IRISH - DUTCH

GEOHYDROLOGY AND ECOLOGY STUDY

- O. P. W. Wildlife Service, Dublin
- Department of Nature Conservation, Environmental Protection and Wildlife Management, The Hague
- Geological Survey of Ireland, Dublin
- National Forest Service, Utrecht

Report on a geophysical survey at Clara bog and Raheenmore bog Co. Offaly Ireland.

by
A.Farenhorst and Dr. D.T. Biewinga.

Fysisch Geografisch en Bodemkundig Laboratorium
University of Amsterdam
Nieuwe Prinsengracht 130
1081 VZ Amsterdam
The Netherlands

Irish/Dutch co-operation project on Clara bog and Raheenmore.
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1. Introduction.

A geophysical survey has been carried out in a three months period, January 5th - April 5th 1990, at Clara bog as well as Raheenmore bog. The survey is part of the first phase of a three year co-operation project between the Wildlife service, Irish government, and Staatsbosbeheer, the Dutch government.
The survey is carried out in order to determine the thickness of the peat, and the thickness and nature of the individual underlying layers including the depth to bedrock, at both bogs.

For this purpose two different techniques were used: (1) an electromagnetic survey with the EM-34-4. (2) an electrical survey with the ABEM Signal Averaging System 300 Terrameter. With the first technique it is possible to map terrain conductivity. The second technique is used to detect the resistivity layering.

In order to map terrain conductivity the researchers, M. Smith and A. Farenhorst, surveyed roughly 20 kilometer on the bogs. Preliminary at both bogs, 10, 20, and 40 meter coilspacing were used, with both horizontal and vertical coils. This to obtain information of all possible exploration depths.
At Raheenmore bog the 20 meter intercoil spacing, horizontal coils, with an exploration depth of 30 meter, reflects the most variation with distance. This coilspacing is used to survey the grid-lines crossing the bog, and to map contour-lines of 30 meter exploration depth.
Interesting locations for EM 34-4 survey at Clara bog are the Eskers to the north of the bog, and the ridge near the soak. Clara bog is extensive. EM 34-4 survey, resulting in mapping the electrical conductivity of Clara bog and surrounding area in 2 months is impossible. Therefore little attention is given to cross the bog itself.
In this report, all traversed lines are grafically reflected, where smoothed conductivity is plotted against distance. Interpretation of the layered earth, relative depths or if possible depth values of the layers, are given below each graphic.

A total of twenty-four Vertical Electrical resistivity Soundings (VES) were carried out, using the Schlumberger array. Mostly, the maximum value as AB/2 = 500 meter, to ensure that bedrock could be determined. The computerprogram Resint (version 3.1) written by D.T. Biewinga was used for final interpretation.
At Raheenmore bog thirteen soundings were carried out at 200 meter intervals along two traverse lines, approximately 600 meter apart, running North-West to South-East relative to the National Grid. One sounding is made between both traverse lines on farmers land at the North side of the bog. After interpretation, the soundings are reproduced in a map, with the same scale as the terrain conductivity contour-map of Raheenmore. Both maps are used to reach a settlement according to the depth to bedrock and the thickness and nature of overlying layers at Raheenmore bog.
At Clara bog ten soundings were carried out. Four Schlumberger soundings were taken at 300 meter intervals along a line running South, parallel to the main road. Four other shorth soundings were taken parallel to each other on the esker edge to the north of the bog, and two soundings were taken across the longitudinal axis of the ridge near the soak. Besides direct information of the resistivity layering at specific locations of Clara bog, the information of the interpretated soundings are used for (graphical) interpretation of the traverse lines with the EM 34-3 at Clara bog.
The interpretation and model parameters of all the soundings are given in Appendix A in this report.

The co-operation project deals with a wide range of interests, such as Geological, Geophysical, Hydrological, and Ecological research. The people involved in the project, students and supervisors, will have a different specific background. I decided, therefore, to write my report to various involved persons as informative and understandable as possible.
Chapter 2, background information, is written for students who are new in this project or for those which are not (yet) involved. Chapter 3 is written for those who are interested in the Geophysical theory, although the interpretation and results of the geophysical survey can be understood without.
Chapter 4, 5, 6 and 7 are written for students and supervisors which are involved in this project.

2. Background information.

2.1. The research project.

Most of the raised bogs, which once covered 310,000 ha (Cross, 1988) of the Irish countryside (about 26 percent of the total land area in Ireland), have been removed or extensively damaged during the present century. Turf cutting, either by hand, or the more intensive mechanisation, which started in 1946 by Bord na Mona, as well as afforestation have reduced the raised bogs, intact and remnant areas, to 22,000 ha (Cross, 1988).

Although most people in the past, and still some nowadays, thought or think that peatlands can be used only for fuel and energy, realization of the intrinsic value of intact peatlands is more common at present today. The appreciation of conserved peatlands, not as wastelands for rough grazing or, after 'improvements' for agriculture and forestry, but as intact peatlands has made the government more active in the preservation of bogs and in management.

First of all not only the pure nature side is important. Many plants and animals live exclusively on bogs. The beauty of boglands is incomparable with any other scenery. Secondly there is also the importance for mankind to preserve boglands. Many organisms, which inhabit the bogs, are used in medicines to treat diseases. Besides bogs are interesting from a scientific point of view. It tells us our past environment, principally by pollenanalysis, and it is a living outdoor laboratory for continuous studies of the inhabitants of the bog and their present-day environment.

Not only the Irish government has aquired various bogs as reserves and hopes to purchase several more in the coming years, but also from outside Ireland, there is an interest in the Irish boglands. 'The Irish raised bogs systems are the only remaining more or less intact systems comparable to the original Dutch peatlands' (project organization paper, 1989). Mainly from this point of view and from the fact that there are no intact peatlands left in The Netherlands, the knowledge and experience from research projects on boglands in Ireland are of interest to both countries. The Dutch government needs information for their bog restoration projects. The Irish government needs the same information, but their purpose is the preservation of their last 22,000 ha of intact raised bogs.

In october 1989 the first phase of a three year co-operation project between the Wildlife service, Irish government, and Staatsbosbeheer, the Dutch government started. Area of interest are two protected raised bogs (Figure 1.1), Clara bog (460 ha.) and Raheenmore (162 ha.), both owned by the Wildlife service.

Especially Clara bog, but also Raheenmore, is mentioned in various publications and documents. Often, the information has a strong descriptive character towards the public (Bellamy, 1986; Cross, 1988).
Raheenmore is a raised bog with well-developed hummocks and hollows. 'The depth of peat is exceptional, being over 15 meter in places' (Bellamy, 1986). Clara bog is one of the largest remaining Midland raised bogs, containing the only well-developed examples of soak systems. 'The soak system and the associated flora are the main reasons for conservations of Clara bog' (Hammond, Warren and Daly, 1987).
The same authors remark that 'yet there has been little research on the source of the "soak", on hydrology of the bog, and its relationship with the surrounding area'.

The first steps of the project are hydrological observations, mapping of the topography, mapping of the geology and related geophysical research and soil and vegetation studies. The final report must propose a hydrological management scheme, which is an essential element for preserving Clara and Raheenmore bog.Probable, the project will also give relevant information for related or comparable raised bogs. Besides the project make inquiries to the posibility for a heritage centre near Clara bog, an attraction for tourism in the area.

Tourism can save bogs by preservation of bogs. Instead of destruction by turf cutting it gives economic security. This is only possible if public opinion is aware of the speciality of bogs and the obligation to preserve peatlands.

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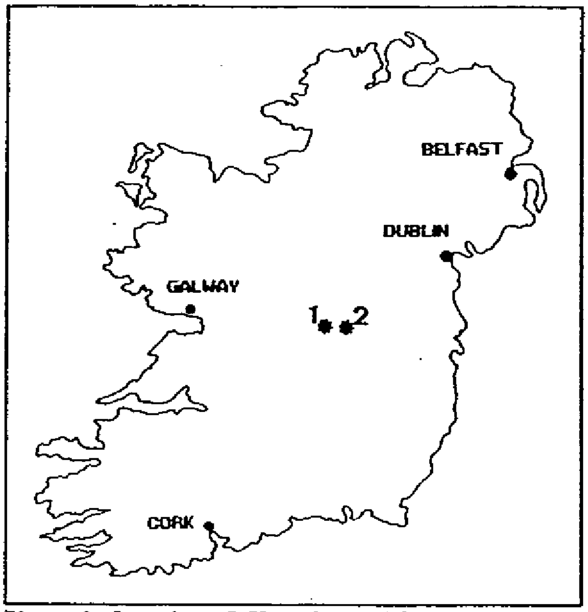

Figure 1. Location of Clara bog and Raheenmore
1. Clara bog (Co. Offaly) 460 ha., 2 km south of Clara.
2. Raheenmore Bog (Co. Offaly) 162 ha., 7 km south-east of Tyrrellspass.

2.2. Geology of Co.Offaly.

'In Ireland we find our oldest rocks at Rosslare and Kilmorequay in Wexford, and these have been given an age of 2000 million years.' (Mitchell, 1976).

The oldest rocks in Co. Offaly, however, are present in the core of the Slieve Blooms and near Moneygall. These grey and grey-green clayey sandstones and slates were slightly metamorphosed by a phase of folding at the end of the Silurian Period (395 - 435 million B.P.). The rocks are folded with the axes of the folds trending NE-SW.
Beside these rocks we can find also other Palaeozoic rocks in Co. Offenly, overlying the Silurian rocks.
First of all there is a mixed sequence of red sandstones, siltstones, mudstones and occasional conglomerates, wich were deposited on the Devonian land mass by meandering rivers. These in turn are overlain by Basal Sandstone, a coarse-grained pale-grey or yellow sandstone also of Devonian (345 - 395 million B.P.) age.

The remainder of Co. Offaly consists of a variety of limestones with a small area of volcanic rocks forming Croghan Hill. This is a volcano which was active in Carboniferous times, and consists of dark grey or black basalt and dark green volcanic ash.
The limestone rocks were deposited as sediments in the Carboniferous (290 - 345 million B.P.) under a range of marine environments. Figure 2, the bedrock geology of Co. Offaly, shows the variety of limestones caused by variations in sea depth and the amount of mud washed in. The Reef Limestone is the most abundant rock type, probable also the bedrock type of Clara bog. Two sets of faults are present, the dominant set trends NE-SW and the subsidiary set trends NW-SE.' (Hammond, Warren and Daly 1987).

The palaeozoic and Mesozoic bedrock of Co. Offaly is mostly masked by Quaternary (2.5 million B.P. - present) sediment (figure 3).

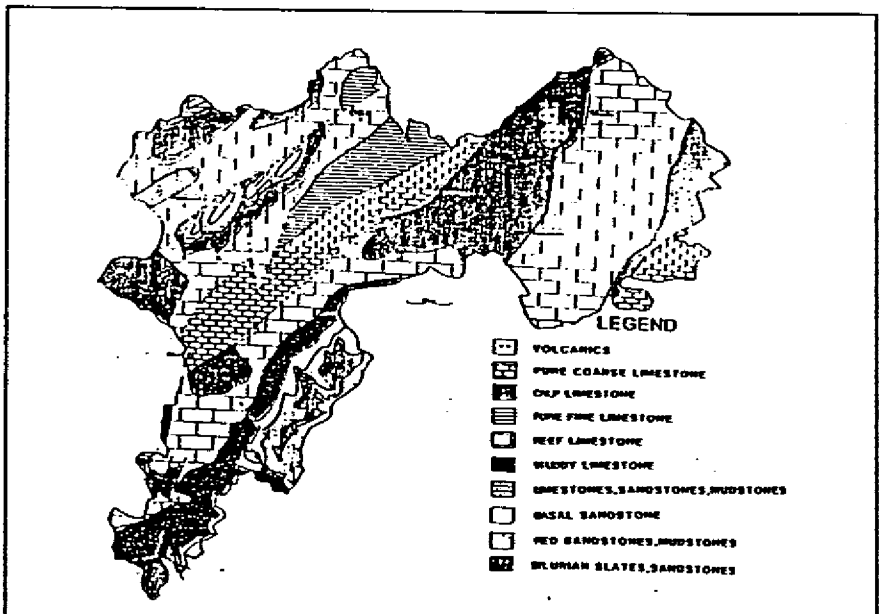

Figure 2. Bedrock geology of Co.Offaly. (Hammond, Warren and Daly, 1987).

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The present topography and geology mainly exists of different Till units, which have been deposit in the last glacial stage, the Fenitian (70.000-10.000 B.P.). Other Fenitian features in Co.Offaly are fluvioglacial deposits, like the large esker ridge which runs in an east-west direction north of Tullamore (Hammond, Warren, and Daly, 1987).

During deglaciation the ice-front retreated westwards to Galway, leaving behind a strongly irregular landscape overflown with melt-water. In the Littletonian, lacustrine deposits appeared in the rain and snowmelt-water filled depresions. Besides in this postglacial period extensive alluvial deposits accumulated in the flat river valleys and new fluviatile systems were formed.

In the poorly drained lowlying areas and the waterlogged depressions peat began to develop, and so our two raised bogs of special interest: Clara bog and Raheenmore bog.

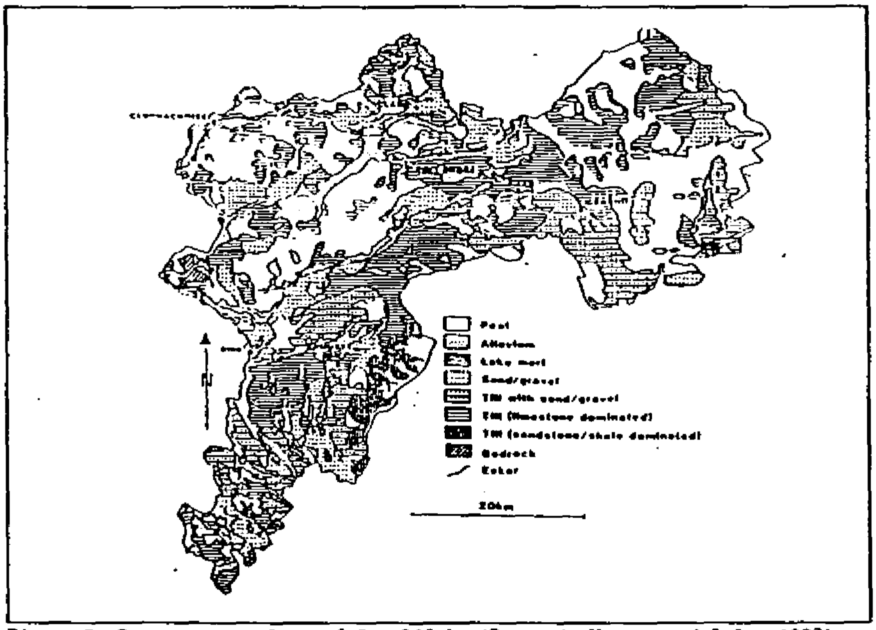

Figure 3. Quaternary geology of Co. Offaly (Hammond, Warren and Daly, 1987).

3.Geophysical theory.

3.1 General.

'Geophysics is the application of the principles of physics to study the earth' (Parasnis, 1989). Application of physics, in combination with geologial information, is often the only satisfactory way to learn about the secrets of the deeper earth without drilling. Geophysics can determine type and thickness of sediment and hardrock layers, geological faults, saltdomes, anticlines and synclines, etc.

Geophysics, however, has its restrictions. The theory, often only deals with a horizontal layered earth, which is far from reality, because geology is complicated. Besides, clear differences in geological deposits or facies do not automatically cause a clear differences in the geophysical data.
However, valuable additional information (i.e. borehole information near the locations), literature, and common sence mostly solve the problems.

There are a large number of geophysical methods. We used the electrical and electromagnetic method, both methods are based on resistivity difference of materials. The theory of the methods will be discussed in the next section.

3.2. The electrical method.

3.2.1. The basic principle.

If an electrical current I [A] is injected in an imaginary uniform cross-section, it causes a potential difference dV given by Ohm's law as:

$$I = - dV/R \qquad (I)$$

where R [Ohm] is the resistance of the conductor. The minus sign expresses the fact that the current flow is from high to low potential, that is, in a direction opposite to that of the increase of potential (the gradient). R is directly proportional to the lenght dl [m] of the conducter and inversely to the cross-section s [m2] expressed in:

$$R = \rho \, dl/s \qquad (II)$$

where ρ is the resistivity [Ohm.m] or physical property of the material of the conducter.

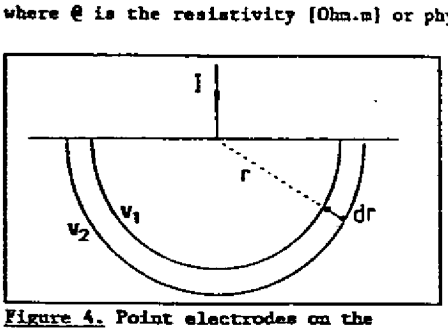

Figure 4. Point electrodes on the surface of a homogeneous earth.
Source: Biewinga 1989/1990.

Describing a half hemisphere with surface $s = 2\pi r^2$ and length $dl = dr$ [m], the potential difference is given by:

$$dV = - I \rho \, dr/2\pi r^2 \qquad (III)$$

Integrating, and assuming that potential V is zero at an infinite distance $r = \infty$ and the arbitrary constant is zero (c=0) we get:

$$V(r) = I \rho/2\pi r \qquad (IV)$$

Potential functions are scalar. Therefore, the potential difference between the electrodes, used by resistivity measurements, can be calculated by addition.

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The potential difference between M and N is:

$$V_M = (+ I/AM + - I/BM) \cdot \varrho/2\pi \qquad (V)$$

$$V_N = (+ I/AN + - I/BN) \cdot \varrho/2\pi \qquad (VI)$$

$$V_M - V_N = \varrho\, I \,(1/AM - 1/BM - 1/AN + 1/BN) / 2\pi \qquad (VII)$$

The resistivity is given by:

$$\varrho = 2\pi (V_M - V_N)/(I (1/AM - 1/BM - 1/AN + 1/BN)) \quad (VIII)$$

or:

$$\varrho = K \Delta V/I \qquad (IX)$$

where K is the geometrical factor, only dependent on the distances between the electrods.

Equation (IX) can be used for resistivity calculation in a homogeneous earth. In case of measurement on a non-homogeneous earth we can use equation (IX) as a definition of the apparent resistivity. The resistivity of different layers can be found by measuring the apparent resistivity with increasing electrode distances. Figure 6 shows the Schlumberger array, where the gradient of the potential is measured in the middle. The geometrical factor is given by: $K = \pi (a^2/b - b/4)$ (X)

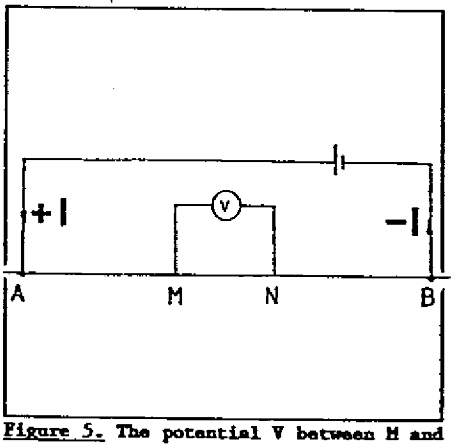

Figure 5. The potential V between M and N is caused by influx of current + I at point A and an outflux of current - I at point B.
Source: Biewinga 1989/1990.

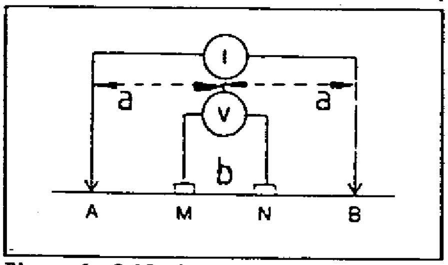

Figure 6. Schlumberger drafting.
Source: Biewinga, 1989/1990.

3.2.2 Schlumberger soundings.

The purpose of a sounding is to determine the resistivity as a function of depth.

The MN electrodes are kept fixed and the AB electrodes are moved outward, both symmetrically in steps. MN must be as small as possible but large enough to measure the potential difference, as a thumb rule MN $\leq$ AB/3. If the voltage difference between M and N falls below the accuracy of the voltmeter or when the signal to noise ratio becomes too small, the distance between the MN has to be increased symmetrically, and with an overlap in the reading at the same AB distance.

When the electrode distance increases the current will flow deeper in the ground, and the influence of the deeper layers will be noticeable.

The apparent resistivity is plotted against AB/2. Slight adaption of the measured values make a smooth sounding curve, and the Schlumberger curve is ready for intrepertation.

For the interpretation of the apparent resistivity curve it is necessary to calculate the surface potential, which is produced by an influx of current in a point on the surface of a horizontal layered earth.

The layering is inferred from the sounding curve by means of curve fitting.

The surface potential Vo from a horizontally layered earth is given by:

$$V_o = \rho_1 \, I/2\pi \int_0^\infty K1(\lambda) \, J_o(\lambda r) \, d\lambda \qquad (XI)$$

where: λ - integration constant.
r - distance between current point and measuring point.
K1 - the Kernel function, a function of the thickness of the layers and resistance.
J0 - the Bessel function of order zero.
J1 - the Bessel function of order one.

