A PRACTICAL APPLICATION AND EVALUATION OF THE DPM-2 ELECTROMAGNETIC METHOD

A Thesis

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by

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ABSTRACT

DPM-2 designates an electromagnetic method used in mineral exploration. The source is either a large loop or long grounded wire. The receiver measures the dip and axes-ratio of the field ellipse.

The test site is in Precambrian terrain located in southeast Manitoba and contains multiple steeply dipping shallow conductors. Measurements were made over the area using DPM-2, VLF, and Vertical Coil equipment. The results show the DPM-2 method to be an effective exploration tool.

ACKNOWLEDGEMENTS

The writer wishes to express his sincere thanks to Dr. C.D. Anderson of the Department of Earth Sciences for his direction, suggestions, and assistance during the course of his M.Sc. studies and thesis work.

Thanks are also due to Central Geophysics Ltd. of Winnipeg, Manitoba for the use of the DPM-2 and Vertical Loop instruments.

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CHAPTER I

INTRODUCTION

The DPM-2 electromagnetic system measures the characteristics of a time-varying electromagnetic field ellipse resulting from the combination of a generated source field and the induced secondary fields from conductors in the ground. The source field is usually generated by a long grounded wire several thousand feet in length or by a large rectangular wire loop, several thousand feet to each side. The long grounded wire gives both a conductive and inductive response, while the large wire loop gives only an inductive response associated with its field. The DPM system has been described in detail by Anderson and Sutherland (1971).

The thesis area is located in the Whiteshell Park approximately 100 miles east of the city of Winnipeg immediately west of the intersection of Highway No. 44 and the Howe Bay Road (Figures 1 and 2).

From previous work in the area using VLF-EM and magnetic methods, two conductive zones were found that ran parallel on either side of an elongated swamp (Figures 2 and 3). This site is a good location for testing the DPM-2

Figure 1. Location map of the work area near the Manitoba-Ontario border.

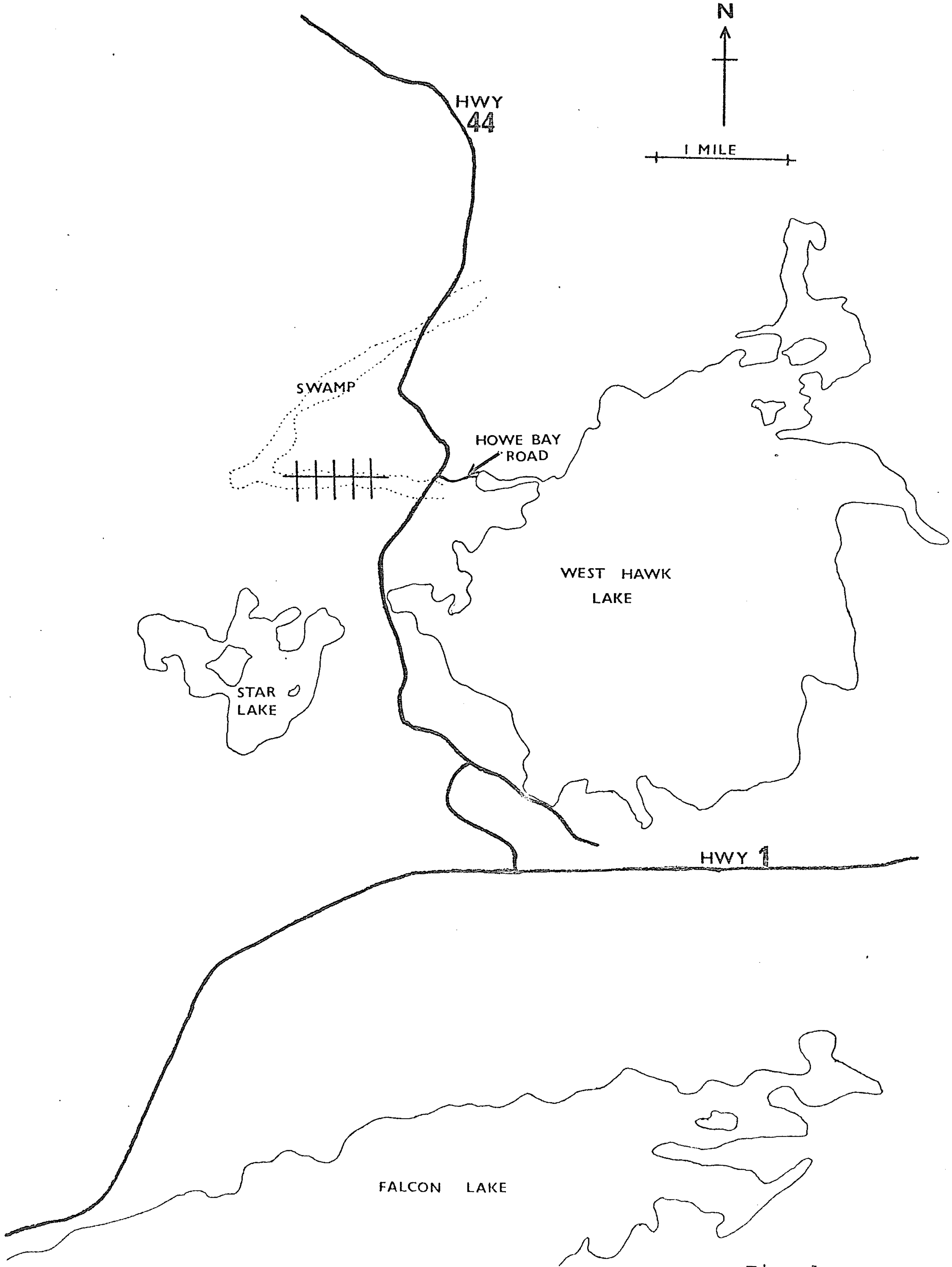
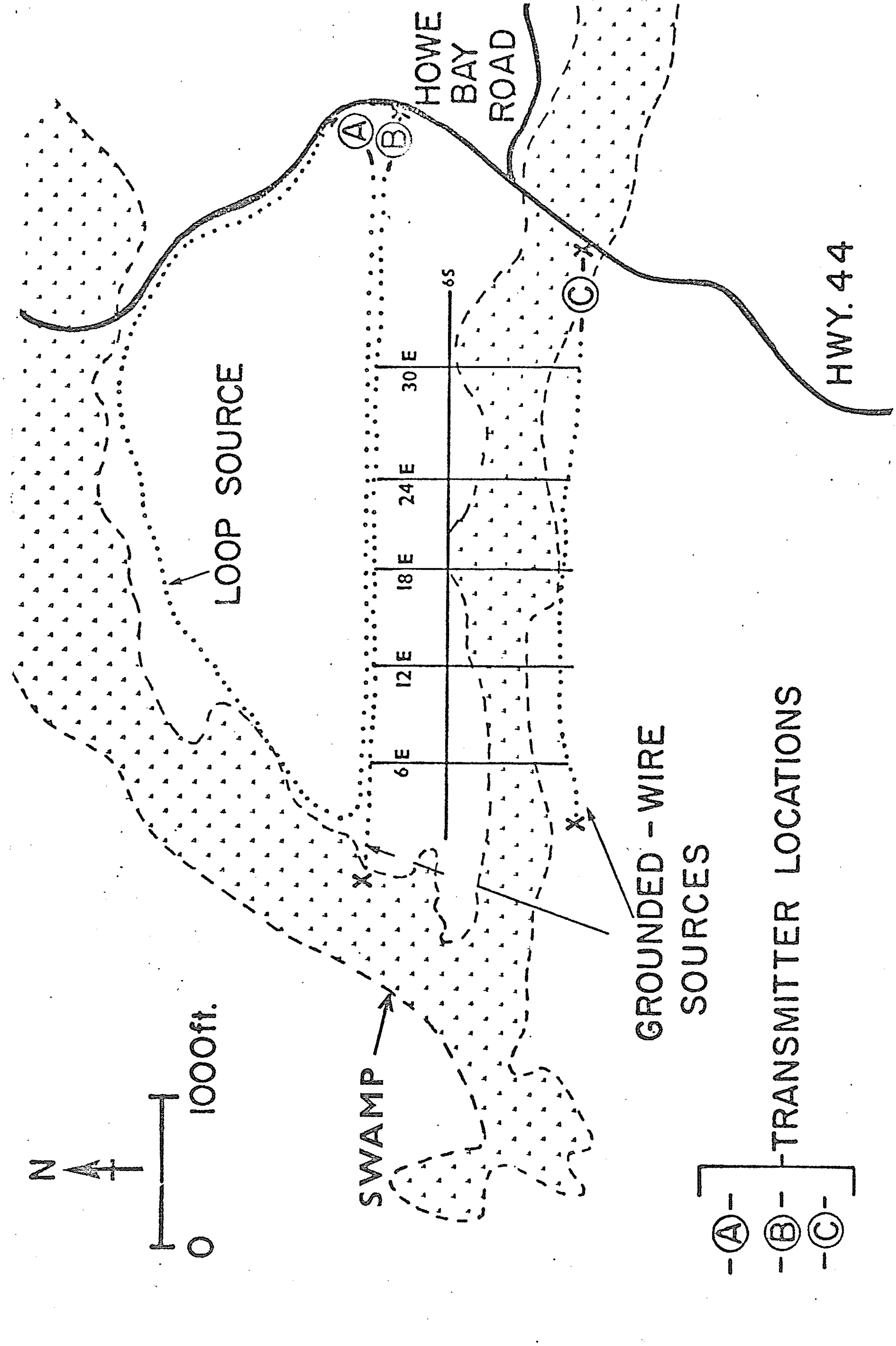

N
I MILE
HWY
44
SWAMP
HOWE BAY
ROAD
WEST HAWK
LAKE
STAR
LAKE
HWY 1
FALCON LAKE

Fig. 1

Figure 2.   Line and transmitter locations.



HOWE BAY ROAD
HWY. 44
LOOP SOURCE
GROUNDED - WIRE SOURCES
TRANSMITTER LOCATIONS
SWAMP
1000ft.
0
N
A
B
C
6E
12E
18E
24E
30E
6S

Fig. 2

Figure 3. (a) A simplified cross-section model of the area.
(b) and (c) Proposed sub-surface models.

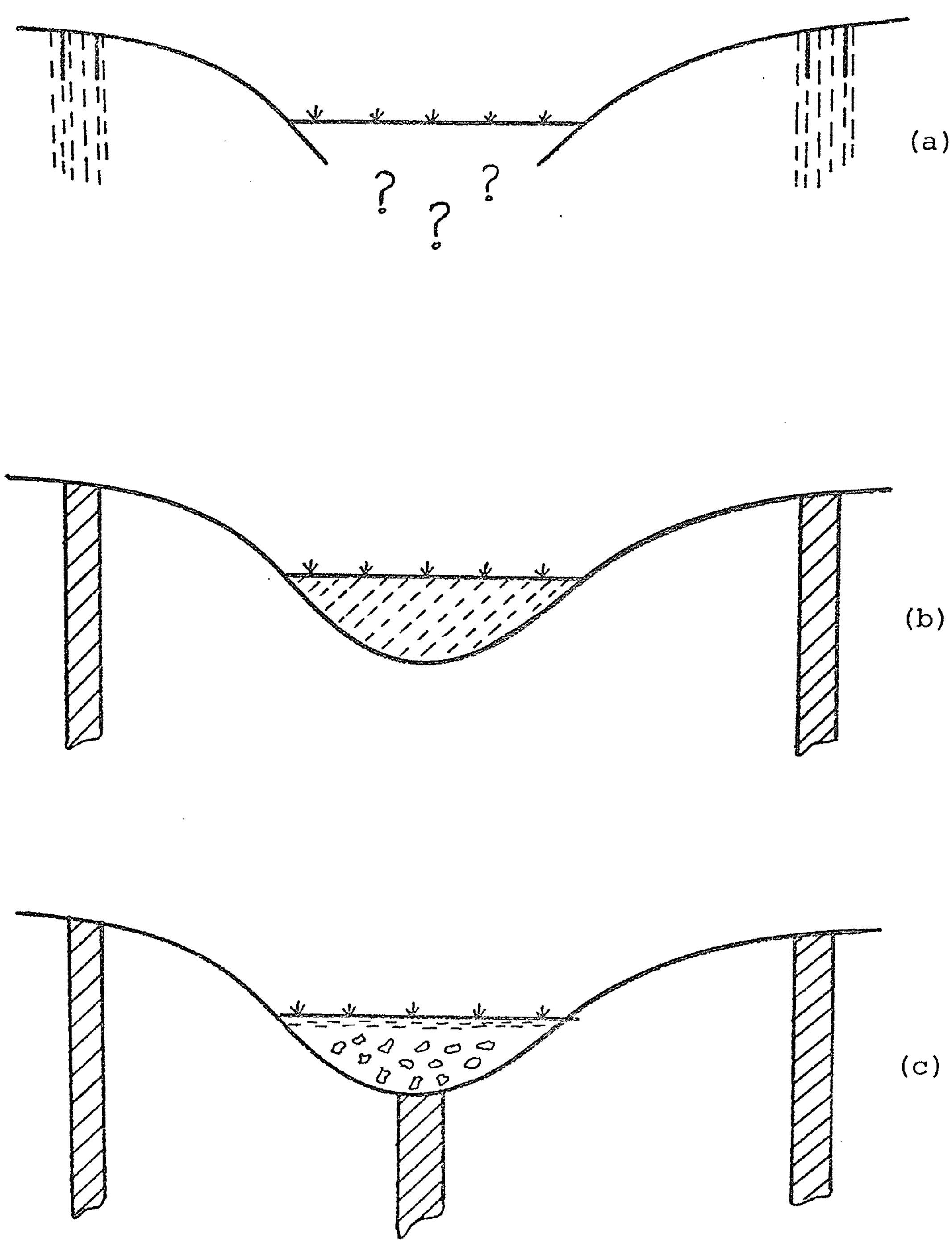


Fig. 3

response over a known conductor very near a swamp.

To gain more information on the conductor and swamp properties, a complete survey over a series of grid lines (Figure 2) was made using the VLF (EM-16), magnetometer, and the vertical loop instruments. With this information, a comparison has been made to the DPM-2 results. A simplified model of the area is given in Figure 3a.

CHAPTER II

PURPOSE

Objectives

The primary objectives of this thesis work are to:

(1) measure and compare the DPM-2 responses over the conductors at two frequencies and using three source configurations,

(2) compare the results of the DPM-2 measurements to the results from other EM methods, and

(3) determine the most probable subsurface model for the area (see Figures 3b and 3c).

