~~Restricted until after publication~~
~~Manuscript submitted for publication~~
to: GEOPHYSICS

DEPARTMENT OF MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

014130

BUREAU OF MINERAL RESOURCES LIBRARY COPY 3 CANBERRA, A.C.T.

RECORD 1974/126

THE DUAL LOOP CONFIGURATION OF THE TRANSIENT ELECTROMAGNETIC METHOD

by

BRIAN R. SPIES

The information contained in this report has been obtained by the Department of Minerals and Energy as part of the policy of the Australian Government to assist in the exploration and development of mineral resources. It may not be published in any form or used in a company prospectus or statement without the permission in writing of the Director, Bureau of Mineral Resources, Geology and Geophysics.

BMR Record 1974/126 c.3

Record 1974/126

THE DUAL LOOP CONFIGURATION OF THE TRANSIENT ELECTROMAGNETIC METHOD

by

Brian R. Spies*

* Bureau of Mineral Resources, Geology & Geophysics, Australia. (presently on study leave at School of Earth Sciences, Macquarie University, Sydney).

** Published with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics.

ABSTRACT

The transient electromagnetic method offers considerable advantages over conventional electromagnetic systems which make the method attractive under typical Australian conditions of conductive overburden. Most transient electromagnetic ground systems utilize a horizontal loop which is strongly coupled to horizontal conductors. By means of scale model studies and a field example it is shown that a dual loop configuration provides optimum detectability of a vertical or steeply dipping conductor. In addition, the dual loop configuration reduces the problem of electrical interference.

INTRODUCTION

Electromagnetic (EM) methods have been used in mineral exploration for more than fifty years and have been particularly successful in the search for sulphide ore deposits. Most of the systems operate in the frequency domain, involving continuous transmission at a fixed frequency. A more recent development is that of time domain electromagnetic systems, in which pulses are transmitted and the transient decay of any resultant secondary field is recorded during the interval between pulses. The name commonly applied to such systems is transient EM.

The concept of using electromagnetic transient signals in prospecting for highly conductive orebodies was proposed by Wait (1951). Since that time, Russian researchers have been particularly active in the development and application of the method (Velikin & Bulgakov, 1967). In addition, much success has been achieved with an airborne version of the method known as INPUT[(R)] (Boniwell, 1967).

Electromagnetic methods in general have met with varied success in Australia; intensely weathered conductive near-surface rocks and saline water commonly cause difficulties in producing and recording a significant response from an underlying conductor.

The transient electromagnetic (TEM) method offers a means of overcoming this problem and has been used in Australia for a number of years. The INPUT system was first flown in Queensland in 1964 and has since been used in other parts of Australia. The first Russian-built ground transient electromagnetic system was used in Australia in 1970, and several such systems are in operation at present. Examples of case histories and scale model studies using the Russian-built MPPO-1 equipment, which is normally used with a combined transmitting and receiving loop, have been given by Spies (1974). This paper presents field results and scale model studies of an alternative loop configuration using the MPPO-1 equipment.

BASIC THEORY OF THE TRANSIENT ELECTROMAGNETIC METHOD

Any transient electromagnetic system basically operates on the principle of inducing eddy currents in the ground and analysing their decay, to provide information on subsurface conductors. The changing current in the transmitting loop generates a magnetic field in the surrounding environment which in turn induces electric fields and resultant eddy currents in any nearby conductors.

(R) Registered tradename of Barringer Research.

These electric fields depend on the conductivity, shape, and size of the conductor, and on its position with respect to the loop. After their initial establishment, the eddy currents in the conductor tend to diffuse inwards towards the centre of the body, being gradually dissipated as resistive heat losses. With a highly conducting body, the currents tend to circulate on the boundary of the body and to decay more slowly.

The decaying eddy currents produce a secondary magnetic field, which decays within a relatively short time depending on the physical and geometrical properties of the conductor. The receiving coil obtains an output voltage proportional to the time derivative (rate of decay) of the vertical component of the secondary field. In general, the resistivities encountered in the field produce transient decays lasting from a fraction of a millisecond to 10 or 20 milliseconds.