The Kernel function, Kn, of the last layer, n, is always 1. The Kernel function of the top layer can be calculated by:

$$K_n = [K_{n+1} + \rho_n/\rho_{n+1} \tanh(\lambda d_n)]/[\rho_n/\rho_{n+1} + K_{n+1} \tanh(\lambda d_n)] \qquad (XII)$$

According to the fact that Kn-1, it is possible to calculate Kn-1 for a certain layer model until K1 is reached. The integral can be solved and with this potential it is possible to calculate the apparent resistivity. The most common expression for the apparent resistivity is function VIII, substitution of MN-b and AB/2-a (figure 6) in the function gives the next function:

$$\rho_{as} = \pi/I \, \Delta V/b \; a^2 [1 - (b/a)^2] \qquad (XIII)$$

To measure a horizontal potential gradient, the electrode distance, b, between M and N is kept as small as possible. Although an infinite small distance between M and N is practically not possible, the difference with theory is small as long as MN $\leq$ AB/3. For an infinite small distance we can assume:

$$\rho_{as} = /I \; a^2 \, \partial V/\partial r \qquad (XIV)$$

The horizontal gradient of the surface potential equals:

$$\partial V/\partial r = \partial/\partial r \, [\rho_1 \, I/2 \int_0^\infty K1(\lambda)] \, {}_0(\lambda r) \, d\lambda] \qquad (XV)$$

Ultimate, the apparent resistivity of the Schlumberger array is found (Koefoed, 1979) by:

$$\rho_{as} = \rho_1 + \rho_1 \, a^2 \int_0^\infty [K1(\lambda)-1] \;]_1 (\lambda r) \lambda \, d\lambda \qquad (XVI)$$

The integration will be, even with the most modern computers very time-consuming. Gosh and Koefoed develloped a digital liniear filter (Koefoed, 1979), how the time-consuming integration can be replaced by a summation of several terms:

$$\rho_{as}(i\Delta x) = \sum_{j\,min}^{j\,max} T((i - j)\Delta x + S) \; C(j\Delta x - S)) \qquad (XVII)$$

where: i. x - AB/2.
T - transform function.
C( ) - the filter coefficient.
S - a shifting which accelerates the convergence.

The computation of a sounding involving any number of layers is now a matter of seconds with a personal computer. Starting with a certain model (resistivities and thicknesses), the user of the computer program tries to fit the model- and fieldcurve.

The difference between the field curve and the model curve is given by the equation of the error criterion::

$$E = 1/M\sqrt{\sum_{i=1}^{M} ((\rho vi - \rho ai)/\rho vi)^2} \, .100\% \qquad \text{(XVIII)}$$

where: M = number of measurements.
ρvi = apparent resistivity of the field curve at point i.
ρai = apparent resistivity the model at point i.

3.3. The electromagnetic method.

Electromagnetic methods are based on the induction principle. The time-varying magnetic field arising from an alternating current of frequency f Hertz in a transmitter coil Tx, induces current flows in the earth (shorted turn). These currents generate a secondary magnetic field Hs, which is sensed, together with the primary field, Hp, by the receiver coil, Rx (figure 7). The secondary magnetic field has the same frequenty as the primairy field, but the size and the direction will be different. The measured quantity is the ratio between these two, and is expressed by:

Horizontal coils (vertical dipole).

$$(Hs/Hp)_V = 2/(\gamma s)^2 \{9 - [9 + 9\gamma s + 4(\gamma s)^2 + (\gamma s)^3] e^{-\gamma s}\} \qquad \text{(XIX)}$$

Vertical coils (horizontal dipole).

$$(Hs/Hp)_H = 2[1 - 3/(\gamma s)^2 + [3 + 3\gamma s + (\gamma s)^2] e^{-\gamma s}/(\gamma s)^2] \qquad \text{(XX)}$$

where: $\gamma = \sqrt{i w u \rho}$
$w = 2\pi f$
f = frequency [Hz].
u = permeability of free space.
$i = \sqrt{-1}$
s = intercoil spacing.

These expressions are complicated functions of the variable s which is in turn a function of frequency and conductivity. Under certain conditions (McNeill, 1980) these expressions can be reduced to the simple expression:

$$(Hs/Hp)_V \approx (Hs/Hp)_H \approx iB^2/2 = i w u_o \rho s^2/4 \qquad \text{(XXIII)}$$

The ratio of the secondary to the primary magnetic field is now linearly proportional to the terrain conductivity, a fact which makes it possible to construct a direct-reading. The apparent conductivity, measured by the instrument in millimhos per meter or milliSiemen per meter (mS/m) is expressed by:

$$\rho = 4/w u_o s^2 (Hs/Hp) \qquad \text{(XXIV)}$$

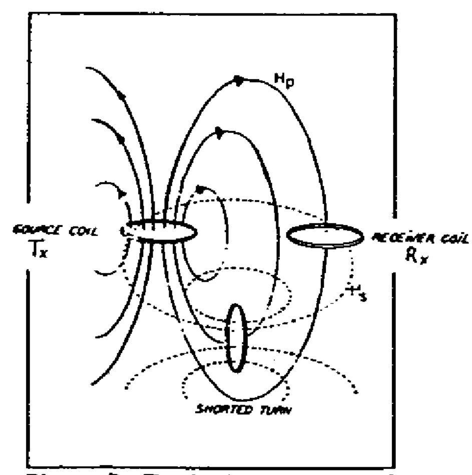

Figure 7. The basic principle of the electromagnetic method.
Source: Biewinga 1989/1990.

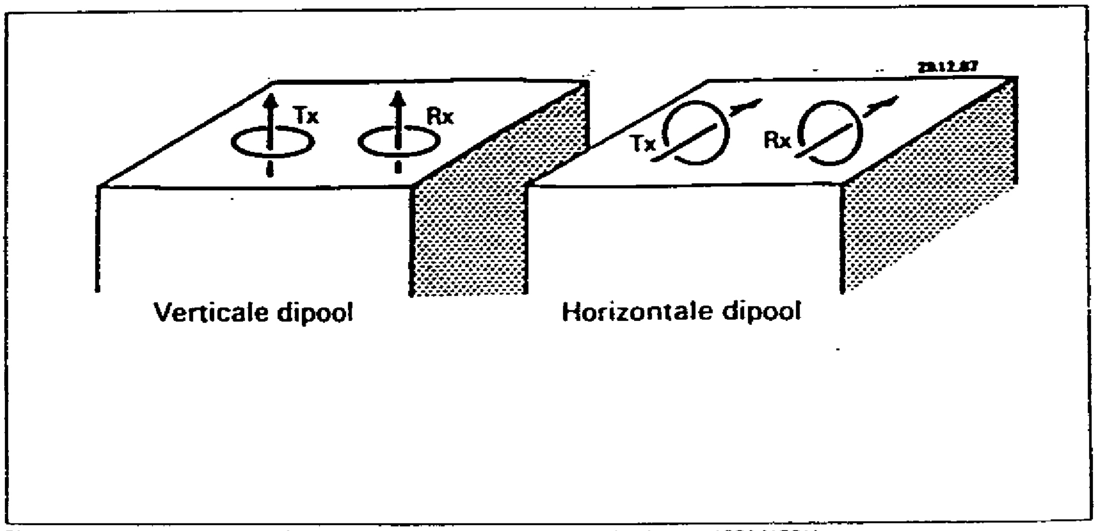

Figure 8. Vertical and horizontal dipool configuration (Biewinga, 1990/1991).

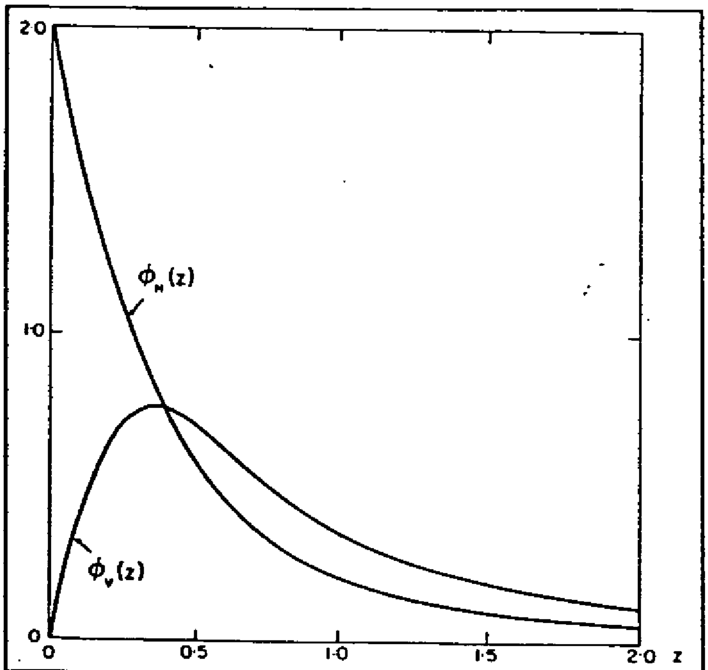

Figure 9. Comparisation of relative responses for vertical and horizontal dipoles. (McNeill, 1980).

We used the EM34-4 to measure terrain conductivity. The instrument can be used with either horizontal oils (vertical dipole) or vertical coils (horizontal dipole) (figure 8). The spacing between the coils ay be 10, 20 or 40 meter. The exploration depth of horizontal dipoles is 0.75 times the intercoil pacing. The exploration depth of the vertical coils is 1.5 times the intercoil spacing. An combinations etween the various intercoil spacing and either horizontal or vertical coils reflects a variation in xploration depth as is shown in table 1. So theoretically, assuming a homogeneous or horizontally tratified earth, the depth of penetration is limited only by the intercoil spacing s.

Intercoil Spacing (meters)	Exploration Depth (meters)	
	Horizontal Dipoles	Vertical Dipoles
10	7.5	15
20	15	30
40	30	60

Table 1. Exploration depths for EM34-3 at various intercoil spacings. (McNeill, 1980).

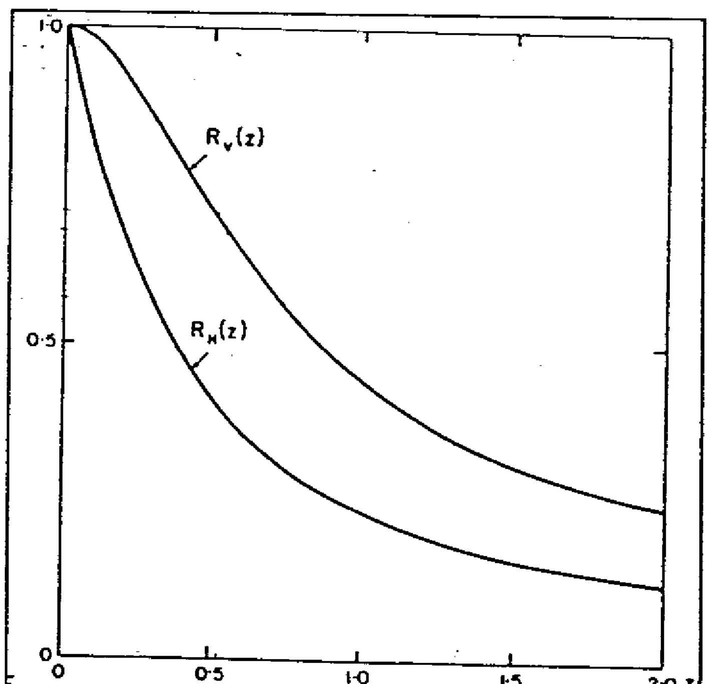

Figure 10. Cumulative response versus depth for vertical and horizontal dipoles. (McNeill, 1980).

The measured conductivity is a mean conductivity of the different layers in the earth at the measured point. The relative contribution of the layers to the secondary magnetic field is a function of the depth and the used coil configurations, either horizontal dipoles or vertical dipoles. The relative sensitivity of either of the two coil configurations to the material at various depths is given in figure 9. If 20 meter intercoilspacing with vertical dipool is used then a layer at 8 meter (0.4 times s) depth has maximum influences. If horizontal dipool is used their will be a maximum contribution of the surface layer to the secondary magnetic field.
The functions derived from the functions are shown in figure 9 are:

Horizontal coils (vertical dipole).

$$R_V(z) = \int_z^{\infty} \phi_V(z)dz \qquad (XXVa)$$

and:

Vertical coils (horizontal dipole).

$$R_H(z) = \int_z^{\infty} \phi_H(z)dz \qquad (XXVb)$$

This reflects the relative contribution to the secondary magnetic field or apparent conductivity from all material below a depth z, called the cumulative response. The resultant of their derivation is given in expression (XXVI) and (XXVII). These expressions are illustrated in figure 10.
The cumulative response for horizontal coils (vertical dipoles) is:

$$R_V(z) = 1/(4z^2 + 1)^{½} \qquad (XXVI)$$

The cummulative response for vertical coils (horizontal dipole) is:

$$R_H(z) = (4z^2 + 1)^{½} - 2z \qquad (XXVII)$$

It is now possible to calculate the instrument reading on an arbitrarily layered earth, as long as the intercoil spacing is much less than the skin depth in all of the layers. This, by simply adding the contribution from each layer independently weighed, according to its conductivity and depth, as in figure 10. For example a three layer-model, 10.5 meter peat, 2.0 meter clay, and infinity hard rock with respectively a conductivity of 7, 20 and 1 mS/m will give an apparent resistivity (measured with a vertical coils and 20 meter coilspacing) of:

Upper layer: $@1 = @1\ [1 - R_V(z1)]$ thus: $@1 = 7\ [1 - 0.7125]$

Middle layer: $@2 = @2\ [R_V(z2) - R_V(z1)]$ thus: $@2 = 20\ [0.7125 - 0.6875]$

Lower layer: $@3 = @3\ R_V(z2)$ thus: $@3 = 1 \times 0.6875$

Calculated response, apparent resistivity: $@a = @1 + @2 + @3$ thus: $@a = 3.45 + 0.5 + 0.6875 = 4.6375$

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4. Fieldwork and instruments.

4.1. EM34-3: fieldwork and interpretation.

To measure terrain conductivity with the Geonics EM-34-4, the transmitter (photo 2) operator stops at the measurement station (figure 11). The operator of the receiver moves the receiver coil (photo 3) backwards and forwards until the meter indicates correct intercoil spacing, he or she reads the terrain conductivity from the second meter (photo 1). The operator of the receiver marks the place with a plastic tube, and both surveyers move forward until the operator of the transmitter has reached the mark spot. Now a new measurement can be made.

At the beginning and the end of each traversed line a wooden peg has been placed, and also every 300 meter. So the lines could be reoccupied by the second or third traverse, when an other coilspacing is used. The pegs are also a "grid" reference for other traverse lines. To settle a precise course a compass and recognizable terrain spots, like churches and houses, are used.

Figure 11. Operating the EM34-4.
Source: Geonics limited.

After every field-survey a Lotus spreadsheat was used for datafiling and processing. The following data were filed: location, date, linenumber, starting and end point, course w.r.t. magnetic North, remarks, coilspacing and coilfiguration. Finally, a table is made with distance, measured conductivity (mS/m) and remarks along the traverse line.
From the measured conductivity we calculated and filed the resistivity, and the smoothed conductivity and resistivity.

The smoothed conductivity is calculated by:

$$C^{*} = (MC(d-1) + 2 * MC(d) + MC(d+1)) / 4$$

where $C(d)^{*}$ = smoothed conductivity [mS/m] at station number d.
$MC(d)$ = measured conductivity [mS/m] at station number d.

The resistivity [Ohm/meter] is calculated by:

$$CR(d) = 1000/MC(d)$$

where $CR(d)$ = resistivity [Ohm/m] at station number d.

and the smoothed resistivity by:

$$R^{*}(d) = (CR(d-1) + 2 * CR(d) + CR(d+1)) / 4$$

where $R^{*}(d)$ = smoothed resistivity [Ohm/m] at station number d.

Next, all traversed lines are graphically reflected; the smoothed conductivity is plotted against the distance. For plotting the program Supercalc version 5.0 was used.

4.2. Resistivity soundings with the ABEM SAS 300 Terrameter: fieldwork and interpretation.

<u>Table 2.</u> AB/2 and MN/2 configuration used for the resistivity soundings.

AB/2	MN/2	AB/2	MN/2
[meter]			
1.5	0.50	50	10.0
2.5	0.50	60	10.0
4	0.50	75	10.0
6	0.50	100	10.0
4	1.00	60	20.0
6	1.00	75	20.0
8	1.00	100	20.0
10	1.00	125	20.0
12	1.00	150	20.0
8	2.00	175	20.0
10	2.00	125	40.0
12	2.00	150	40.0
15	2.00	175	40.0
20	2.00	200	40.0
15	5.00	250	40.0
20	5.00	300	40.0
25	5.00	350	40.0
30	5.00	400	40.0
40	5.00	350	50.0
30	10.0	400	50.0
40	10.0	500	50.0

The resistivity instrument used was an ABEM SAS 300 Terrameter with a current output setting of usually 10 mA. The centre of the each sounding was marked by a bamboo cane with five red horizontal stripes so as these locations can be reoccupied at a later date. In some cases the centre of the sounding is placed on the centre of a conductivity measurement.

To settle a precise course the researchers used a compass and 3 ranging rots (photo 5 and 6). To save a lot of time in surveying in the electrode positions, every AB/2 and MN/2 distances on each cable were marked with 2 leaping (tape) colours. Radiotelephones and flag signals were used for communications.

The AB/2 spacings are draft in such way (table 2) that they can be used in Resint (version 3.1) written by D.T. Biewinga 1985.
A Limitation was caused by the length of the MN/2 cable available. The end tot end separation of the inside (potential) electrodes being a maximum of 100 meter apart. As soon as the AB/2 distance exceed 250 meter, the dataset should be interpeted with great caution, because then MN becomes too small to measure the potential correct difference.

For interpretation, a Lotus spreadsheat was used for datafiling and processing. The following data were filed: AB/2, MN/2, 2(MN/2), K, measuring (@V/I), program (input Resint program), and remarks (sounding number, course w.r.t. magnetic North etc.).

AB/2, MN/2 and measuring (@V/I) are known field-data. 2(MN/2) is calculated, multipling MN/2 by 2. The geometrical factor, K, is calculated by $(a^2/b - b/4)$ where a = AB/2 and b = 2(MN/2) or MN. The apparent resistivity is calculated by multipling the geometrical factor by the measured value of @V/I.

Secondly, the computerprogram Resint (version 3.1) was used for the final interpretation. The data input, AB/2, MN/2, and apparent resistivity in the computerprogram Resint 3.1, resulted in a fieldcurve, where the distance AB/2 is plotted against the apparent resistivity. A starting earth model was given and the programm calculates the apparent resistivity curve and compares this with the fieldcurve.

The model will be adapted until the error criterion is as small as possible. The thickness and resistivities of the final model are the solution as the resistivity sounding.

4.3. Measuring locations and traversed lines on Raheenmore and Clara bog.

4.3.1. Raheenmore: EM34-4 surveying.

The traverse lines with the EM34-3 on Raheenmore have a total length of 10 kilometer (figure 12a), and are between 100 and 700 meter apart.

All the traverse lines crossing Raheenmore bog and surrounding farmingland (line A, B, C, D, E, F, G and MS1) have been carried out with 20 meter intercoilspacing, horizontal coils. Some traverse lines also include EM34-3 surveying with 10 and 40 meter coilspacing (line C and line E), and 20 meter coilspacing vertical coils (line C, line E, and line MS1). Therefore extra information, on other exploration depths, of some parts of the bog is also available.
A summary of the conductivity measurements is given in table 3a.

Table 3a. Information of the traversed lines at Raheenmore bog.

LINE NUMBER	COILSPACING-CONFIGURATION						TOTAL LENGTH
RAHEENMORE	10HC	10VC	20HC	20VC	40HC	40VC	METER
A			X				1120
B			X				220
C		X	X	X			1860
D			X				760
E	X	X	X	X	X	X	480
F			X				1200
G			X				1060
MS1			X	X			500

4.3.2. Raheenmore resistivity soundings.

At Raheenmore 13 soundings (figure 12b) were carried out at 200 meter intervals along two traverse lines approximately 600 meter apart running North-West to South-East relative to the National Grid.

The most Westward traverse line counts 7 soundings, where RHSVES 11 and RSVES12 share the same centre. The other traverse line counts 6 soundings where RHSVES01 and RHSVES02 share the same centre. One sounding (RHSVES08) is made between both traverse lines on farmingland at the North side of the bog. Due to practicle problems was it not possible to fit the centre allong neither the westwards traverse line nor the eastwards traverse line. The National Grid Reference for the centres of the soundings, and the course -w.r.t. magnetic North- of the electrodes positions are given in table 3b.

Table 3b. Information of the resistivity measurements.

SOUNDING	EASTING	NORTHING	COURSE W.R.T. MAGN. NORTH	REMARKS
RHSVES01	243910	232400	60 - 240	Raheenmore bog
RHSVES02	243910	232400	150 - 330	Raheenmore bog
RHSVES03	244020	232050	60 - 240	Raheenmore bog
RHSVES04	244140	232080	60 - 240	Raheenmore bog
RHSVES05	244230	231960	60 - 240	Raheenmore bog
RHSVES06	243810	231440	60 - 240	Farmingland (C.Mallon Fields)
RHSVES07	243790	232530	76 - 256	Edge bog
RHSVES08	243420	232510	60 - 240	Farmingland (Killeen,Harte,Brennan)
RHSVES09	243280	232240	71 - 251	Raheenmore bog on D26 (EM34-3)
RHSVES10	243370	232060	71 - 251	Raheenmore bog
RHSVES11	243470	231880	161 -341	Raheenmore bog
RHSVES12	243470	231880	71 - 251	Raheenmore bog
RHSVES13	243570	231710	71 - 251	Raheenmore bog
RHSVES14	243670	231540	71 - 251	Raheenmore bog

4.3.3. Measurements at Clara bog.

The traversed lines carried out with the EM34-3 on Clara bog and surrounding area have a total length of 7460 meter (figure 12c). Information of the traversed lines is given in table 4a.

Most attention is given to the eskers north of the bog (photo 7). Here the traversed lines have been carried out with 10 meter coilspacing, horizontal and vertical coils (line 3, 4, 6, and 7), and with 20 meter coilspacing, horizontal and vertical coils (line 1). Four resistivity soundings (CLSVES05, 06, 07, and 08), roughly 40-60 meter apart, were taken parallel to each other on the same esker edge at line 6 (figure 12d). Information of the resistivity soundings is given in table 4b.

The ridge near the soak is studied in detail. At this location two resistivity soundings (CLSVES09 and 10) were taken to determine the nature of the underlying material. Line R1, R2, R3, and R4 (10 and 20 meter coilspacing with horizontal and vertical coils) were carried out to determine the changes in the layered earth on the ridge and direct surrounding.