Approach

The geophysical measurements were made along the grid lines shown in Figures 1 and 2. The line spacing is 600 ft. The station interval along the lines was 50 ft. for the EM measurements and 25 ft. for the magnetic measurements.

The DPM-2 source configurations are shown in Figure 2 and labelled A, B, and C. A large loop source (A) and two grounded wire sources (B and C) were used. The DPM frequencies are 150 Hz and 510 Hz.

The vertical loop instrument operates at a frequency of 1000 Hz and was used in the Broadside mode. Coil separation was 300 ft. with the transmitting coil on the grid lines and the receiving coil 300 ft. to the east.

The VLF instrument was a Geonics EM-16 and the station used for the measurements was Kidd Creek, Washington which operates at a frequency of 18.6 kHz.

A vertical-component fluxgate magnetometer was used for the magnetic measurements.

CHAPTER III

GENERAL GEOLOGY

The following discussion is based on work by Davies (1953), and observations by the author.

The rocks of the area are comprised of an Archean belt in the Canadian Shield and are overlain by numerous lakes and swamps. The area is thickly wooded. The northern portion is comprised of predominantly mixed Keewatin rocks of andesitic and granodioritic composition intruded by pegmatitic material. The major portion of the area to the south consists of clastic sedimentary and related rocks also of Keewatin age (see Figure 4). The volcanic and sedimentary units generally show an easterly strike and dip steeply to the south.

Sulphide mineralization is found in steeply dipping shear zones trending east-west in the thesis area.

The basic mineralization of the sulphide zones is pyrite and pyrrhotite, with minor amounts of chalcopyrite. The results of a lateral survey, estimating the amounts of the predominant conductive minerals over a sixty foot interval along Highway No. 44 of the northern conductive zone, are summarized in Table 1.

Figure 4. The basic rock units within the area (After Davies, 1953) are:

(1) Grey gneissic granite
(2) Mixed Keewatin rocks and pegmatite
(3) Basic tuff
(4) Clastic sedimentary and related rocks.

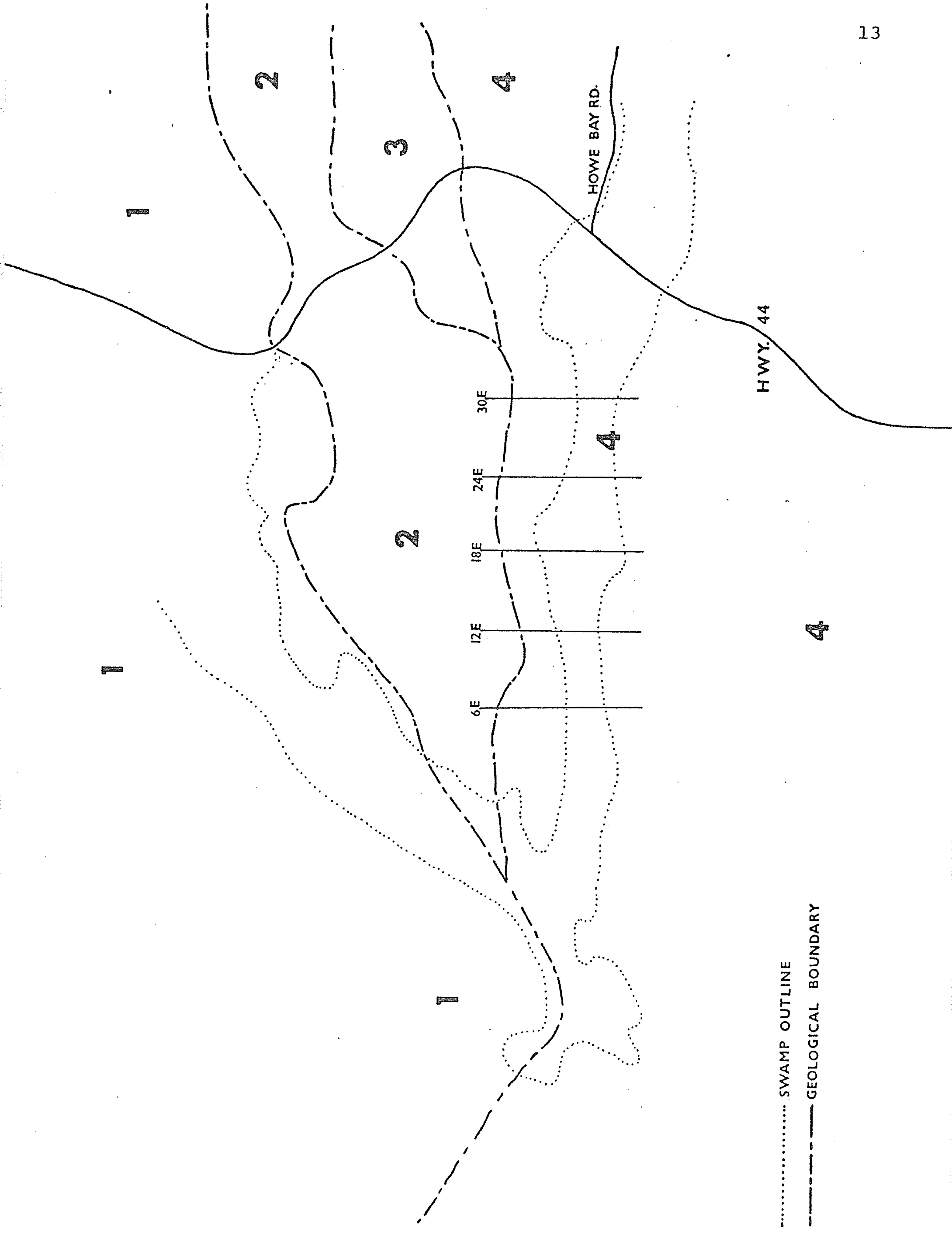

1
2
3
4
HOWE BAY RD.
HWY. 44
30E
24E
18E
12E
6E
SWAMP OUTLINE
GEOLOGICAL BOUNDARY

Fig. 4

TABLE I

Geological Sampling Results of

the Mineralized Conductor

	Ft. x 5	Pyrrhotite (%)	Pyrite (%)
	6	0.5	0.5
	5	0	1
	4	0.5	1.5
	3	7	1
	2	5	1
	1	0	0
N/S	0	1	3
	1	11	2
	2	0.5	2
	3	1	1
	4	2	1
	5	1	5
	6	0.5	2

Topographic profiles of the area are shown in Figure 5. The profiles were obtained by relative inclinometer readings between line stations. A major shear zone exists around station 9.5 S through the area.

Figure 5. Topographic profiles along survey lines.

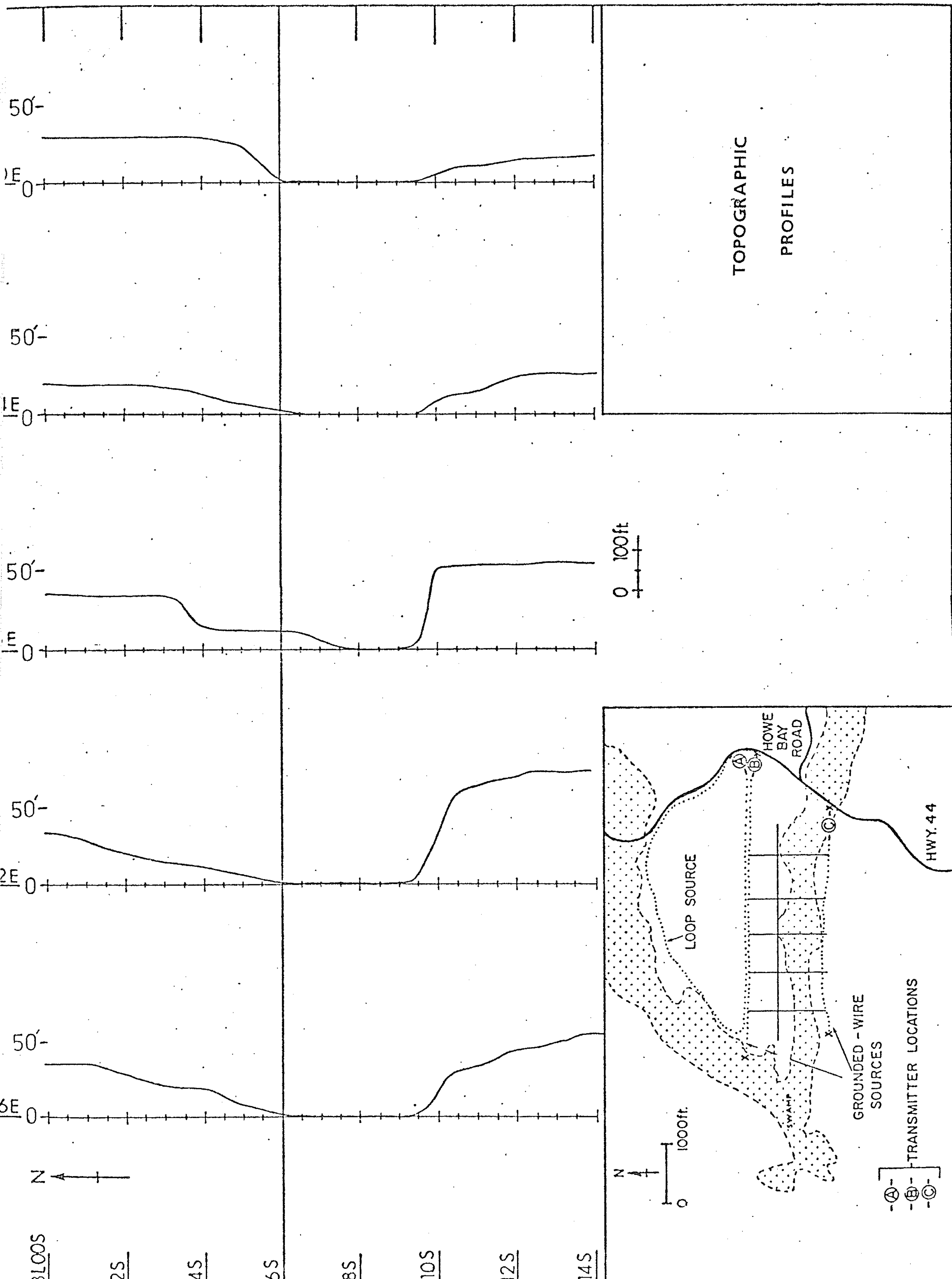

TOPOGRAPHIC
PROFILES
50'
0
0
100ft
HOWE
BAY
ROAD
HWY. 44
LOOP SOURCE
GROUNDED - WIRE
SOURCES
SWAMP
TRANSMITTER LOCATIONS
A
B
C
0
1000ft.
N
BL00S
2S
4S
6S
8S
10S
12S
14S
2E
6E

Fig. 5

CHAPTER IV

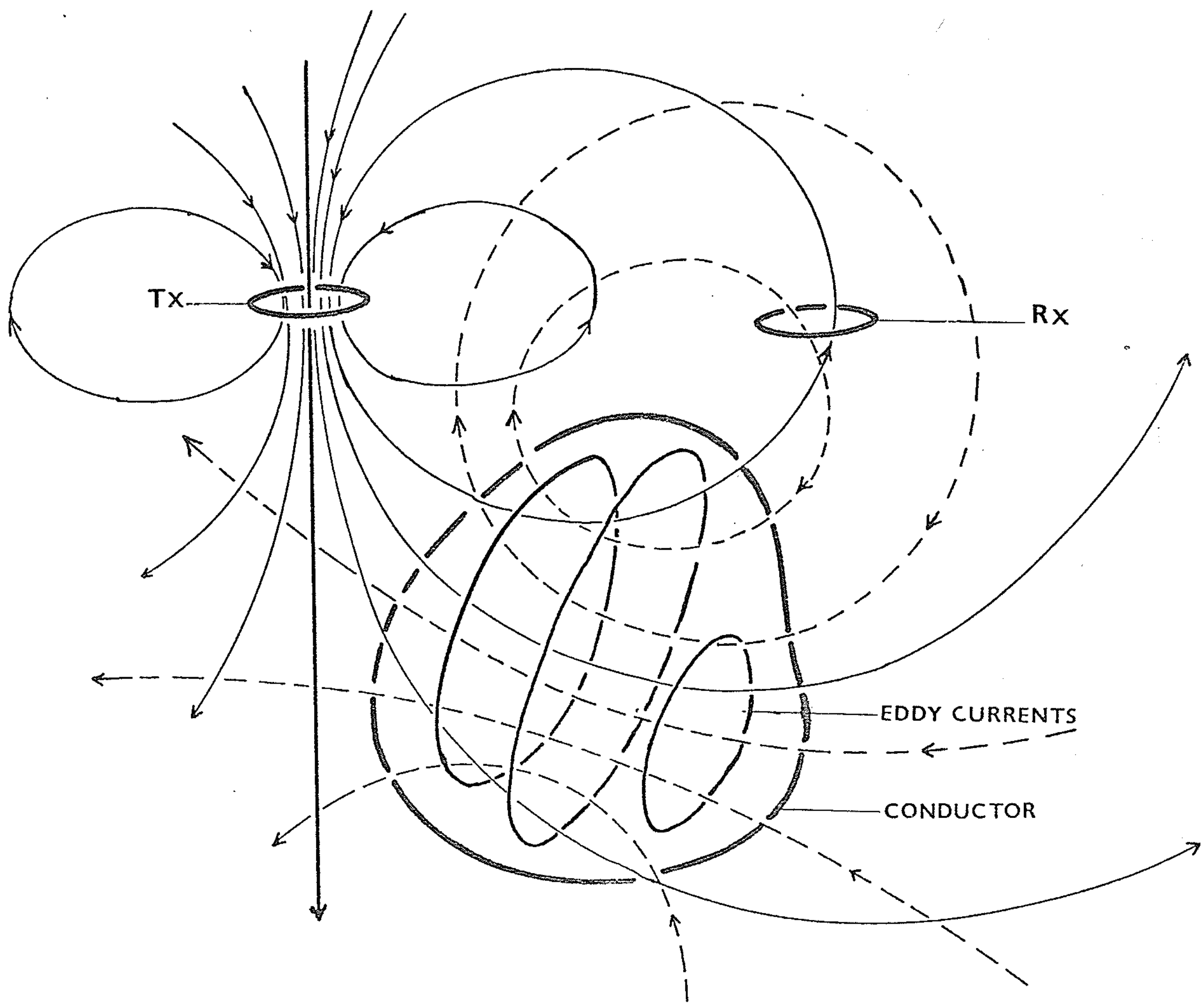
EM METHODS

Most electromagnetic-induction methods measure properties of a field resulting from the combination of a man-made primary field, and secondary fields from induced eddy currents in conductive zones in the ground (Figure 6). The source for the primary field is usually a coil or long-wire carrying A.C. current. A coil is used to detect the resulting field. The source-receiver separation is commonly a few hundred feet. A notable exception is the VLF method which utilizes the signals from radio transmitters several hundred miles away operating at very low frequencies (VLF) in the broadcast band.