Analysis of the shape of the received transient waveform is equivalent to measuring the response at a number of frequencies for a harmonically varying source. Although the transient curve involves the whole frequency spectrum, different elements contain differing proportions of high- and low-frequency components. Morrison, Phillips & O'Brien (1969) point out that at early times the response is due to both low- and high-frequency groups whereas at later times only the low-frequency response remains and that this hypothesis, coupled with the fact that skin depth varies inversely as the square root of the frequency, suggests that the early part of the transient is governed by rapid decay at shallow depths, whilst the later part of the response is due to lower-frequency energy which has penetrated to greater depths. This result has been verified by model studies by Velikin & Bulgakov (1967) and proved theoretically by Wait (1956), Negi & Verma (1972), and others.

SCALE MODELLING RELATIONS

A description of the general theory of scaling electromagnetic models is given by Frischknecht (1971). It is sufficient to state here that the requirements for similitude between a field (full-scale) situation and a laboratory model are:

$$\sigma_m \mu_m \omega_m L_m^2 = \sigma_f \mu_f \omega_f L_f^2$$

where the subscript f indicates a quantity measured in the field situation and the subscript m indicates a quantity measured in the model, and:

σ = conductivity (S/m)

μ = magnetic permeability (H/m)

ω = 2π frequency (Hz)

L = linear dimensions (m)

The magnetic permeability is assumed to be that of free space for both the field situation and the model. For a time domain system the time T can be substituted for $\frac{1}{\omega}$. The parameter T was not scaled in the model studies described in this paper.

Thus the modelling relation is reduced to

$$\frac{\sigma m}{\sigma f} = \frac{Lf^2}{Lm^2}$$

Measurements were made using the standard field equipment, and models consisted of aluminium in air. Results have been normalized according to the relation:

$$\frac{e(t)}{I} = \frac{e(t)m}{Im} \times \frac{S.F.}{2500} \quad \text{microvolts/amp}$$

where e(t) is the reading in microvolts at sample time t after primary current cutoff.

Im is the current flowing in the model loop, in amps

S.F. is the scaling factor.

THE DUAL LOOP SYSTEM

The conventional horizontal loop used in the TEM method is maximally coupled to horizontal conductors as shown in Figure 1. However, many ore deposits are dyke-like and dip steeply; for these, it is preferable to use a loop geometry that will provide maximum coupling with vertical conductors and minimum coupling with shallow horizontal conductors. Vertical loops give optimum coupling with vertical conductors but are impracticable to use in the field.

An alternative coil configuration involves a dual loop system. In this, two adjoining loops are connected in parallel as shown in Figure 1 such that the current flow through the two adjoining centre wires is in the same direction, producing a strong local horizontal magnetic field.

A comparison of the energizing primary magnetic field produced by the single and the dual loop coil configurations is also shown in Figure 1. The lines of magnetic flux are not influenced by the presence of underlying conductors if a constant primary current is considered. This will be the case for a transient electromagnetic system if the energizing current pulse is long enough for the magnetic field to become stable. At the instant when the primary current is cut off, the primary field vanishes, and the lines of magnetic flux present in the conductor will 'collapse', causing eddy currents to flow. These time-varying eddy currents will in turn produce time-varying secondary magnetic fields which are sensed by the receiving loop.

Thus, by examination of the flux linkage provided by a particular loop/conductor geometry it is possible to predict the expected response from a conductor. By referring to Figure 1 it can be seen that if a thin vertical plate is at the centre of the single loop, the flux linkage is nil, which explains why the TEM response is zero directly over the plate irrespective of depth to the top (Velikin & Bulgakov, 1967, pp. 16-17). With the dual loop system, on the other hand, there is a strong horizontal field at the centre of the coil configuration which has maximum coupling with a vertical conductor.

To test the relative merits of the single and dual loop systems in an environment involving conductive overburden, a model (shown in Fig. 2) was set up with a vertical conductor of 20 S/m conductivity overlain by a horizontal conducting sheet. The sheet had a conductivity-thickness product of 16 Siemens, and could thus simulate a layer 16 m thick with 1 S/m conductivity. Such a sheet would effectively mask any response from a deeper body for most EM methods. Profiles recorded from both configurations are presented in Figure 2. The profiles for the single loop system show that for early sample times after primary current cut off the response is primarily due to the horizontal sheet, and only at later sample times can the response of the underlying conductor be resolved as a two-peak anomaly, the peaks being about twice the amplitude of background values at t = 10.1 ms.