Little attention is given to cross the bog itself. Line MA1 runs parallel to the westside of the road. The line starts in the 'Esker Associated Sand & Gravel area" (Tatenhove, 1990: map1), and is crossing the esker and the bog towards the south. The line ends in the 'Sandy-loamy stony Till' (Tatenhove, 1990, map1) associated areas. Sounding CLSVES01, 02/03, and 04 at 300 meter intervals are carried out on Clara bog at line MA1.

The results of the measurements will be discussed in Chapter 5.1 (Raheenmore bog) and 5.2 (Clara bog).

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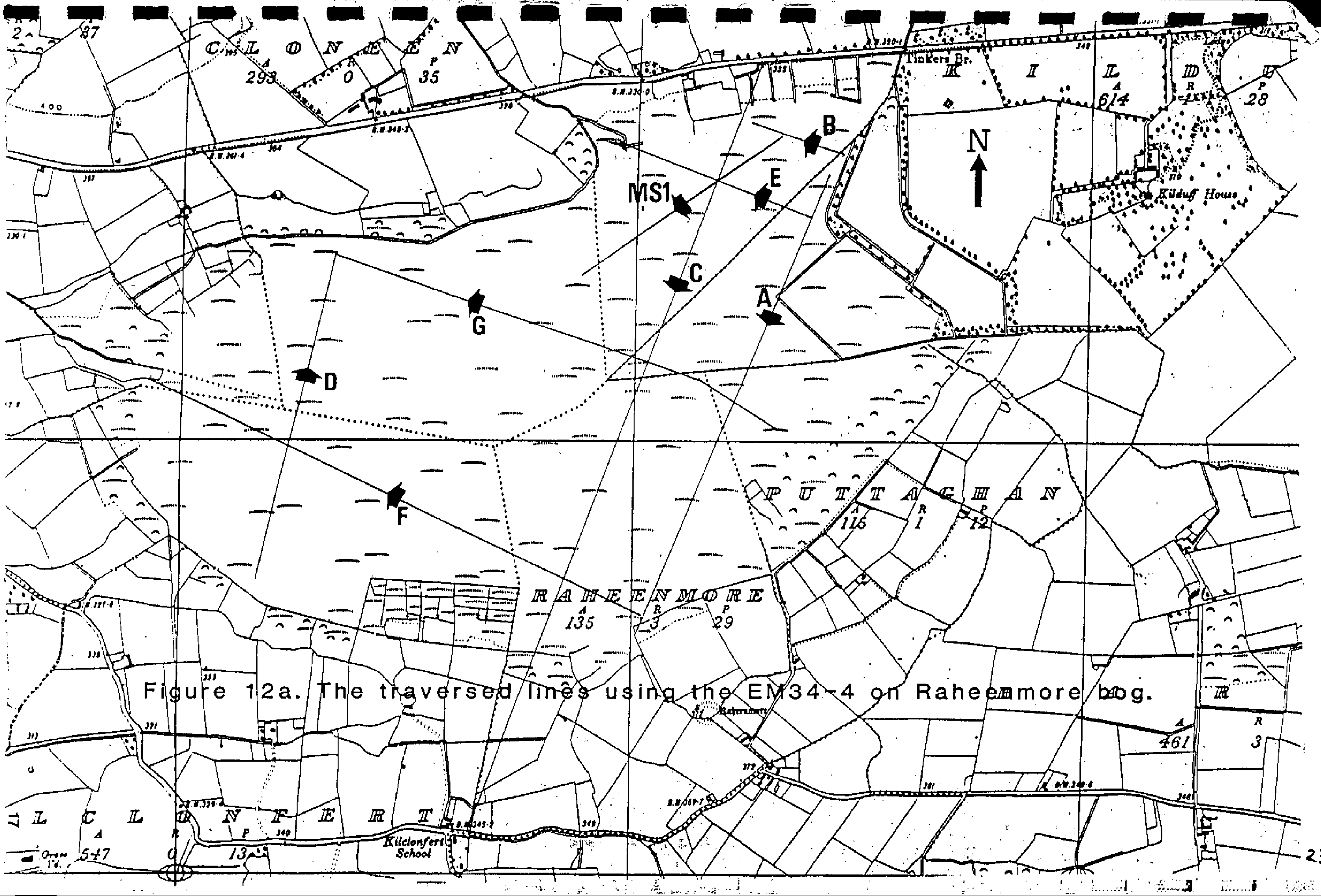

Figure 12a. The traversed lines using the EM34-4 on Raheenmore bog.

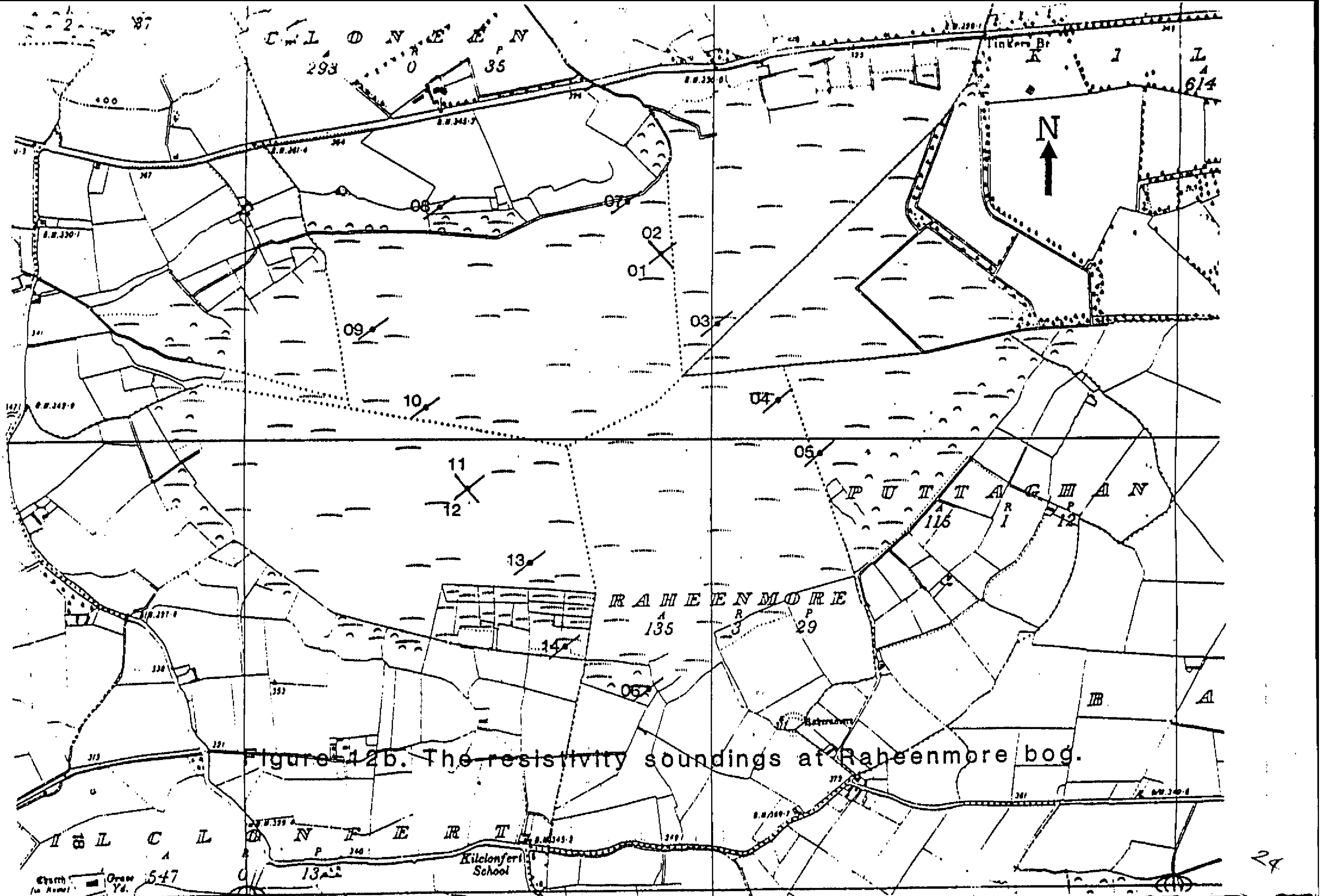

Figure 12b. The resistivity soundings at Raheenmore bog.

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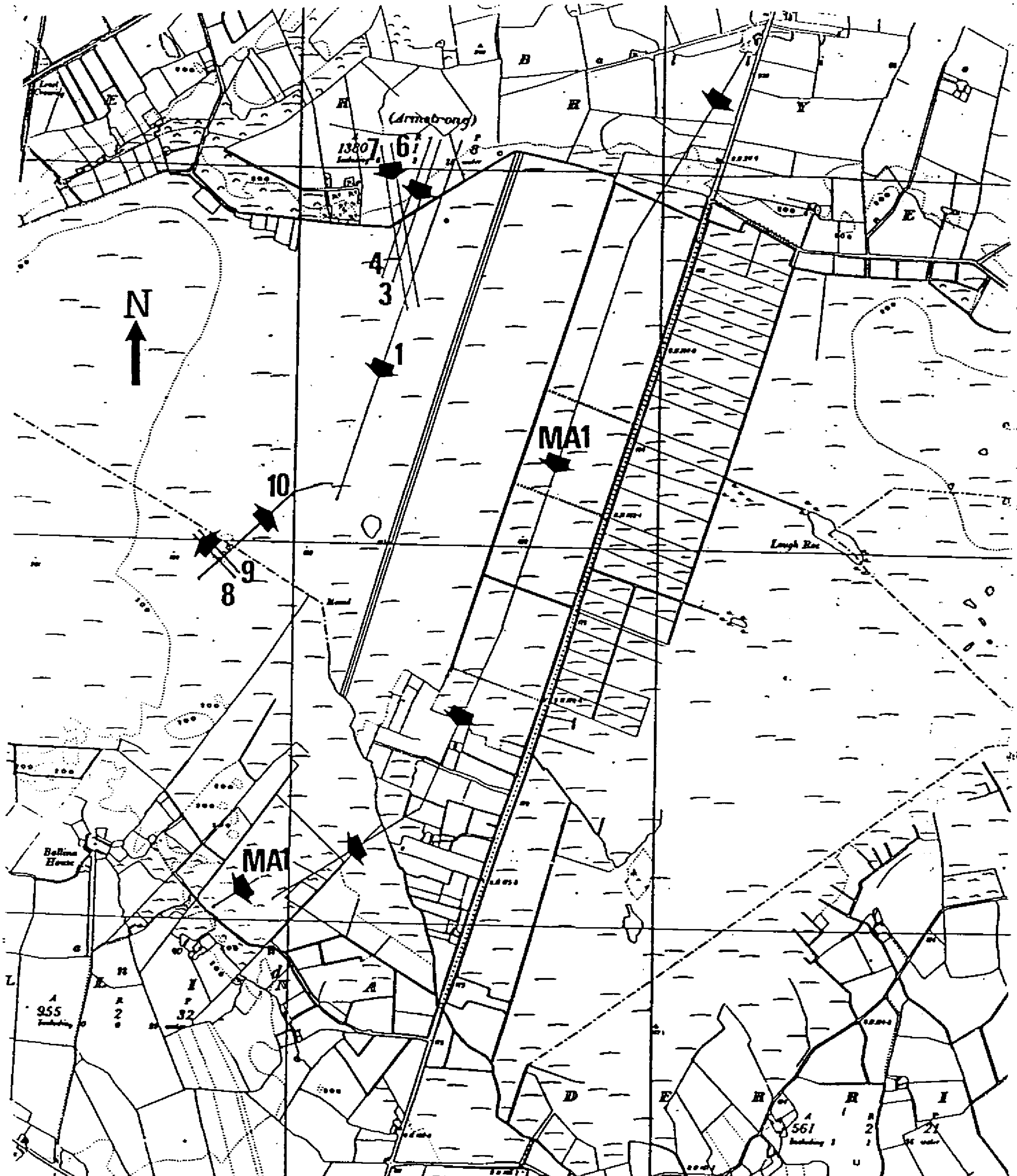


Figure 12c. The traversed lines using EM34-4 on Clara bog.

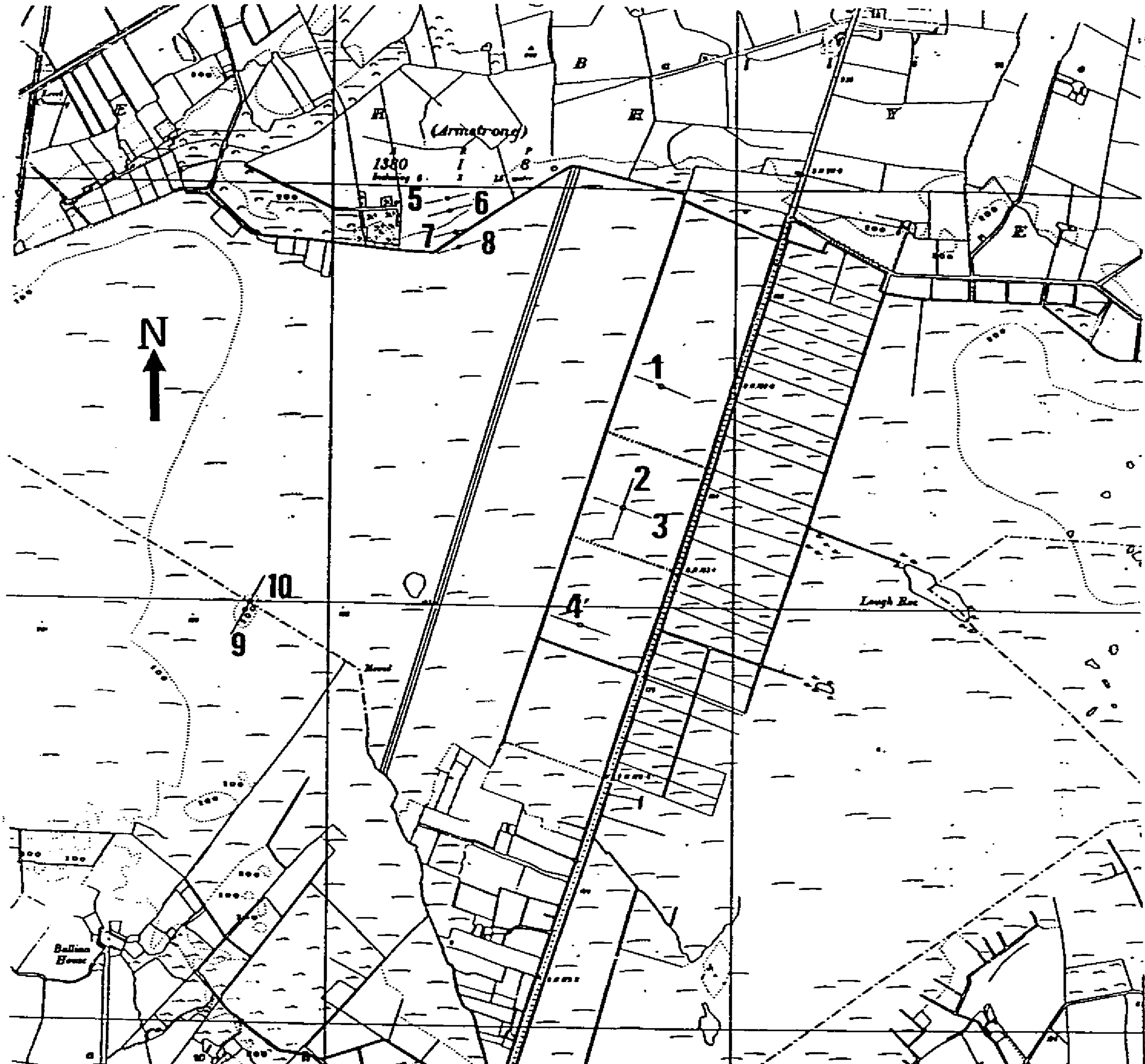


Figure 12d. The resistivity soundings at Clara bog.

Table 4a. Information of the traversed lines at Clara bog.

LINE NUMBER	COILSPAC.-CONFIG.				TOTAL LENGTH
CLARA BOG	10HC	10VC	20HC	20VC	meter
1			X	X	1020
3	X	X			400
4	X	X			430
6	X	X			300
7	X	X			300
MA1	X	X	X	X	2900
R1	X	X			220
R2	X	X			220
R3	X	X			400
R4	X	X			60

Table 4b. Information of the resistivity measurements at Clara bog.

SOUNDING	EASTING	NORTHING	COURSE W.R.T. MAGN. NORTH	REMARKS
CLSVES01	224800	230530	108 - 288	Clara bog on line MA1 (EM34-4)
CLSVES02	224710	230250	18 - 198	Clara bog on line MA1 (EM34-4)
CLSVES03	224710	230250	108 - 288	Clara bog on line MA1 (EM34-4)
CLSVES04	224620	239960	108 - 288	Clara bog on line MA1 (EM34-4)
CLSVES05	224240	230970	86 - 266	Esker on line 6 (EM34-3)
CLSVES06	224250	230920	86 - 266	Esker on line 6 (EM34-3)
CLSVES07	224250	230890	86 - 266	Esker-bog margin on line 6(EM34-3)
CLSVES08	224260	230860	86 - 266	Clara bog on line 6 (EM34-3)
CLSVES09	223960	239960	46 - 226	Ridge near soak
CLSVES10	223720	230000	46 - 226	Ridge near soak

5.1. Results.

5.1. Raheenmore bog.

5.1.1. Resistivity interpretation.

To reduce the effects of equivalence on the interpretation we used a standard model, with ranges for the resistivities (table 5). The standard model is based on geological information and resistivities that often occured at first trial interpretations.

The most common model is a four layered earth with respectively a surface (peat) layer, a peat layer, a Till layer, and limestone bedrock (RHSVES04, 05, 09, 12, 13, and 14). The two resistivity measurements on the fields near the bog show two different models (table 6).

Peat.

The thickness of the peat at Raheenmore bog varies between 2.7 and 22.7 meter (figure 18). The most easten traverse line shows a strong contrast. Although, from a Geological point of view the thickness of peat is not likely to be over 15 meter (van der Meer, personal communication), three soundings (RHSVES03, 04, and 05) at the middle of the bog towards the southeast of the bog show an exeptional thickness of peat between 18 and 22.7 meter. In contrast to the thin peat layer towards the north of the bog (RHSVES01, 02, and 07) were the thickness varies between 2.7 (RHSVES07, the margin of the bog) and 7 meter. The most westen traverse line shows a relative uniform thickness of peat of 5.6 - 10 meter (RHSVES10, 11, 12, 13, and 14) and 15.4 meter for RHSVES09.

Limestone.

Equal to the relative uniform thickness of peat, the traverse to the West of Raheenmore bog shows a (uniform) decrease in depth to bedrock, with a variation in depth of between 29.0 meter (northwest of the bog) and 15.2 meter (south of the bog). The resistivity measurement RHSVES06, at C.Mallon fields, which is in line with the westen traverse on the bog, shows a very shallow depth to bedrock, 3.9 meter, with a thin Till layer on top. The resistivity measurements at the south side of the bog reflecting a very steep gradient of the limestone bedrock between the bog itself and the adjacent (field) area.

At the easten traverse, the depth to bedrock is much deeper than at the westen traverse. The traverse to the east of Raheenmore bog shows the bedrock to be varying in depth from 23.6 to 62.3 meter. The variation in depth to bedrock between the western and eastern traverses might indicate a fault line somewhere between the two traverses (Smith, Farenhorst and Barton, 1990). Also the difference in depth to bedrock at the northern end of the bog (46.6 and 54.4 meter) and the limestone outcrop occuring in the vicinity (found south of the Mullagharugh Hill (Tatenhove, 1990)) might indicate a fault or steep slope.

Till.

At the westen traverse the Till layer, above the bedrock, is thickest where bedrock is deepest. The Till layer decrease in thickness from the northwest towards the south of the bog.
The locations where the bedrock is deepest, RHSVES08 (on the Harte fields at the north side of the bog), 07 (at the north side on the bog), and 03 (in the middle of the bog at the most easten traverses) show the presence of an very thick layer. At the north side of the bog, the resistivity of this layer, respectively 187 and 203 Ohm.meter, is in the same range. This reflects an equal characteristic of material. According to the measured resistivity values the material is more sandy than the Till layer on top of the thick layer (RHSVES07, 08) and under the thick layer (RHSVES07). The resistivity of the 40-meter thick layer at location RHSVES03 is 100 Ohm.meter (conductivity 10 mS/m), reflecting also a more sandy material than the Till layer on top of the 40-meter thick layer. However the 40-meter layer is less sandy than the thick layers at location RHSVES07 and 08. With respect to the thickness of the

TABLE 5. BOG MODEL RAHEENMORE			
LAYER (NUMBER)	THICKNESS RANGE	CONDUCTIVITY	RESISTIVITY
PEAT SURFACE (1)	0.2 - 0.7	2.6 - 10.0	100.0 - 380.5
PEAT (2)	0.7 - 1.0	5.2 - 5.5	182.0 - 191.0
CLAY	1.1 - 4.2	20.0 - 20.1	49.8 - 50.0
PEAT (3)	2.7 - 22.7	4.2 - 6.6	152.0 - 238.0
TILL (4)	3.4 - 22.6	15.6 - 20.0	50.0 - 70.0
(SANDY)TILL (5A)	34.4 - 40.0	4.9 - 10.0	100.0 - 204.8
TILL (5B)	7.2 - 22.6	20.0 - 22.2	45.0 - 50.0
LIMESTONE (6)	15.3 (MIN.DEPTH) 62.3 (MAX.DEPTH)	0.3	3000

SOUNDING	MODEL LAYERS
RHSVES01	1 - 2 - 4 - 6
RHSVES02	1 - 2 - 4 - 6
RHSVES03	1 - 3 - 4 - 5A - 6
RHSVES04	1 - 3 - 4 - 6
RHSVES05	1 - 3 - 4 - 6
RHSVES07	1 - 4 - 5 - 6
RHSVES09	1 - 3 - 4 - 6
RHSVES10	1 - 3 - 4 - 6
RHSVES11	1 - 3 - 4 - 6
RHSVES12	1 - 3 - 4 - 6
RHSVES13	1 - 3 - 4 - 6
RHSVES14	1 - 3 - 4 - 6

TABLE 6. FIELD MODEL RAHEENMORE			
LAYER (NUMBER)	TICKNESS RANGE	CONDUCTIVITY	RESISTIVITY
TILL SURFACE (1)	0.1 - 0.5	8.7 - 33.6	29.8 - 114.9
TILL (2)	2.8 - 3.4	20.0 - 21.2	47.2 - 50.0
(SANDY)TILL (3)	51.5	5.3	187.6
LIMESTONE (4)	3.9 (MIN) 54.4 (MAX)	0.3	3000

SOUNDING	MODEL LAYERS
RHSVES06	1 - 2 - 4
RHSVES08	1 - 2 - 3 - 4

TABLE 7. THE CONDUCTIVITY [mS/m] OF MATERIAL AT RAHEENMORE BOG ONE LAYERED MODEL.