There are methods that use naturally occurring electromagnetic fields but these were not used in this study. A discussion of these methods can be found in Grant and West (1965, Chapter 17).

The exploration targets for EM methods are zones of anomalously high electrical conductivity, most notably, massive sulphide deposits. Other geological conditions such as graphitic zones may give unwanted responses and must be separated from the massive sulphide responders by other

Figure 6. Electromagnetic Induction Principle
(After Grant and West, 1965)



PRIMARY FIELD ⟶

SECONDARY FIELD — — — — — — →

Tx .... TRANSMITTER COIL

Rx .... RECEIVER COIL

Fig. 6

means (Ward, S.H., 1966).

Electrical properties of massive sulphide deposits determine the frequency used for maximum response. The resistivity of sulphide minerals generally falls in the range of between 0 and 10 ohm-meters (Bosschart, 1964, Chapter 2). Figure 7 illustrates the secondary field components which are dependant on resistance and frequency. This was obtained from a simple case of a single wire loop which represents the essential details of more complicated cases where the resistivity parameter is proportional to conductivity-thickness product. Optimum inductive response would be attained if the relative scale of resistivity and frequency fall in the range between 0.5 and 5.

Given a resistivity value, the diagram in Figure 7 serves to illustrate the frequency range required to give an optimum response. For typical resistivity values associated with massive sulphide zones, the suitable frequency range is 100 to 5,000 Hz.

The operating frequencies of about 20,000 Hz for the VLF instruments are above this range and give rise to a greater number of unwanted responses (e.g. swamps, water-filled shear zones, etc.). The availability of the source field, however, makes the system inexpensive for use as a reconnaissance tool and, in some cases, it can be used as the primary method prior to drilling.

Figure 7. Real and imaginary components of the secondary field plotted in arbitrary units as a function of the parameter (resistence/frequency) (After Parasnis, 1966, p. 202).

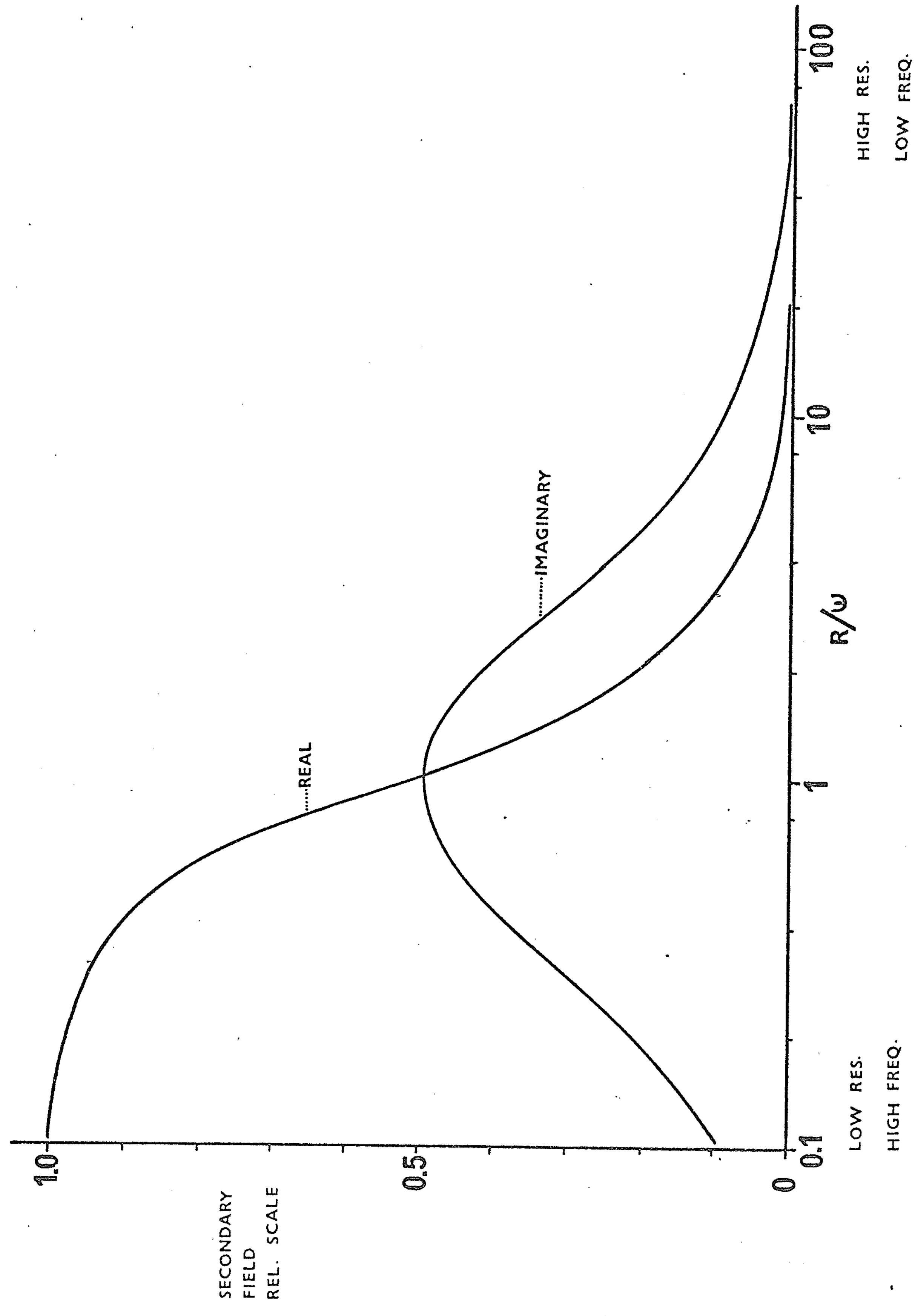

SECONDARY
FIELD
REL. SCALE
1.0
0.5
0
0.1
1
10
100
R/ω
REAL
IMAGINARY
LOW RES.
HIGH FREQ.
HIGH RES.
LOW FREQ.

Fig. 7

The skin depth is defined as that depth where the signal strength is $\frac{1}{e}$ (i.e. $\frac{1}{2.7183}$) of its surface value. This depth is also referred to as the maximum depth of exploration. Parasnis (1962) gives the formula for skin depth (d) as:

$$d = 503.8\left(\frac{R}{f}\right)^{\frac{1}{2}},$$

with d in meters, R in ohm-meters, and f in Hz.

A typical value of 10,000 ohm-meters for the rocks in the Canadian Shield and a frequency of 5,000 Hz gives a skin depth in excess of 1,500 ft. The factors of practical coil separation, target size, and geological noise limit the exploration depth to a value considerably less than this so that skin depth is not a significant factor in frequency selection.

With virtually every type of electromagnetic induction prospecting system, an alternating magnetic field is employed and, with a conductor present, a secondary field exists. Generally, the primary and secondary fields are not parallel in direction and differ both in magnitude and phase (Grant and West, Section 16.8). The result is an elliptical field.

The electromagnetic instruments are designed to detect certain properties of the field ellipse. The vertical loop, EM-6 (VLF), and DPM-2 systems used in this thesis all detect the dip of the major axis of the field ellipse. The EM-16 (VLF) and DPM-2 methods also detect the ellipticity or ratio of minor to major axis for its quadrature readings.

The vertical loop responds best to a horizontal dipole source. Any secondary fields will be reflected as vector additions to the primary to yield the resultant field ellipse.

The EM-16 (VLF) instrument, for comparison, uses essentially an infinite source. The VLF primary field is also horizontally polarized.

The DPM-2 differs mainly in the source of the primary field. It uses a linear source in the form of a long grounded wire or a large wire loop (Figure 2). The primary field direction changes in dip from the vertical with distance from the source cable and with conductivity of the half-space environment. An example of primary field fall-off is given in Figure 8, which shows the relative changes with superimposed secondary field effects from a conductor. This is shown in more detail in Figure 9 with three environment resistivities considered. Measurement of the ellipticity and inclination with the DPM-2 unit is achieved with a pair of orthogonal coils connected to a high-gain amplifier (Figure 10). The major difference instrumentally in using the two source configurations is that the large loop source has only inductive secondary

Figure 8. Shows the normal fall-off of the primary field from the transmitter wire, the secondary field, and the resultant field. The location of the conductive body is shown lying under the maximum gradient of the resultant field (After Parasnis, 1966).

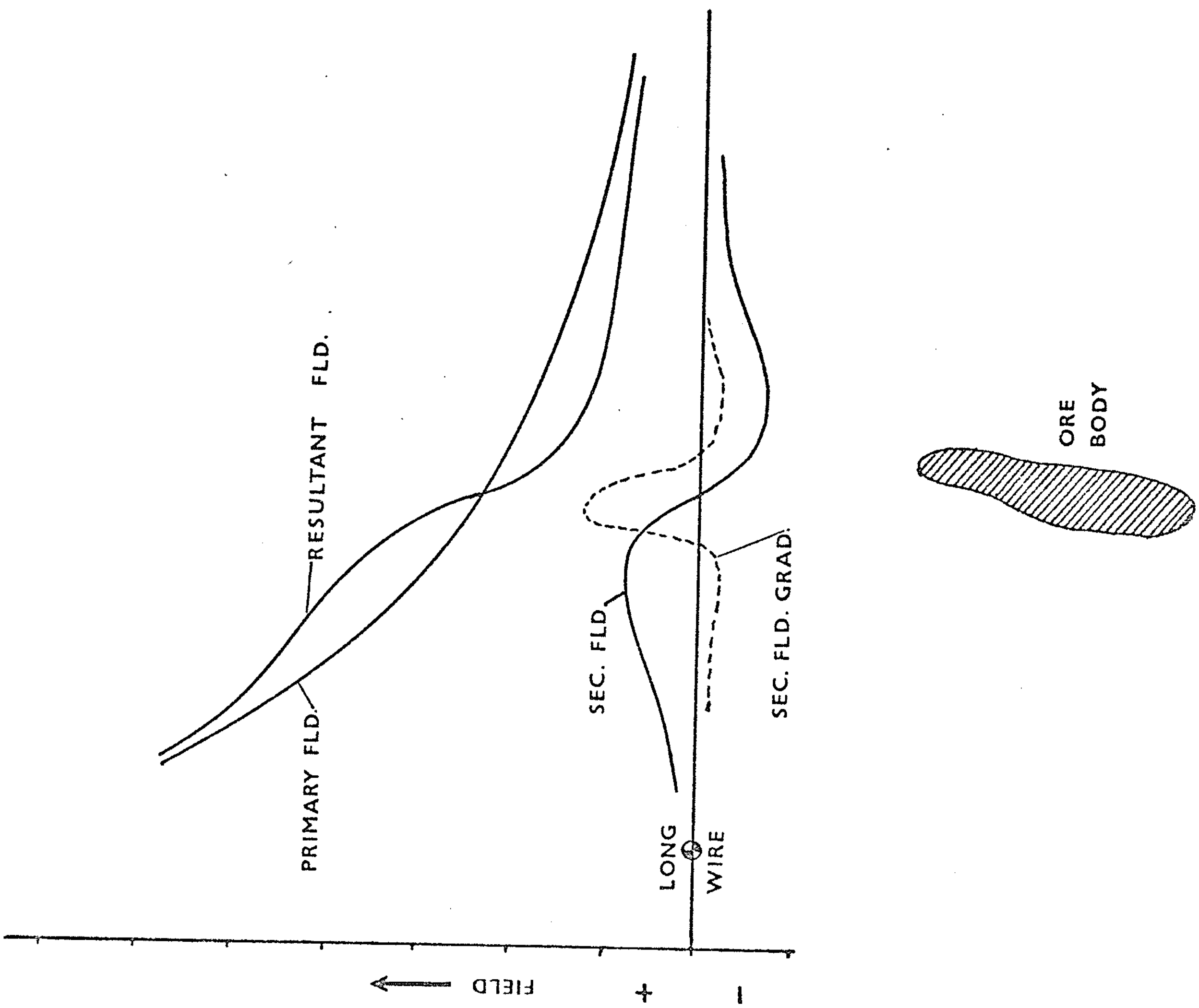

RESULTANT FLD.
PRIMARY FLD.
SEC. FLD.
SEC. FLD. GRAD.
LONG WIRE
ORE BODY
FIELD
+
-

Figure 9. The vector $H(\zeta)$ of an infinite straight cable as a function of distance for the resistivities 33, 100 and 1200 ohm-meters at 660 Hz. The figure shows the ellipticity and dropoff variation of the electromagnetic fields with distance from the transmitter cable; A being the major and B being the minor axis. For comparison of A and B, the dashed line represents B drawn at three times the regular scale (After Bezvoda, 1968).