The profiles for the dual loop system show that this coil configuration is more loosely coupled to the horizontal sheet, the response at 1.1 ms being only onefifth of that recorded with the single loop. At later sample times the effect of the underlying vertical plate is clearly recognized; at 10.1 ms the response is effectively due only to the deeper conductor. The peak of the anomaly at 10.1 ms has an amplitude well above background values.

To test the relative merits of the two loop configurations a field test was conducted at Dobbyn, 115 km north-northeast of Mount Isa in northwestern Queensland. The area contains steeply dipping sulphide lodes in metamorphosed rhyolite and dolerite. The results of a TEM survey using 100 m, 50 m, and 25 m loops over one such mineralized zone are shown in Figure 3 for both single and dual loop configurations. The profile shape for a single loop has two maxima separated by a distance equal to the loop size. The dip of the body can be computed from the ratio of the amplitude of the larger peak to the smaller peak by the relation:

$$\frac{e(t)\ \mathrm{Max}_1}{e(t)\ \mathrm{Max}_s} = e^{2.7\emptyset} \quad \text{(Velikin \& Bulgakov, 1967)}$$

where $\emptyset$ is the angle between the plane of the plate and the vertical,

$e(t)\ \max_1$ is the amplitude of the larger peak,

$e(t)\ \max_s$ is the amplitude of the smaller peak.

Substituting in values from the profiles, $\emptyset = 20^\circ$ (dip = 70°) for both 100 m and 50 m loop sizes. This agrees with a dip value of 80° estimated from drilling results (Fig. 3).

On the profiles for the dual loop configuration the main peak occurs directly over the top of the body, with smaller peaks either side, and corresponds in position to the Turam anomaly. The larger of the two minor peaks is located on the down-dip side of the conductor. The field results agree with the profiles expected from model studies for a thin conducting plate dipping at 70°.

An important advantage in using the dual loop configuration is the inherent noise rejection. One of the main difficulties in using TEM is electrical interference. However, many noise sources (such as power lines) produce coherent noise, which can be effectively cancelled by a dual loop system.

Thus, advantages in the dual loop system are:

(1) Reduction of electrical interference whose phase is identical in the two loops.

(2) A peak occurs directly over the top of the conductor instead of being displaced to the side.

Disadvantages are:

(1) Electrical interference from impulse sources, e.g. wind moving the loop wire, may be increased.

(2) Areal coverage is reduced because of the extra time needed to lay out a dual loop.

CONCLUSIONS

The transient electromagnetic method offers considerable advantages over conventional electromagnetic methods. Most TEM ground systems employ a horizontal loop which is strongly coupled to horizontal conductors. It has been demonstrated by scale model studies and a field example that the dual loop configuration provides advantages when the target is a steeply dipping conductor. In addition, use of a dual loop reduces some troublesome electrical interference.

ACKNOWLEDGEMENTS

I wish to thank the Director of the Bureau of Mineral Resources for permission to publish this paper. The possibility of using a dual loop configuration was first pointed out to me by Professor L.V. Hawkins.

REFERENCES

BONIWELL, J.B., 1967 - Some recent results with the Input airborne EM system: Canad. Min. Metallurg. Bull., v. 60, p. 325-332.

FRISCHKNECHT, F.C., 1971 - Electromagnetic scale modelling, in: Electromagnetic probing in geophysics (Wait., J.R. ed.): Boulder, Golem Press.

MORRISON, H.F., PHILLIPS, R.J., and O'BRIEN, D.P., 1969 - Quantitative interpretation of transient electromagnetic fields over a layered half space: Geophys. Prosp., v. 17, p. 82 - 101.

NEGI, J.G., and VERMA, S.K., 1972 - Time domain electromagnetic response of a shielded conductor: Geophys. Prosp., v. 20, p. 901-909.

SPIES, B.R., 1974 - Experience with the transient electromagnetic method in Australia: Bur. Miner. Resour. Aust. Report (in prep.).

VELIKIN, A.B., and BULGAKOV, J.I., 1967 - Transient method of electrical prospecting (one-loop version): International seminar on geophysical methods of prospecting for ore minerals. Moscow, 1967.

WAIT, J.R., 1951 - A conducting sphere in a time varying magnetic field: Geophysics, v. 16, p. 666-672.

WAIT, J.R., 1956 - Shielding of a transient electromagnetic dipole field by a conducting sheet: Canad. Jour. of Physics, v. 34, p. 890-893.

