DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

056109

RECORD 1975/44

TRANSIENT ELECTROMAGNETIC MODEL STUDIES, 1974.

by

B.R. Spies

RECORD 1975/44

TRANSIENT ELECTROMAGNETIC MODEL STUDIES, 1974.

by

B.R. Spies

CONTENTS

FIGURES

2

SUMMARY

Two model studies were made following the 1973 field season to aid interpretation of results of transient electromagnetic (TEM) surveys. Models studied were constructed of aluminium in air using scaling factors of 640 and 1000.

The dual-loop configuration was studied with respect to a dipping thin plate. It was found that the dual-loop configuration is advantageous when searching for thin dipping conductors in that the main peak of the anomaly lies directly over the top of the body.

The second model study involved the production of decay curves attributable to horizontal tabular bodies of different sizes at various depths. The transient decay curves were in all cases exponential in shape and the time constant $\tau(t)$ was found to be independent of the depth of the model and loop size. Although $\tau(t)$ generally did increase with the size of the model, the relation $\tau_0 = \mu\sigma Q$ did not hold for the models studied. The fall-off of the TEM response with depth was also found to be exponential, the depth decay constant $\tau(d)$ depending only on the loop size. For bodies of similar size and conductivity a relation is given for determining the depth of any of the bodies providing the depth to one is known.

1. INTRODUCTION

Laboratory modelling of transient electromagnetic (TEM) fields began in early 1973 with the objective of gaining an insight into responses produced by bodies of different size, shape, and conductivity to aid interpretation of field results (Spies, 1974).

The two models described in this report were studied to aid interpretation of the 1973 field results described by Hone & Spies (in prep.).

Results of a TEM survey at Dobbyn, Queensland, indicated that when using a dual-loop configuration over a dipping bed the amplitudes of the anomaly peaks depended on the dip of the bed. A model study was made to confirm this observation and to determine the relation between the ratio of the peaks and the dip of the bed.

The relation $\tau_o = \mu \sigma Q$ has been recommended for use in the interpretation of survey results, (Velikin & Bulgakov, 1967) but the definition of Q, the "effective cross section of the body" is not clear. Models of different sizes were studied to investigate the validity of the relation.

The experimental setup used was essentially the same as that described by Spies (1974) using the MPPO-1 equipment and models of aluminium in air.

2. RESULTS

Dual loop - dipping plate.

The model consisted of a 90 cm x 60 cm x 3.18 mm ($\frac{1}{8}$ inch) aluminium sheet, which was large enough to simulate a thin tabular body infinite in both the strike and dip dimensions. A scaling factor of 640 was used such that the simulated conductor (geological model) was a dyke-like body 2 m thick at a depth of 11.5 m with conductivity 90 siemens per metre (S/m). Loop size was 50 m diameter.

Profiles of $e(t)/I$ for different dips of the plate are presented in Figure 1. Three peaks are present, the largest of which lies over the top of the plate for dips larger than 10°. This is an obvious advantage over the response obtained from a single loop, where two peaks are produced, symmetrically displaced about the top of the plate (Velikin & Bulgakov, 1967). There is evidently a relation between the dip of the plate and the ratio of the size of the peaks, but it is not an exponential one as is the case with a single loop (Velikin & Bulgakov, 1967). Figure 2 shows a graph of the ratio of largest to second largest peak versus dip of the plate. For dips less than 10° there are two possible positions of the plate that will result in the same ratio value, although it will be evident from the profile shape which way the bed is dipping.

In summary the dual-loop configuration offers the advantage over a single loop that the peak of the anomaly is located directly over the top of a bed dipping at angles greater than 10°.

<u>Horizontal tabular bodies</u>

Square aliminium tabular blocks were used as models with loops of two different sizes to test the relation.

$$\tau_o = \mu \sigma Q \qquad \ldots(1)$$ (Velikin & Bulgakov, 1967)

where τ_o = time constant of transient decay at late times (see Appendix)

μ = magnetic permeability

σ = conductivity

Q = effective cross-section of body

Decay curves were read using all combinations of the following parameters:

Model size:	3 cm, 5 cm, 8 cm square.
Model thickness:	3.17 mm, 4.76 mm, 6.35 mm, 12.7 mm.
Loop size:	9.6 cm, 12.4 cm diameter.
Depth to model:	Between 1 cm and 8 cm, depending on the size of the model.

