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OPERATING MANUAL

BH43-3D
(With Tilt Sensor)

THREE COMPONENT BOREHOLE LOGGING ATTACHMENT
FOR PROTEM GROUND TRANSIENT ELECTROMAGNETIC SYSTEM

GEONICS LIMITED

LEADERS IN ELECTROMAGNETICS

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May 1996

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BH43-3D THREE COMPONENT BOREHOLE LOGGING ATTACHMENT

1. TECHNICAL SPECIFICATIONS

1.A BOREHOLE PROBE

- Components:	Sensor; Preamplifier-Battery Pack; Cable Head.
- Sensing:	Three orthogonal coils (One axial and two radial)
- Overall Length:	334 cm
- Maximum Diameter:	3.8 cm
- Weight:	9.5 kg
- Operating Temperature:	-30°C to +80°C
- Sensor Area-Turns Product:	5000 m^2 for axial and 1250 m^2 for radial sensors(with amplification)
Sensor-Preamplifier Resonant Frequency:	10 kHz for all sensors
- Probe Rotation Correction:	Two orthogonal tilt meters with range from ±1° to ±80° (from vertical)
- Battery:	Rechargeable nickel cadmium battery sealed pack for 40 hrs continuous operation

1.B CONTROL BOX

- Description:
  - Channel selection
  - Impedance and Gain matching network between probe and PROTEM receiver (normalizes sensors effective area to 100 m^2 for all three sensors)
  - Preamplifier battery charging
  - Preamplifier testing
  - VLF filter
- Size: 22 x 13.5 x 8 cm
- Weight: 1.5 kg

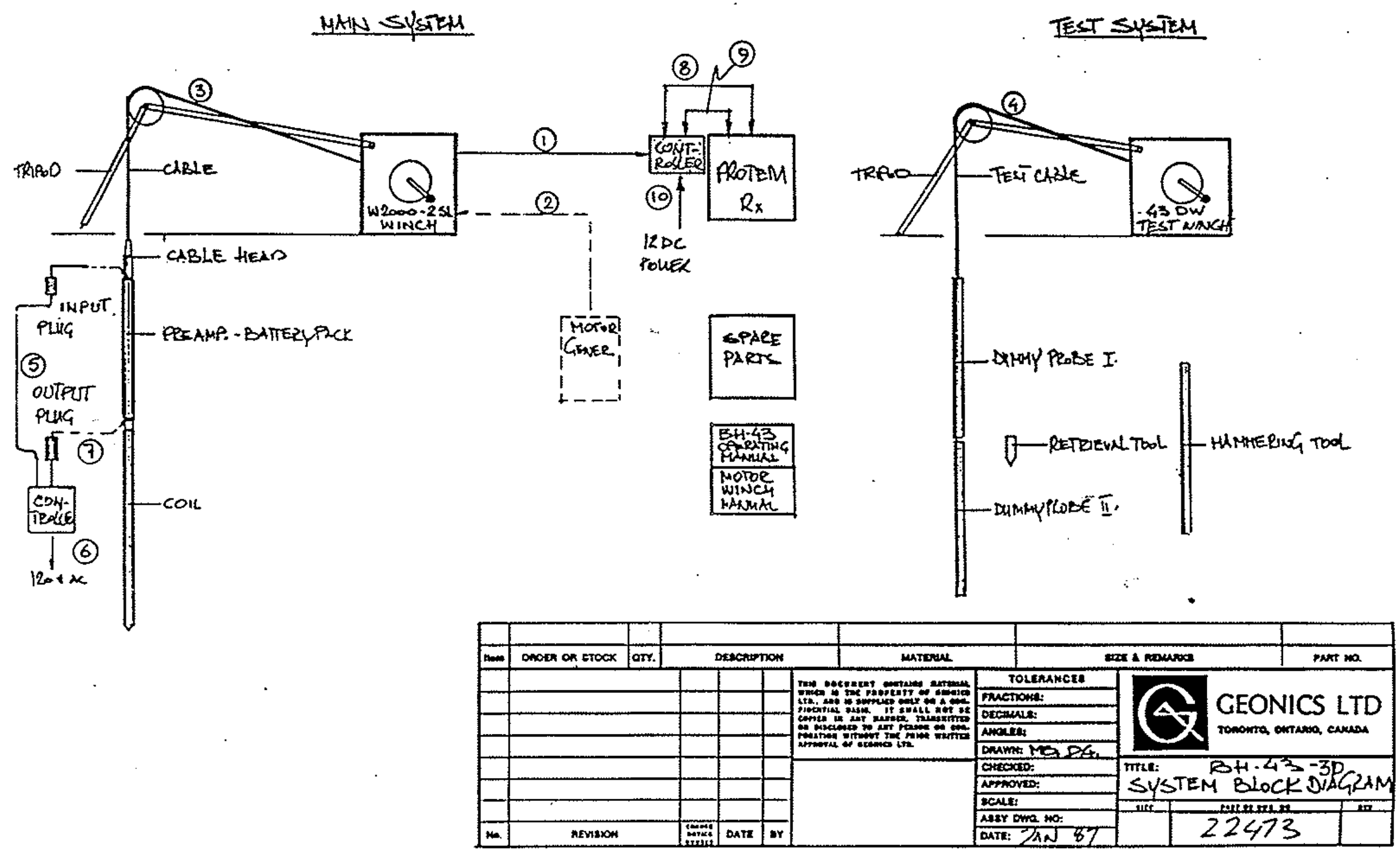
2. CABLE

- Type: Two-conductor shielded; polyurethane jacket; Kevlar strength membrane

-	Diameter:	5.6 mm
-	Weight:	40 kg/km
-	Length:	Standard 1000 m Optional 2000 m
-	Breaking Strength:	500 kg

3. WINCH

-	Drum Capacity:	2000 m
-	Size:	91.4 x 67.3 x 64.3 cm
-	Weight:	52.3 kg
-	Mechanical Counter Resolution:	0.1 m
-	Operation Mode:	Manual or motorized


MAIN SYSTEM
TEST SYSTEM
TRIPOD
CABLE
CABLE HEAD
PREAMP. - BATTERY PACK
COIL
INPUT PLUG
OUTPUT PLUG
CON-TROLLER
120 v ac
W2000-25L WINCH
MOTOR GENER.
CONT-ROLLER
PROTEM Rx
12 DC POWER
SPARE PARTS
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MOTOR WINCH MANUAL
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-43 DW TEST WINCH
DUMMY PROBE I.
DUMMY PROBE II.
RETRIEVAL TOOL
HAMMERING TOOL
1
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9
10
ITEM
ORDER OR STOCK
QTY.
DESCRIPTION
MATERIAL
SIZE & REMARKS
PART NO.
TOLERANCES
FRACTIONS:
DECIMALS:
ANGLES:
DRAWN: MB DG.
CHECKED:
APPROVED:
SCALE:
ASSY DWG. NO:
DATE: JAN 87
GEONICS LTD
TORONTO, ONTARIO, CANADA
TITLE: BH-43-3D SYSTEM BLOCK DIAGRAM
22473
No.
REVISION
DATE
BY

Figure 1.

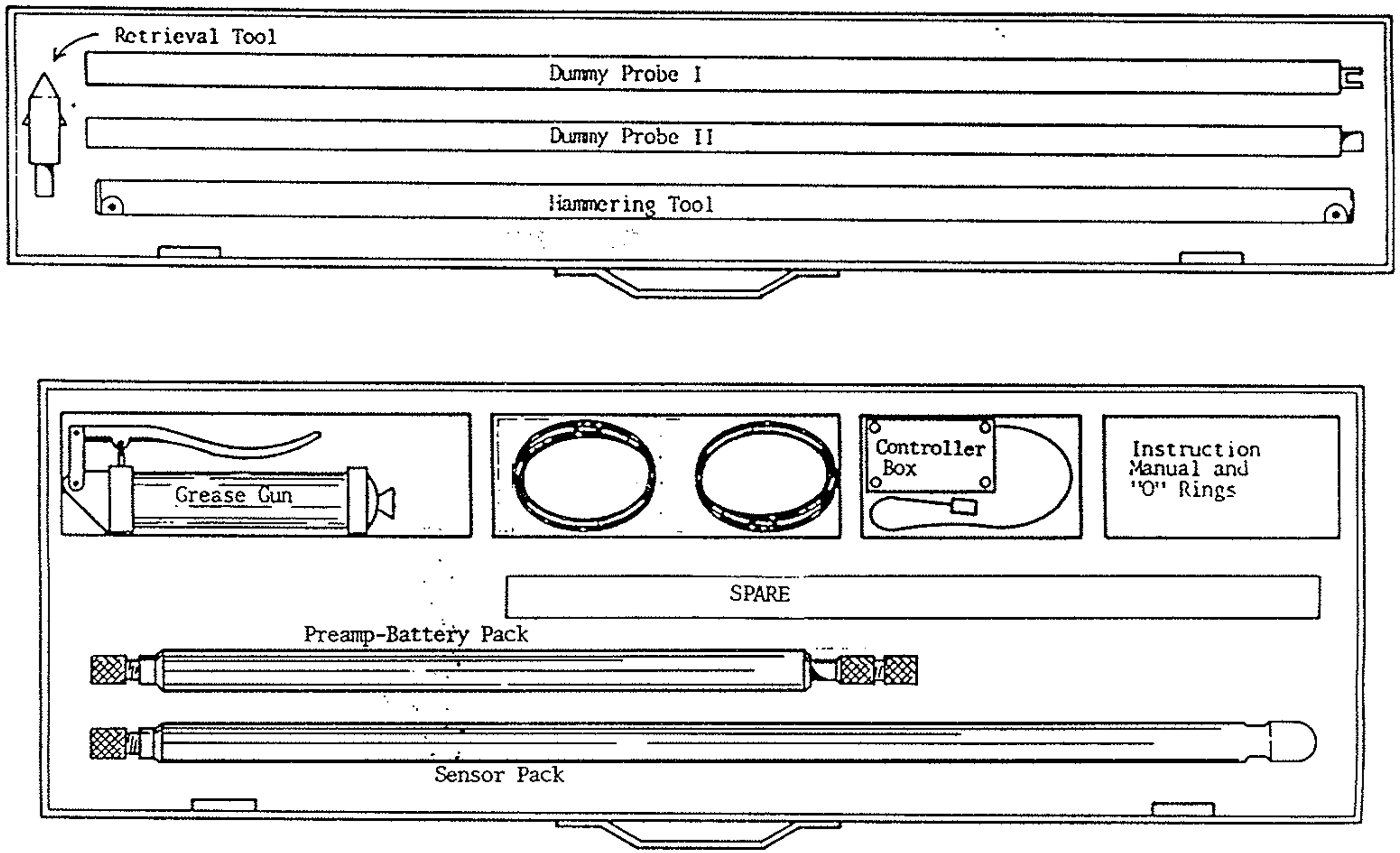

Retrieval Tool
Dummy Probe I
Dummy Probe II
Hammering Tool
Grease Gun
Controller Box
Instruction Manual and "O" Rings
SPARE
Preamp-Battery Pack
Sensor Pack

Figure 2.