MATERIAL/ONE LAYERED MODEL	CONDUCTIVITY [mS/m]
Peat	7.0
Till	20.0
Limestone	0.3

layers and the resistivity values we probably have to deal with Till with a sandy matrix (gravelly sandy Till), opposite the Till with a clay matrix (gravelly clay Till) which is common found.

Thin clay(?) layer.

At the North side of the bog (RHSVES08, 07, 01 and 02) a remarkable thin layer is found with a low resistivity. At location RHSVES08 the layer thickness is 0.1-2.9 meter, at RHSVES07 between 3.2-5.2 meter, and at RHSVES01/02 between 0.7-1.8/7.5-11.7 meter present. The resistivity of the layer is respectively 47.1, 46.5, and 49.7/50.0 Ohm.meter. The thin layer is found on top of the gravelly sandy Till (RHSVES08), between the peat layer and the gravelly sandy Till (RHSVES07) and between two peat layers (RHSVES01/02). With respect to the resistivity values and the thickness of the layer, it could be a clay.

None of (other) interpreted resistivity measurements demonstrate the presence of a lacustrine deposit or lake marl between the Till layer and the peat layer. Although the theory assume presence of this layer under the bog, there are three possible reasons for the absence of it:

1. The clay sedimentation only occurred in certain parts under the bog area, depending on the location of depressions in the landscape and the possibilities of the stagnation of rain and snow-melt water in these depressions.
2. Due to the inadequate thickness of the clay layer it is impossible to determine the lacustrine deposits or lake marl with this method.
3. Due to the inadequate resistivity difference between the clay layer (resistivity around 50 Ohm.meter) and the gravelly clay Till layer (resistivity 50 Ohm.meter) it is impossible to determine the lacustrine deposits or lake marl with this method.

The model and curves of soundings RHSVES11 and 12, which share the same centre, are coincident. This indicates that the ground under investigation is lateral uniform.
The model and the curves of soundings RHSVES01 and 02, which share the same centre at the eastside of the bog, are sligthly different. This suggest lateral inhomogenity along the axes of the soundings. The westside of the bog is according to the soundings at the traverse line, much more lateral uniform than the soundings at the eastside of the bog.

5.1.2. EM34-4 interpretation.

It was possible to infer a kind of thumbrule relation (code model) between the measured conductivity and the bog materials, by using the standard models and conductivities of table 5.
If the earth is one-layered, all of the material below zero depth yield a relative contribution of unity or 100 % to the meter reading, the actual instrument reading indicates the conductivity of the homogeneous material. The conductivity of an one-layered earth, with respect to the properties of the material, is given in table 7.

TABLE 8. EXPLANATION OF GRAPHIC CODE RAHEENMORE BOG.

CODE	CONDUCTIVITY VALUE CS20,HC	EXPLANATION	
		STRONG INFLUENCE OF	LAYER TICKNESS
A	< or = 5	Limestone	Tickness of peat and/or Till layer at most 10 meter. Limestone close to surface, within 10 meter below the surface.
B1	5 - 7	Peat (Limestone)	Tickness of peat layer at least 10-15 m. Tickness of Till layer at most 10 meter Limestone within 20 meter below surface
B2	7 - 9	Peat (Till)	Tickness of peat layer at least 10-15 m. Tickness of Till layer at least 10 meter. Limestone at least 20 meter below surface
D	> or = 9	Till	Tickness of peat layer at most 10 meter Tickness of Till layer at least 15 meter Limestone at least 25 meter below surface

If the earth is multi-layered, it is possible to state the relative influence of material at different depths to the indicated apparent conductivity (chapter 3.3).

The code-model (table 8) is based on table 7, (equations XXVa and XXVb, figure 9 and 10), and overall interpretation of the traversed lines on Raheenmore bog. The conductivity values and corresponding codes are only valid for measurements with the 20 meter coilspacing, horizontal coils, on Raheenmore bog. The code is reflecting the depth to bedrock and the thickness of the peat layer or the Till layer.

The relation between layer conductivities and measured conductivity can also be calculated with the computer program EMIX 34; we shall discuss this at the recommendations.

Figures 13a - 13e give the smoothed conductivity plotted against the distance, measured with the 20 meter coilspacing. Under the graph a code (table 8) is given. This gives an impression of the changes in distance, occured in the layered earth with an exploration depth of 30 meter.

Line A (fig.13a) crossing the east-side of the bog, shows most fluctuations with the distance. At first 600 meter, northeast of the bog, a strong influence of the Till layer is measured. Striking are the higher values in this part of the traverse line compared the measured lower values, after 600 meter, at

the southeast part of the bog. The dividing-line of these two parts is a very low conductivity at 600 meter distance, reflecting limestone close to the surface.

The other lines B, D, F and G (resp.fig 13b, 13c, 13d, and 13e) show less fluctuations. It appears that in most cases a (relative) thick peat layer is present (code: B2 and B1). At begin and end of each line, close to the edge of the bog, code A or B1 occurs.

Figure 14 shows line MS1 measured with 20 meter coilspacing, horizontal and vertical coils. Again at the north side of Raheenmore bog, a strong influence of the thick Till layer is, as the code D reflects, observable. The Till layer is close to surface (high values CS20,VC) and will be thick (high values CS20,HC). Limestone bedrock will be found at least 20-25 meter below surface, except between 30 and 70 meter where the bedrock is expected within 10-20 meter below the surface (code B1).

Line C (fig. 15a and 15b) is measured with 20 meter coilspacing horizontal and vertical coils and 10 meter coilspacing vertical coils (exploration depth 7.5 meter).

On the fields, at the north side of the bog, high conductivity values, with CS20,HC, CS20,VC, and CS10,VC indicate a strong influence of the Till layer, from the surface uptil an exploration depth of 30 meter. At the begining of the bog, less influence of the Till layer lo
wer values CS20,HC and CS20,VC) indicates an increase of the peat layer and decrease of the Till.

At the first 400 meter on the bog (code B2), the peat layer will be relative thick compared with 420-640 meter distance at the traversed line (code D) where the Till layer is much more important. The higher conductivity values of CS20,VC in traject 420-640 meter compared with lower conductivity values at the first 400 meter on the bog supports the codes (resp. D and B1 / B2).

The high smoothed conductivity values measured with 20 meter coilspacing vertical coils, at 840 - 1240 meter distance, indicates again a strong influence of the Till layer, uptil a (exploration) depth of 15 meter. The values measured with coilspacing 20 meter horizontal coils are in this traject relative low (code B1). The limestone will be, as the code reflects, within 20 meter below surface. The thickness of the peat layer is 10 meter, or - because a strong influence of the Till layer is measured - even smaller.

After 1400 meter distance, on the farmingland the peat layer is absent, while the thickness of the Till layer is exeptional (very high conductivity values of CS20,HC). Probably the Till layer increase in clay content with depth, pointed out by the higher values of CS20,HC compared lower values of CS20,VC and CS10,VC.

At 1600 meter the limestone will be close to the surface. Here, the CS10,VC values reflecting a very thin Till layer between 5 and 7.5 meter thick. Both CS20,HC and CS20,VC values are low, and with the exploration depths in mind, limestone will be present between 7.5 and 15 meter.

From 1650 meter distance onwards, the limestone will be again at greater depths and the Till layer much thicker, uptil 30 meter (high values of CS10,VC, CS20,VC and CS20,HC from 1650 onwards). The two opposite peaks (high value of CS20,VC and low value of CS20,HC) at 1740 meter distance indicate a very strong gradient or a fault.

Line E (figure 16a and 16b) is measured with all possible coilspacings and coilfigurations. In the field, using the 40 meter coilspacing, strong extreem fluctuating values at one measurement station or between measurement stations reduce the utility of these values for interpretation. Therefore the smoothed conductivity values of the 40-meter coilspacing, horizontal and vertical coils, will only be plotted against the distance but will not be explained.

Figure 13a.

Smoothed conductivity plotted against distance. Raheenmore bog.

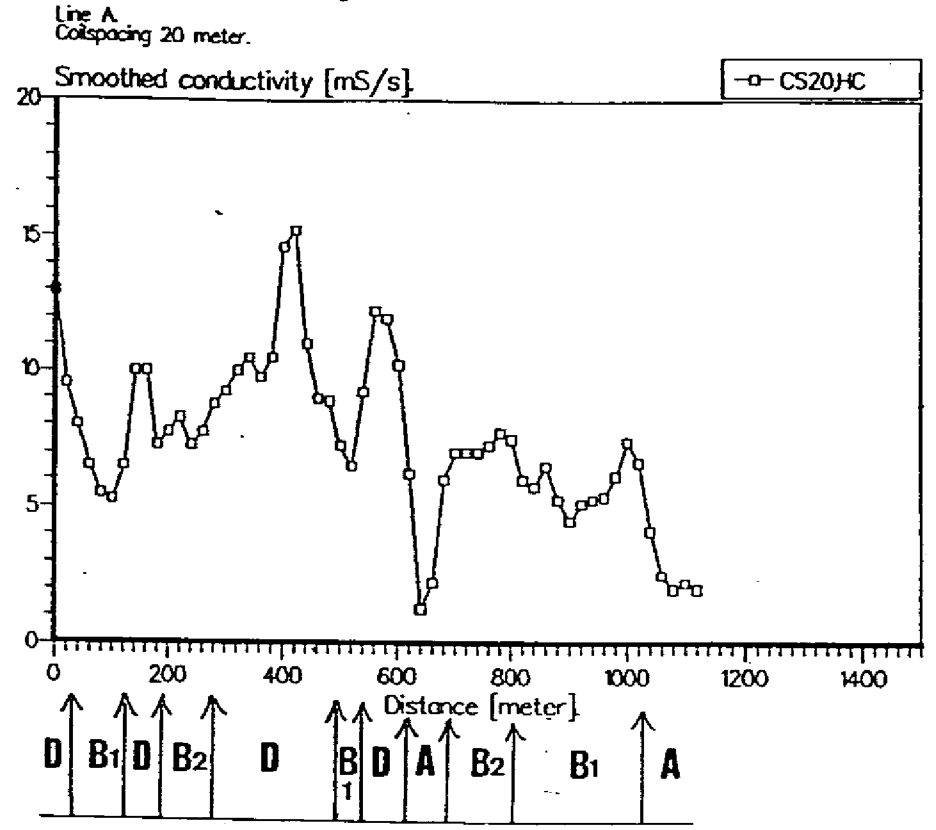


Figure 13b.

Smoothed conductivity plotted against distance. Raheenmore bog.

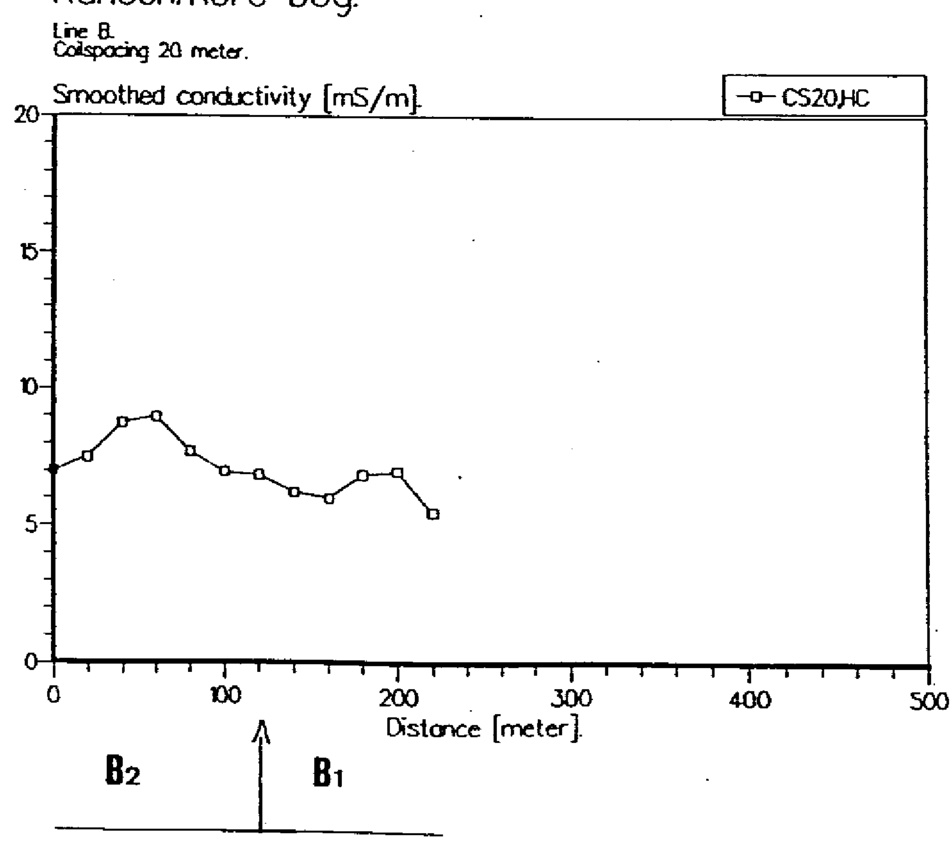


Figure 13c.

Smoothed conductivity plotted against distance.
Raheenmore bog.

Line D.
Coilspacing 20 meter.

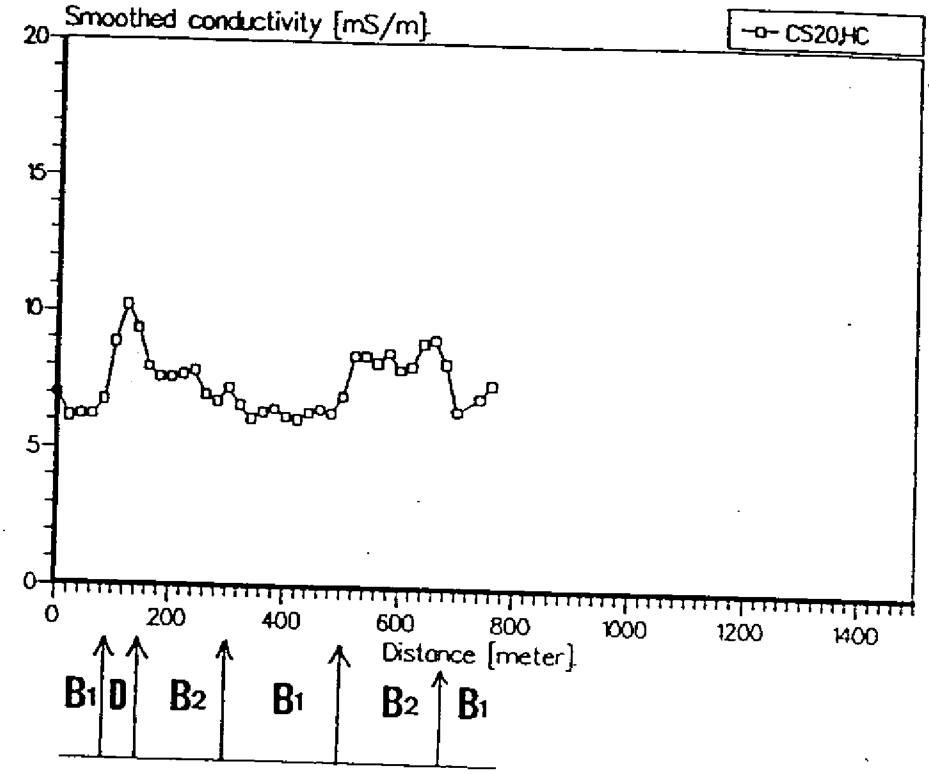


Figure 13d.

Smoothed conductivity plotted against distance.
Raheenmore bog.

Line F.
Coilspacing 20 meter.

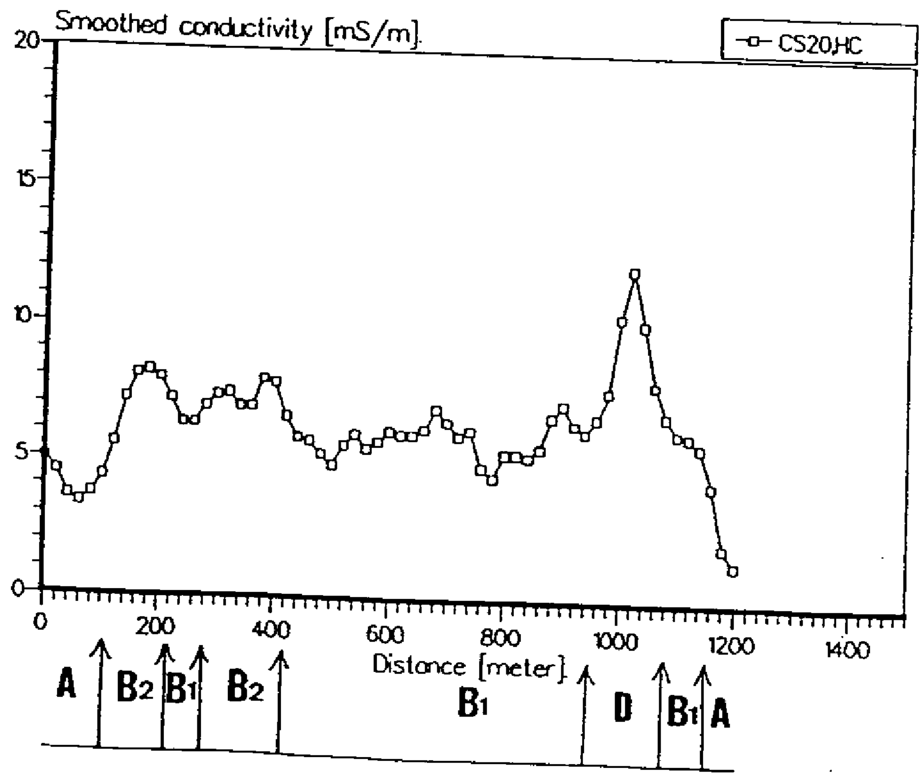


Figure 13e.

Smoothed conductivity plotted against distance.
Raheenmore bog.

Line G.
Coilspacing 20 meter.

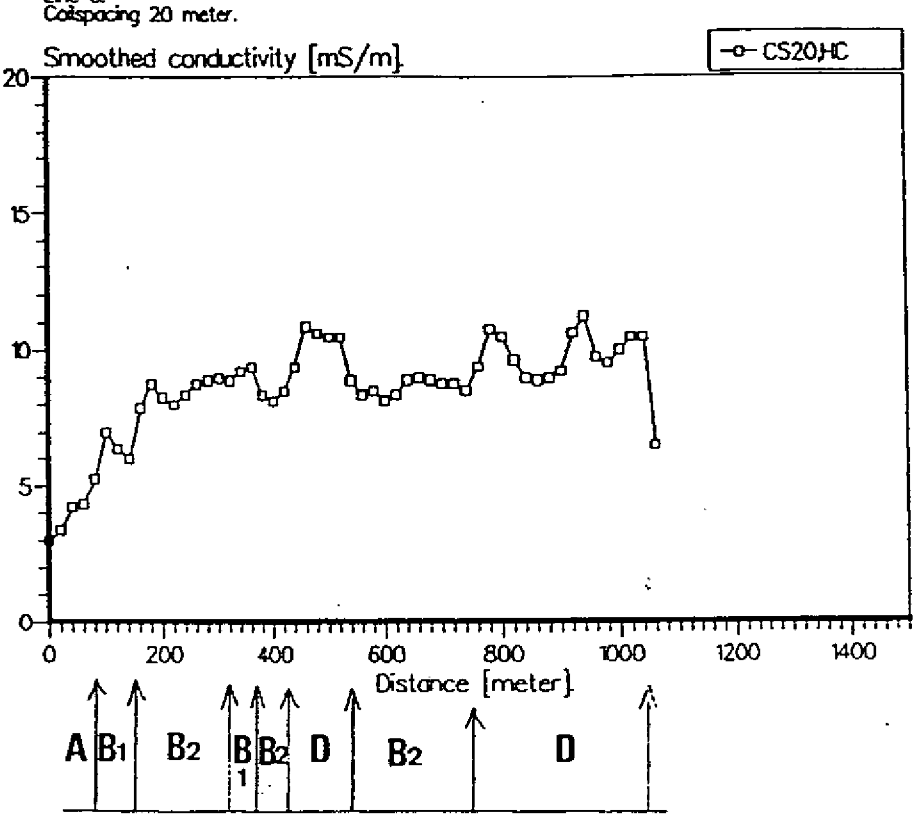


Figure 14.

Smoothed conductivity plotted against distance.
Raheenmore bog.

Line MS1.
Coilspacing 20 meter.