5

Using a scaling factor of 1000 the aluminium block had a simulated conductivity of 35 S/m. The loop was centrally located over the top of the model and readings were normalized to microvolts per ampere of current in the loop.

Transient decay curves over a typical model are presented in Figure 3a. The curves are plotted on a log-linear scale, and it is evident that the decay curves are exponential. The time constant of the decay, $\tau(t)$, is constant for all depths of the model ($\tau(t) = \tau_o$), and in this case is 1.45 ms. Figure 3b presents a graph of the response at 2 ms versus depth, again plotted on a log-linear scale. Since the graph is exponential, we may define the response/depth relation as:

$$E(d) = E(o)e^{-d/\tau(d)} \qquad \ldots (2)$$

where E(d) is the response measured at depth d at a certain time. In the example (Fig. 3b) E(30) = 1160 μV/A, and E(o) = 4000 μV/A, and $\tau(d)$ = 23 m, $\tau(d)$ is the depth in which the response will fall to 1/e or 37% of its initial value.

Three quantities are sufficient to describe the transient decay curves obtained for each model. These parameters are:

E (o,o) - the response extrapolated to time t = 0 and depth d = o

$\tau(t)$ - the time constant (ms) of the decay

$\tau(d)$ - the depth constant (m) of the decay

The results of the model study are summarized in this fashion in Table 1.

6

TABLE 1

LOOP SIZE 124 m

Model thickness	3.17 m			4.76 m			6.35 m			12.7 m		
	E(o,o)	τ(t)	τ(d)	E(o,o)	τ(t)	τ(d)	E(o,o)	τ(t)	τ(d)	E(o,o)	τ(t)	τ(d)
Model size (m) 30	4 350	0.29	23	3 000	0.34	24	2 770	0.48	25	4 700	0.44	25
50	12 100	0.5	25	9 160	0.68	24	6 130	0.9	25	7 140	0.9	24
80	22 500	0.9	24	24 200	1.14	22	16 900	1.45	23	11 500	1.75	24
LOOP SIZE 96 m												
30	9 300	0.27	19	4 380	0.34	17.5	5 800	0.45	18	4 390	0.51	19
50	21 700	0.5	19	15 000	0.7	17.5	9 770	0.9	18	10 500	0.95	17.[illegible]
80	35 700	0.9	17.6	29 400	1.2	17.5	22 800	1.5	17.5	17 500	1.7	18

The following trends are evident from the above table and from Figure 3a:

(1) The transient decay time constant τ (t) is a function of the size of a model and is dependent of the depth of the model and the size of the loop.

(2) The fall-off of the response with depth, τ(d) is relatively constant for all sizes of the model, and depends only on the size of the loop. An equation describing this relation for the two loop sizes used is:

$$\tau(d) = L/5.3 \qquad ...(3)$$

where L is the loop diameter (loop size). Further work could be done with other loop sizes to determine the generality of the relation.

Although it is not clear at this stage if the factor 5.3 will vary with conductivity, this relation makes it possible to determine the depth to horizontal tabular conductors (of similar conductivity and size) if the depth of one of the conductors is known. The parameter τ(d) is independent of the dimension of the conductor. If the depth to one of the conductors is known, the value of E(o) can be obtained from equation (2) by measuring the response E(d) at a certain sample time. Then by substituting in the same equation the response over another anomaly at the same sample time a value of d can be obtained. Note that it is necessary for the two anomalies to have transient decays of similar shape.

Returning to the relation

$$\tau_0 = \mu \sigma Q \qquad ...(1)$$

and substituting values of τ_0 equal to 0.27 ms to 1.7 ms, $\mu = 4\pi \times 10^{-7}$ H/m, and $\sigma = 35$ S/m, Q ranges from 6.2 to 40 m^2 for the models studied. The vertical cross-sectional areas of the models ranged from 95 to 1016 m^2, and so it appears that there is no direct relation between Q and the product of the thickness (d) and length of side (l) of the models used. The fact that τ_0 varies both with thickness and size of the block indicates that Q is a function of both d and l.