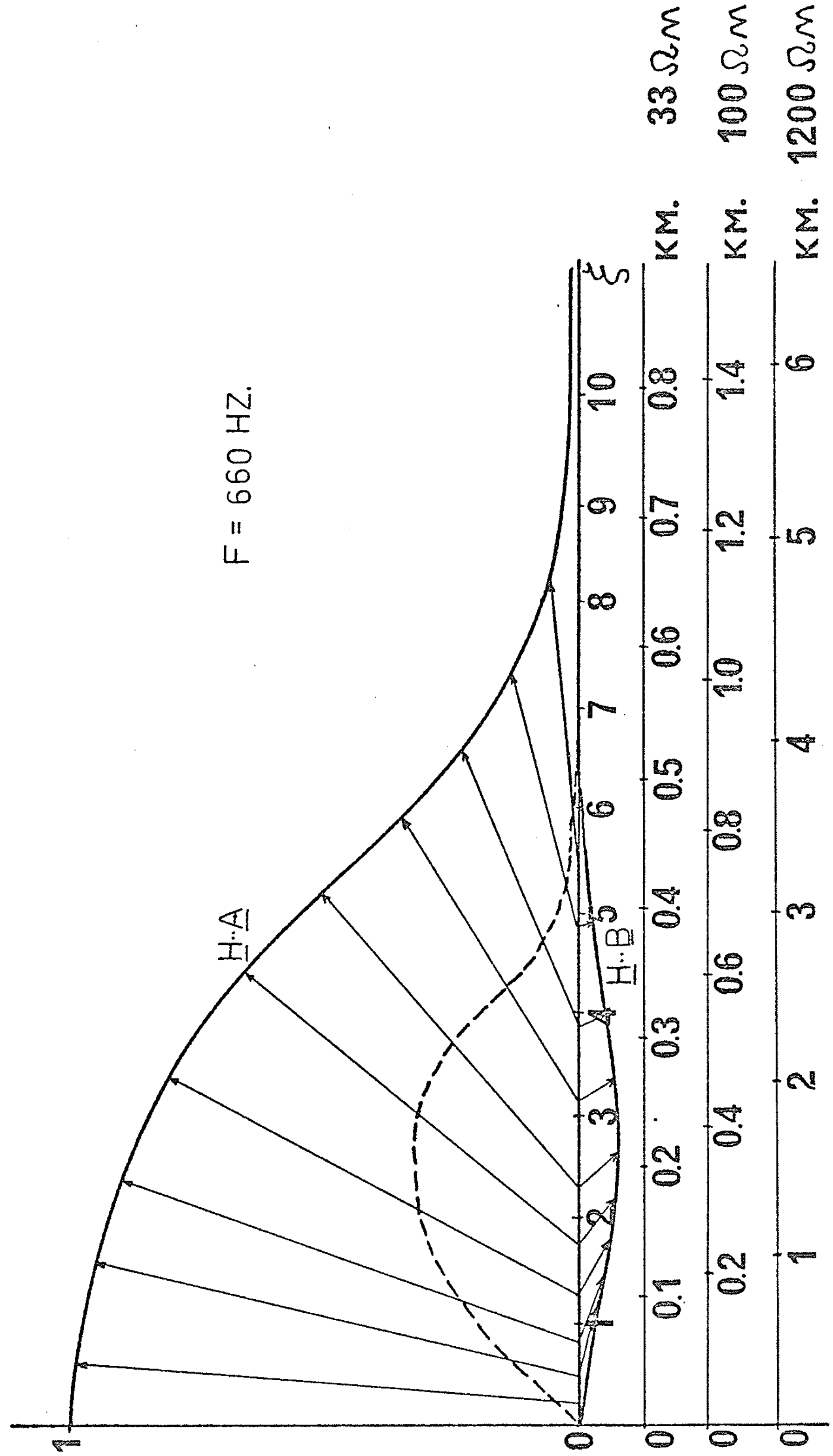
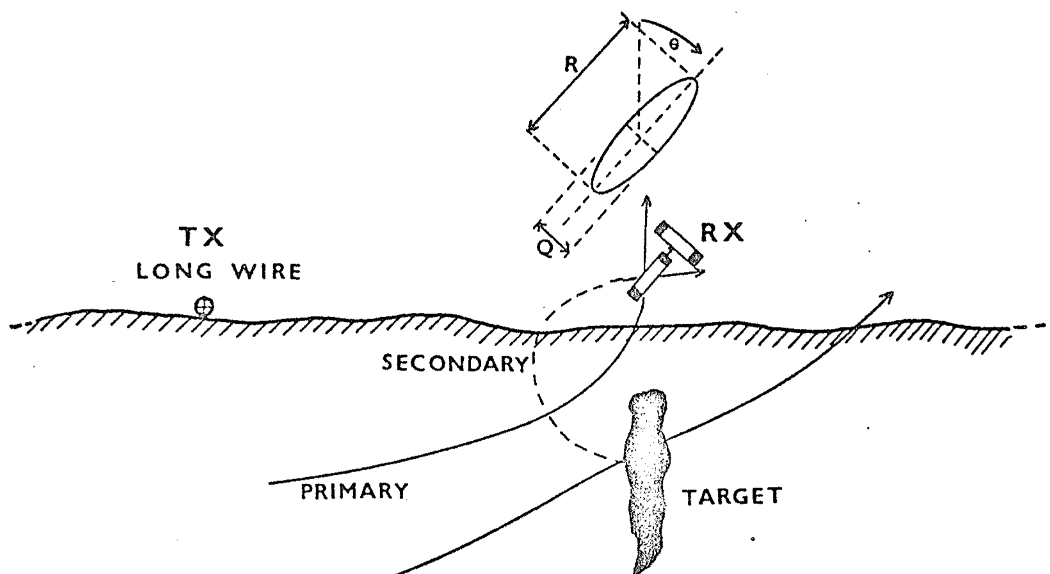


Fig. 9

Figure 10. The principle of the DPM-2 showing the inclination of the resultant field and the simulated ellipticity ratio for the quadrature reading (After Paterson, 1972).



DPM-2 PRINCIPLE

$\frac{Q}{R}$ = ELLIPTICITY

θ = INCLINATION

Fig. 10

effects, whereas the long grounded cable source also includes the conductive effects from return current paths which may be going through the target zone. This is discussed in Sutherland and Anderson (1971).

Results from electromagnetic surveys usually take the form of plots of the resultant field against station interval. To improve resolution and anomalous effect, filtering of the data may be carried out. The bandpass filter described by Fraser (1969) was used on all electromagnetic data:

$$f(X_{n+\frac{3}{2}}) = \frac{1}{2}((\theta_n + \theta_{n+1}) - (\theta_{n+2} + \theta_{n+3}))$$

Figure 11 diagrammatically shows the attenuation and amplification of signal in cycles per foot for station spacing of 50 feet. Signals with wavelengths between 125 and 1,250 feet are amplified in effect, whereas those outside this range are attenuated.

Figure 11. Frequency response of filter operator for station spacing of 50 ft. (After Fraser, 1969).

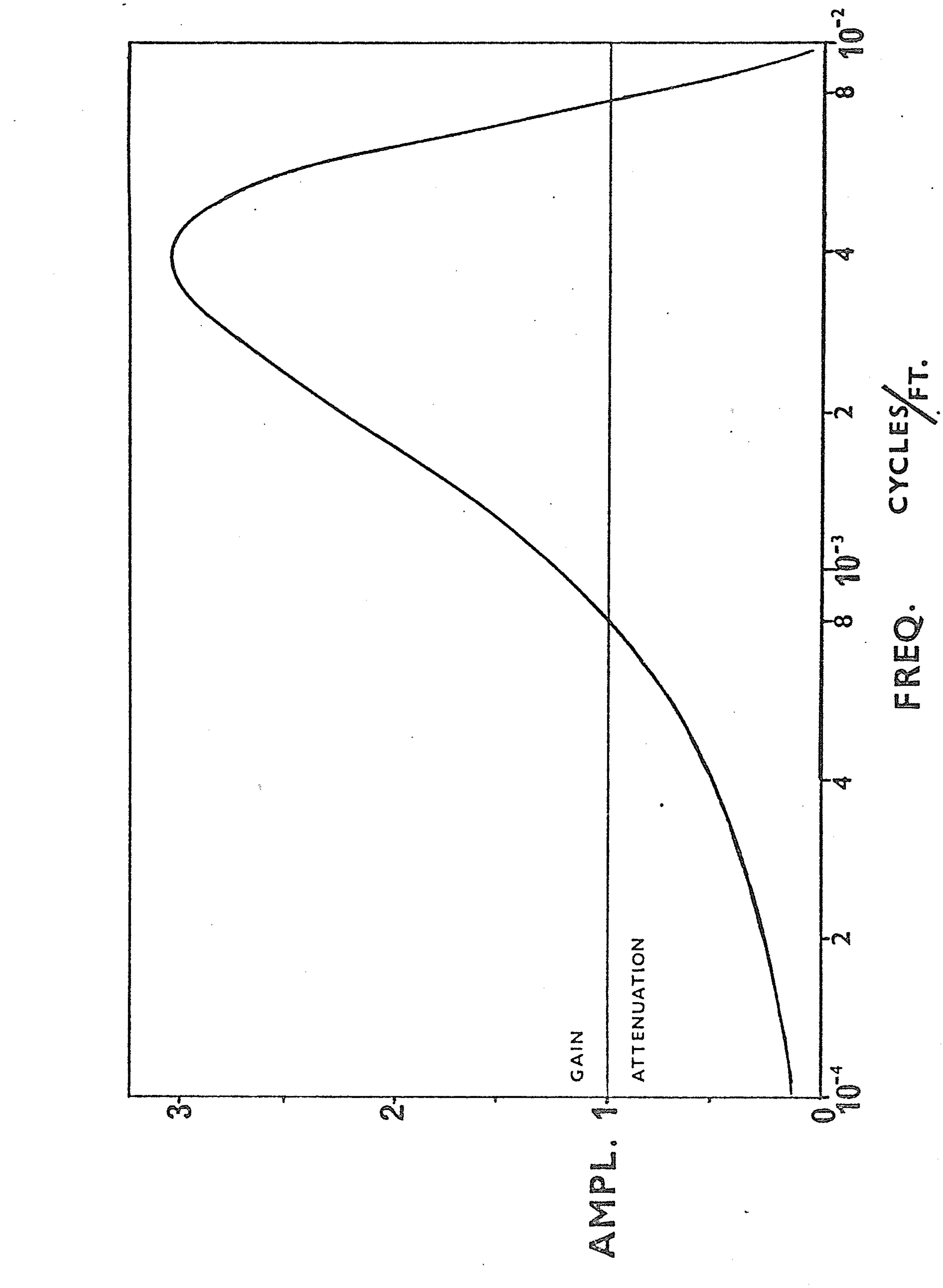


Fig. 11

CHAPTER V

FIELD RESULTS

Figures 12 to 16 inclusive are the DPM-2 results with the instrument parameters as indicated. An interesting feature about the swamp-conductor zone is illustrated in Figure 12, line 12E. The magnitude of the dip-angle gradient over the swamp is increased by more than the ellipticity amount as compared to the other responses on this line. This may indicate that the material beneath the swamp is more conductive than the mineralized zones on either side.

The magnetic responses are shown in Figure 17. Note that there are no indications of extensive magnetic mineralization beneath the swamp.

Contoured, filtered data from the EM-16 (VLF) and DPM-2 is presented in Figures 18 to 23 inclusive. These were contoured from positive filtered data peaks resulting from processing through the Fraser Filter. Contour magnitudes from the EM-16 (VLF) and high frequency DPM-2 (Figures 18 - 21) indicate three prominent conductor zones, each of comparable magnitude. These contour maps each indicate similar conductor zones.

Figures 12, 13, 14, 15, and 16. DPM-2 profiles with dip and ellipticity values at 150 Hz and 510 Hz at different transmitter locations.. Observed swamp edges are indicated by square brackets.

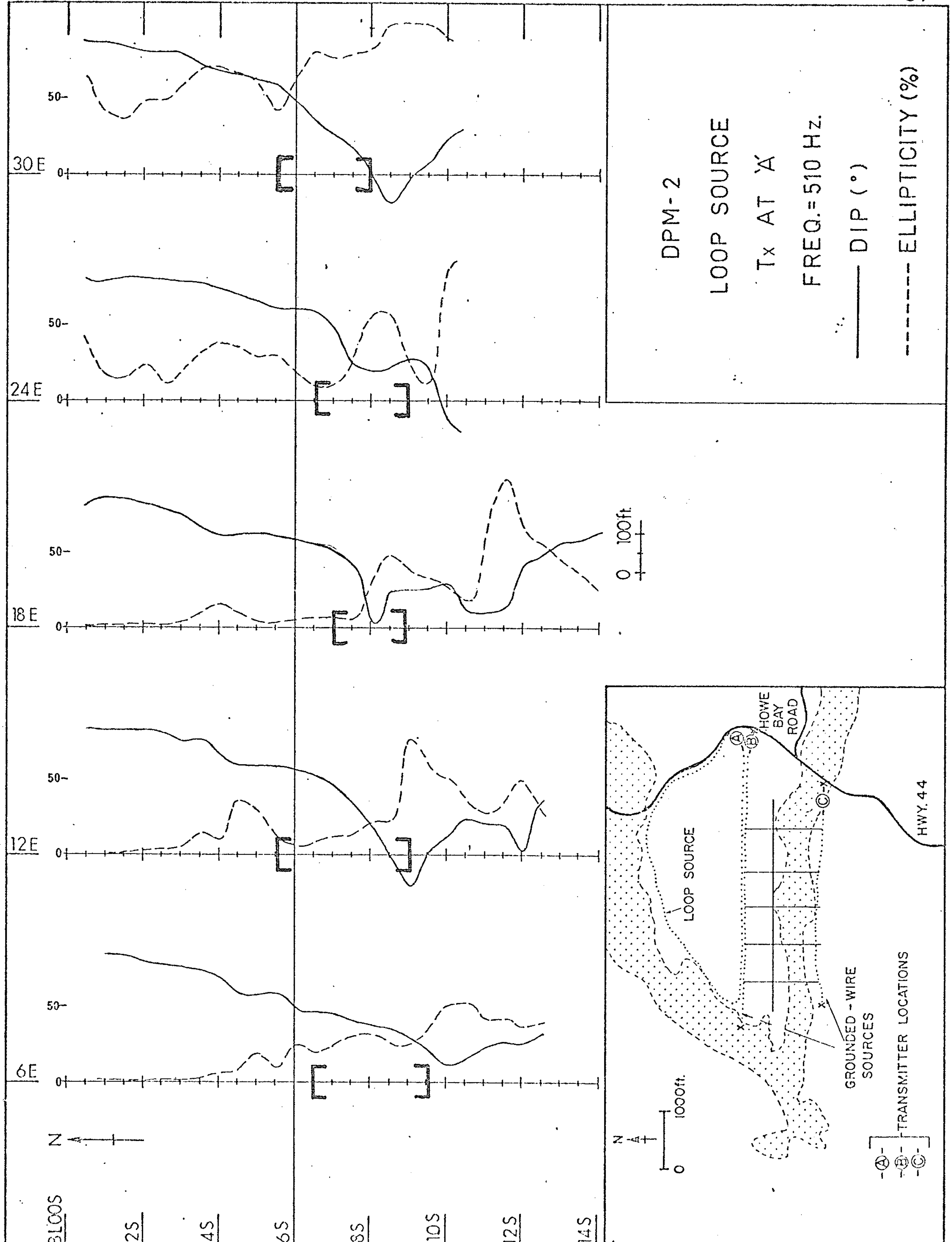

DPM-2
LOOP SOURCE
Tx AT A-A'
FREQ.=510 Hz.
DIP (°)
ELLIPTICITY (%)
30 E
24 E
18 E
12 E
6 E
50
0
0 100ft.
N
BL00S
2S
4S
6S
8S
10S
12S
14S
HOWE BAY ROAD
HWY. 44
LOOP SOURCE
GROUNDED-WIRE SOURCES
TRANSMITTER LOCATIONS
A
B
C
0 1000ft.
N