Fig. 1

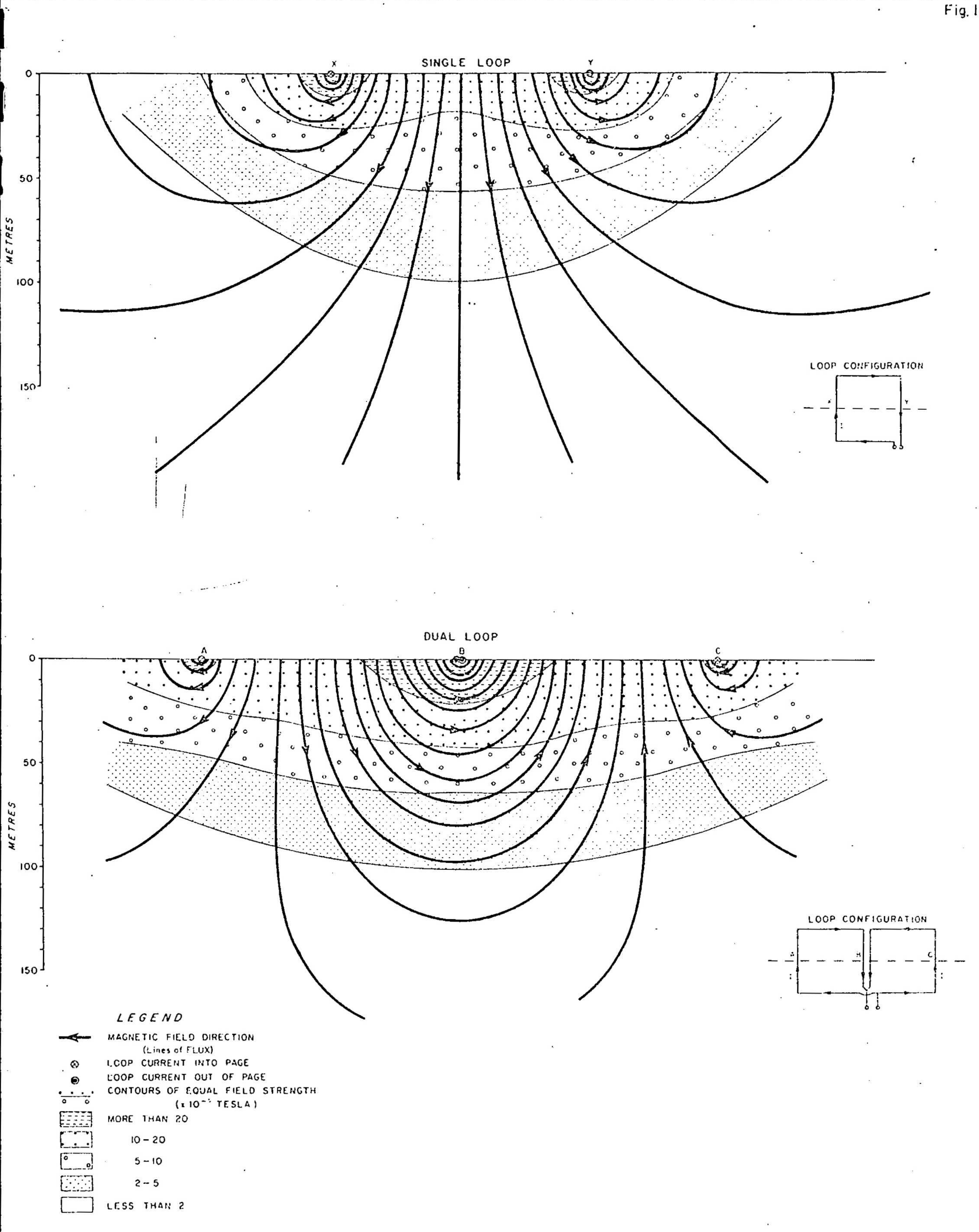