Velikin & Bulgakov (1967) give the following values of Q for simple bodies:

Cylinder: $Q = a^2$; a = radius of cylinder

Sphere: $Q = a^2/\pi^2$; a = radius of sphere

Semi-infinite conducting plate: Q = dl; d = thickness, l has dimensions of length and is related to the size of the plate along dip and its location with respect to the loop; Q has the dimensions of area and may be considered as an effective cross-section of a body (Velikin & Bulgakov, 1967, p.18).

Thus, as in the case of a semi-infinite conducting plate, there is no simple relation describing Q for a horizontal square plate.

3. CONCLUSIONS

From the two models studied, relations were evolved which should be of assistance in the interpretation of field surveys.

The dual-loop configuration may be useful in the search for thin dipping conductors because the peak of the anomaly is located directly over the top of the conductor, provided that the angle of dip is greater than 10°. A graph has been drawn in which the dip can be obtained from the ratio of the largest peak to the second largest peak.

The model study of horizontal tabular bodies resulted in three main conclusions:

8

(1) The relation $\tau_0 = \mu\sigma Q$ does not hold for the horizontal, square models studied, although τ_0 is independent of the loop size and depth of the model and in general increases with the size of the model.

(2) The transient decay curve is a simple expontial one, with a time constant $\tau(t) = \tau_0$ which is a function only of the size of the model.

(3) The fall-off of the response with depth is also exponential with a decay constant $\tau(d)$. $\tau(d)$ depends only on the size of the loop and is independent of the size of the model. For the models studied and the two loop sizes used $\tau(d)$ can be described by:

$\tau(d) = L/5.3$ where L is the loop diameter.

The relation makes it possible to determine the depth of any conductor if the depth to another of similar size and conductivity is known. Conductors of similar size will have a decay curve of the same shape (equal values of $\tau(t)$. Further work should be done to establish whether the factor 5.3 varies with conductivity, and whether it holds for other loop sizes.

4. REFERENCES

HONE, I.G., & SPIES, B.R., - Transient electromagnetic field tests, NT & Qld, 1973. _Bur. Miner. Resour. Aust. Rec._ (in prep.)

SPIES, B.R., 1974 - Transient electromagnetic model studies, 1973. _Bur. Miner. Resour. Aust. Rec._ 1974/152 (unpubl.).

VELIKIN, A.B., & BULGAKOV, Yu, I., 1967 - Transient method of electrical prospecting (one loop version). Seminar on geophysical methods of prospecting for ore minerals. UNO, Moscow, July 1967.

APPENDIX

Time constant of the TEM decay.

An exponentially decaying quantity can be expressed as

$a = Ae^{-t/\tau}$

Where

a = instantaneous value

A = initial value

t = time

τ = time constant of the decay.

In logarithmic form the equation is $\ln a = -\frac{t}{\tau} + \ln A$, which is the equation for a straight line with negative slope of $1/\tau$

The transient decay curve is generally not of simple exponential decay form but rather a sum of exponential decays and has a time constant $\tau(t)$, which varies with time. When a sufficiently large time has elapsed from the start of the transient decay, $\tau(t)$ becomes constant and is denoted by τ_o .