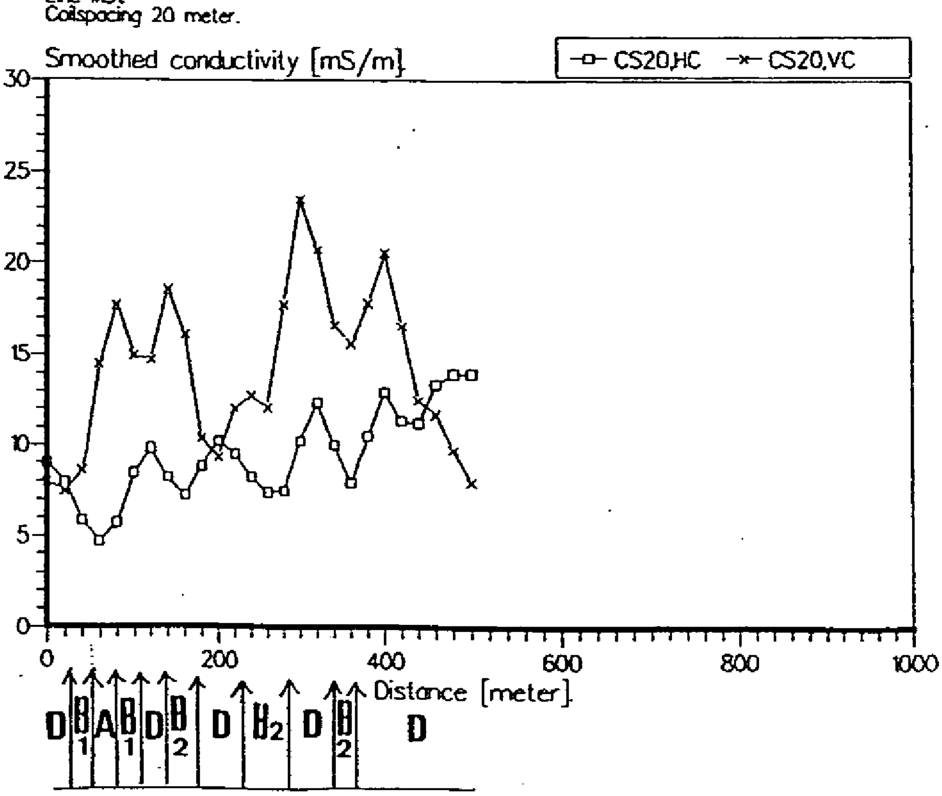


Figure 15a.

Smoothed conductivity plotted against distance. Raheenmore bog.

Line C.
Coilspacing 10 and 20 meter.

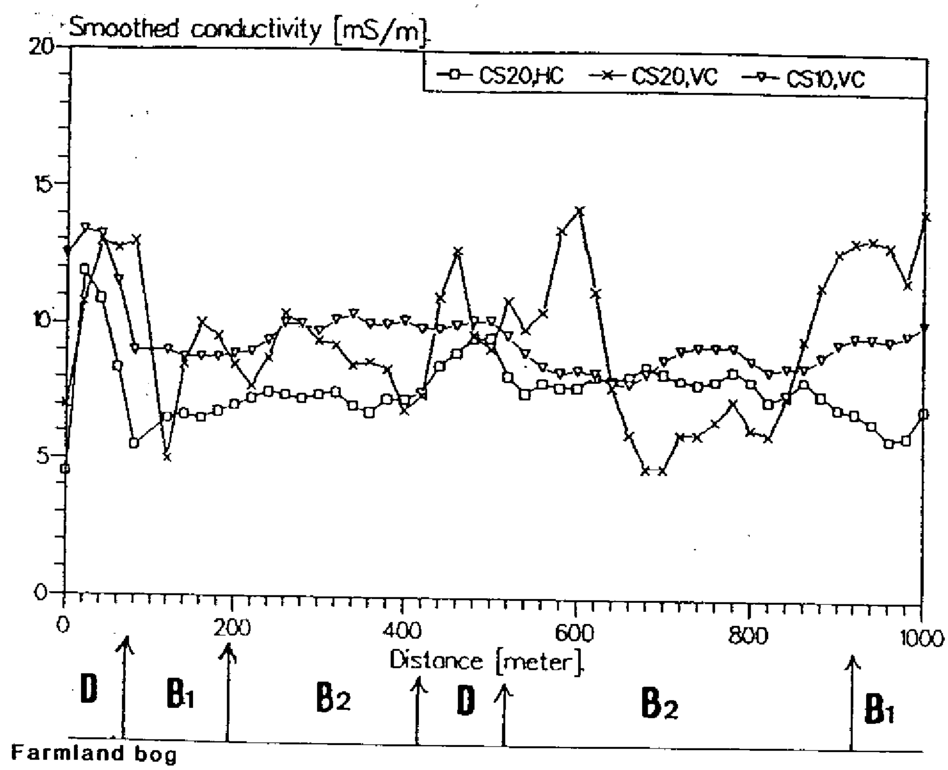


Figure 15b.

Smoothed conductivity plotted against distance. Raheenmore bog.

Line C. CONTINUED
Coilspacing 10 and 20 meter.

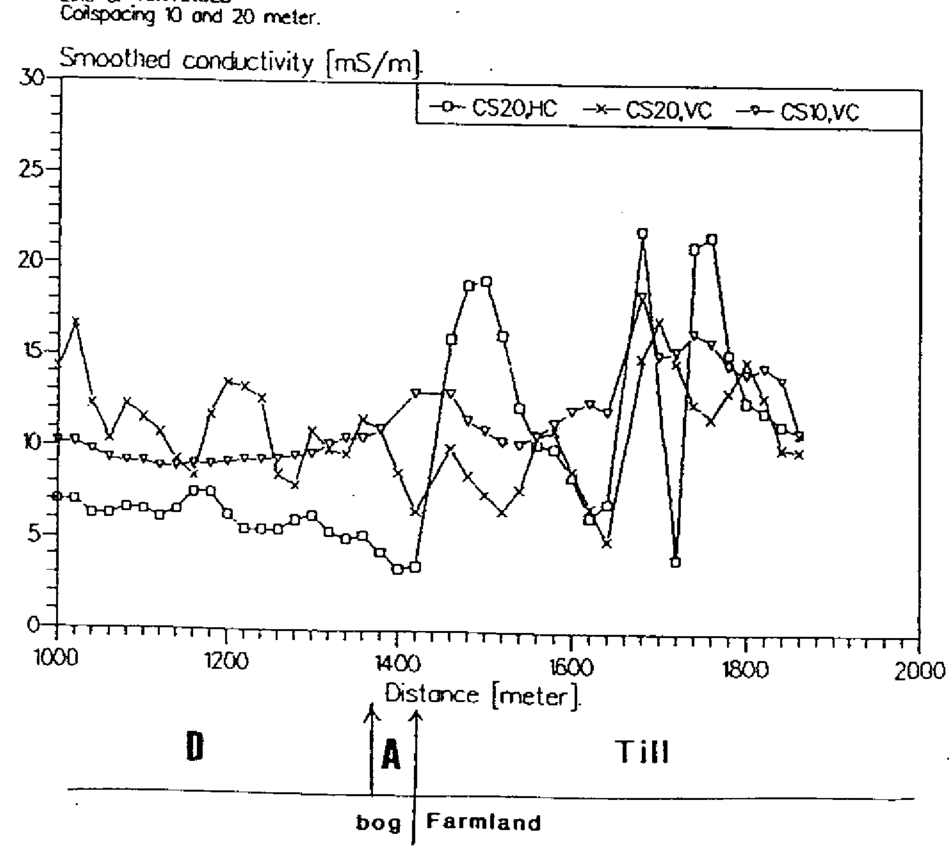


Figure 16a.

Smoothed conductivity plotted against distance.
Raheenmore bog.

Line E.
Coilspacing 10, 20, and 40 meter.

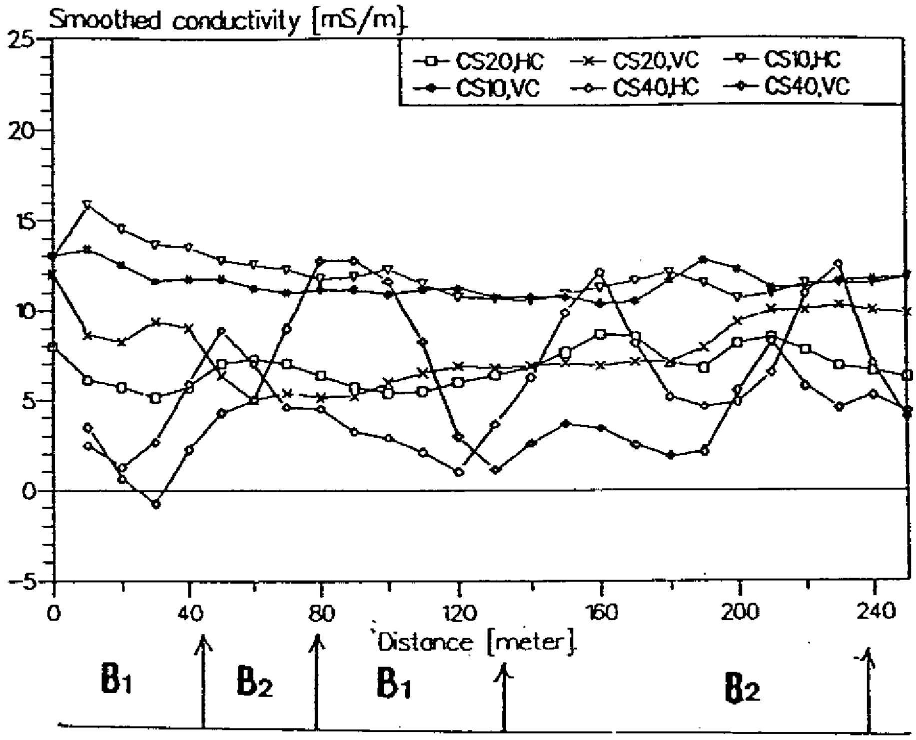
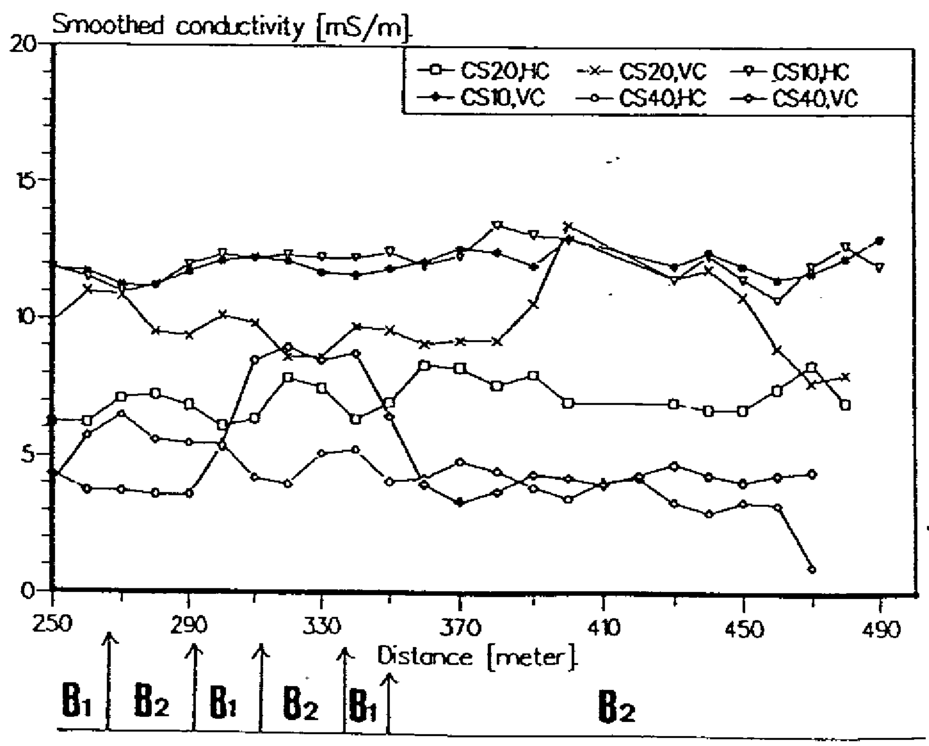


Figure 16b.

Smoothed conductivity plotted against distance.
Raheenmore bog.

Line E. CONTINUED
Coilspacing 10, 20, and 40 meter.



The smoothed conductivity values of CS20,HC show an equable course in distance, code B1 or B2. Both codes are reflecting a relative thick peat layer.

The values measured with the 10 meter coilspacing, vertical and horizontal, are equel with each other at the traversed transect. This reflects a homogeneous layer at least uptil 15 meter depth: the peat layer. This supports the given code, B1 and B2, at the traversed line.

The measured values of the 20 meter coilspacing vertical coils are smaller than the values measured with the 10 meter coilspacing, horizontal and vertical coils. An strong influence of the Till layer is absent and the Till layer will be relative thin. Above argument also supports the presence of an thick peat layer at this part of Raheenmore bog.

Figure 17 shows a contour map of the electrical conductivity [mS/m] of Raheenmore bog. The values could be interpreted according to table 8. Figure 18 reflects the interpretation of the 14 Schlumberger resistivity soundings at Raheenmore bog. The resistivity values are converted to conductivity values [mS/m].

At the north side of the bog, the high concuctivity values measured with the EM34-4 (Fig. 17: 9, 10, and 13 mS/m) as well as the resistivity soundings (Fig. 18: sounding RSVES01, RHSVES07, and RHSVES08) indicates an very strong influence of the Till layer, and a limestone depth of at least 20 meter below surface. The thickness of the Till layer is exeptional, at least 15 meter.

Most northwards of the bog a lower conductivity value is found, 5 mS/m, between higher values 7 and 10 mS/m (fig. 17). This indicates a spherically shape ('hill') of the limestone, interesting site for a Schlumberger sounding..

At the east side as well as the west side of Raheenmore bog, towards the edge of the bog, high conductivity values are found, 9 and 10 mS/m. The Till layer will be (also) at these sides of the bog relative thick. This argument is supported by sounding RHSVES04.

Towards the centre of the bog, the conductivity decrease to 7 mS/m and at the westside of the bog furthermore to 5 mS/m (fig. 17). These values at the west side side of the bog and the results of the interpretation, with respect to table.8, are supported by soundings RHSVES09 and 10 wich show Till within 15 meter depth. The values at the east side of the bog and the results of the interpretation, with respect to table 8, is supported by sounding RHSVES03.

At the south(east) side of the bog, low conductivity values at the edge of the bog, 3 mS/m, indicate limestone close to the surface. Sounding RHSVES06 on the farmingland supports this argument.

Towards the centre of the bog, at the southeast side, a relative thick layer of peat is present: from 10 to more than 15 meter. At the southwest side, the influence of a relative thick Till layer is noticeable between the areas with a relative thick peat layer. Sounding RHSVES11/12, at the southwest-centre part of the bog supports the conductivity value 5 and the results of the interpretation, with respect to table 8, in this location.

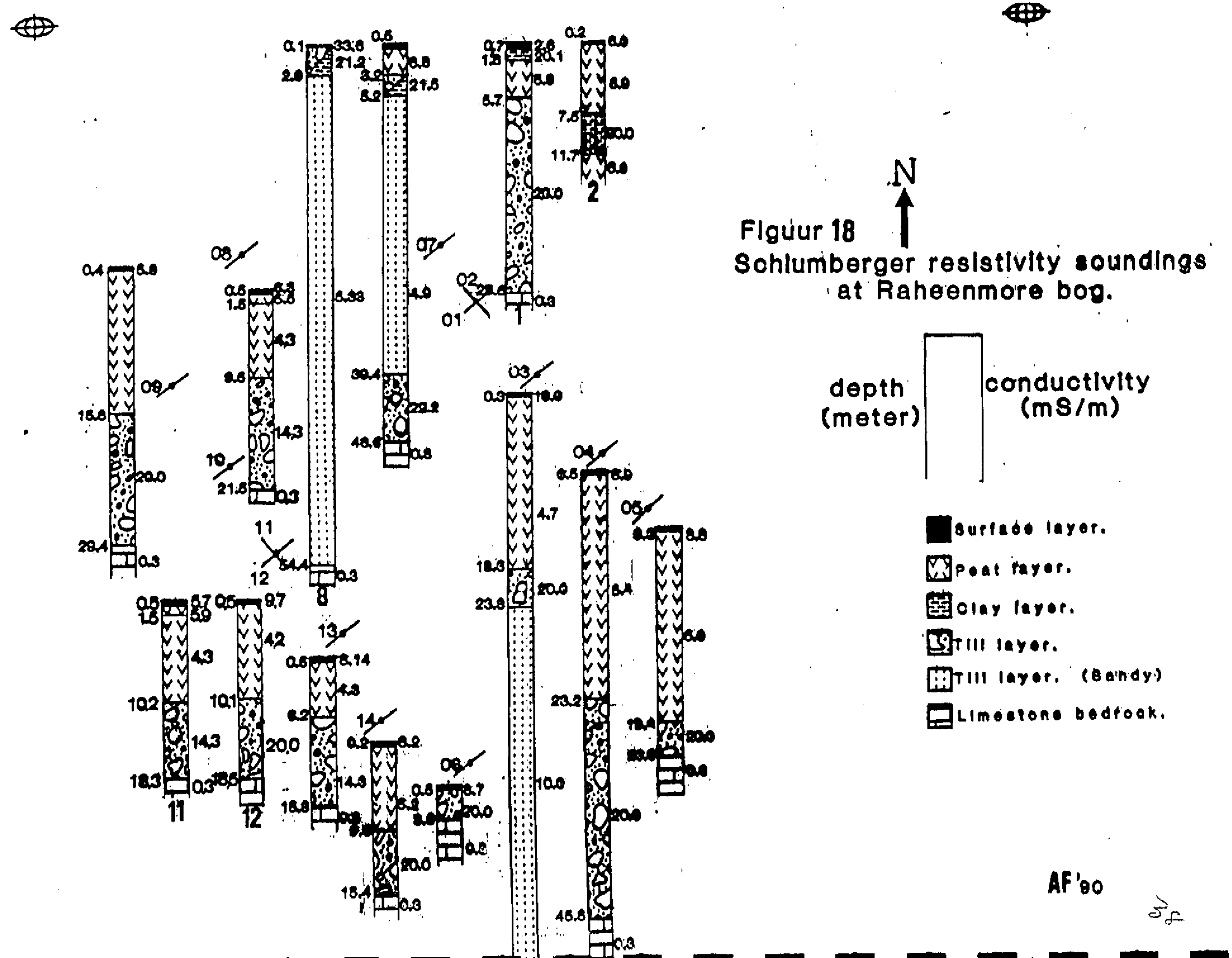
5.2 Clara bog.

5.2.1. The ridge near the soak.
(Fig. 12c and 12d).

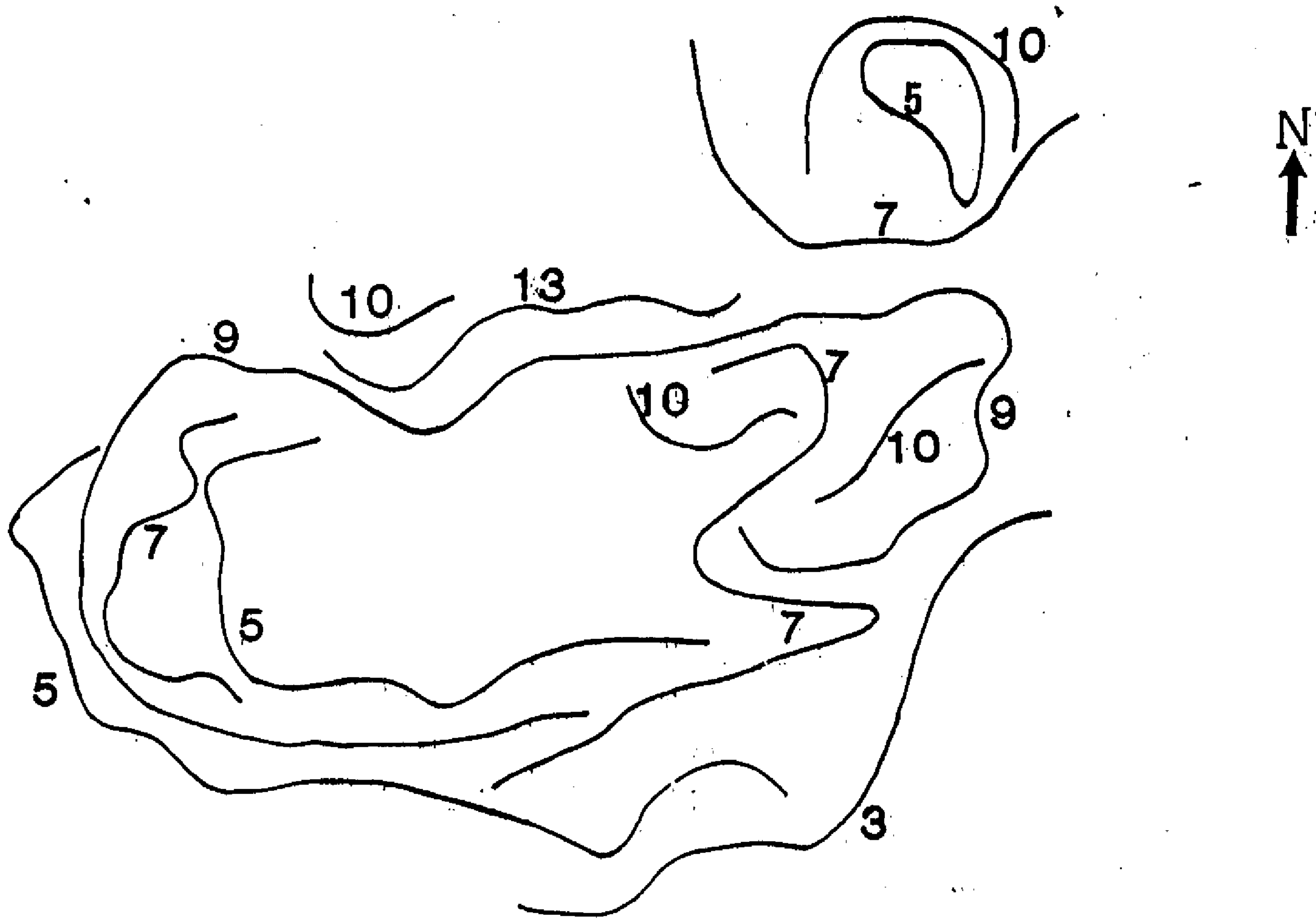
Soundings CLSVES09 and 10 (the centres are 100 meter apart) on the ridge near the soak reveal a three layered model. First a surface peat layer, approximately 0.5 meter thick, while the "second" peat layer has a thickness of 11.4 meter (CLSVES10) to 12.4 meter (CLSVES09). The depth to bedrock is respectively 12.0 meter (CLSVES10) to 12.9 meter (CLSVES09). Since the ground surface at sounding CLSVES09 is slightly higher than the ground surface of CLSVES10, the resistivity soundings seem to suggest that the bedrock is at an uniform depth along the longitudinal axis (north-south) of the ridge.