Fig. 12

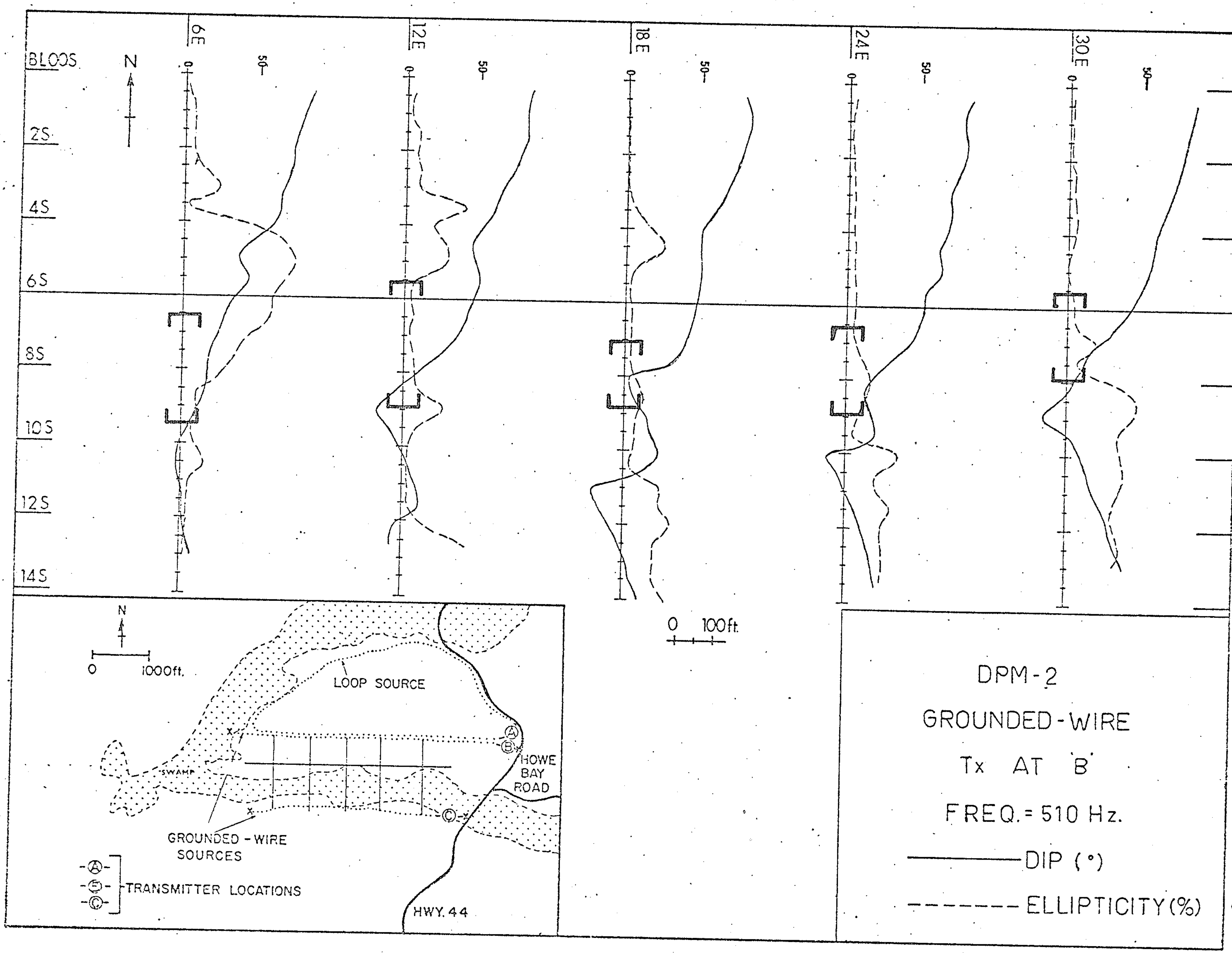
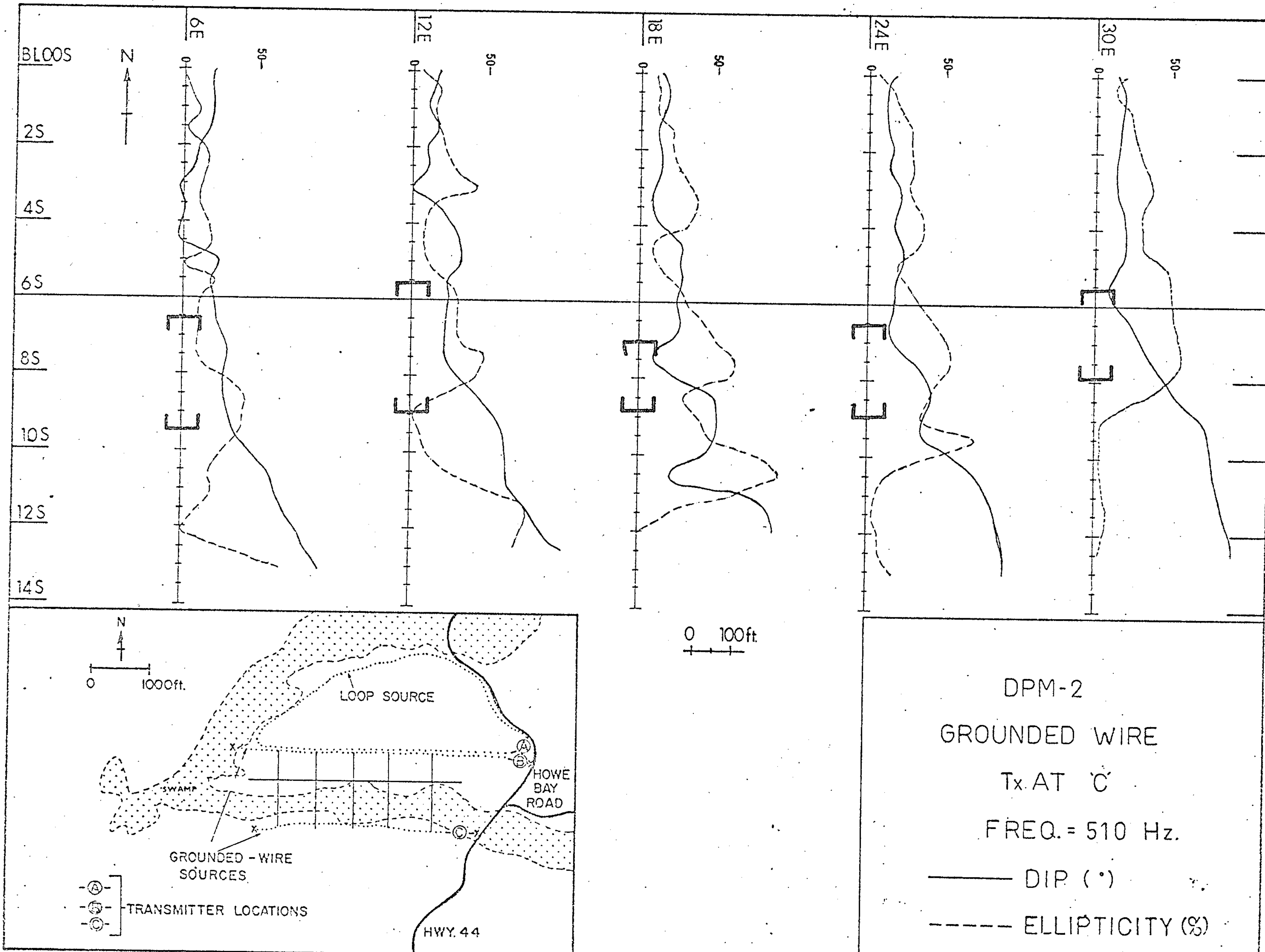

DPM-2
GROUNDED-WIRE
Tx AT B
FREQ. = 510 Hz.
DIP (°)
ELLIPTICITY (%)
BL00S
2S
4S
6S
8S
10S
12S
14S
6E
12E
18E
24E
30E
N
0
50
0 100ft.
0 1000ft.
LOOP SOURCE
HOWE BAY ROAD
SWAMP
GROUNDED - WIRE SOURCES
A
B
C
TRANSMITTER LOCATIONS
HWY. 44

Fig. 13


BLOOS
2S
4S
6S
8S
10S
12S
14S
N
6E
12E
18E
24E
30E
0
50-
0 100ft.
N
0 1000ft.
LOOP SOURCE
SWAMP
HOWE BAY ROAD
HWY. 44
GROUNDED - WIRE SOURCES
-Ⓐ- -Ⓑ- -Ⓒ- TRANSMITTER LOCATIONS
DPM-2
GROUNDED WIRE
Tx. AT 'C'
FREQ. = 510 Hz.
DIP (°)
ELLIPTICITY (%)

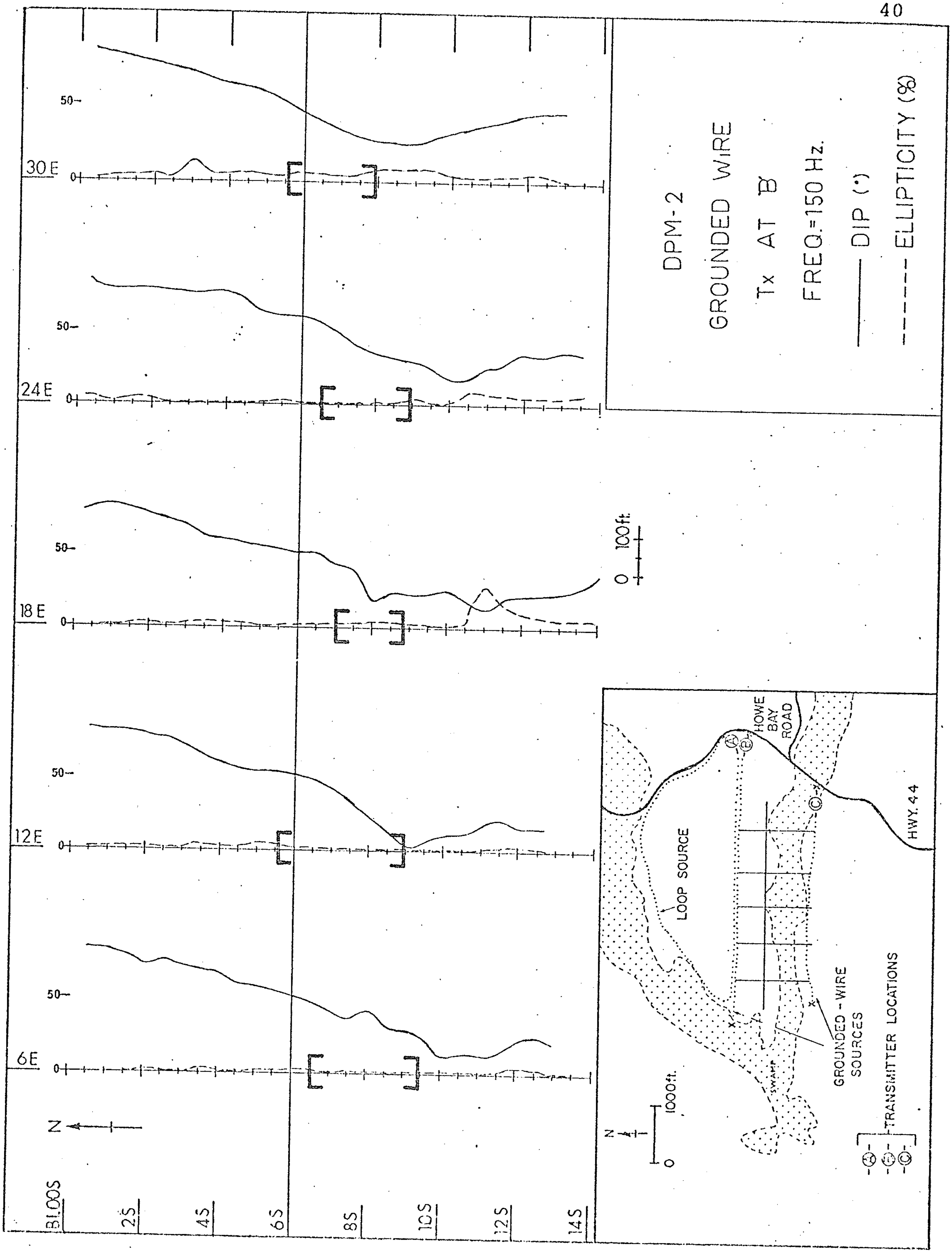
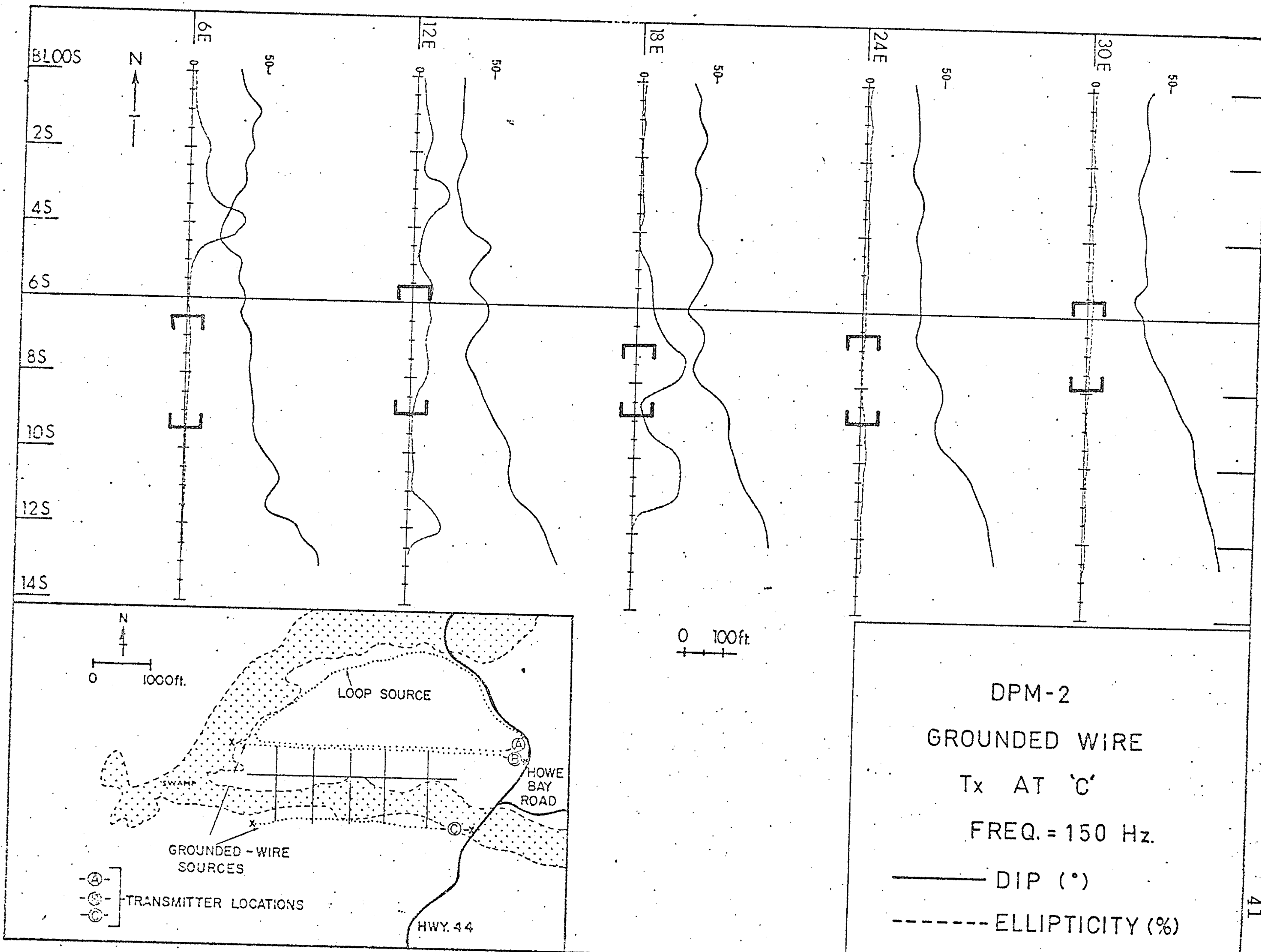

DPM-2
GROUNDED WIRE
Tx AT B
FREQ.=150 Hz.
DIP (°)
ELLIPTICITY (%)
30E
24E
18E
12E
6E
50
0
0 100ft.
N
BL.00S
2S
4S
6S
8S
10S
12S
14S
HOWE BAY ROAD
HWY. 44
LOOP SOURCE
SWAMP
GROUNDED-WIRE SOURCES
TRANSMITTER LOCATIONS
0 1000ft.