Record No. 1975/44

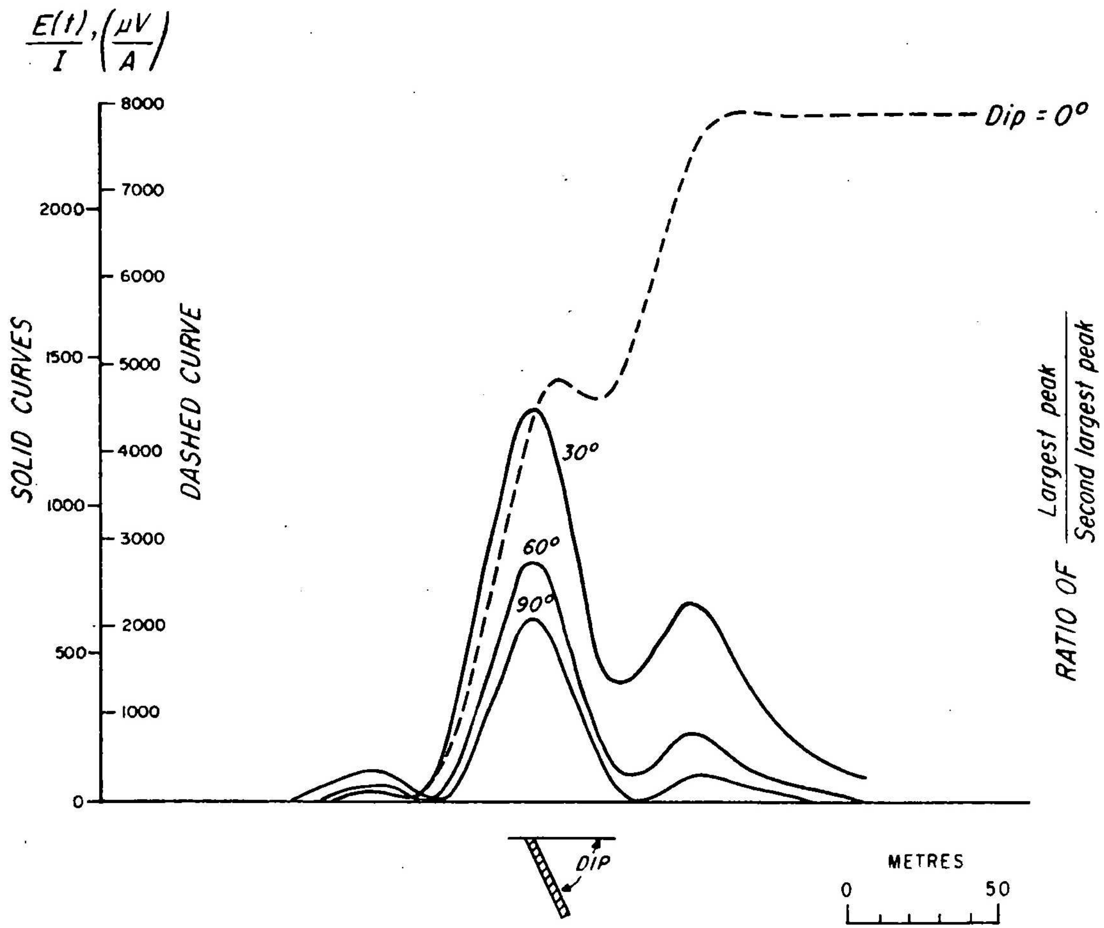

Fig. 1 DUAL LOOP: $\frac{E(t)}{I}$ PROFILES OVER A THIN DIPPING PLATE, 50m loop t = 1·1 ms