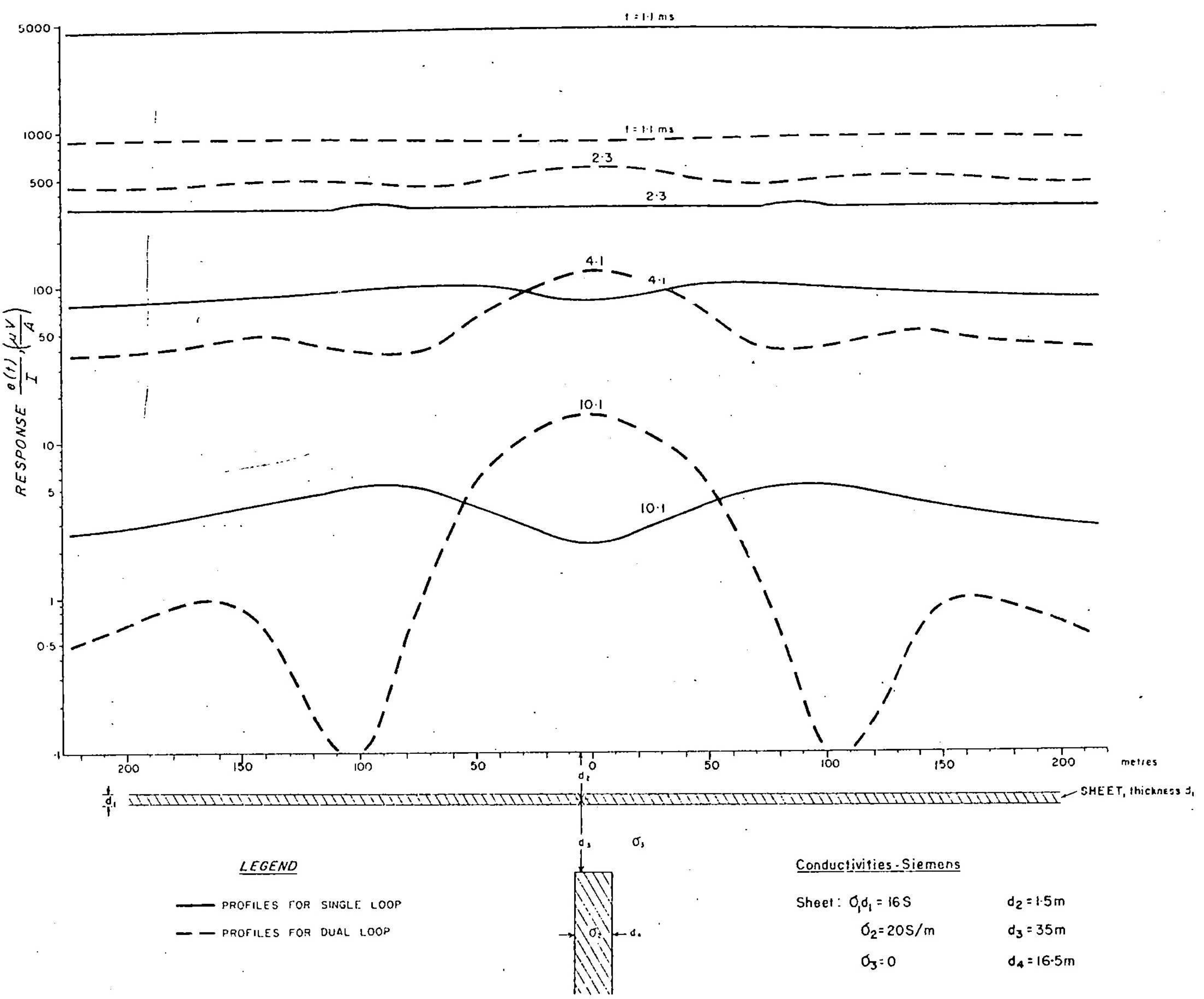