2. INTRODUCTION

The BH43-3D provides 3-dimensional time-domain EM exploration from boreholes, in conjunction with a PROTEM system. Boreholes as deep as 2 km can be surveyed using a PROTEM system with a 500 x 500 m transmitter loop; at developed mines, the transmitter loop can be laid out in underground workings.

The probe has 3 EM sensors, which sequentially measure orthogonal components of decay. Along the hole, spatial resolution as fine as 1 m can be obtained; the actual measurement interval depends on the desired resolution of the response. Two orthogonal tilt sensors allow for correction of probe rotation in the borehole.

The wide bandwidth of the probe, coupled with the excellent temporal resolution and large dynamic range of the PROTEM system provides maximum diagnostic information and a high degree of rejection of powerline and other noise sources.

Computer programs for editing, displaying and interpreting BH43 responses are supplied with the probe, including a program for calculating all three field-components for thin plate, sphere, homogeneous half-space (HHS) and thin sheet. In conjunction with the borehole log information and the signal from the tilt sensors, the coil rotation correction is obtained.

General theory on quantitative interpretation of drill-hole EM surveys can be found in: Dyck, V.A., 1981, "A Method for Quantitative Interpretation of Wideband, Drill-Hole EM Surveys in Mineral Exploration", Ph.D. Thesis, University of Toronto.

3. OPERATING INSTRUCTIONS

3.1 Probe Assembly

a) First identify components in the main probe shipping box, using Figures 1 and 2 as a guide.

b) Check the "O" Rings on Preamplifier-Battery Pack and Cablehead. Apply Silicone grease.

c) Make sure the Battery Pack is fully charged. (See Section 3.4 for battery charging).

d) Re-apply the Silicone grease around "O" Rings and assemble probe together as per Figure 3, and connect Sensor Assembly to Preamp-Battery Pack Assembly.

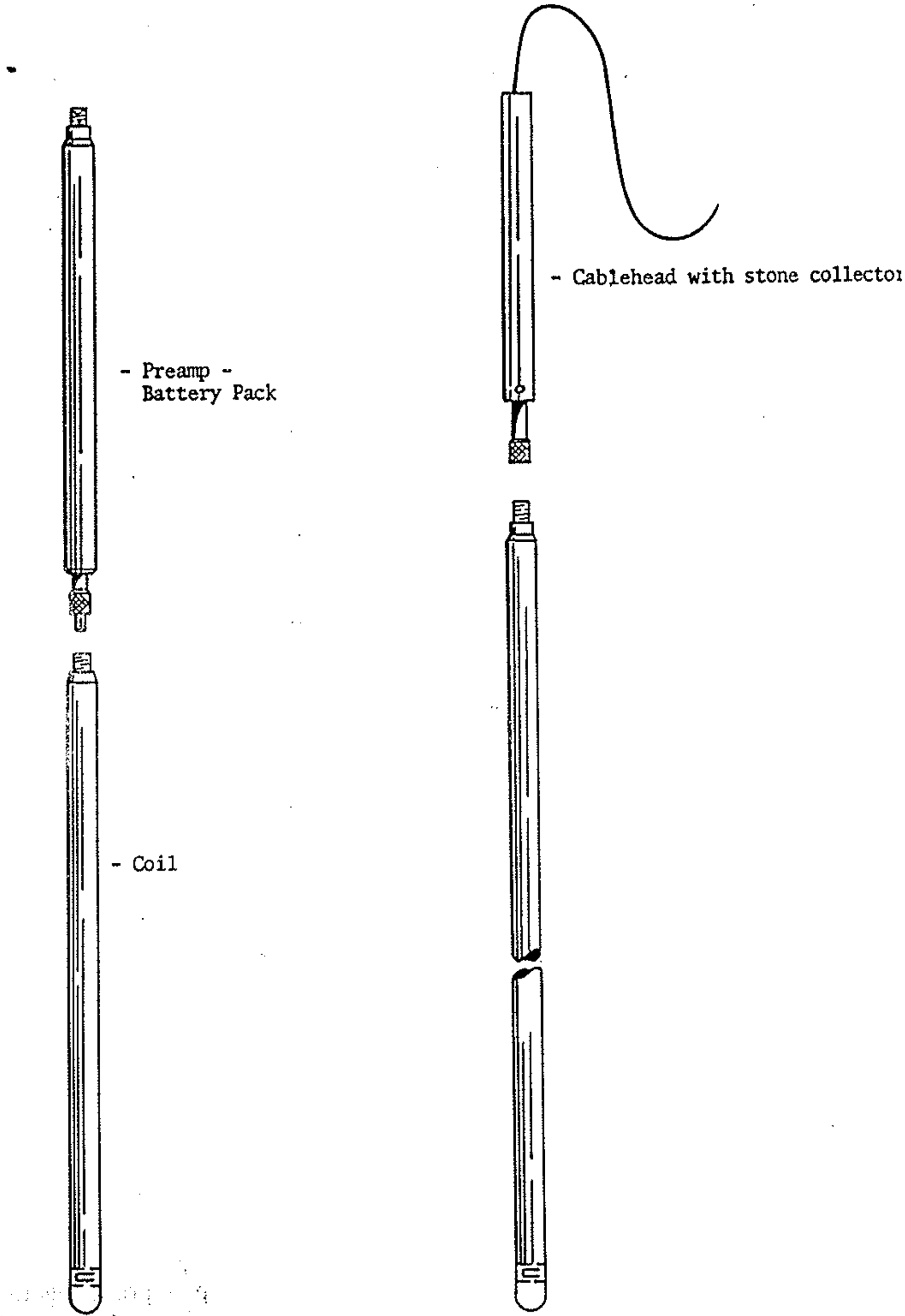


Figure 3.

e) Connect the Cablehead with the Stone Collector Assembly (Cablehead Assembly) to the assembled probe. (If cablehead is not connected to the winch cable(3), see SECTION 3.3 for Cablehead Termination Procedure). Please Note: Sensor connected to the Preamp-Battery Pack, switches on the battery. If the probe is not being used - disconnect preamplifier from sensor assembly to conserve battery.

f) Connect the signal output from the winch, to the BH43-3D Control Box, using signal cable (1). Then connect output from the control box to the input of the receiver, with the control box to receiver cable (8).

g) Connect power to the control box by connecting DC power cable (10) from receiver power output to the control box power input.

h) Connect the control box REF input (banana jack) to the jack on the receiver console (silver jack next to the REF terminal) with the sensor REF cable (9).

i) The interface/control box is used to normalize output from probe to the PROTEM receiver as well as to allow selection of particular component. To select particular component (z,x,y,α,β) push the appropriate push button on the control box front panel and keep it pressed for at least several seconds until a light associated with the particular component goes on. Normally five indicator LED's will be addressed in sequence from z to β.

j) When working near a strong VLF station a low pass filter can be activitated to reject the VLF signal interference. To activate filter set the filter switch on the control box front panel to the "Filter in" position. Do not use filter if it is not necessary, since it will introduce distortion to the signal for the first several hundred microseconds.

3.2 SYSTEM FUNCTIONAL CHECK AND MEASUREMENTS

3.2.1 Once familiarized with the PROTEM System operation, set the instrument for logging. Use the desired transmitter loop configuration (usually square with the side equal to 1/2 depth of the hole) and the appropriate receiver setting. Position the receiver about fifty meters from the transmitter loop wire and take a set of measurements using the standard surface receiver coil. Replace the coil with the BH43-3D probe attachment and make measurements with the same receiver settings. Compare results. Readings may vary slightly due to the difference in the coils frequency response. In areas with very resistive ground, readings for comparison could be very small. In such a case, use the transmitter case cover as an anomaly. Position the cover about half a meter from the coil. Since the magnitude of response is very sensitive to relative position between coil and cover, readings between two measurements may differ. This test is still beneficial as a rough check of attachment performance.

3.2.2 If you are not certain about the condition of the hole that you are going to log, use the dummy probe to ensure that the hole is clear and free of obstruction. See Section 3.6 on retrieval tool and dummy probe.

3.2.3 At the beginning of logging, for the first fifty meters, readings may be affected by borehole casing, winch, drilling rigs and the rest of the hardware in the vicinity of the hole.

3.2.4 Hole may be logged with the probe going down or up but the reading should be taken only when the probe is stationary. Measurements taken with the moving probe will be affected by microphonic noise. The method of taking measurements going down has the advantage that some measurements can be cross checked on the way up. Taking measurements going upwards has the advantage that on the way down the probe is pulled by gravity and at the end of measurements the probe is at the surface. Readings are taken in general at intervals of 10 meters with the possible smaller increments in the anomalous region. For three component measurements each component has to be measured separately at each measuring position. Adding two components (α and β) for tilt sensor measurement amounts to five separate measurements at each station.

3.3 CABLEHEAD TERMINATION PROCEDURE

In case of retermination or new termination of the cablehead to the cable, use the following procedure: (Figure 4).

3.3.1 Slide strain relief housing over cable.
3.3.2 Slide cup over cable.
3.3.4 Slide cone over cable (tapered end first).
3.3.5 Strip off 2.5" of cable outer jacket.
3.3.6 Carefully separate shield braid to one side.
3.3.7 Line up nylon cone with edge of cable outer jacket. (Figure 4-2).
3.3.8 Flair out Kevlar strain member (yellow strands) and bend backwards over nylon cone. Cut off 1/4 of Kevlar strains to produce a weak link. (See Figure 4-2). Tape Kevlar ends to cable below the cone.
3.3.9 Slide cup towards cone (see Figure 4-3) pulling cable downwards and cup upwards, homing cone snug into the cup.
3.3.10 Cut braid shield to approximately 3/8" long above end of outer jacket. Tin and solder a length of approximately 2.5" of #26 insulated wire to the braid.
3.3.11 Slide 1.25" of Teflon shrink tube or waste piece of outer jacket over wire conductor down into cup.
3.3.12 Pour epoxy into cup just below the top and leave it to set.
3.3.13 Slide retaining washer over conductor to the cup.
3.3.14 Feed conductors through rear of neoprene boot in a proper order to align with solder pins on connector. (See Figure 4-4).

3.3.15 Strip wire insulation (approximately 3/16"). Twist and tin conductors carefully. Do not apply excessive heat as the insulation would tend to flow back.
3.3.16 Pre-tin pins on the connector. Remove all excess solder. New pins may be difficult to tin - a good grade of rosin alcohol flux maybe used.
3.3.17 Solder conductors to corresponding pins (Figure 4-4). Solder should flow out and on to the rim of pins to ensure good solid contact. Make sure pins 2 and 4 are shorted.
3.3.18 Slide neoprene boot over pins. A bit of silicone grease may be used to ease sliding of the boot.
3.3.19 Slide conductors through sleeve slot - countersink end to face boot.
3.3.20 Remove set screw on barrel housing and slide the quick change nut over barrel housing.
3.3.21 Slide barrel housing over connector. Line up notch on top of connector with keyway on outside of barrel housing. A slight push is necessary. It may also be necessary to guide the connector over step inside the barrel housing.
3.3.22 Loosen set screw on strain relief housing. Slide strain relief housing toward barrel housing and thread it tightly to barrel housing. Do not twist barrel housing. Tighten set screw.
3.3.23 Thread grease fittings to barrel housing. Using grease gun, apply grease. Observe grease flow between connector and barrel housing -indicating sufficient grease. THIS STEP IS VERY IMPORTANT. Replace grease fitting with set screw and tighten.
3.3.24 It may be necessary to align notch on the top of connector with keyway on outside of barrel housing. This may be done by inserting spare male connector into connector and turning towards keyway.
3.3.25 Finally, check electrical connections with ohm-meter.