Fig. 15



B1.00S
2S
4S
6S
8S
10S
12S
14S
N
6E
12E
18E
24E
30E
0
50
0 100ft.
0 1000ft.
LOOP SOURCE
HOWE BAY ROAD
SWAMP
GROUNDED - WIRE SOURCES
TRANSMITTER LOCATIONS
HWY. 44
DPM-2
GROUNDED WIRE
Tx AT 'C'
FREQ. = 150 Hz.
DIP (°)
ELLIPTICITY (%)

Figure 17. Magnetic profiles with observed swamp edges shown by square brackets with respect to indicated station numbers.

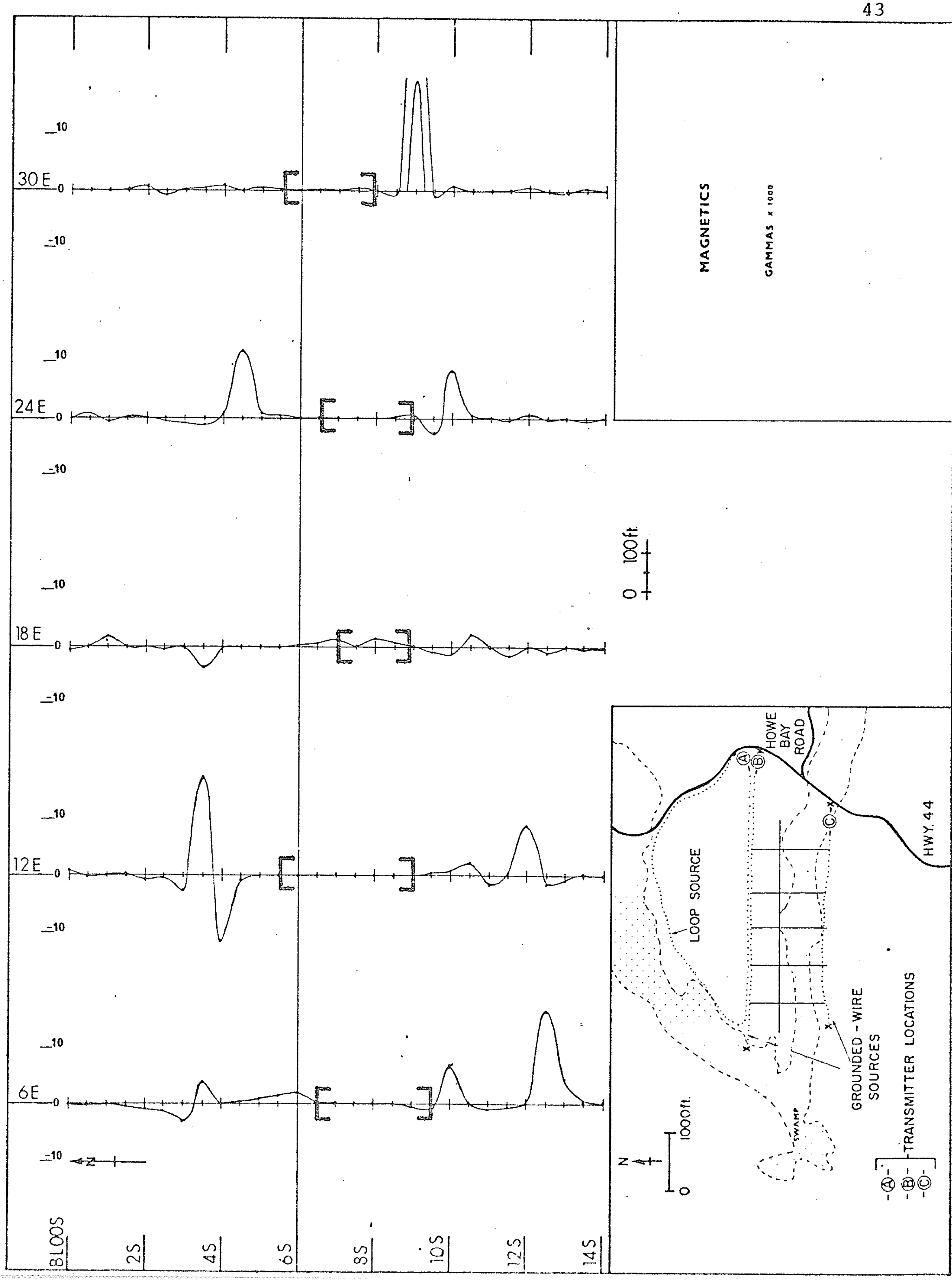

MAGNETICS
GAMMAS x 1000
30 E
24 E
18 E
12 E
6 E
10
-10
0
BL00S
2S
4S
6S
8S
10S
12S
14S
0 100ft.
HOWE BAY ROAD
HWY. 44
LOOP SOURCE
GROUNDED - WIRE SOURCES
SWAMP
0 1000ft.
N
TRANSMITTER LOCATIONS

Figure 18. EM-16 contour map with observed swamp edges shown by square brackets with respect to indicated station numbers.

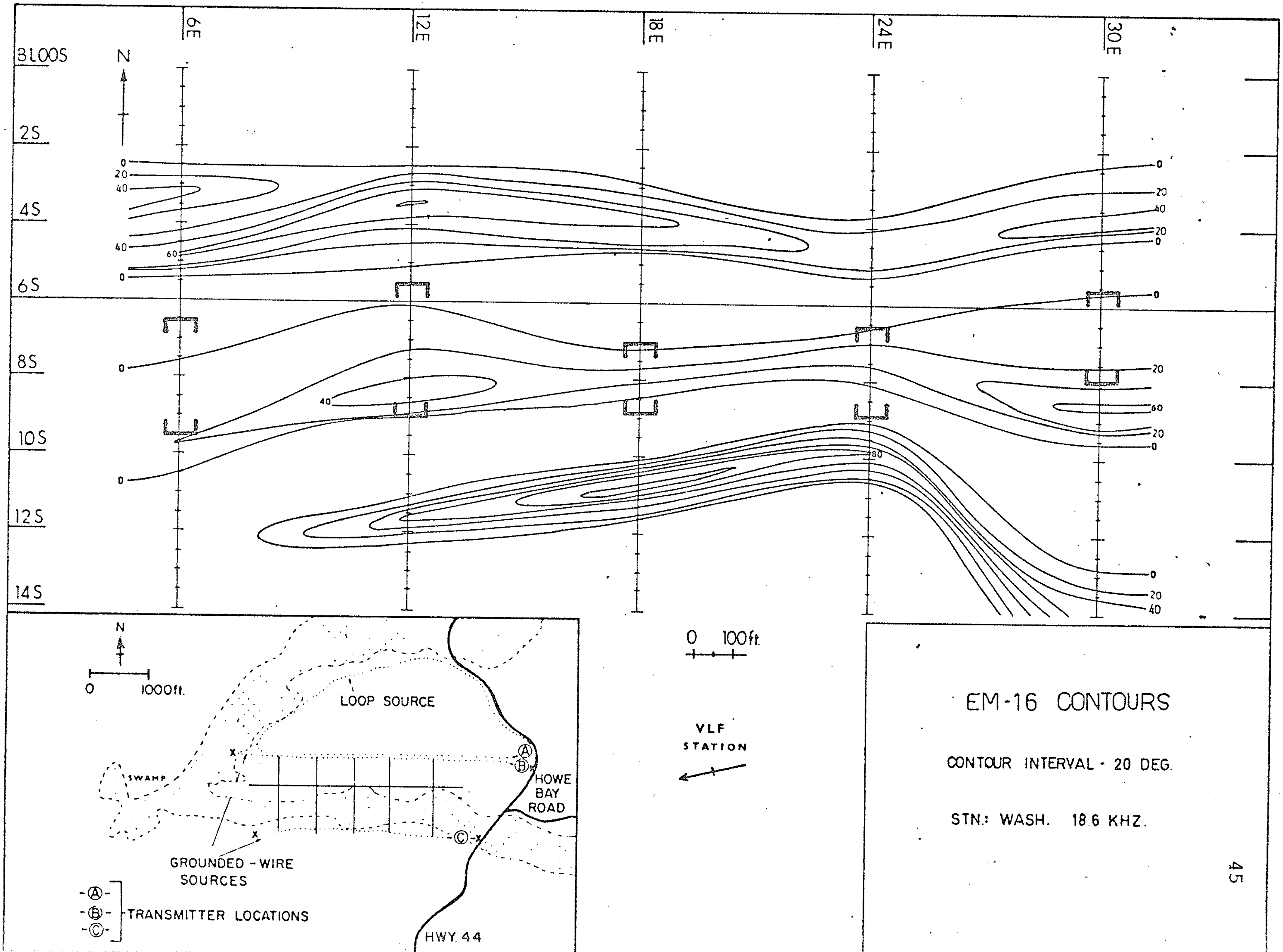

EM-16 CONTOURS
CONTOUR INTERVAL - 20 DEG.
STN.: WASH. 18.6 KHZ.
BLOOS
2S
4S
6S
8S
10S
12S
14S
6E
12E
18E
24E
30E
N
0 100ft.
VLF STATION
0 1000ft.
LOOP SOURCE
SWAMP
HOWE BAY ROAD
GROUNDED - WIRE SOURCES
-Ⓐ- -Ⓑ- -Ⓒ- TRANSMITTER LOCATIONS
HWY 44

Fig. 18

Figures 19, 20 and 21. Contours at 510 Hz for different transmitter locations. Observed swamp edges are indicated by square brackets.

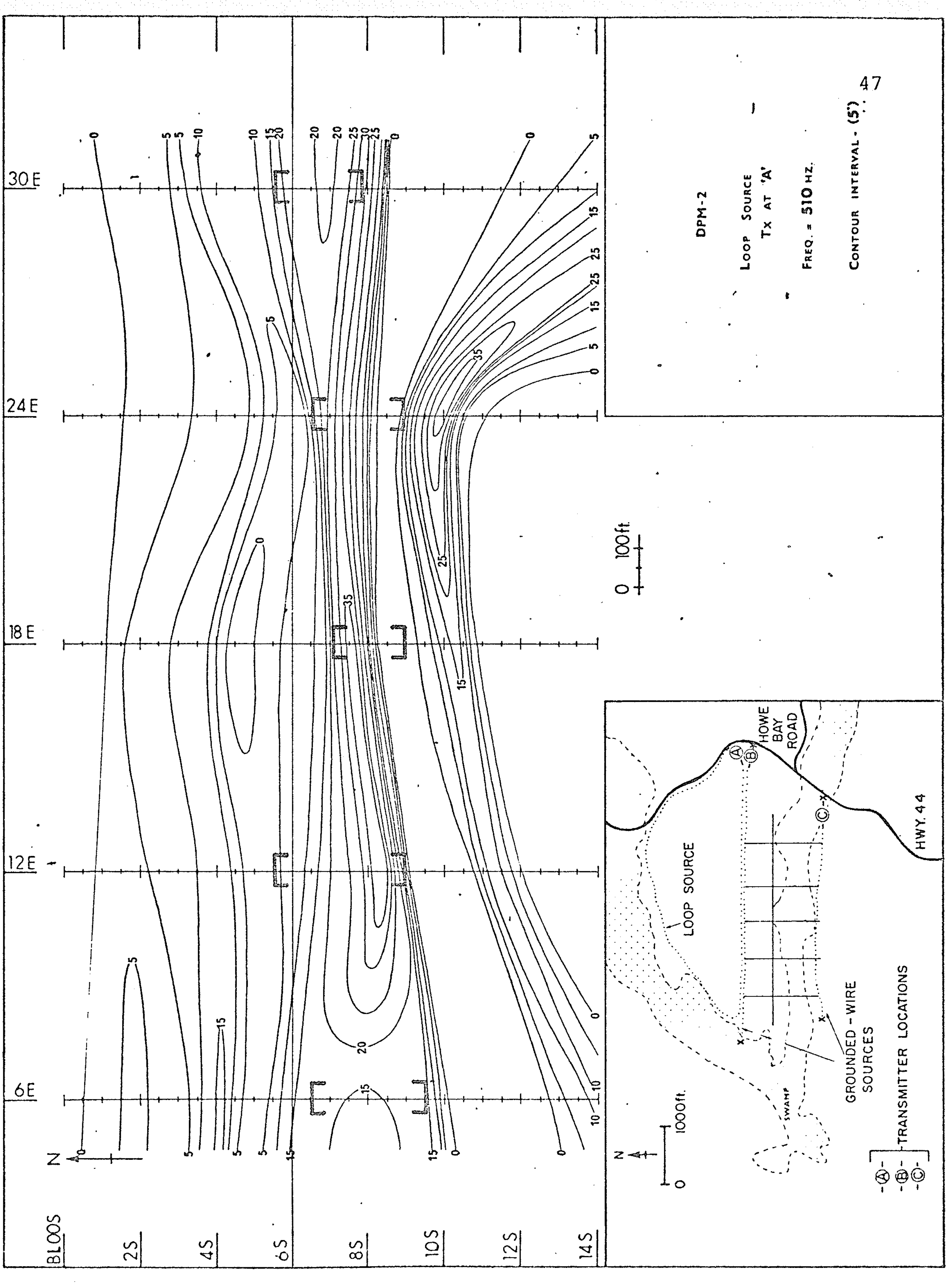

DPM-2
Loop Source
Tx at 'A'
Freq. = 510 Hz.
Contour interval - (5')
0 100ft
BL00S
2S
4S
6S
8S
10S
12S
14S
6E
12E
18E
24E
30E
N
LOOP SOURCE
HOWE BAY ROAD
HWY. 44
GROUNDED-WIRE SOURCES
SWAMP
0 1000ft
-(A)- -(B)- -(C)- TRANSMITTER LOCATIONS