However, the EM34-4 traversed line R3 (figure 21c), along the longitudinal axis of the ridge, shows two different areas of interest (figure 20a):

1) A strong influence of a Till or clay layer at 0-60 meter, 160-240 meter, and 320-400 meter. (high conductivity values with CS20,VC, CS20HC).
2) Bedrock relative close to the surface at 60-160 meter and 240-320 meter (low conductivity values with CS20VC, CS20HC, and CS10HC).



Figuur 18
Schlumberger resistivity soundings at Raheenmore bog.



Figuur 17
Contour map of the electrical conductivity (mS/m) of Raheenmore bog.
20 meter intercoilspacing, horizontal coils.
Exploration depth 30 meter.

AF'90

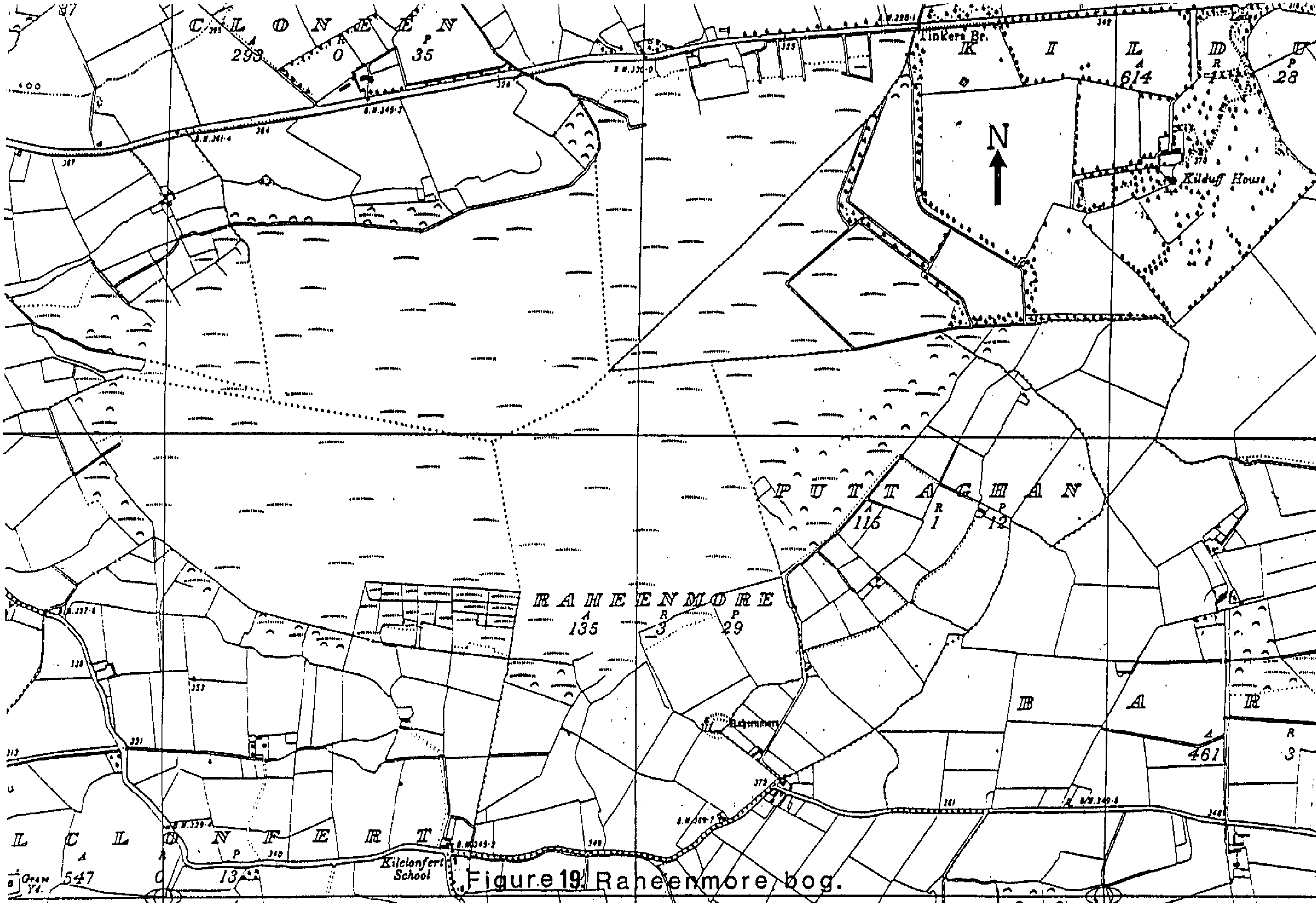


Figure 19. Raheenmore bog.

We can conclude that the depth to bedrock has a small variation along the longitudinal axis of the ridge. If the bedrock is deeper there will be a Till or clay layer present between the peat and the limestone. On the other hand, if the bedrock is relative close to the surface the Till or clay layer will be absent or very thin. The possible structure along the longitudinal axis of the ridge is given in figure 21e. The figure is based on the conductivity measurements of line R3.

The EM34-4 lines Line R1 and R2 (fig. 21a, 21b, and 21c) traversed the ridge from east to west. Both lines show the same course in distance. From the bog (0 meter distance) to half-way the slope at the eastside of the ridge (at 60-80 meter distance) we measured a strong decrease in conductivity with the 20 meter coilspacing, vertical coils. The data obtained with the other coilspacing and coil configurations show also a sligth decrease in conductivity values in this traject. This reflects a decrease in the influence of a layer with a high conductivity between the peat layer and the bedrock, probably a Till or a clay layer.
Towards the top of the ridge until half-way the slope of the westside of the ridge the data show, according to the relative low measured values with CS10HC, CS20HC, and CS20VC, bedrock relative close to the surface (between 7.5 and 15 meter). The values measured with the 10 meter coilspacing vertical coils reflect a peat layer of (at least) 7.5 meter.
Further down from half-way the slope towards the bog on the westside of the ridge a strong increase of the values with CS20VC and a sligth increase of the values with the other coilspacing and coilfiguration is measured. This indicate, in the same way as the eastside of the ridge, an (increasing) influence of a Till or clay layer between the peat layer and the bedrock.

The possible structure along the short axis of the ridge is given in figure 21d. The figure is based on the EM34-4 conductivity measurements of line R1 and R2.
The gradient of the conductivity at the west side is stronger than at the east side, so probably the slope of the bedrock is also stronger at the westside.
The EM34-4 line 4 shows an increasing influence of the Till or clay layer in the layered earth. (increasing conductivity values with CS10,VC and CS20,HS). The Till or clay layer below the surface will increase in thickness with distance (fig.20b). Probably, the depth to bedrock increase (increasing conductivity values CS20,VC) and the thickness of the peat layer below the surface will decrease (increasing values of CS10,VC).

5.2.2. The Esker.
(Fig. 12c and 12d).

5.2.2.1. EM34-4 measurements.

Figure 22a to 22e shows the smoothed conductivity, measured at the surface, plotted against the distance of the lines along the top of the Esker towards the bog.
Table 9 gives the "surface" material at the traversed lines with distance.

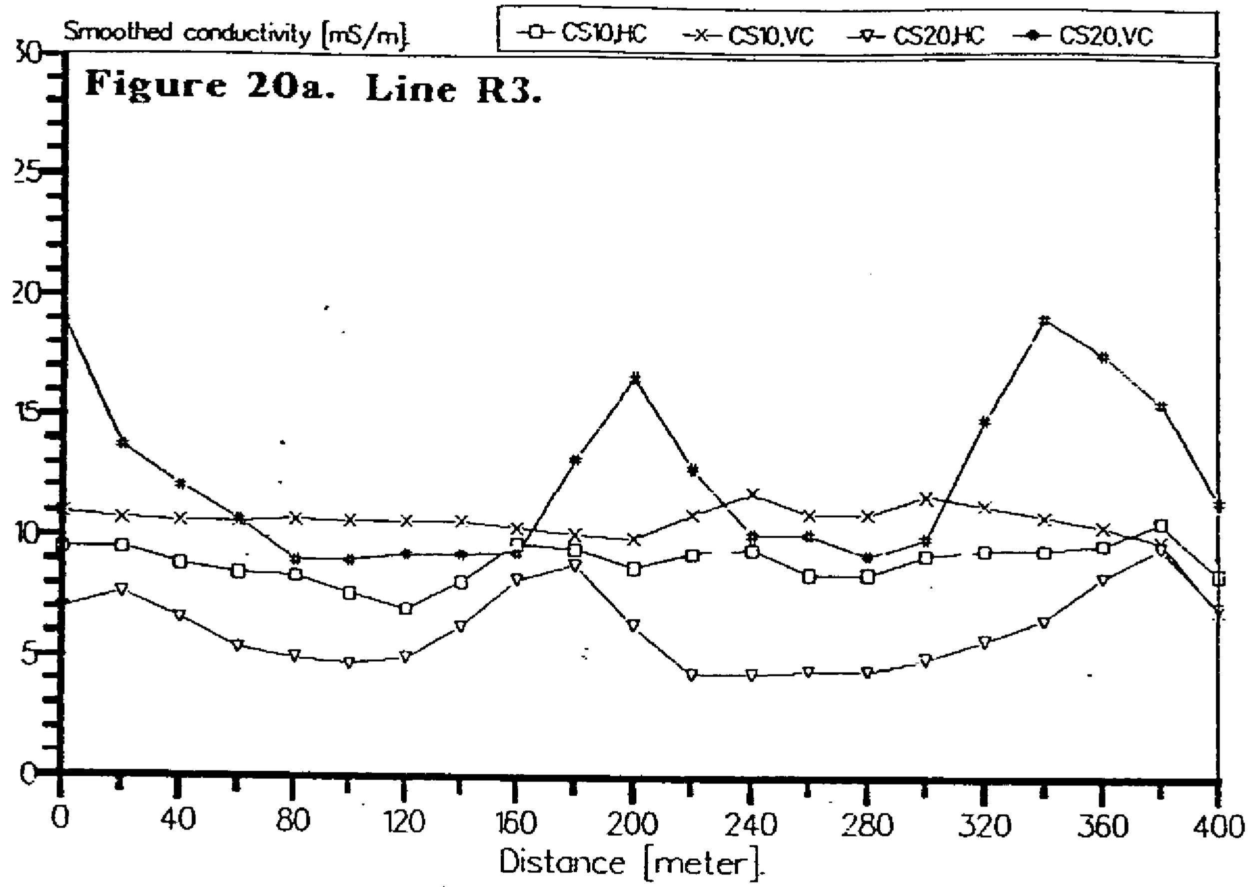
The measured values of traversed lines 3, 4, 6, and 7 show exactly the same course of the conductivity with distance. As a consequence of the steep slope, most attention is given to CS10,VC, as the vertical coilfiguration is relative insensitive to terrain topography, compared to horizontal coilfiguration.

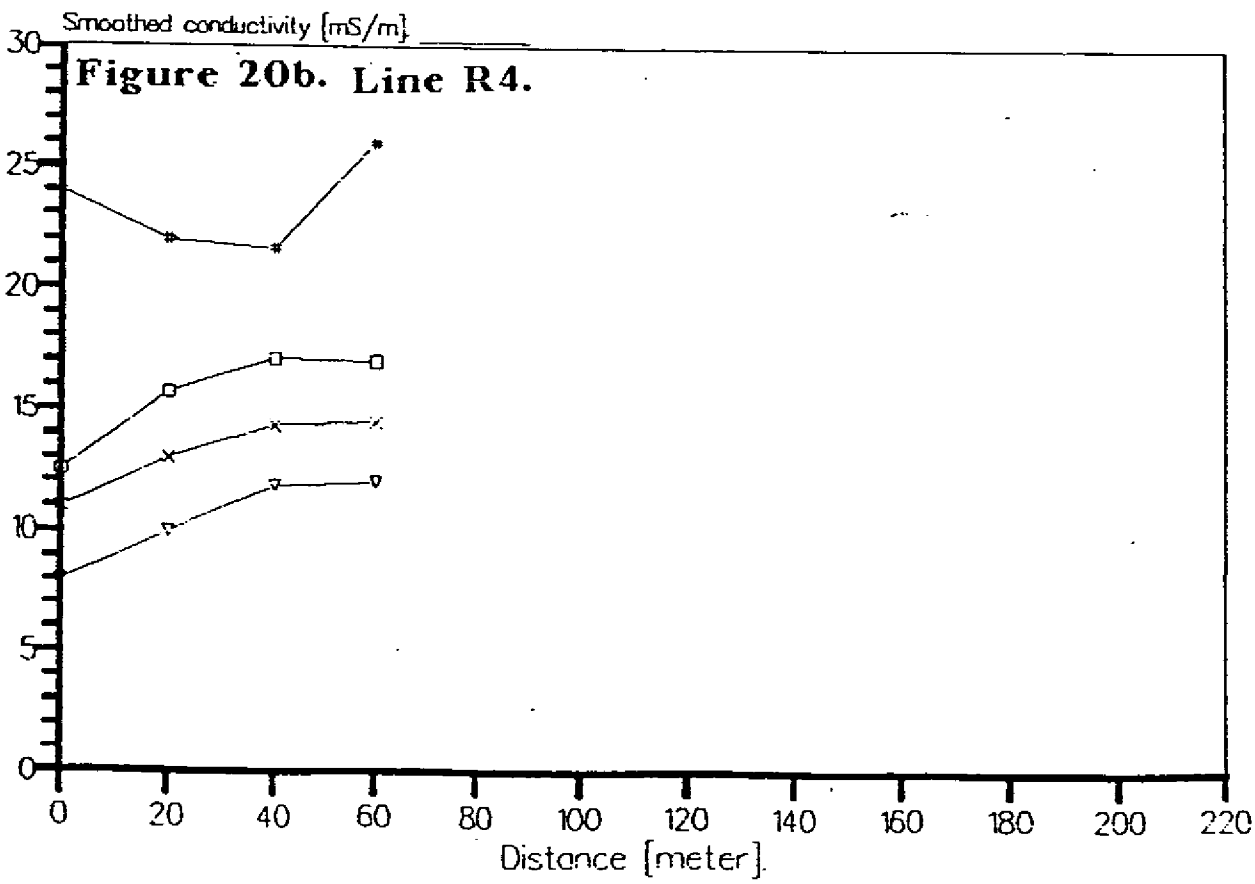
In the graph of the lines 1,3,4,5, and 7, the measured conductivity (CS10,VC) shows four different sections.
First relative low conductivity values at 0-70 (line 6 and 7) and 0-100 meter (line 3 and 4). These relative low conductivity values indicate unsaturated Esker material.
The second section shows a strong gradient in the conductivity between 70-120 (line 6 and 7) and 100-150 meter (line 3 and 4). The increase of the the conductivity starts at the same point on the Esker for all traversed lines: 60 meter before the Esker/bog border. The strong gradient of the measured values could indicate:

1) An increase in clay content of the Esker material.
2) The existance of Till under the Esker (material) at the Esker/bog border.

Smoothed conductivity plotted against distance.
Clara bog.
Ridge near the 'soak'.

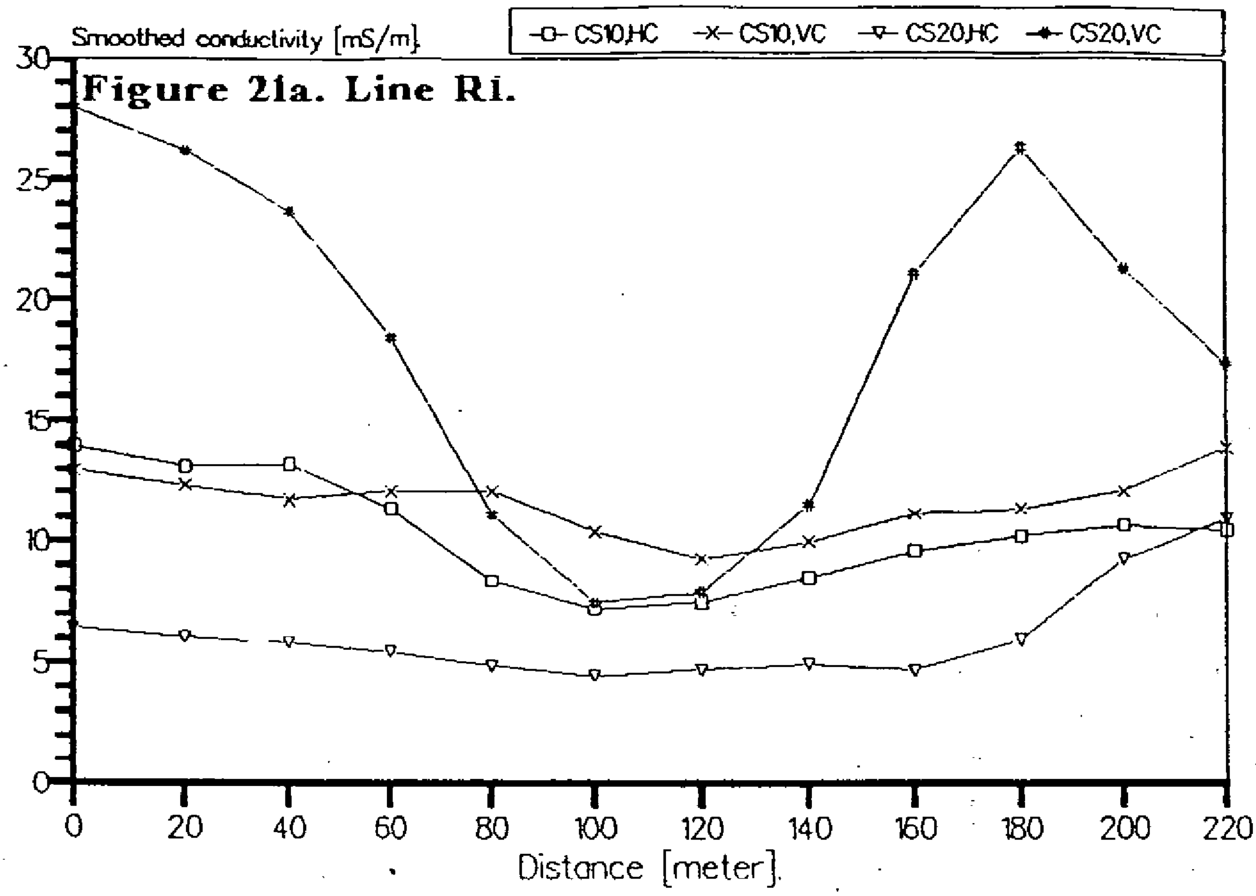
Coilspacing 10 and 20 meter.





Smoothed conductivity plotted against distance.
Clara bog.
Ridge near the 'soak'.

Coilspacing 10 and 20 meter.



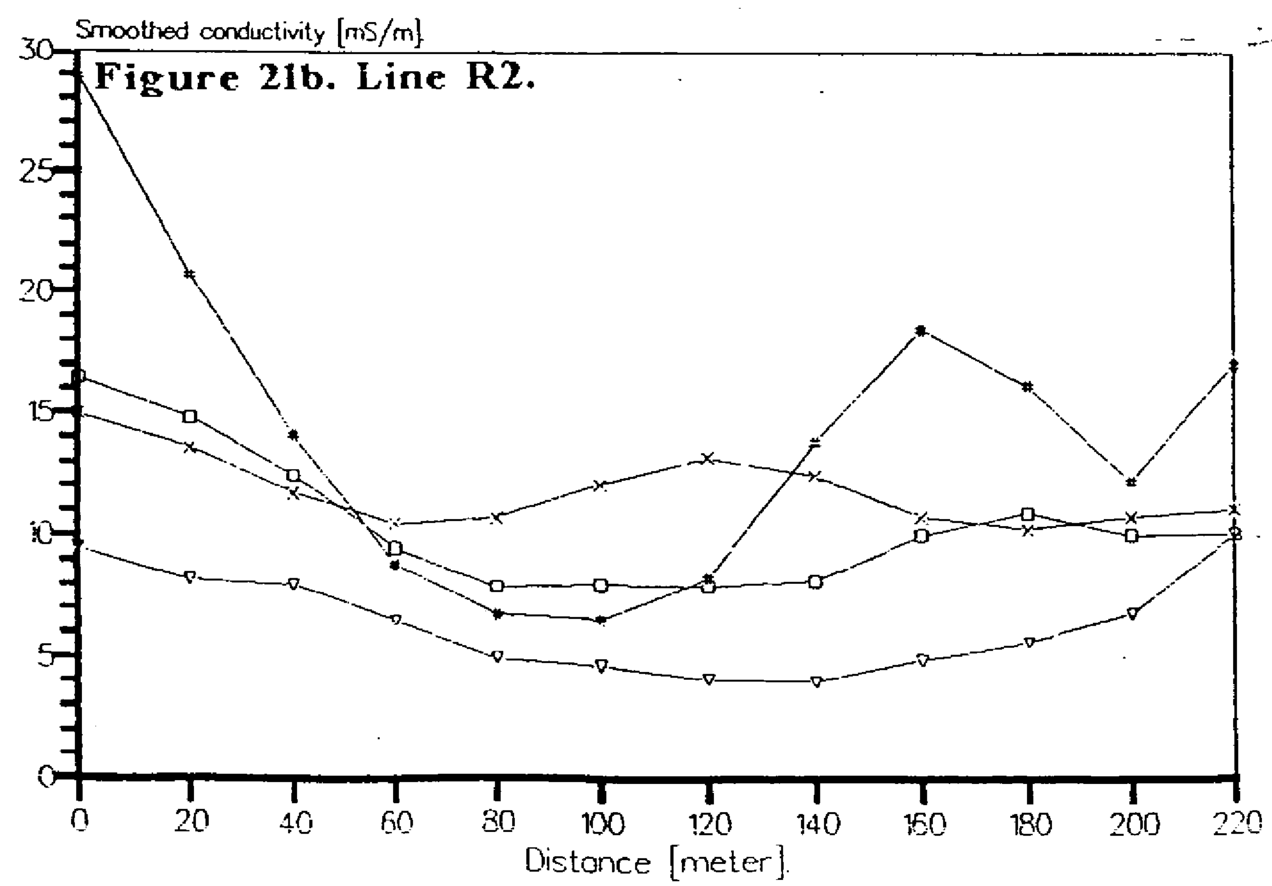


Figure 21c. Traversed lines on the ridge near the soak.