3.4 BATTERY PACK CHARGING

The BH43-3D controller has four functions:

a) for selection of components to be measured

b) for charging of BH43-3D preamplifier battery

c) for checking calibration of BH43-3D preamplifiers and

d) rejection of VLF signal

Note:

- The preamplifier sensor connection is also used as a battery ON/OFF switch therefore, to disconnect battery from circuit, disconnect the preamplifier from sensors.

- Battery Pack consists of 7 "C" size rechargeable nickel-cadium batteries.

BH43 BASIC CABLE HEAD ASSEMBLY

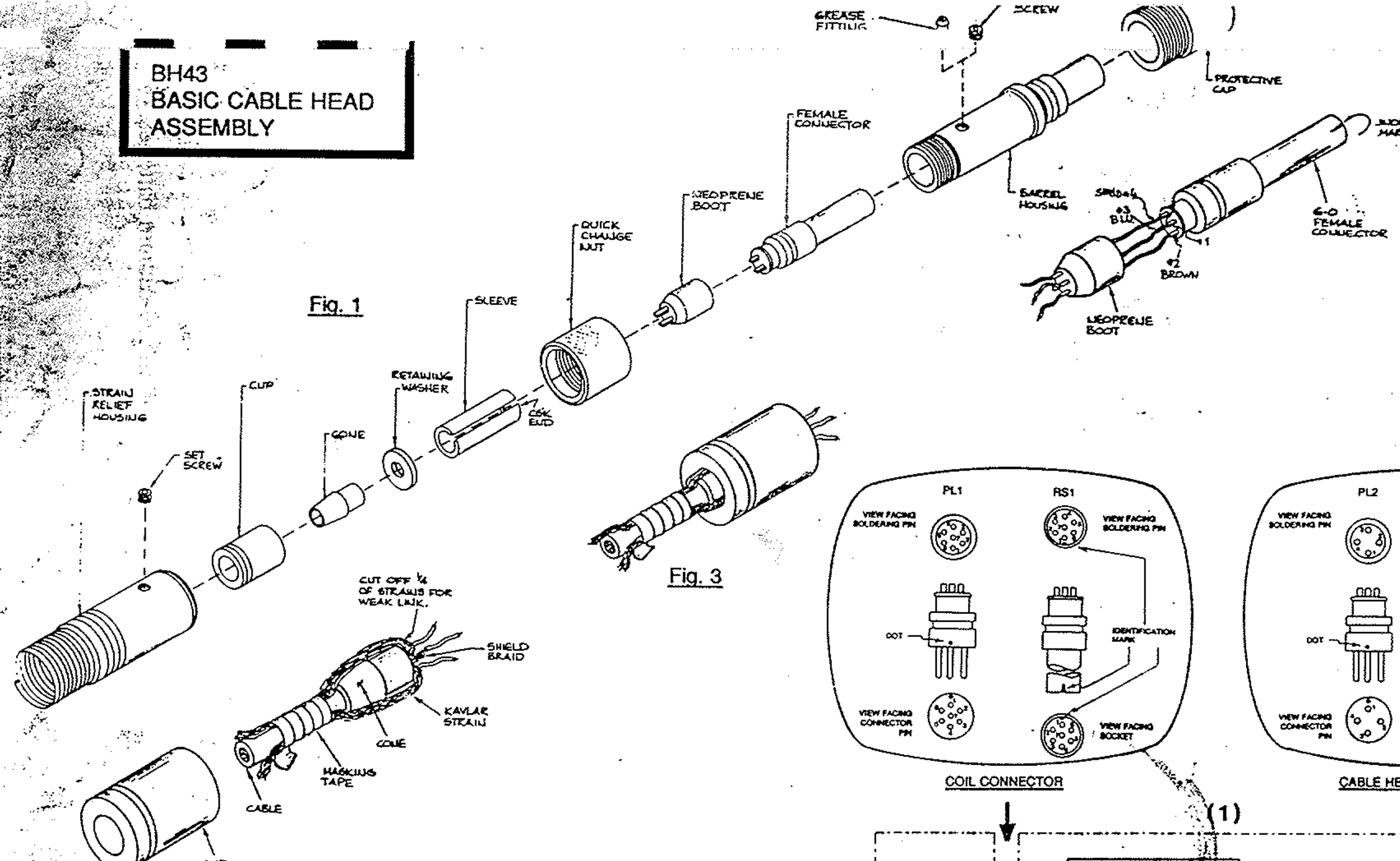
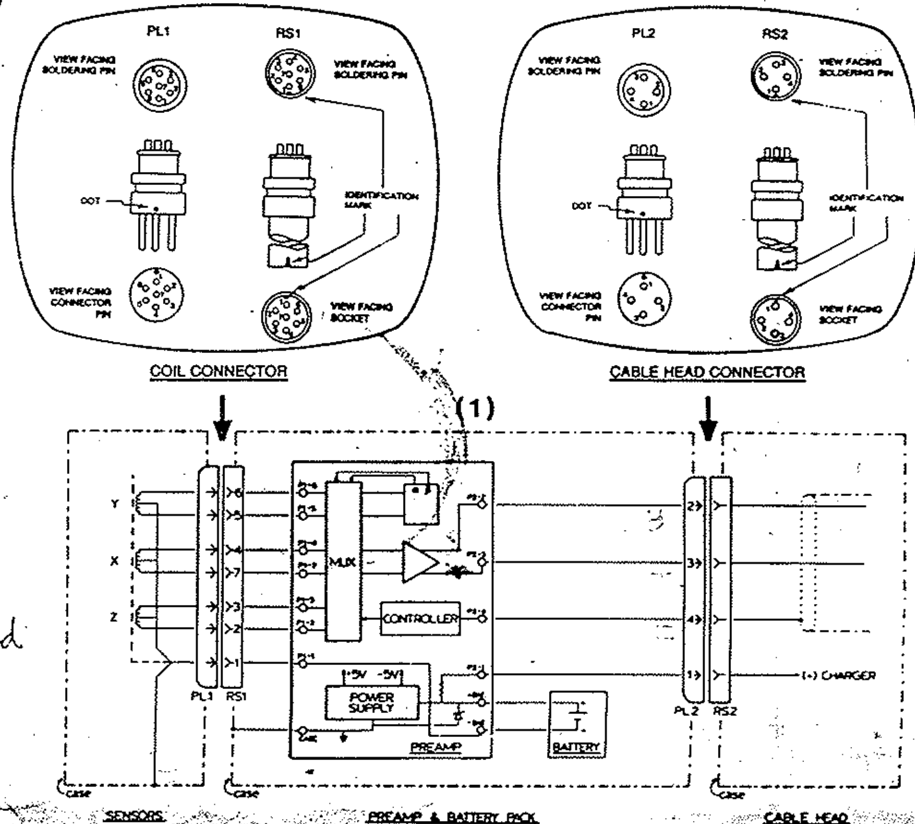


Fig. 1

Fig. 2

Fig. 3



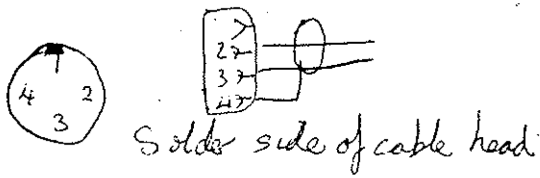


Fig. 4

- Service of fully charged Battery Pack is 40 hours continuous duty.

- Recharging time for fully discharged battery is 15 hours.

- Battery will not be overcharged by prolonged charge.

3.4.1 <u>Battery Charging</u> See memo to SID. for Mio Bosnar for new cables.

- Connect controller to 110 VAC power supply using AC power cable (6). Check that controller internal batteries, one 1.5V AA size and one 9V battery, are in good condition. Note that the batteries should last many months of operation. Batteries are located inside controller box. To get access to the batteries undo the 4 screws on the top of the control box, and remove cover.

- Interconnect "INPUT" of the control box to the cablehead side of the preamplifier with the charging cable (5).

- Interconnect "OUTPUT" of the control box to the sensor side of the preamplifier with the test cable (7).

- Set the mode switch to the "B(mA)" position. will not charge otherwise

Depending on the battery conditions following charging current level will be indicated :

a) Initial charging current of discharged battery: $I \approx 130$ mA.

b) Current after several minutes of charging: $I \approx 110$ mA.

c) Trickle current after several hours of charging: $I \approx 100$ mA.

3.4.2 <u>Battery Voltage Check</u>

To measure the preamplifier battery voltage set the mode switch to B(V) position with the interconnection the same way as for battery charging. Charger meter will indicate battery voltage. The battery voltage of discharged battery is less than 8V, while the voltage of battery charged for several minutes will indicate 9.5 V or higher.

3.5 <u>PREAMPLIFIER CALIBRATION CHECK</u>

To check the condition of the preamplifier connect the controller box the same way as for battery charging and set the mode switch to test mode.

To check the gain of z component push the "Z" switch and hold the CALL switch down. Meter should indicate nominally 200 ± 10 mV. To check other two components (x and

y) repeat the procedure as described for the z component, pushing x (y) button. The reading for each component should be 200 ± 10 units.

To check operation of the tilt sensors, tilt the probe 45° from a vertical position, so that the "y" EM sensor dipole is facing upwards (notch on the preamplifier sensor connector facing up) as per Figure 4B. Push the "α" switch on the controller to measure output from "α" tilt sensor. The display should read 90±5 units. To check "β" tilt sensor, with the same tilt as for "α" sensor check, rotate probe axially for 90° and push the "β" switch. The display should indicate 90±5 units.

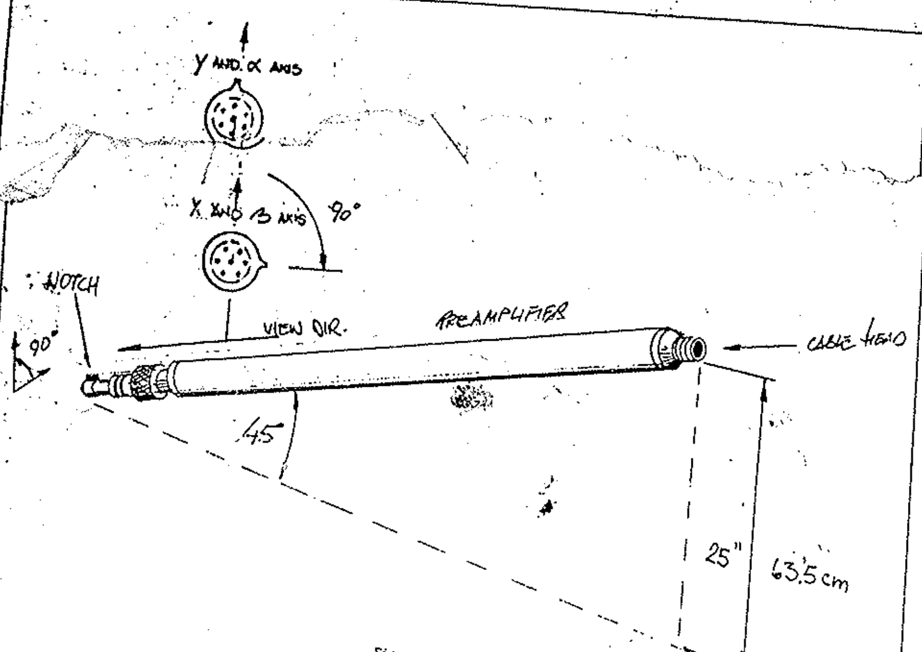


Figure 4-B

.6 RETRIEVAL TOOL AND DUMMY PROBE

The following section describes use and condition for application of the retrieval toll and the dummy probe. Assembly of the tool and probe is self-explanatory and is depicted in Figure 5 and Figure 6.

