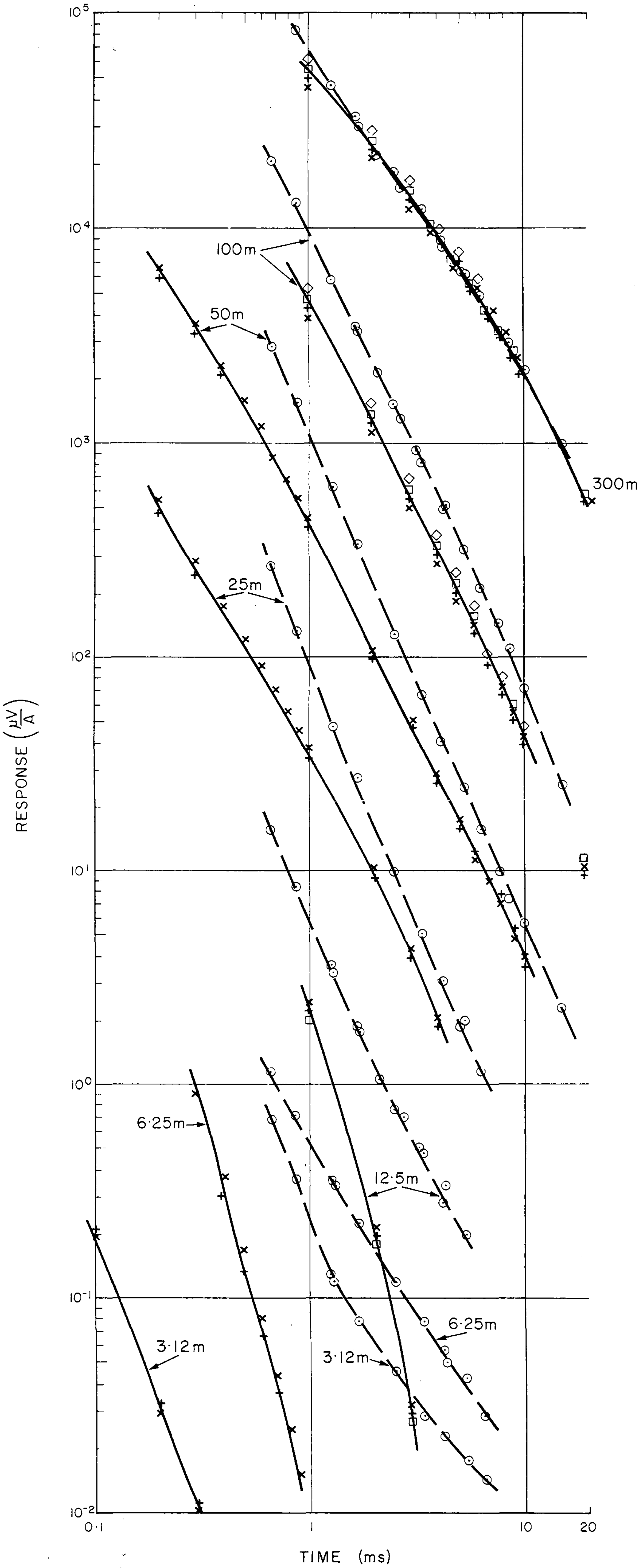

Standard curves for TEM response of homogeneous half-space (6·25m loop)

3·12m SQUARE LOOP




Standard curves for TEM response of homogeneous half-space (3·12m loop)

154/87-1




## RESISTIVITY INVERSION MODELS

### MODEL 1

| | |
|---|---|
| | 0 m |
| 0·0477 S/m | 20·1 m |
| 0·606 S/m | 38·9 m |
| 0·513 S/m | 296 m |
| 0·0122 S/m | |

### MODEL 2

| | |
|---|---|
| | 0 m |
| 0·0493 S/m | 21·8 m |
| 0·682 S/m | 292 m |
| 0·0148 S/m | |

### MODEL 3

| | |
|---|---|
| | 0 m |
| 0·0477 S/m | 19·8 m |
| 0·548 S/m | 314 m |
| 0·0143 S/m | |

### MODEL 4

| | |
|---|---|
| | 0 m |
| 0·0491 S/m | 21·1 m |
| 0·361 S/m | 8 m |
| 0·593 S/m | 279 m |
| 0·0152 S/m | |