Fig. 19

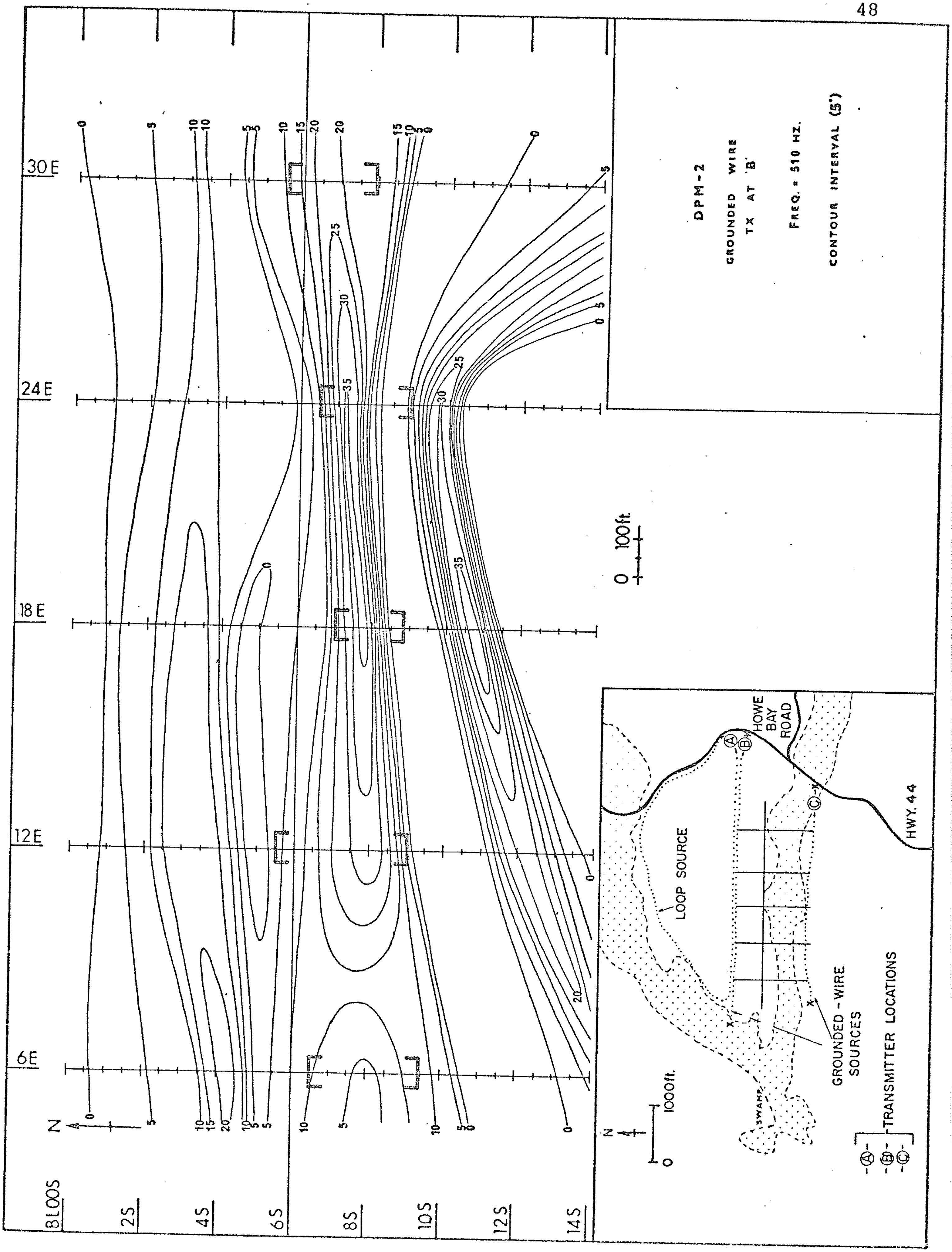

DPM-2
GROUNDED WIRE
TX AT 'B'
FREQ. = 510 HZ.
CONTOUR INTERVAL (5')
BL00S
2S
4S
6S
8S
10S
12S
14S
6E
12E
18E
24E
30E
N
0 100ft.
0 1000ft.
HOWE BAY ROAD
HWY. 44
LOOP SOURCE
SWAMP
GROUNDED-WIRE SOURCES
TRANSMITTER LOCATIONS

Fig. 20

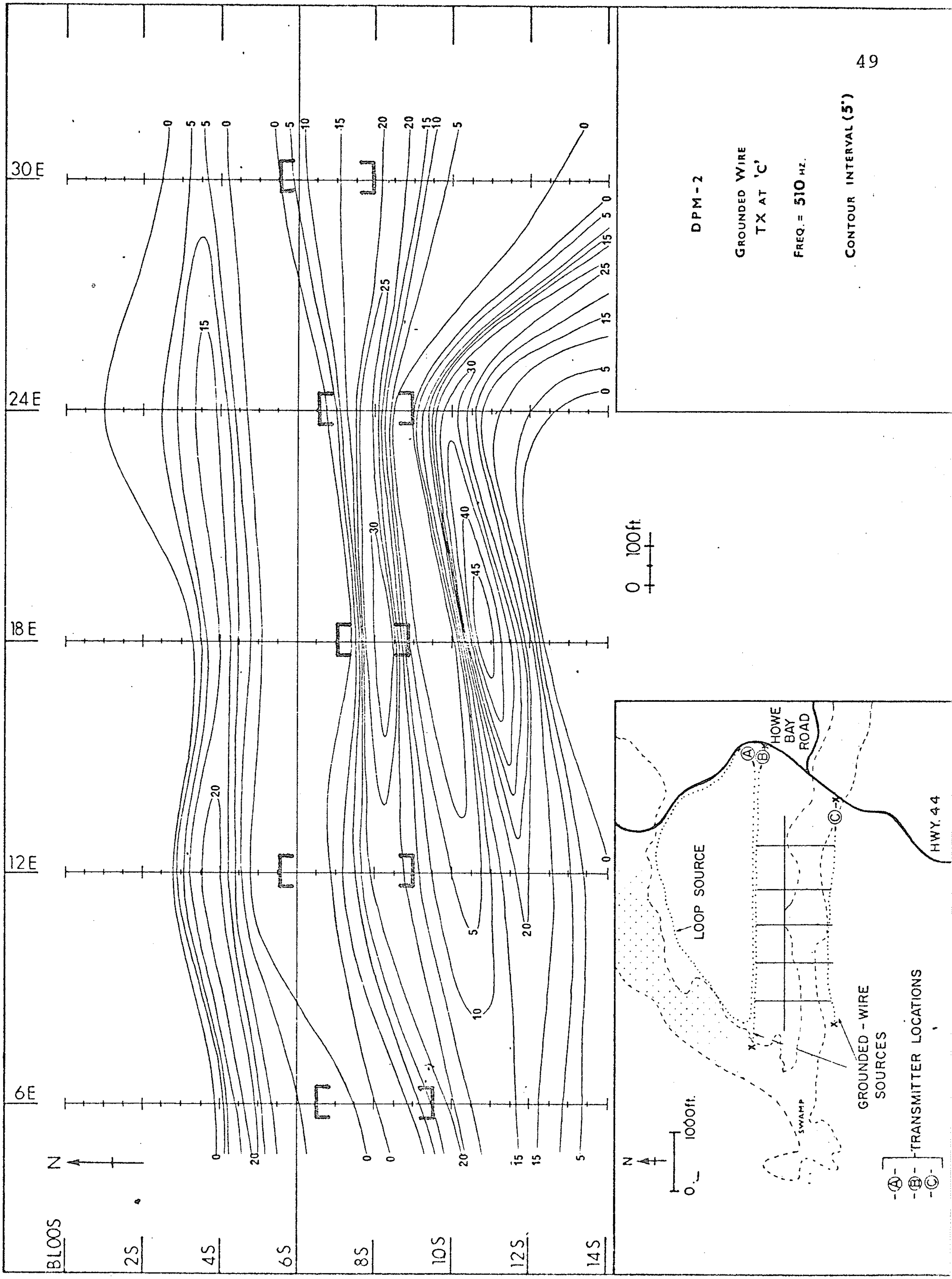

DPM-2
GROUNDED WIRE
TX AT 'C'
FREQ. = 510 HZ.
CONTOUR INTERVAL (5')
BL00S
2S
4S
6S
8S
10S
12S
14S
6E
12E
18E
24E
30E
N
0 100ft.
LOOP SOURCE
HOWE BAY ROAD
HWY. 44
SWAMP
GROUNDED-WIRE SOURCES
-Ⓐ-
-Ⓑ-
-Ⓒ-
TRANSMITTER LOCATIONS
0 1000ft.

Fig. 21

Figures 22 and 23. Contours at 150 Hz for different transmitter locations. Observed swamp edges are indicated by square brackets.

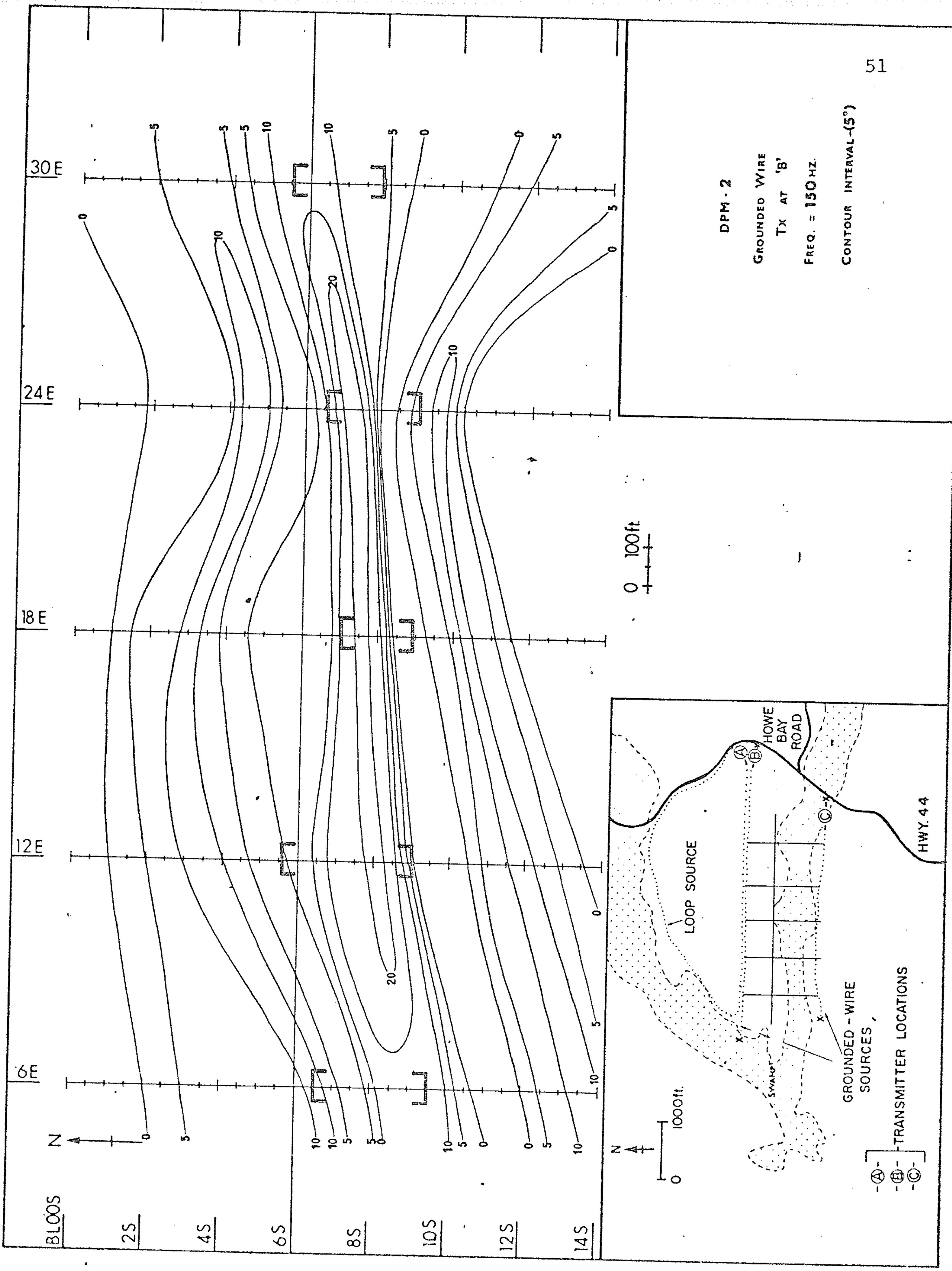

DPM - 2
Grounded Wire
Tx at 'B'
Freq. = 150 Hz.
Contour interval -(5°)
0 100ft.
30 E
24 E
18 E
12 E
6 E
BL00S
2S
4S
6S
8S
10S
12S
14S
N
HOWE BAY ROAD
HWY. 44
LOOP SOURCE
SWAMP
GROUNDED - WIRE SOURCES ,
TRANSMITTER LOCATIONS
0 1000ft.