.1. Dummy Probe Application

If uncertain of the condition of the borehole, lower the dummy probe into the hole to ensure that the hole is clear for passage of the measuring probe.

2 If the dummy probe stops on an obstruction on the way down try to lower and raise the tool in a hammering effect.

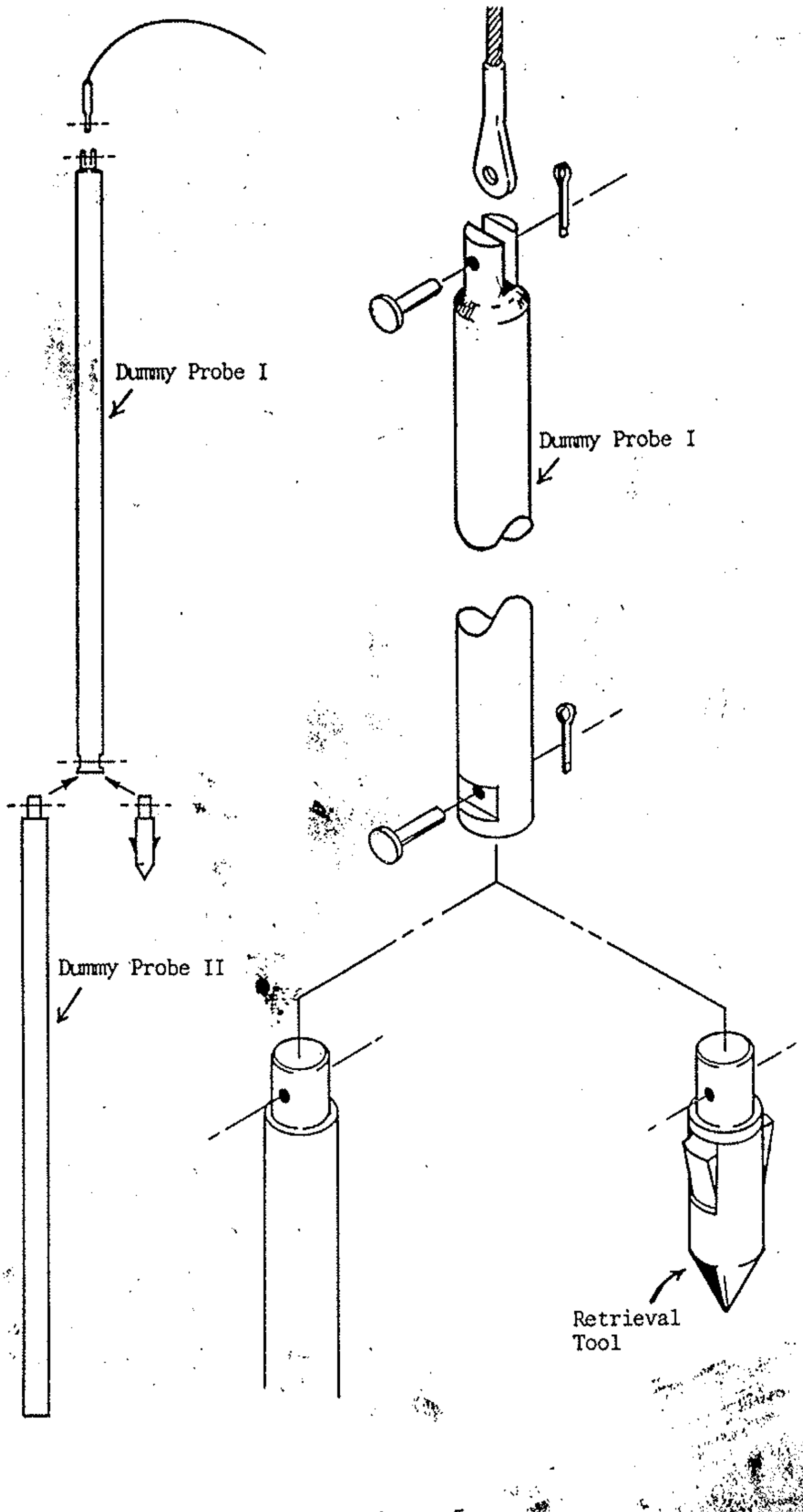


Figure 5.

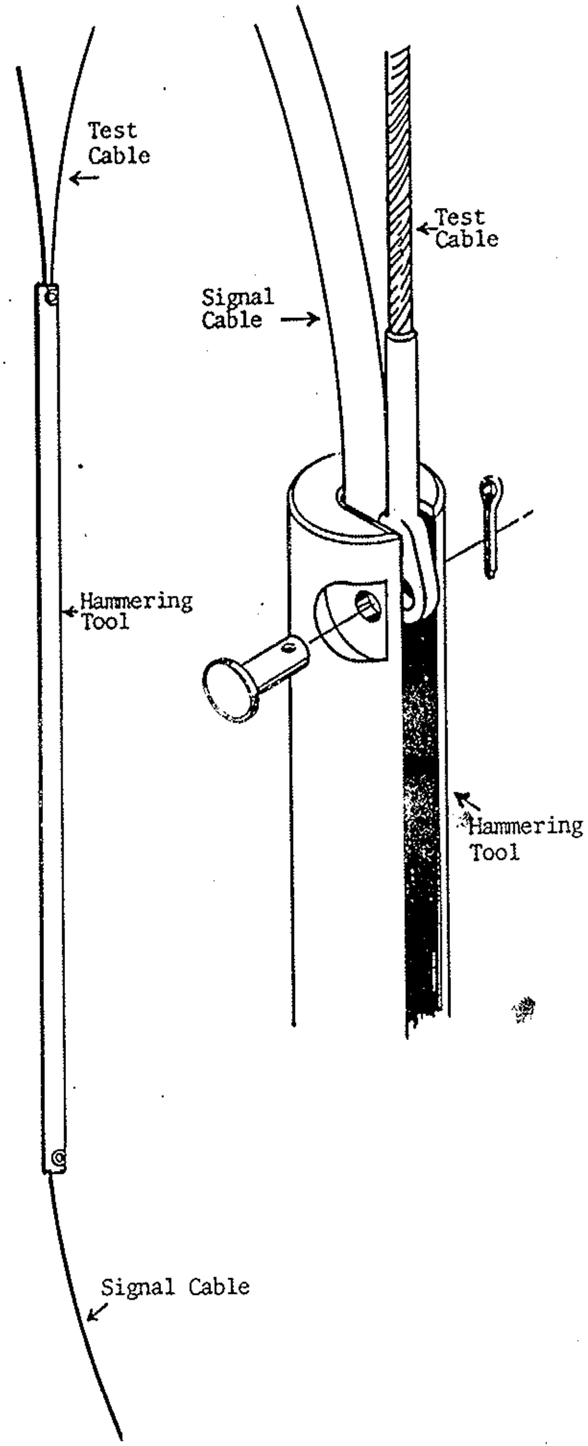

Test Cable
Hammering Tool
Signal Cable
Test Cable
Signal Cable
Hammering Tool

Figure 6.

3.6.3 If the dummy probe reaches the bottom of the hole but stops (without jamming) on the way up, pull upwards, trying both steady pressure and rapid upward movement. Breaking strength of the cable is 350 kg. Endeavor to stay below this limit but if necessary, pull upwards at greater than 350 kg. The cable is designed to break at the neck of the tool. The tool should then fall to the bottom of the hole.

3.6.4 If the dummy probe reaches the bottom of the hole but jams on the way up, pull with steady pressure keeping cable tension below breaking point. If unsuccessful, pull at greater than 350 kg to break the cable. Retrieve the cable. If a second cable is available, attach it to the hammer and attempt to dislodge the dummy probe, bringing it to the surface if possible, or breaking the cable and letting if fall.

3.6.5 If the dummy probe clears both ways but the main probe stops on an obstruction on the way down, retrieve the main probe and try again with the dummy probe.

3.6.6 If the main probe stops (without jamming) on the way up, pull using either steady or rapid movement, cautioning not to exceed 250 kg. Breaking strength of the cable is 350 kg. If unsuccessful lower the main probe and run hammer down the main cable. Use the hammer to attempt to clear the hole, then raise the hammer and the main probe. It is possible that leaving the hammer near the top of the main probe will shift the position of the probe laterally enough to clear the obstruction. If unsuccessful, first retrieve the hammer. Attach the main cable to the winch frame so that it will not run down the hole and run about 10 meters of main cable off the winch and wind it onto the dummy probe winch. Disconnect the main cable from the winch frame and apply sufficient upward pressure to break the main cable which will break at the tool. Replace the main cable on its winch and retrieve. If necessary, use the hammer to ensure that the main probe has fallen to the bottom of the hole.

3.6.7 If the main probe jams on the way up, attempt to use the hammer to drive the main probe further down the hole and if successful, also try to use the hammer to clear above the main probe. If unsuccessful, retrieve the hammer and break the main cable as in 3.6.6 above.

3.6.8 If the main cable detaches from the main probe on the way up, use the retrieval tool to retrieve the main probe. If this fails, attempt to drive the main probe to the bottom of the hole using the hammer.

4. <u>MAIN PROBE WINCH</u>

4.1 <u>Winch Operating Instructions - Cable Installation</u>
(For-W2000-2SL)

4.1.1 Remove one half the split cover on the end of the drum, (the half without the aluminum rivets), to gain access to the brush chamber.

4.1.2 Move the lever at the top of the level wind head towards the front of the winch to disengage the drive pin from shaft. Slide the level wind head to the end of the grooves in the drive shaft near the drive side.

4. .3 Pull the ring underneath the level wind head and feed the cable through the front plastic bushing or roller set, through the head and out the rear bushing or roller set.

4. .4 Insert the cable into the hole in the drum away from the brush end. Slide the cable along the inner tube, under the clamp, through the grommet into the brush chamber.

4. .5 Strip the end of the cable and make desired connections (refer to Figure 7) to the terminals of the brush holders, leaving enough slack in the cable to service the brush holders.

4.1.6 On motorized units depress lever near motor-reducer drive to disengage the reducer. Insert hand crank into one of the square holes of the cranking mechanism.

4.1.7 Engage drive pin at the top of the level wind head and turn crank handle to obtain the desired direction of travel of the level wind head.