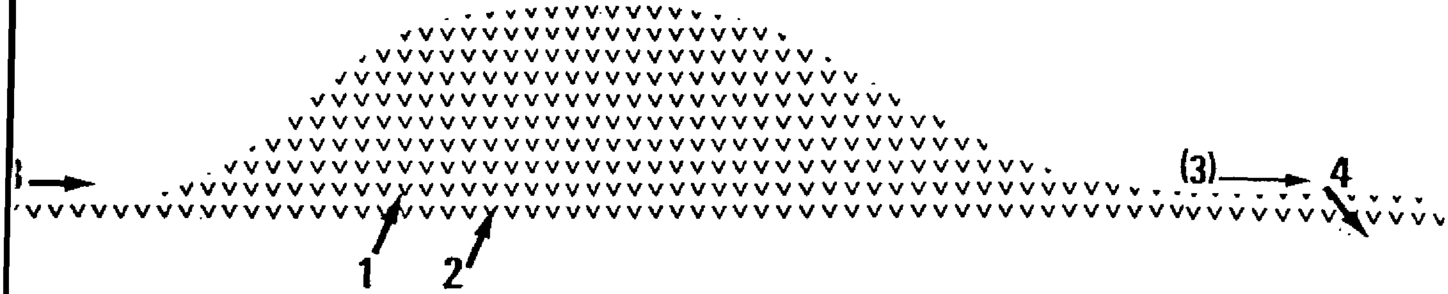


Figure 21d. Possible structure along the short axis of the ridge near the soak.

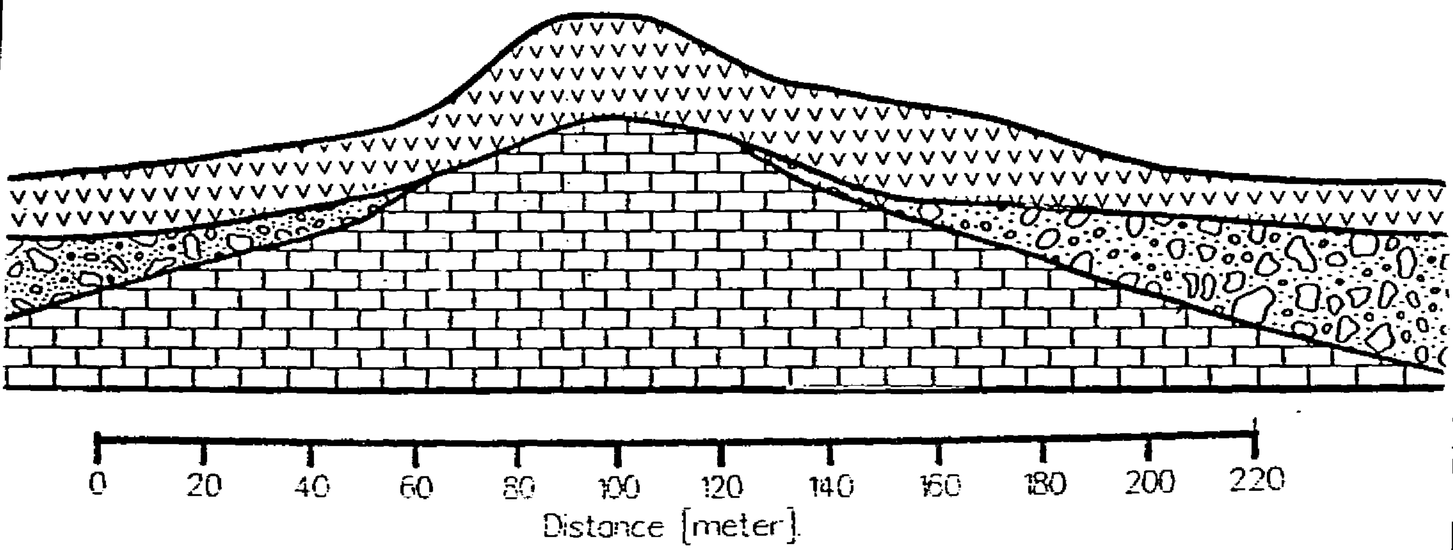
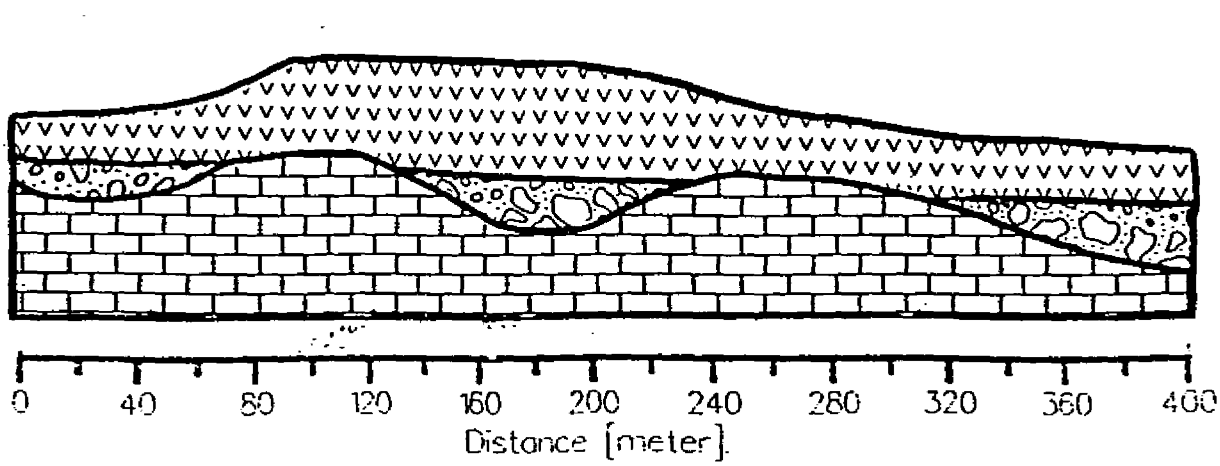


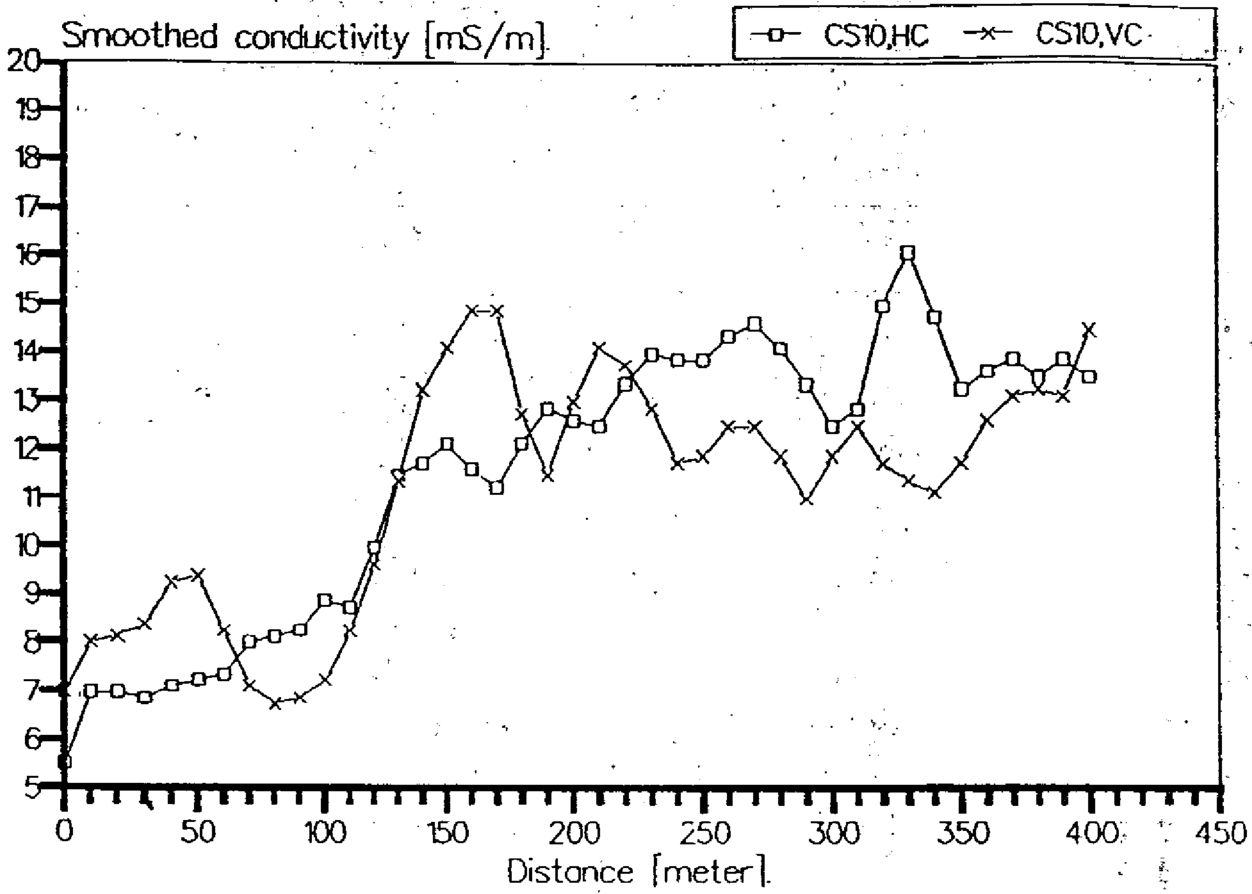
Figure 21e. Possible structure along the longitudinal axis of the Ridge near the soak.



Smoothed conductivity plotted against distance.
Clara bog.
Esker – bog line.

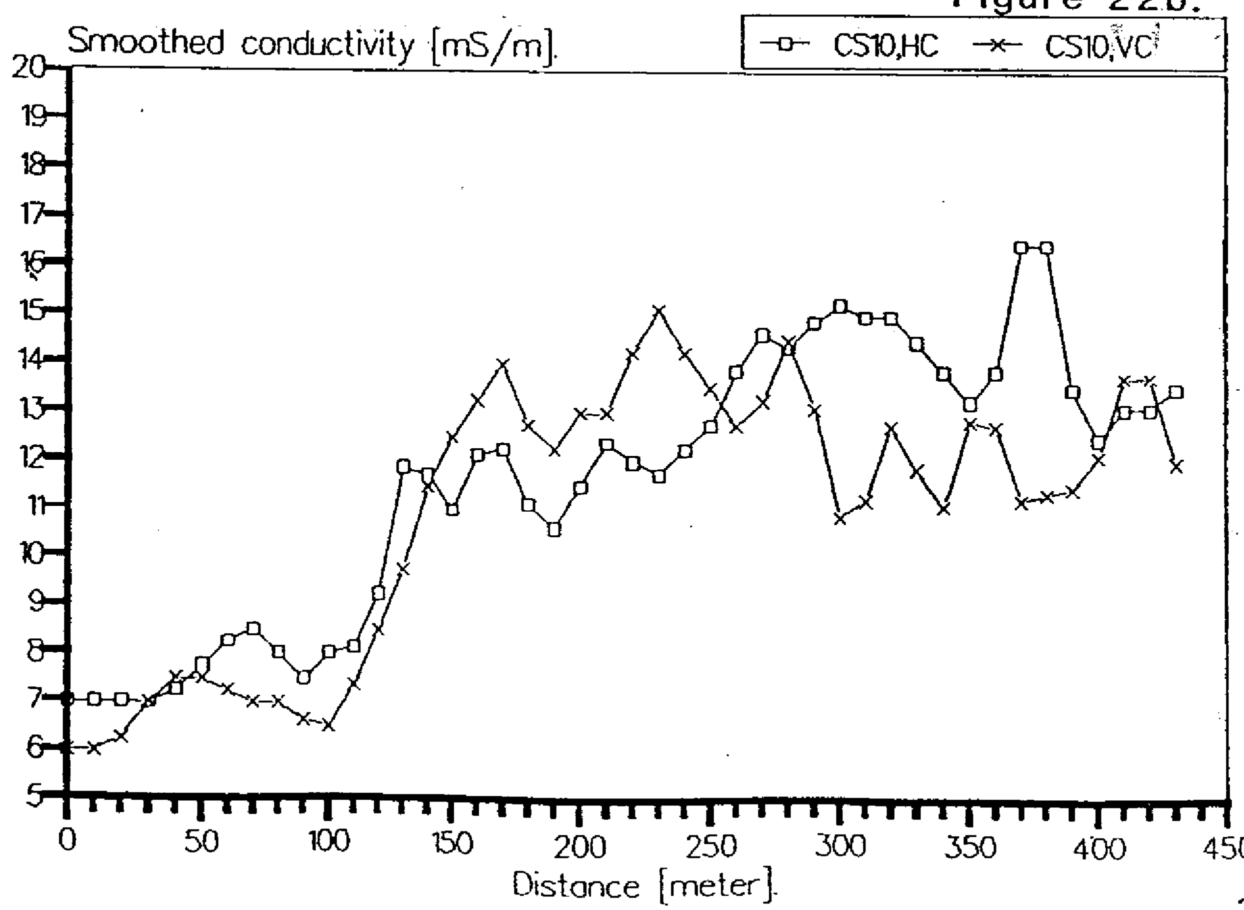
Line 3.
Coilspacing 10 meter.

Figure 22a.



Line 4.
Coilspacing 10 meter.

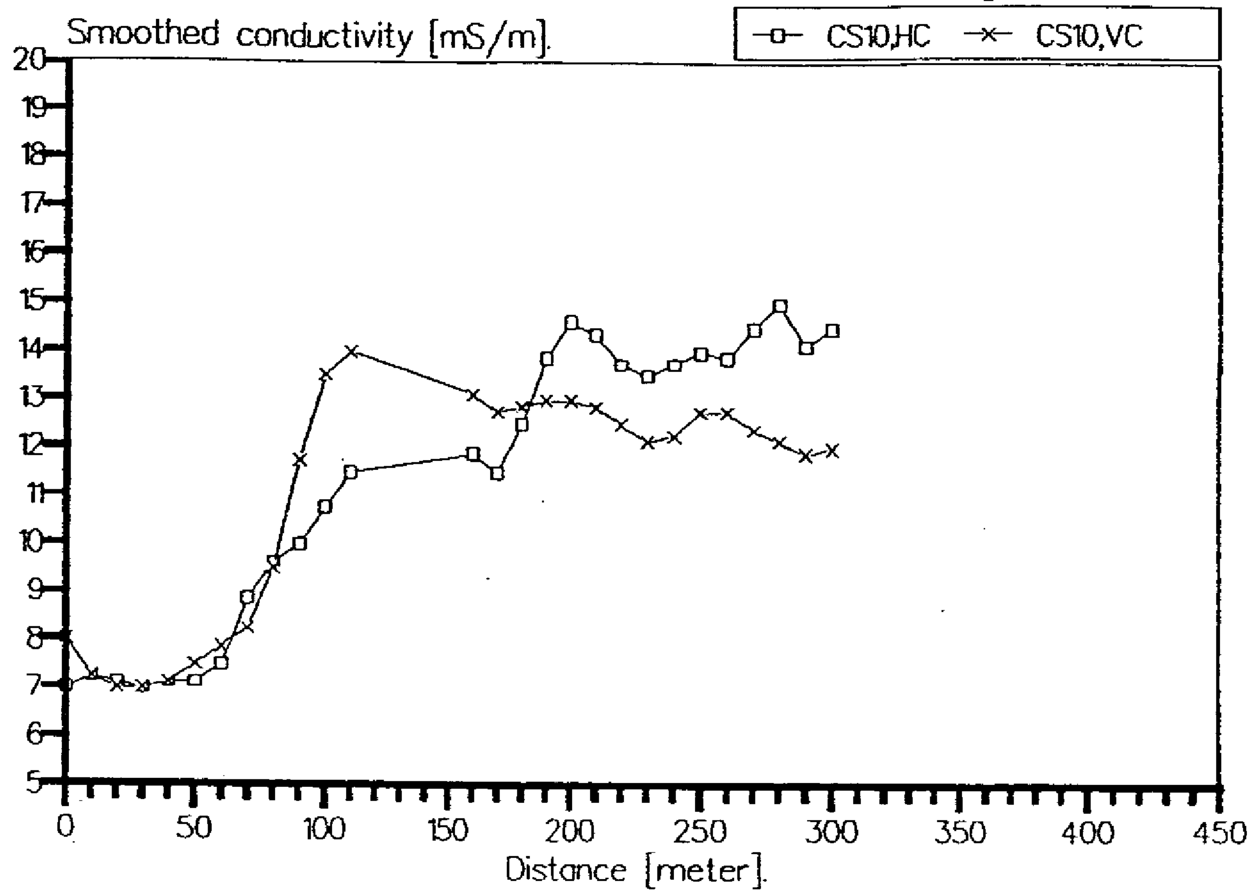
Figure 22b.



Smoothed conductivity plotted against distance.
Clara bog.
Esker – bog line.

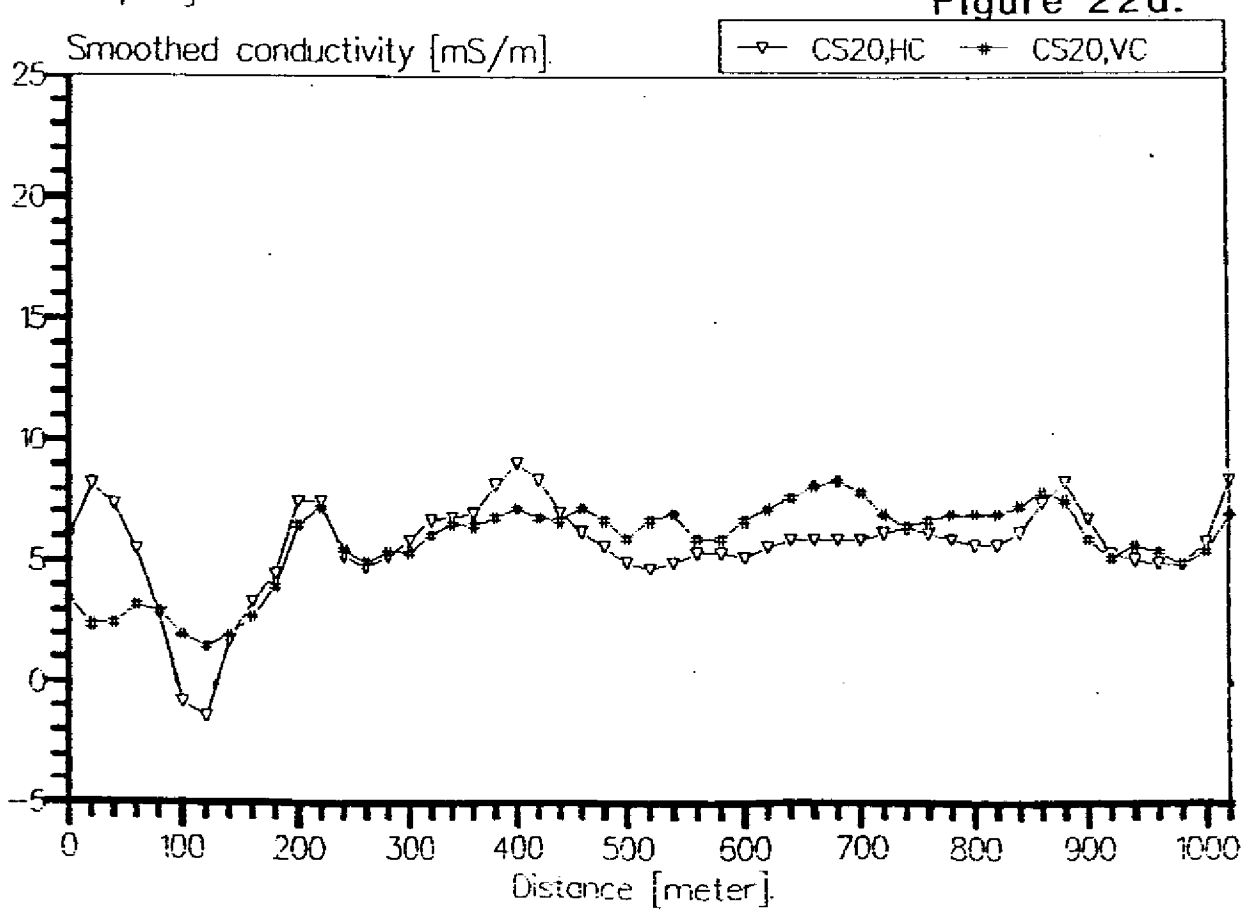
Line 7.
Coilspacing 10 meter.

Figure 22c.



Line 1.
Coilspacing 20 meter.

Figure 22d.



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Smoothed conductivity plotted against distance.
Clara bog.
Esker – bog line.
Line 6.
Coilspacing 10 meter.

Figure 22e.