Fig. 22

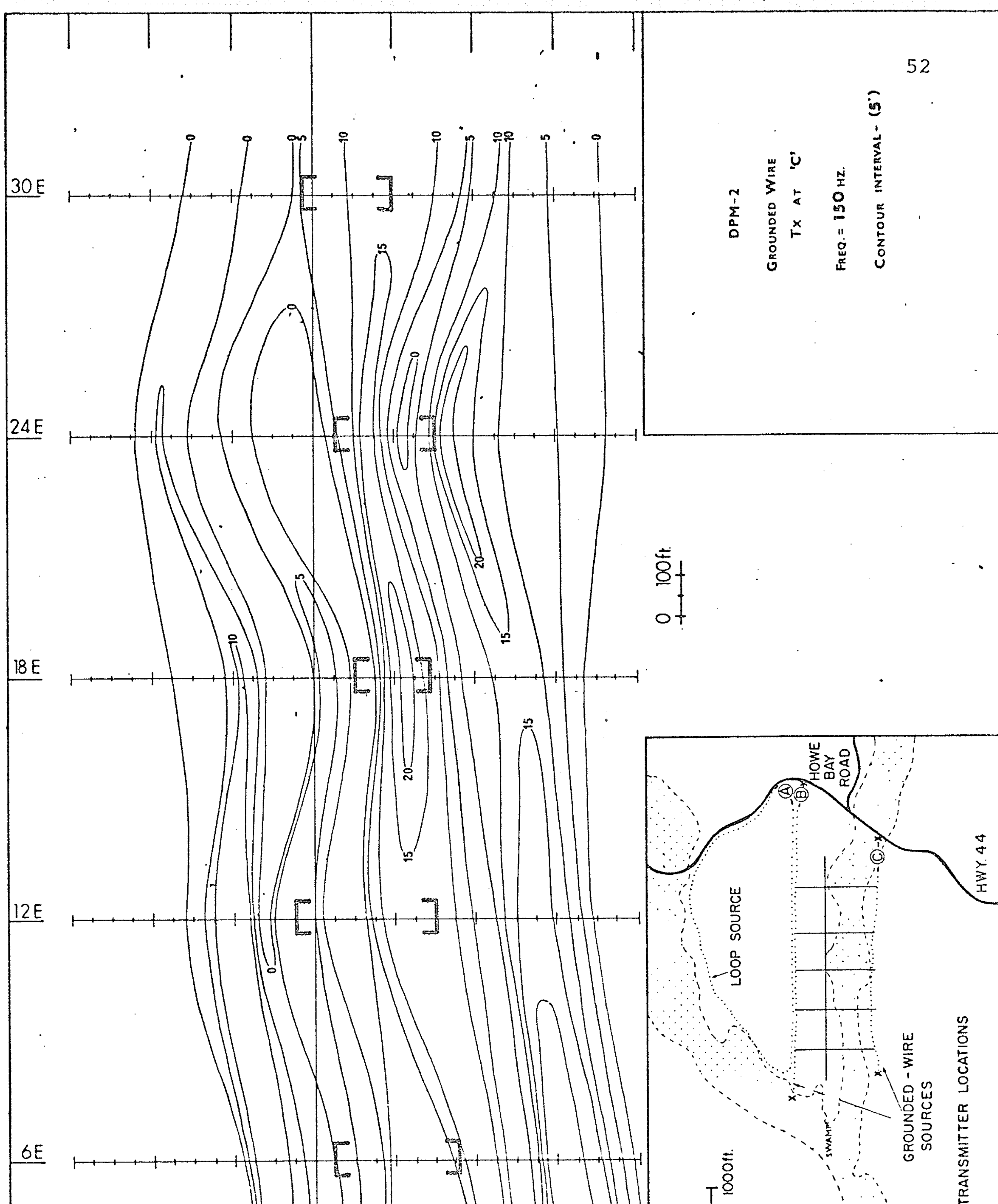

DPM-2
GROUNDED WIRE
TX AT 'C'
FREQ. = 150 HZ.
CONTOUR INTERVAL - (5')
0 100ft.
BLOOS
2S
4S
6S
8S
10S
12S
14S
6E
12E
18E
24E
30E
N
LOOP SOURCE
HOWE BAY ROAD
HWY 44
SWAMP
GROUNDED-WIRE SOURCES
0 1000ft.
-Ⓐ- -Ⓑ- -Ⓒ- TRANSMITTER LOCATIONS

Fig. 23

CHAPTER VI

SUMMARY

In Figure 24, a comparison of filtered dip readings and ellipticity readings are shown with corresponding EM-16 (VLF) data on line 18E. There is a marked difference in response between the lower frequency (A and B) and the higher frequency (C to F).

A comparison of dip-angle peaks and ellipticity peaks can be made using Figure 24. It is noted that the ellipticity peaks (A to E) are offset from the dip-angle peaks. In every instance with the DPM-2 the dip-angle peaks appear first when traversing on the line away from the transmitter wire. The results agree with our present knowledge of the DPM-2 system.

The return current path effect on ellipticity can be seen by comparing responses over station 8S on profiles (A) to (D) inclusive. Notice that profiles (A) and (C), which have the transmitter wire at 'B' show very little return current path effect in comparison to profiles (B) and (D) which have the transmitter wire at 'C'. These include an inductive effect because response changes with frequency. Station 8S is approximately equi-distant from

Figure 24. DPM-2 (A - E) and EM-16 (F) real and quadrature response comparison on line 18E.
(A) 150 Hz, with transmitter at 'B'
(B) 150 Hz, with transmitter at 'C'
(C) 510 Hz, with transmitter at 'B'
(D) 510 Hz, with transmitter at 'C'
(E) 510 Hz, with transmitter at 'A'

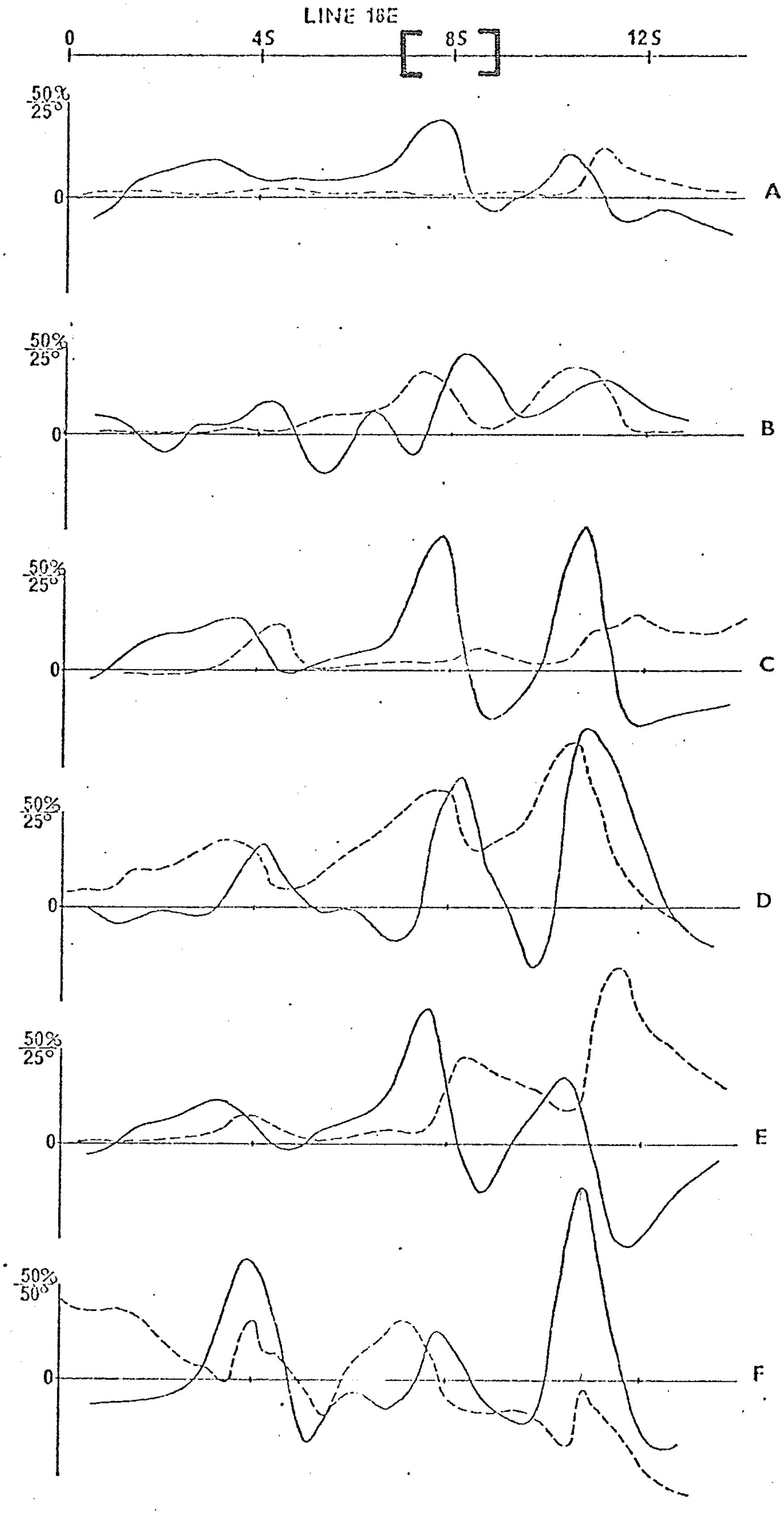


Fig. 24

transmitter locations at 'B' and 'C'.

A problem exists with the magnitude of the EM-16 (VLF) response over 8S. This occurs in both Figures 24 and 25. Here the VLF response is smaller in magnitude than over the two side response zones. It would be expected that the higher frequency would show an equally or greater response in comparison to the lower frequency modes. A possible explanation can be a complex interaction between overburden effects due to high frequency and a shear zone response giving a resultant secondary field lower in magnitude than either response alone.

The magnetic response shown in Figure 25 indicates that only two conductors are magnetic. This can possibly be due to two events of deformation in the area. The first may have been shearing with subsequent mineralization with sulphide and magnetic minerals. At some later geologic time a second shearing event may have taken place with no mineralization. This interpretation is based on the lack of magnetic response and the relatively strong response exhibited by all other electromagnetic instruments used over the middle conductor.

Figure 25. Magnetic (G), EM-16 (H), Vertical Loop (J), and DPM-2 (K, L, M) response comparisons on line 12E.
(K) 150 Hz, with transmitter at 'B'
(L) 510 Hz, with transmitter at 'A'
(M) 510 Hz, with transmitter at 'C'

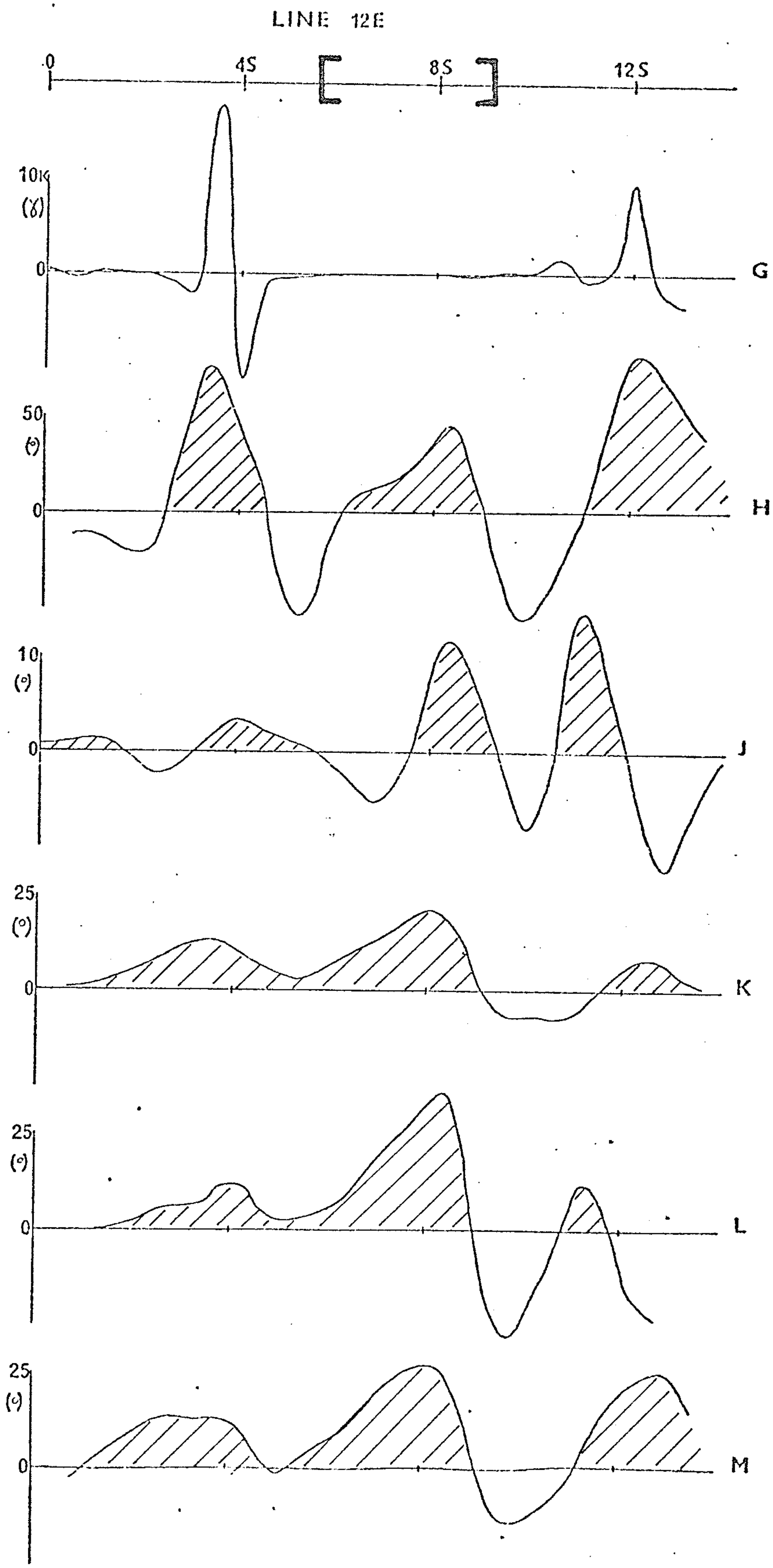


Fig. 25

CHAPTER VII

CONCLUSIONS

The DPM-2 geophysical survey instrument is a reliable tool for detailed studies of an electromagnetic responder. The utilization of more than one frequency and the use of dip and ellipticity readings, can help separate the overburden effect from the response due to the bedrock conductors.

Working results from the DPM series of instruments has progressed from the earlier versions, by Bieler-Watson in the 1930's (Parasnis, 1966), the DPM-1 (Anderson and Sutherland, 1971), to the DPM-2 model used here. Present model studies with the DPM principle is carried out with dipping conductors.

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