4.1.8 Wind the cable on drum.

4. 9 To reset counter on level wind head after cable has been loaded on drum, remove reset knob on the side of the and attach electric drill to the exposed shaft. Pull down on ring underneath head and rotate shaft until desired setting is achieved and replace knob. Minor adjustments to zero the counter may be made by pulling down on the ring and turning the knob by hand.

4. 10 Slight adjustment to the longtitudinal position of the level wind drive shaft may be necessary. To achieve this loosen the collars of the bearings by means of loosening the set screws and rotating the collars counter-clockwise and tap the shaft in the desired direction and relock collars.

Note:

a) Drive Chain Alignment and Tightening

All the bearings used in the winch, except the drum bearings, are of the self-aligning type. To tighten the chain or re-align the chain sprockets simply loosen the fasteners securing the bearing flanges and tap the sprockets with a mallet in the desired direction, then re-tighten the fasteners. For motorized units the chain tension is facilitated by an idler sprocket.

b) Maintenance

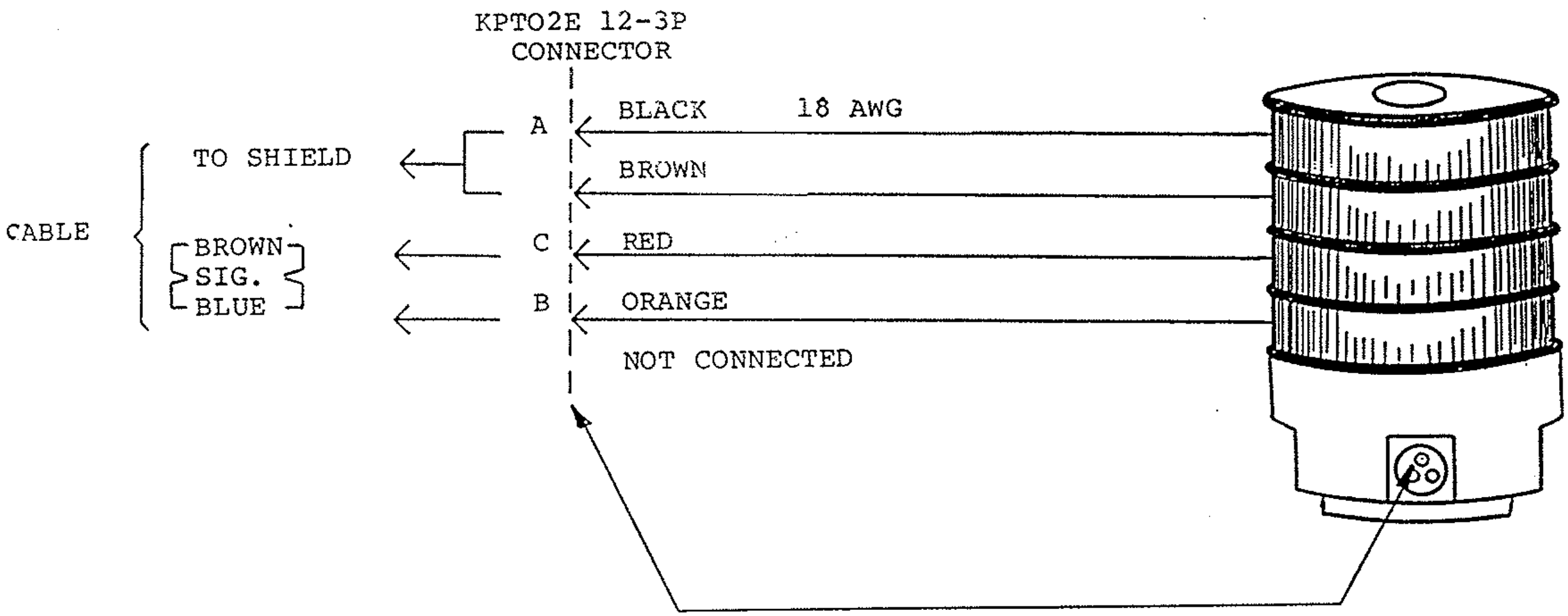
- Slight lubrication of level wind shaft with a light oil or regreasing the chain may be necessary from time to time.

- In hostile environments frequent cleaning of moving parts is essential.

c) Installation of Cable

- In order for the cable to wind properly on the drum, a "dummy" winding is required between the drum ring and the rectangular hold, both of which are furthest from the connector hub.

Use the same type of cable as a main cable and wind it in this space, taping it to the drum. It should be terminated such that when the cable comes out of the rectangular hole, it will lay beside the "dummy" layer and will not cause a lump in the winding.



GEONICS RING ASSY.

Figure 7.

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Telex 06-968688
Cables: Geonics

Technical Note TN-15

TRANSIENT ELECTROMAGNETIC BOREHOLE LOGGING

G.M. LEVY, J.D. MCNEILL

Paper presented at the KEGS/GSC Symposium on Borehold Geophysics
University of Toronto, August 1983

AUGUST 1984

TRANSIENT E.M. BOREHOLE LOGGING

G.M. Levy & J.D. McNeill

INTRODUCTION

The technique of transient or time domain electromagnetic (TEM) surveying is finding ever wider application in the field of resource exploration and development. This paper will describe the technique as embodied in the Geonics EM37/BH43 borehole system, describing the basic physical principles which come into play. The nature of the instrument response to conductive overburden, host rock, and confined bodies will be discussed. More detailed treatments can be found in the references listed at the end of the paper.

MEASUREMENT TECHNIQUE

The procedure used in borehole logging is to lay a large loop transmitter (Fig.1), typically hundreds of meters on a side, in the vicinity of the borehole. Often several different loop positions are used to aid in interpretation. The receiver is lowered into the borehole, and data is collected at each station chosen for measurement, using a magnetic tape data logger located at the surface. An HP85 computer is used for final data editing and reductions.

Transient EM is distinguished from the more familiar frequency domain EM by the transmitter waveform, and by the way in which the receiver signal is analysed (Fig.2). In the case of the EM37, a steady current of up to 30 amperes is caused to flow in the transmitter loop, for a time sufficiently long to allow transients induced in the ground by the switched current essentially to dissipate. This current is then turned off sharply, which results in currents being set up in the surrounding medium so as to oppose any instantaneous change in the magnetic field. These currents then decay away according to the conductivity structure of the medium (as will be discussed in more detail below) and it is the field due to these currents - or more precisely the time derivative of this field, dB/dt, - which is measured at the output of the receiver coil.

The EM37 receiver divides the time period after turnoff into 20 segments or gates, covering a range of 2 decades in time from the earliest to the last, or 3 gates per "octave". The signal for each gate is added to the signal for the same gate for previous repetitions of this basic cycle (stacking), until adequate signal-to-noise is reached.

One principle advantage of TEM over frequency domain EM is that, in the above manner, responses which are analogous to responses for 20 single frequencies ranging over 2 decades, are gathered at the same time, rather than having to be recorded separately. With the EM37 operating at a base frequency of 30Hz, the earliest gate is centered 89 μs after the end of turnoff, and the latest gate at 7.2 ms. If later times are important a lower base frequency may be used.

Another advantage is that, since measurements are made while the TX current is turned off, the measurements are insensitive to small variations in the RX orientation, which could otherwise produce changes in coupling with the primary field.

One complication in analysing the response arises due to the fact that the transmitter turnoff is not actually instantaneous, but rather takes place over a finite period of time. In fact, for the 30Hz base frequency, the turnoff ramp is typically 300 μs long, whereas the 1st gate starts less than 100 μs after the end of turnoff. This means that the response measured by the instrument is not quite the same as would be expected for an ideal impulse, but is rather the ideal impulse response convolved with a rectangular wave-form of width equal to the duration of the turnoff. As the difference can be quite significant for the earlier gates, this must be taken into account, and a deconvolution operation may be carried out as part of the data reduction procedure.

Other TX waveforms are used in TEM work as well. One particular case of interest is the UTEM system, in which the waveform used is essentially triangular in shape. The effect is to provide a response which corresponds to the B field which would be obtained for the case of an EM37 type of waveform, as opposed to dB/dt. The cost is having to make measurements while the TX is on.

The EM37 reduction software routinely provides B, as it is automatically calculated in the process of deconvolving the waveform, and so may be used with interpretation techniques based on this quantity rather than dB/dt.

SECONDARY RESPONSES -

Resistive environment

Returning to the secondary response due to currents set up in the surrounding medium, it is instructive to examine what we might expect in some idealized situations. The simplest case is, of course, free space. In practice this means an environment with resistivity so large that the currents have decayed to levels below the detection limit by the time the 1st gate begins; rather uninteresting except to note that this has happened.

Thin sheet

Not quite so trivial is the situation of a thin conductive overburden, overlying a highly resistive medium which may be considered again as essentially free space (Fig.3). In this case a current flow is set up in the sheet which at very early times is concentrated very closely in the vicinity of the TX loop. (This distribution mirrors the field which existed immediately prior to turnoff). However, the current very rapidly diffuses across the sheet and the field eventually decays as t^{-3}. The field for the thin sheet may be easily calculated, as image theory tells us that the response is that which would be obtained for a current loop which is the size and shape of the TX loop, but which moves away from the measurement point, in a direction perpendicular to the sheet, with a velocity inversely proportional to the plate conductance.

Half-space

In the case of a conductive half-space, the current distribution is again initially confined to the vicinity of the TX loop; however, in this case, the diffusion of the current proceeds downwards as well as outwards. Figure 4 shows current density contours calculated by Nabighian (1979). (Hoversten and Morrison 1982, have published similar contours for up to 3 layers.) The peak current density is seen to move downwards and outwards at about 30° from horizontal. The shape of the current distribution in the ground is a function of ρt, the product of the resistivity and the measurement time: indeed the peak in current density occurs at a horizontal distance from the TX given by 1.6 $(\rho t)^{\frac{1}{2}}$ km. Nabighian also points out that the field as measured at the surface at late time, is in fact close to that due to a current loop decaying as 1/t and travelling downward and outward at 47°. This is a simplification which is useful in understanding the type of response we see in practical cases.

Figure 5 shows responses along a 45° borehole extending to a depth of 500m in a 50 ohm-meter half-space, for 3 different positions of a 200m radius circular TX loop: centered over the upper end, middle portion and deep end of the borehole respectively. The responses plotted are for the axial downhole component of the field in units of nV/m^2 for a 1 amp TX current. (EM37 noise levels are not discernable with this plotting scale, so these responses will occur at high signal-to-noise ratio.) In Figure 5a we see results for earlier gates - 2,5, and 8, corresponding to ρt values of approximately .005, .01 and .02 ohm-m-sec. The response tends to peak in the upper portion of the drill hole, though there is some indication of the peak becoming deeper and broadening towards the later times. At points within the borehole, it can be seen that at earlier times the rĕsponse may actually increase in amplitude with time. The detailed shape of the response, as might be expected, depends very much on TX position. In fact, for these gates, the response with the TX loop centered over the deep end of the hole is opposite in sign to the responses for the other 2 TX positions: the upper portion of the borehole is outside the effective current loop in the ground for the one TX, inside for the other 2.

Figure 5b shows the responses for later gates, ρt being .04, .08 and .16 for gates 11, 14 and 17. As the currents move farther from the original TX positions, the responses become smaller, deeper, and broader, and the differences in TX position become less and less important.