## TEM RESULTS

⊙ Observed (field) reading

× Model 1
\+ Model 2
□ Model 3
◇ Model 4
} Computed TEM values

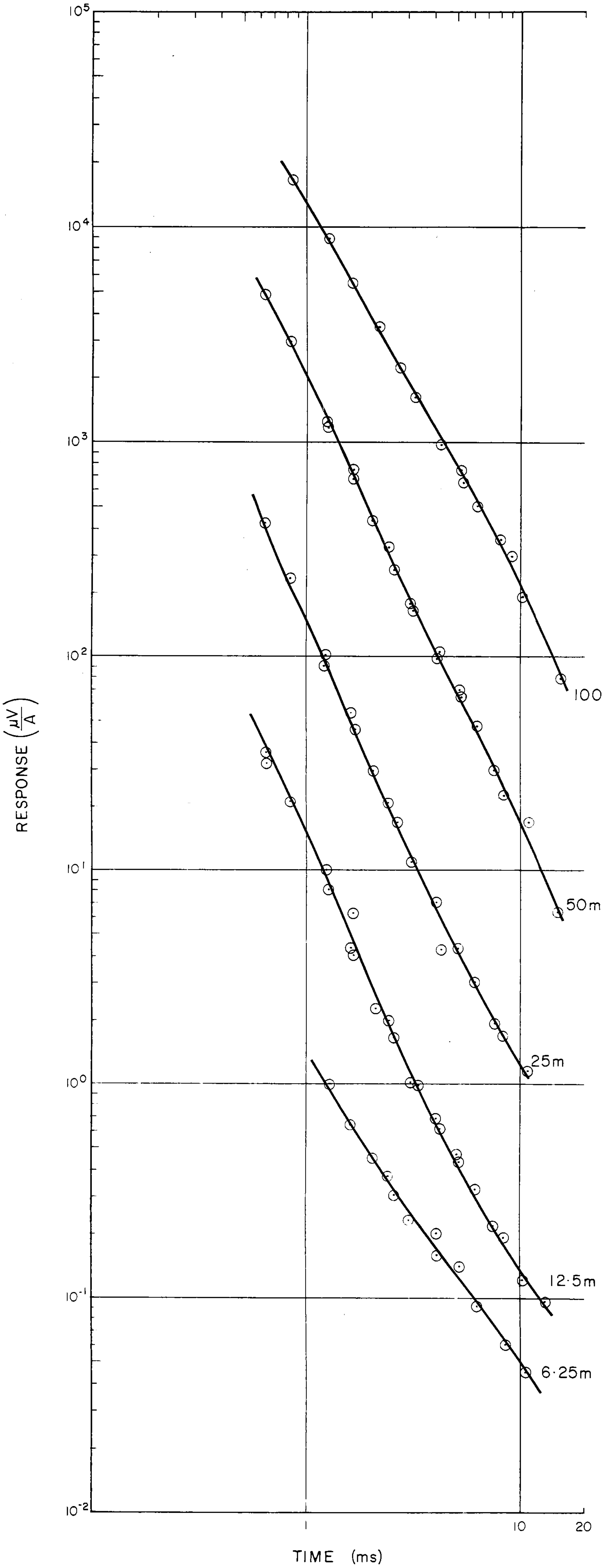
| LOOP SIZE (m) | CURRENT (A) | No. TURNS |
|---|---|---|
| 300 | 0·5 | 1 |
| 100 | 2·0 | 1 |
| 50 | 3·0 | 1 |
| 25 | 3·0 | 1 |
| 12·5 | 2·0 | 3 |
| 6·25 | 2·0 | 6 |
| 3·12 | 2·0 | 12 |

Pooncarie, N S W : Geoelectric section and TEM results

Record No.1978/85

PLATE 9

I54/B7-4




## RESISTIVITY INVERSION MODEL

0 m

0·005 S/m

0·7m

0·3 S/m

4 m

0·2 S/m

25 m

2·0 S/m

160 m

0·7 S/m

## TEM RESULTS

⊙ Observed (field) reading

| LOOP SIZE (m) | CURRENT (A) | No. TURNS |
|---|---|---|
| 100 | 2·0 | 1 |
| 50 | 2·5 | 1 |
| 25 | 2·5 | 2 |
| 12·5 | 2·5 | 4 |
| 6·25 | 2·0 | 4 |

Pirlta, Vic.: Geoelectric section and TEM results

Record No. 1978/85