SINGLE LOOP
X
Y
0
50
100
150
METRES
LOOP CONFIGURATION
DUAL LOOP
A
B
C
0
50
100
150
METRES
LOOP CONFIGURATION
LEGEND
MAGNETIC FIELD DIRECTION
(Lines of FLUX)
LOOP CURRENT INTO PAGE
LOOP CURRENT OUT OF PAGE
CONTOURS OF EQUAL FIELD STRENGTH
(x 10⁻⁹ TESLA)
MORE THAN 20
10 - 20
5 - 10
2 - 5
LESS THAN 2

Fig 2



Record No. 1974/126

G29–213–1A

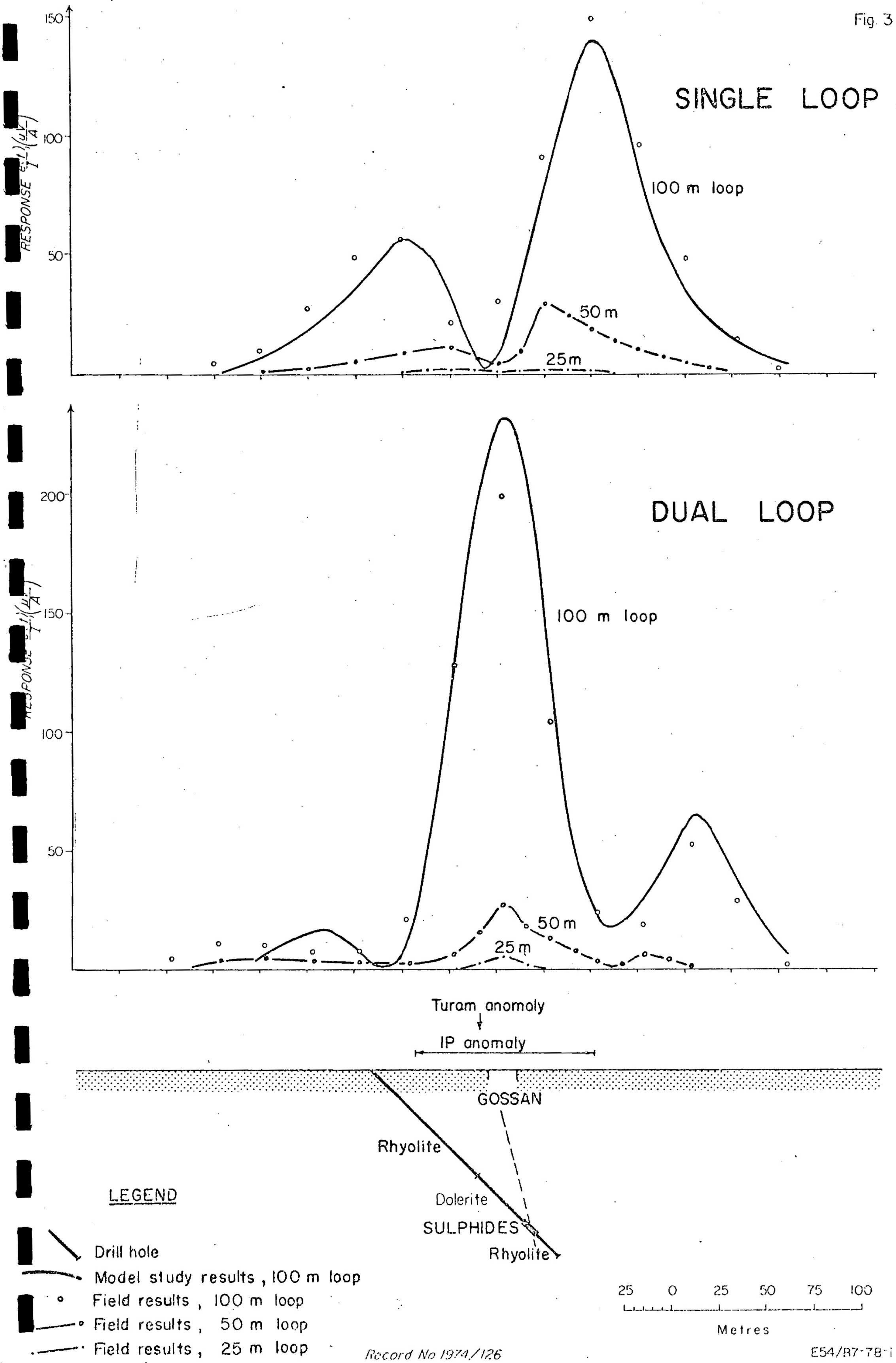


Fig. 3
SINGLE LOOP
RESPONSE
150
100
50
100 m loop
50 m
25 m
DUAL LOOP
200
150
100
50
100 m loop
50 m
25 m
Turam anomaly
IP anomaly
GOSSAN
Rhyolite
Dolerite
SULPHIDES
Rhyolite
LEGEND
Drill hole
Model study results, 100 m loop
Field results, 100 m loop
Field results, 50 m loop
Field results, 25 m loop
25 0 25 50 75 100
Metres

E54/B7-78-1