Confined Conductors

The response of confined conductors is of considerable interest, as this is a model which can often be used to represent ore bodies. Figure 6 illustrates the physical effects which combine to set up current flow in confined conductors. The important factors to be considered are the electric field vector, $\bar{E}$, and the rate of change of the magnetic field vector, $d\bar{B}/dt$ or $\dot{\bar{B}}$.

The effect of the $\bar{E}$ field is rather involved, and dependent on the conductivity and shape of the target body, and the conductivity of the host rock as well (Edwards 1974; Kaufman 1978); however the net result is current flow in the conductive body in the direction of and in proportion to the field itself - the so-called current gathering effect or Galvanic response - accompanied by a diffuse return current in the host medium. Note that if the host medium is highly resistive, the field dies away rapidly, as does this current, according to a $t^{-5/2}$ power law.

The secondary field produced by the Galvanic component of the current can be useful in determining the position of the body; however much more information can be obtained about the body if effects of vortex currents, produced by $d\bar{B}/dt$, can be observed. As in the case of the thin sheet or half-space, any change in the magnetic field sets up currents which initially are confined to the surface of the body and which oppose the change in the field. The currents at this time can be considered as loops at the surface of the body, circulating in planes perpendicular to the $\dot{\bar{B}}$ vector excitation. Once the initial $\dot{\bar{B}}$ disappears, these currents diffuse to the interior of the body, in a manner which is determined by its shape and conductivity. Conceptually, the currents may be resolved into component currents, the paths of which are characteristic of the body's shape (eigen-currents). These eigencurrents each decay exponentially at rates which reflect the effective L/R time constants for the different

:urrent paths. At sufficiently late time (late stage), the current ›a' ı with the largest decay time constant will dominate (Kaufman, .978).

n the case of a thin, plate-like body, the currents will quickly be eċ ıced to those in the plane of the plate, although the distribu- ic.ı within the plane will continue to change until the late stage or the largest loop is reached.

xamination of the secondary field due to vortex currents in a con- in d conductor can reveal several properties. The longest decay ime constant is proportional to the conductivity times the smallest ro s section of the body. The spatial variation of the field is ndıcative not only of the position of the body, but also of the ri-ntation of the effective plane of the vortex current. For xa.ple, a thick body will produce a response which corresponds to ırrents in a plane determined initially by the direction of the ri ary field, but which eventually rotates to a direction character- stic of the body's own geometry. It may often be distinguished by ıi type of behaviour from a thin plate-like target in which the ›rtex currents always remain in the plane of the plate.

: sufficiently early and sufficiently late times, the Galvanic ır-ents due to the $\bar{E}$ field will dominate the vortex currents set i ı the confined conductor by $\dot{\bar{B}}$. However under favourable conditions .e vortex response may be strong enough to be useful in te pretation. It can be shown that the ratio of the vortex current the Galvanic current is at its maximum at a time after turnoff ua to a few vortex decay time constants.

gı ·e 7 shows the borehole response for the late stage vortex rıents in a plate-like confined conductor. The shape is constant, t the amplitude decreases exponentially with time. The asymmetry t .e shape is characteristic of a body which is dipping with respect the borehole direction, while the width of the response reflects e istance from the borehole. The actual plate-borehole geometry shown in Fig. 8 - the curves of Fig. 7 being generated by the plate with the solid boundary. An interpretational problem arises in borehole work when only the field component along the borehole axis is measured, as the response produced by currents in a body in one particular position does not change if the body is rotated arbitrarily about an axis along the borehole. Thus the flat-lying plate in Fig.8 (dashed boundary) can, when suitably excited, produce the same shape response as the vertical plate. The main difference will be the amplitude of the response. Indeed, by using several different psoitions of the TX loop it is possible to resolve such ambiguities, through consideration of the response amplitudes for different possible body positions and how these vary with the TX positions.

Figure 9 shows the vortex response of the vertical plate of Fig. 8, combined by simple addition with the response for the 50 ohm-meter half-space, for the same 3 TX positions used earlier. (Simple adding of the responses is not strictly correct, but often close enough.) The late gates only are shown; at the earlier times the plate response is almost completely lost in the half-space response. As can be seen the plate response is strongest with the TX to the left. Note also the change in sign of the response between the left and the other two TX positions. The variation in behaviour would be very different were the plate lying in the horizontal position.

Another point illustrated by this set of responses is the importance of recognizing the influence of the half-space on the profile shapes. Any attempt to determine attitude parameters for the plate, for example from the shape of the curves with the left TX position, is likely to be considerably in error if the effect of the half-space response is not first removed with sufficient accuracy.

In conclusion, transient EM can be a powerful tool in borehole applications; however, attention must be given to the various interpretational complications if it is to be used most effectively.

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pa e fields.

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Modes of Operation

Borehole

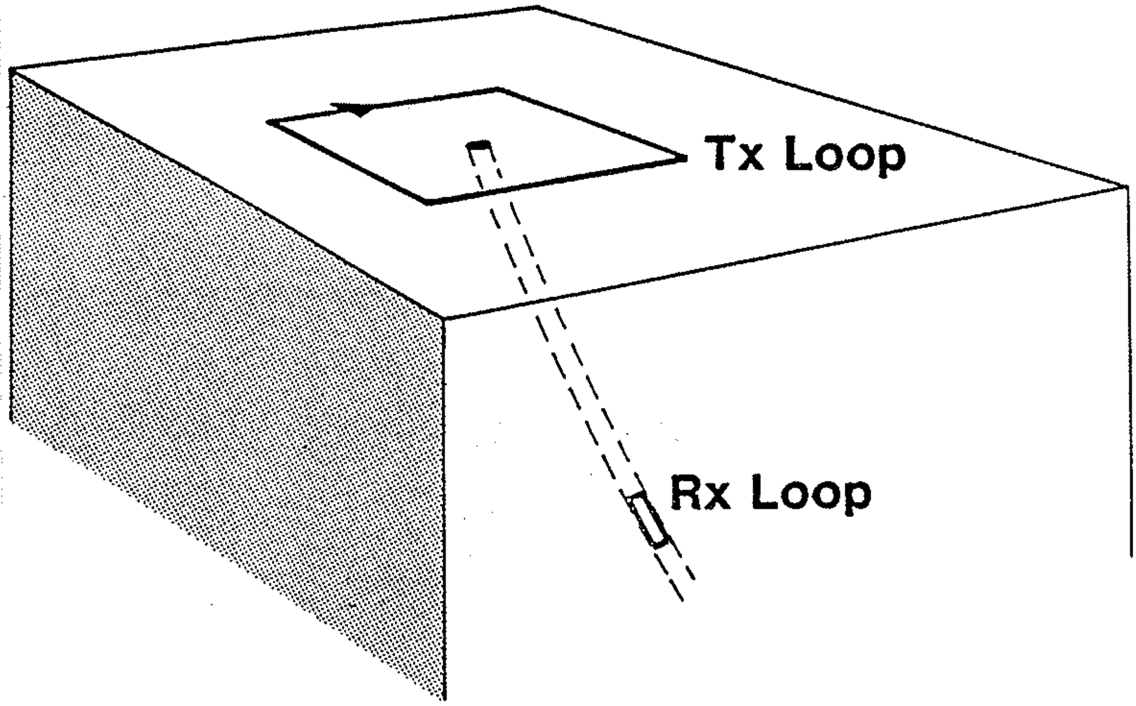


Figure 1

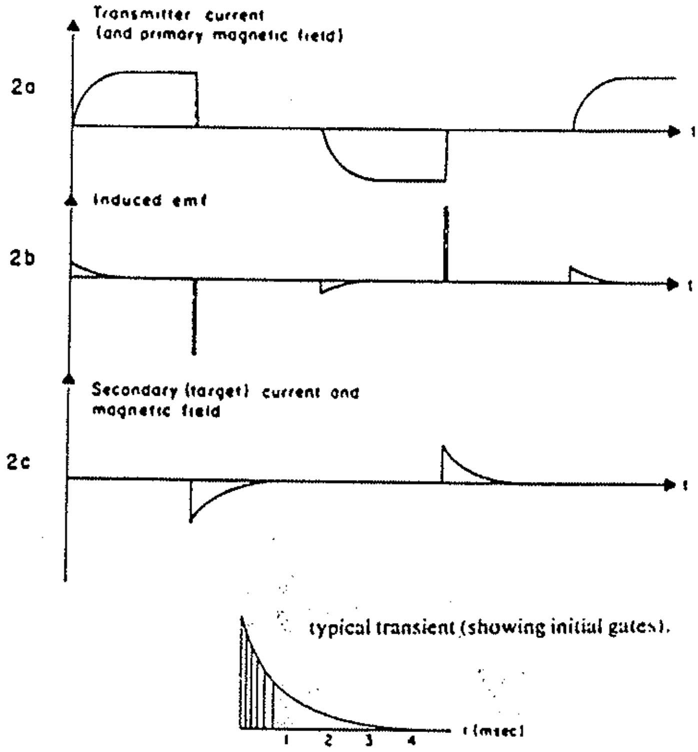
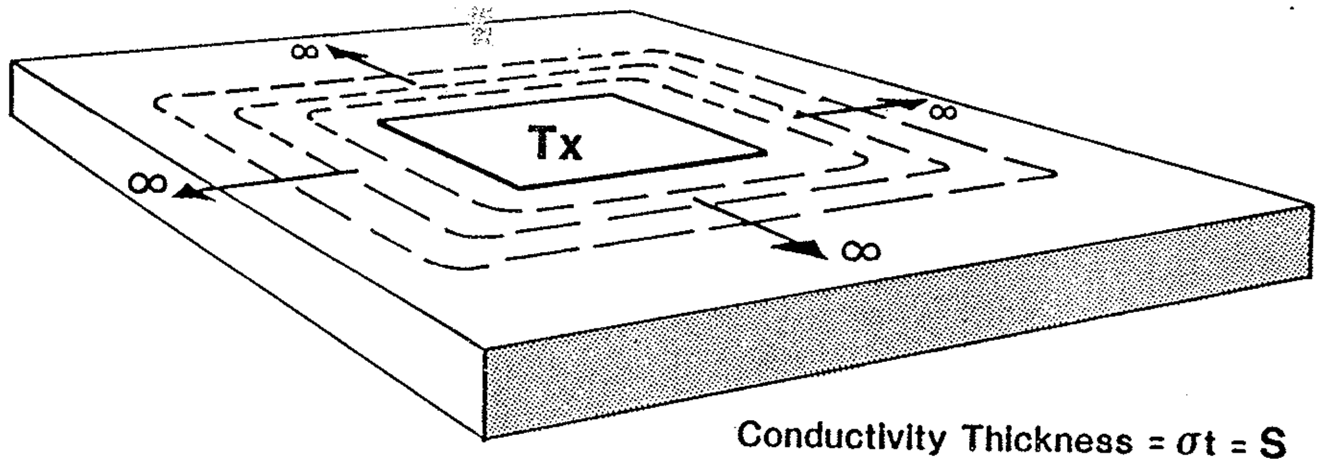


Figure 2. TEM waveforms.