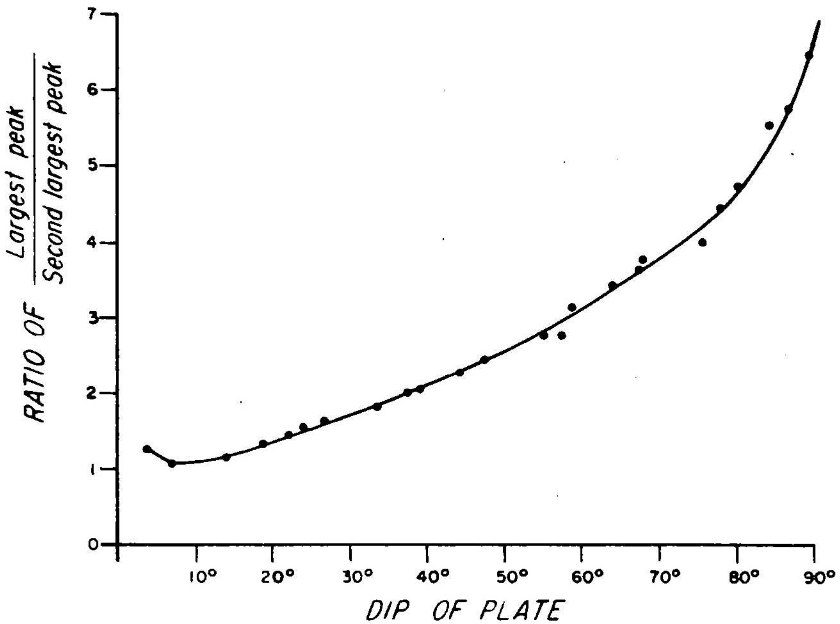

Fig. 2 DUAL LOOP: RATIO OF PEAKS VERSUS DIP OF PLATE

G29-220A

Fig. 3a TRANSIENT DECAY CURVES OVER A HORIZONTAL PLATE

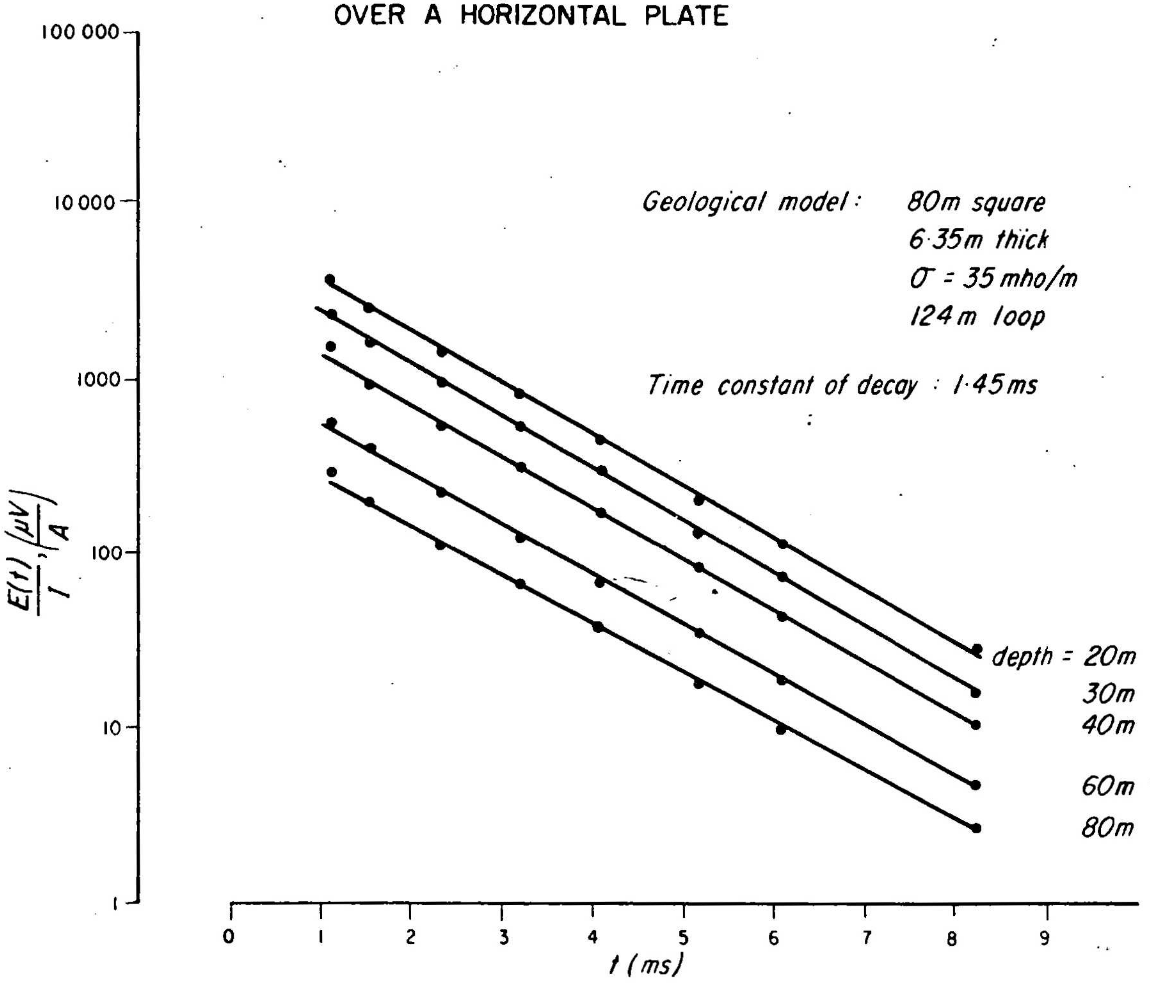

Fig. 3b $\frac{E(d)}{I}$ VERSUS DEPTH FOR t=2ms