Unconfined Conductors

Horizontal Thin Sheet



Conductivity Thickness = $\sigma t = S$

At late time (horizontal coil receiver)

Signal voltage $\propto \frac{S^3}{t^4}$

Figure 3

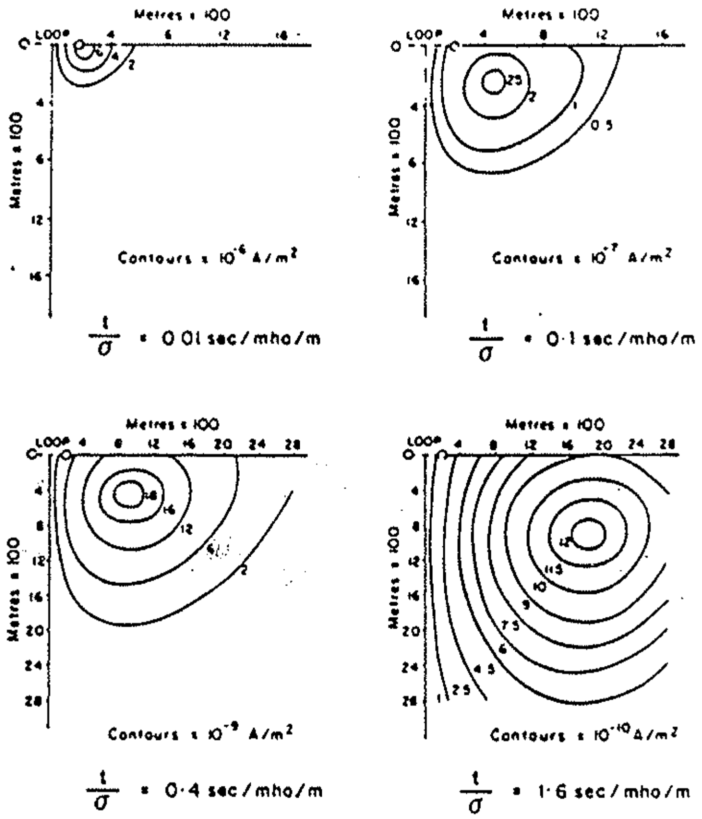


FIGURE 4. Computed contours of current density passing through loop centre (loop has dimensions 400 × 800 m).

)MOGENEOUS HALF-SPACE RESPONSE
ARLY GATES

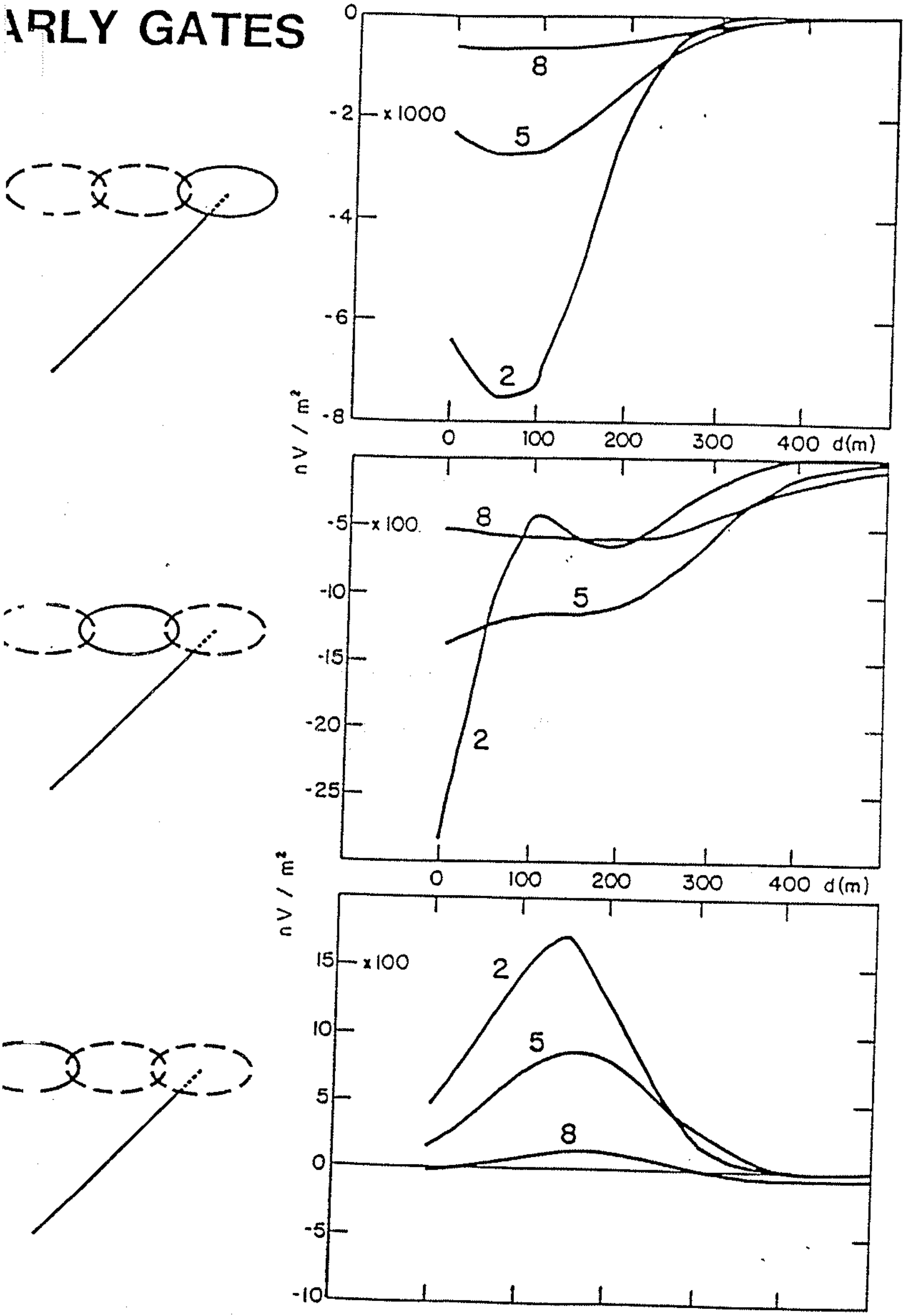


Figure 5A

HOMOGENEOUS HALF-SPACE RESPONSE

LATE GATES

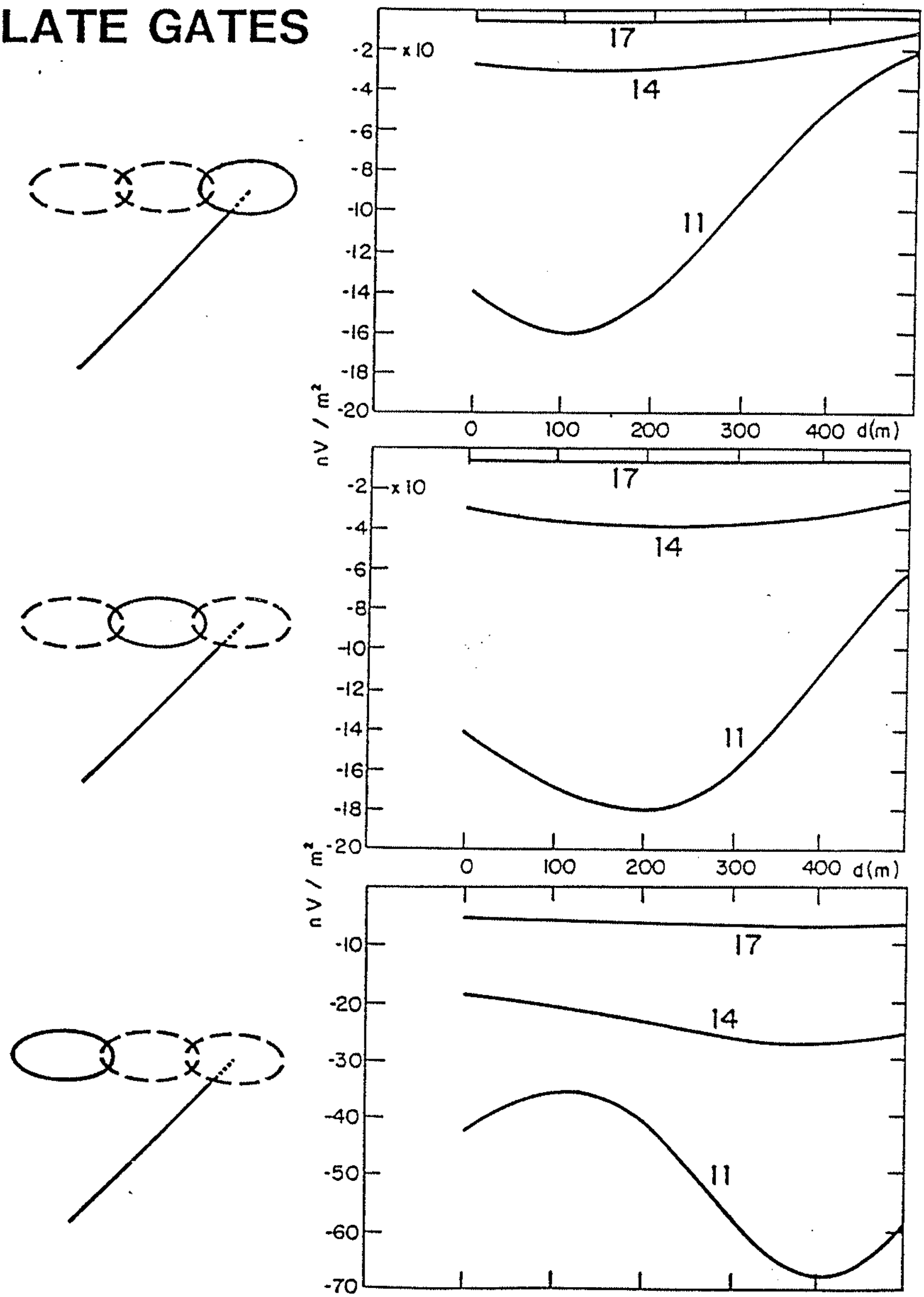
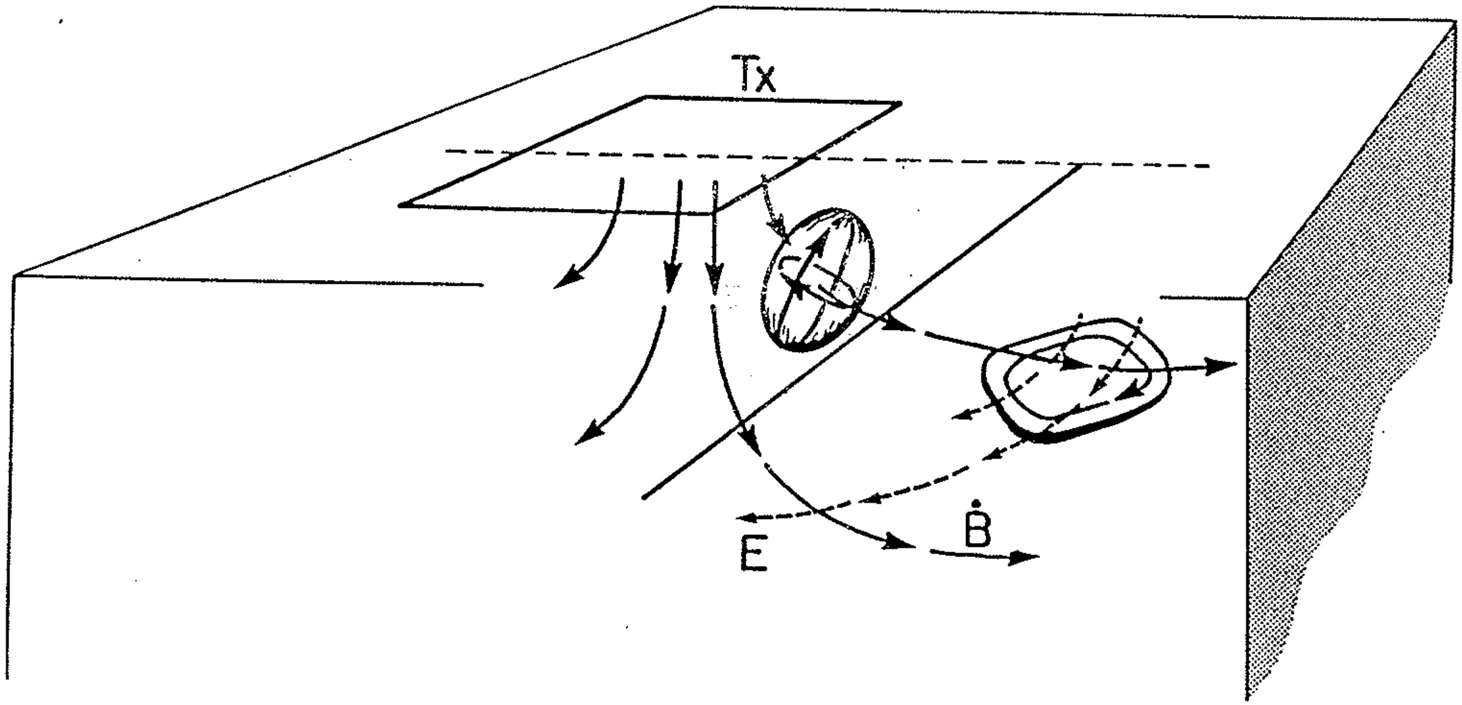


Figure 5B



CONFINED CONDUCTORS

Figure 6

PLATE RESPONSE LATE STAGE

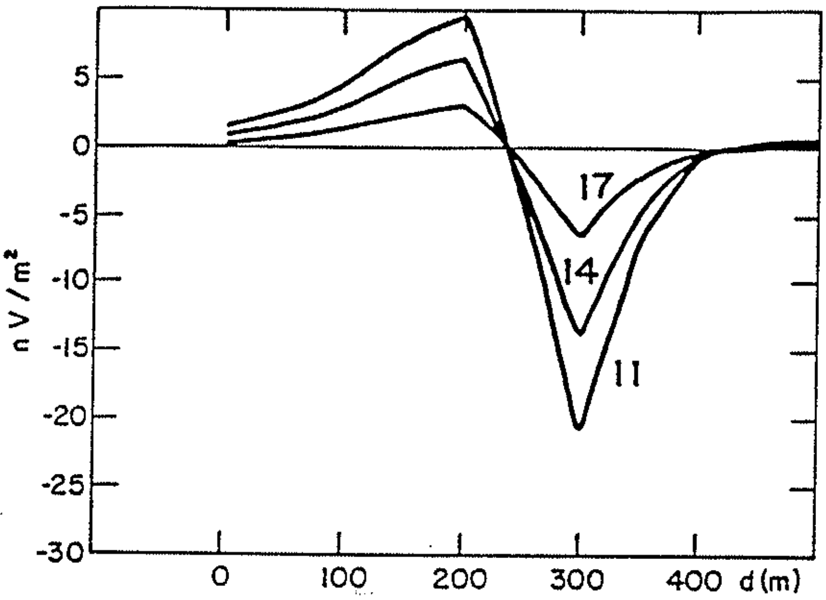
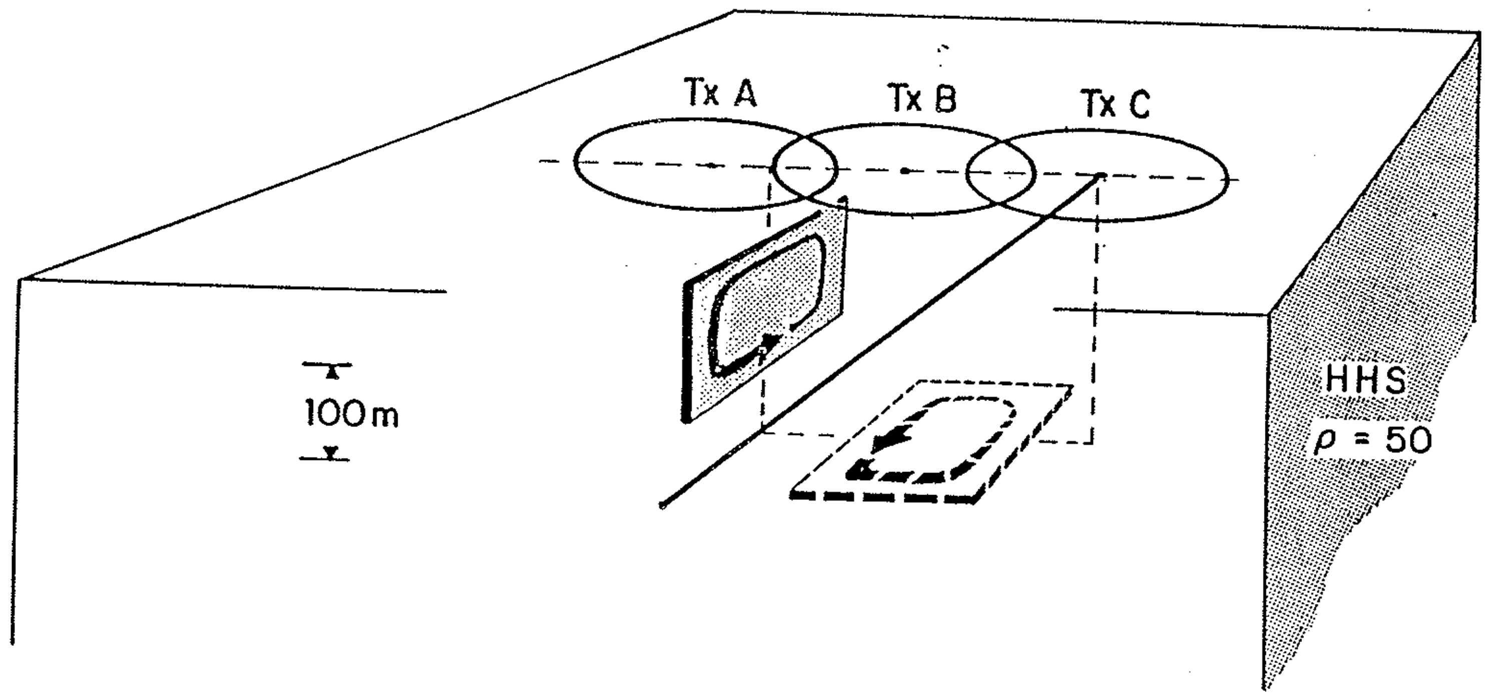


Figure 7



MODELLING GEOMETRY

Figure 8

PLATE AND HALF-SPACE

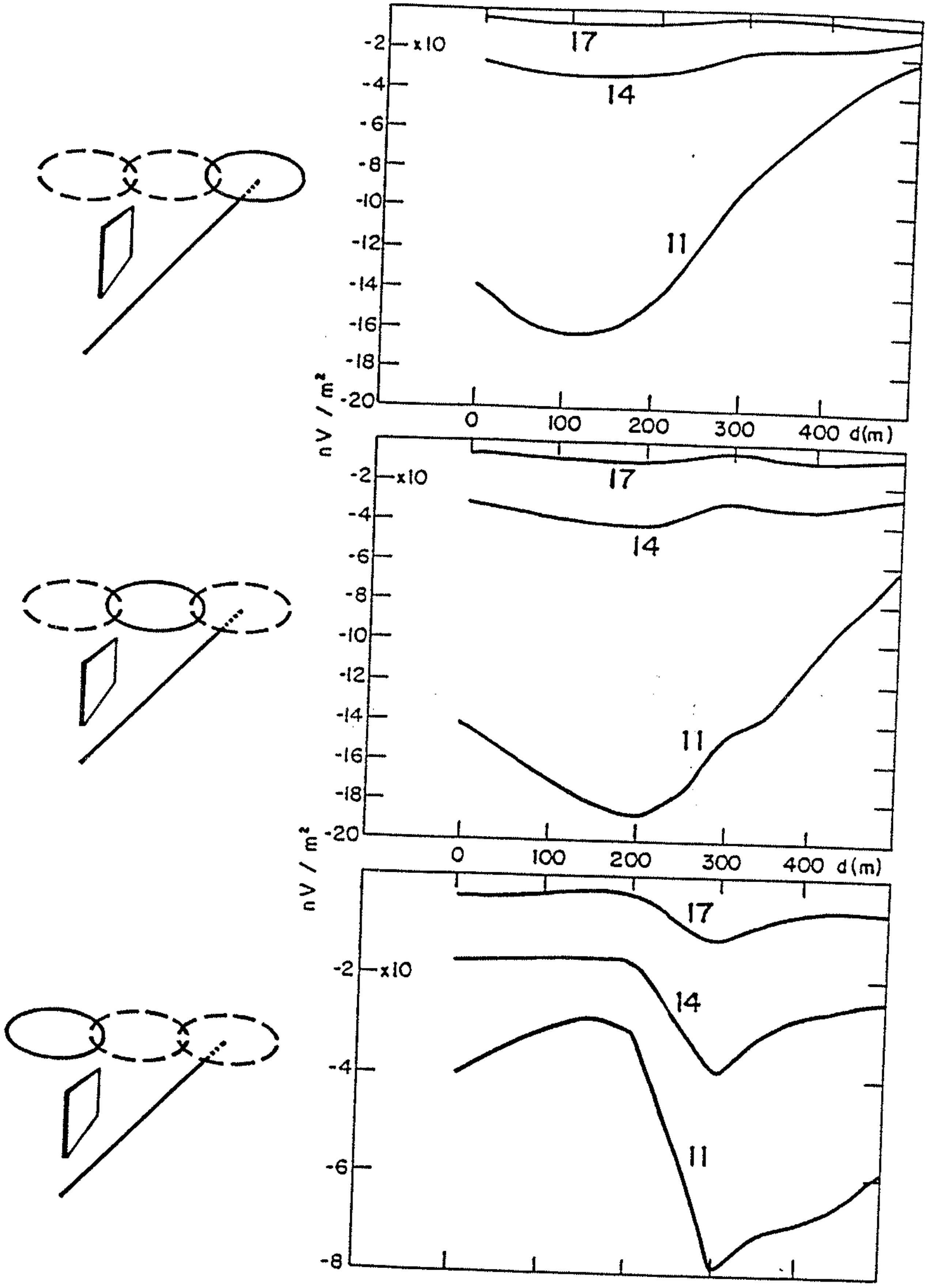


Figure 9