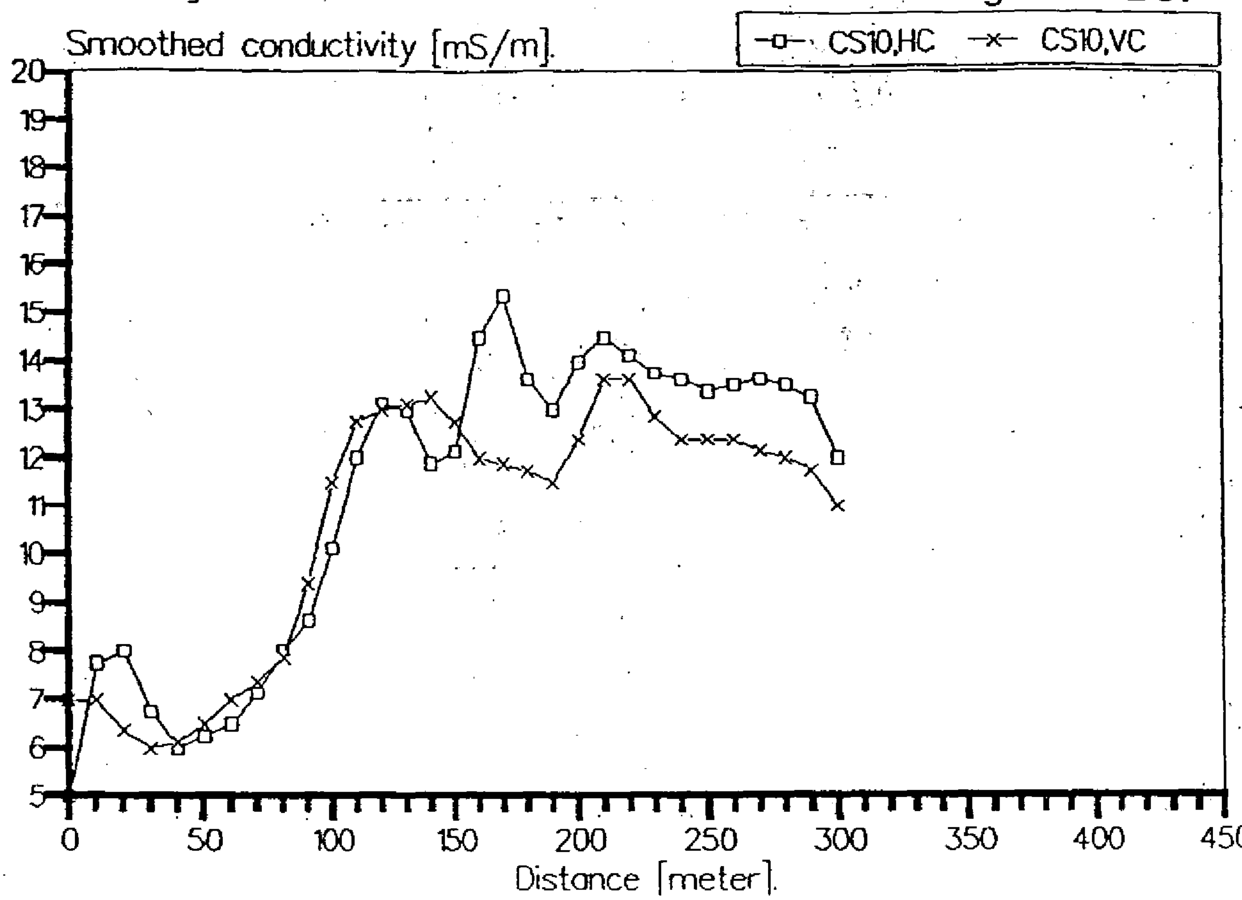
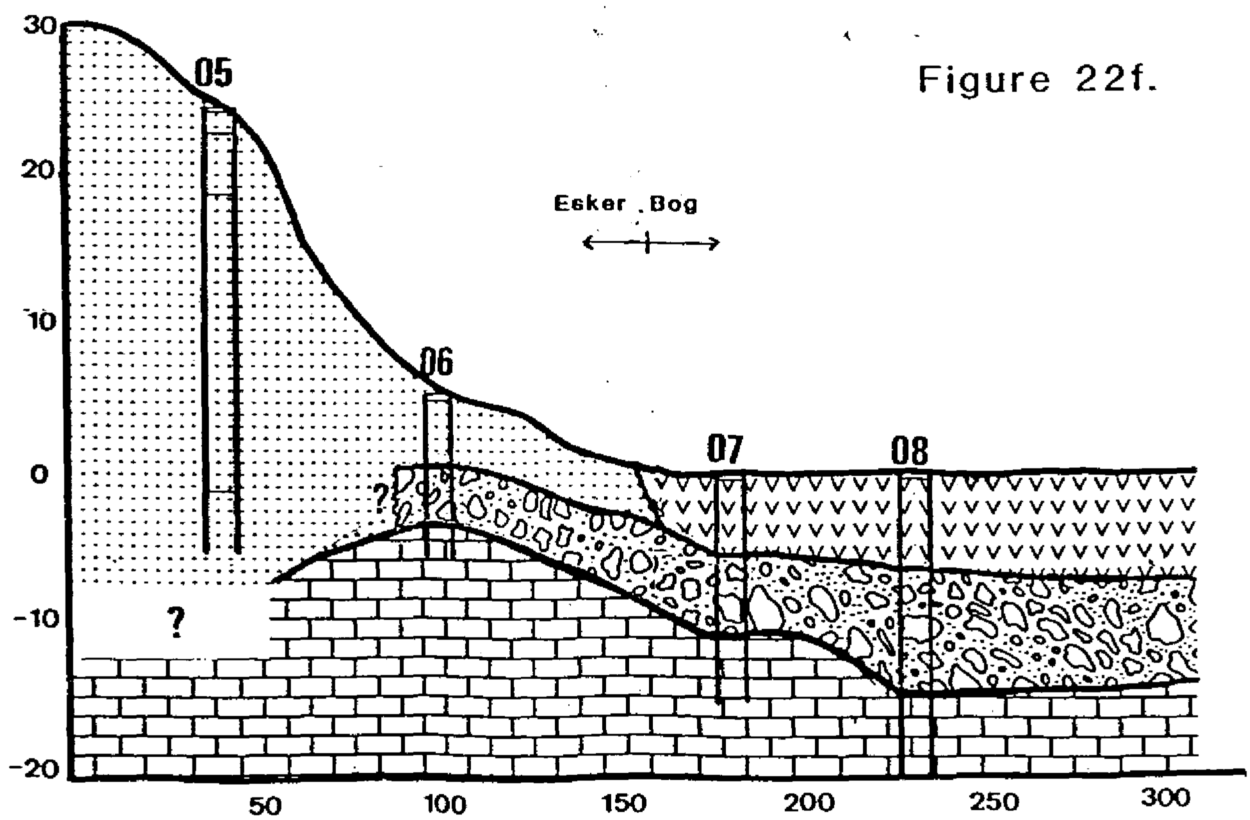


Figure 22f.



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It should be noted that the measured values with the 20 meter coilspacing, horizontal coils show at comparable distance (80-100 meter before the Esker/bog border) two negative values (figure 22d). This indicates a very steep slope in the layered earth or a fault.

The third and the fourth section of the graph show relative high conductivity values. In the third section, the conductivity values measured with CS10,HC are lower compared to CS10,VC. This indicate a strong influence of the Till layer in the layered earth (between 0 and 15 meter). The peat layer is very thin.

The fourth section 'starts' at 10 (line 6 and 7), 20 meter (line 3), and 60 meter (line 4) at the bog. Here, the conductivity values measured with CS10,HC (exploration depth 15.0 meter) are higher compared to CS10,VC (exploration depth 7.5 meter). This indicate an increasing thickness of peat.

5.2.2.2. Resistivity soundings CLSVES05, 06, 07 and 08.

Four resistivity soundings were taken on line 6, at 40 (CLSVES05), 100 (CLSVES06), 180 (CLSVES07), and 230 (CLSVES08) meter distance (fig.22f).

Sounding CLSVES05 shows unsaturated Esker material upto at least 25.4 meter depth, conform to the interpretation of the first section of the graph of line 6 (figure 22e). The depth to bedrock will be deeper than 25.4 meter.

At 100 meter distance from the top of the Esker, bedrock can be found at 8.4 meter below the surface (CLSVES06). On top of the bedrock, a layer with relative low resistivity is found. The layer thickness is 3.8 meter, and with respect to the resistivity value, it could be a clay or Till. Above this layer, Esker material is found: at the surface to 4.6 meter deep. The presence of a clay or Till layer under the Esker (material) at the Esker/bog border is already mentioned in paragraph 5.2.2.1.

Sounding CLSVES07 and 08 reveal a four-layered model: surface peat layer, peat layer, Till layer and limestone bedrock. The possible structure along the top of the Esker towards the bog is given in figure 23. The figure is based on the conductivity measurements of traversed line 6 and the resistivity soundings.

5.2.3. Line MA1.

Figure 23a-d reflect the smoothed conductivity plotted against the distance of line MA1. Interpretation of the EM34-4 conductivity values are given below the graph, as well as the interpretation of the resistivity soundings CLSVES01, 02, 03, and 04.

5.2.3.1. EM34-4 measurements.

The conductivity values (CS10,VC, CS20,HC, and CS20,VC), at 0 - 640 meter distance (fig.23a), are erratic, as a result of the very rapid lateral changes in resistivity arising from the sand and gravel (often occuring in the form of concretions) material (McNeill, 1980).
At 180 meter distance a steep slope in the layered earth or fault is present. At 430 meter distance, low conductivity values of CS20,HC indicate limestone within 15 meter below surface and a relative uplift of the limestone bedrock.

The conductivity measured with the CS10,VC shows values of about 10 mS/m from 600-1650 on line MA1. The conductivity for peat inferred from the Schlumberger sounding is 6 mS/m and 10 mS/m for the top peat layer. So the Cs10,VC value of 10 mS/m is a little bit too high for an infinite thick peat layer, but a reasonable value for a peat layer of about 7.5 meter thickness underlaied by a Till/clay layer (which has a higher conductivity).
Measurements with greater penetration, Cs20 HC/VC, show mostly values lower than 10 mS/m what indicates that the good conductivity Till layer above the limestone is very thin or absent. Values greater than 10 mS/m are found on line MA1 at 920 meter (CLSVES01), 1080 meter and 1220 meter (CLSVES02). Values above the 10 mS/m are also found between 1400 and 1650 meter.

Figure 23a. Line MAI.

Smoothed conductivity plotted against distance.
Clara bog.

Coilspacing 10 and 20 meter.

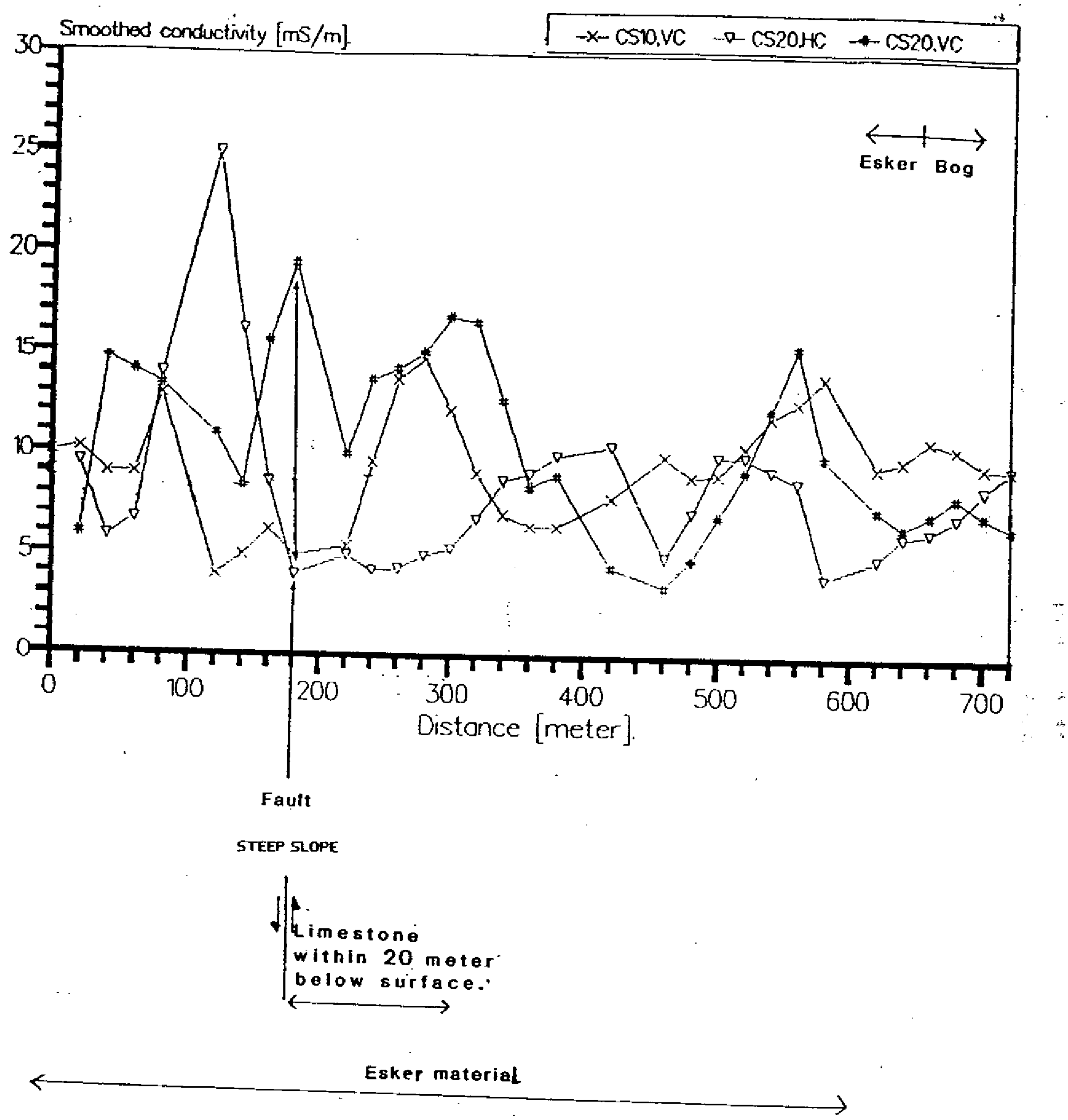

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Figure 23b. Line MA1 continued.

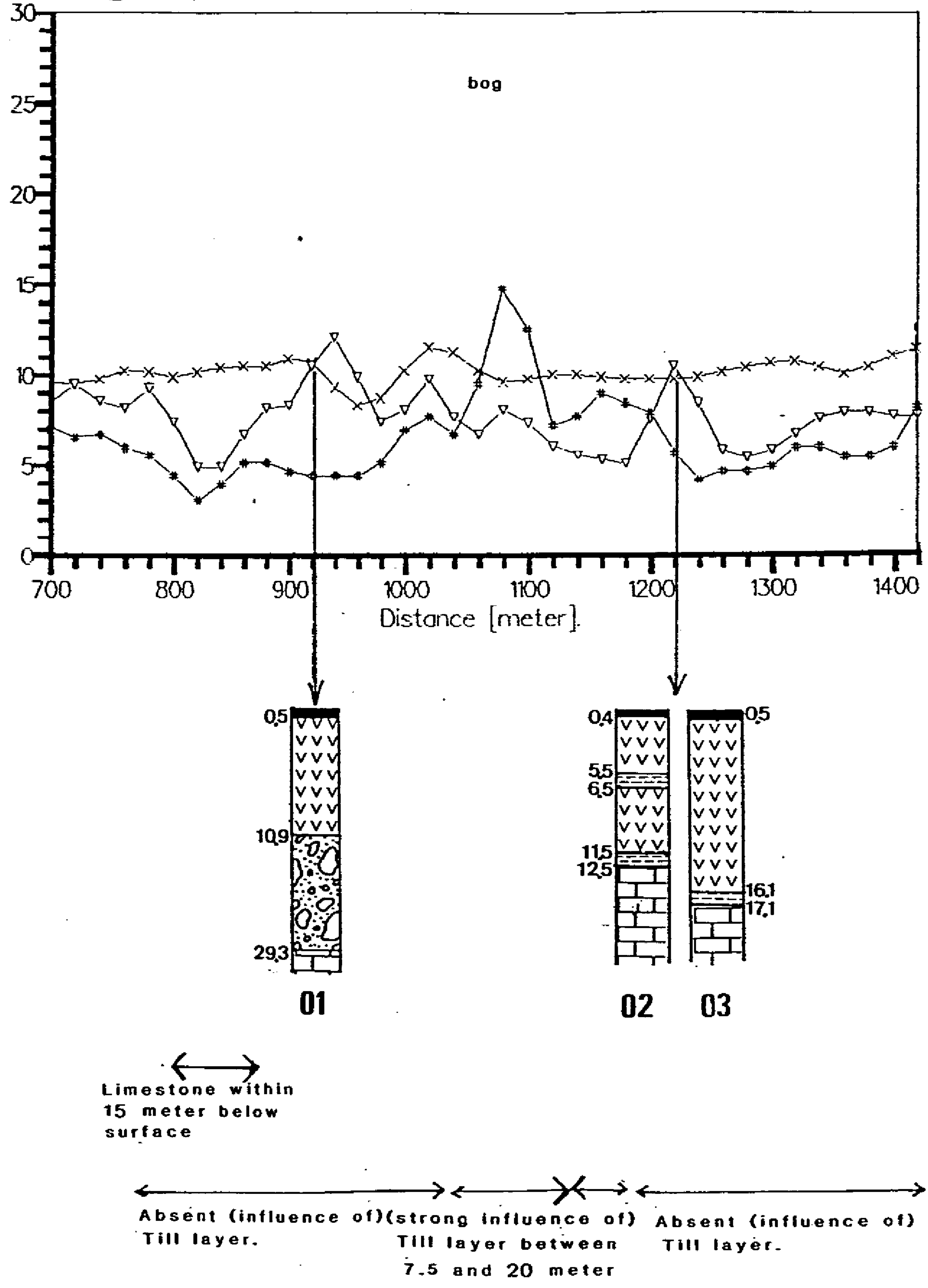
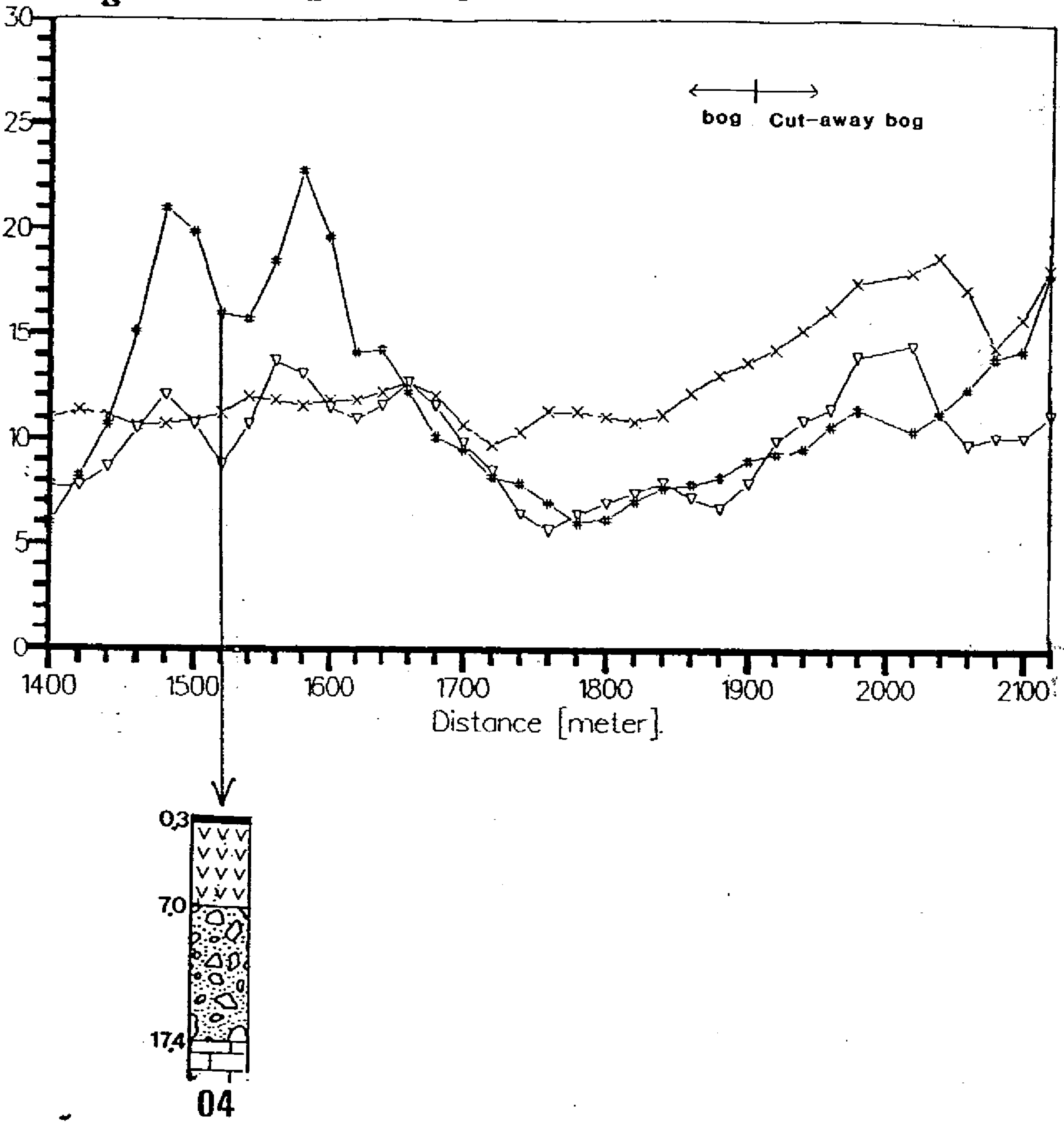


Figure 23c. Line MA1 continued.



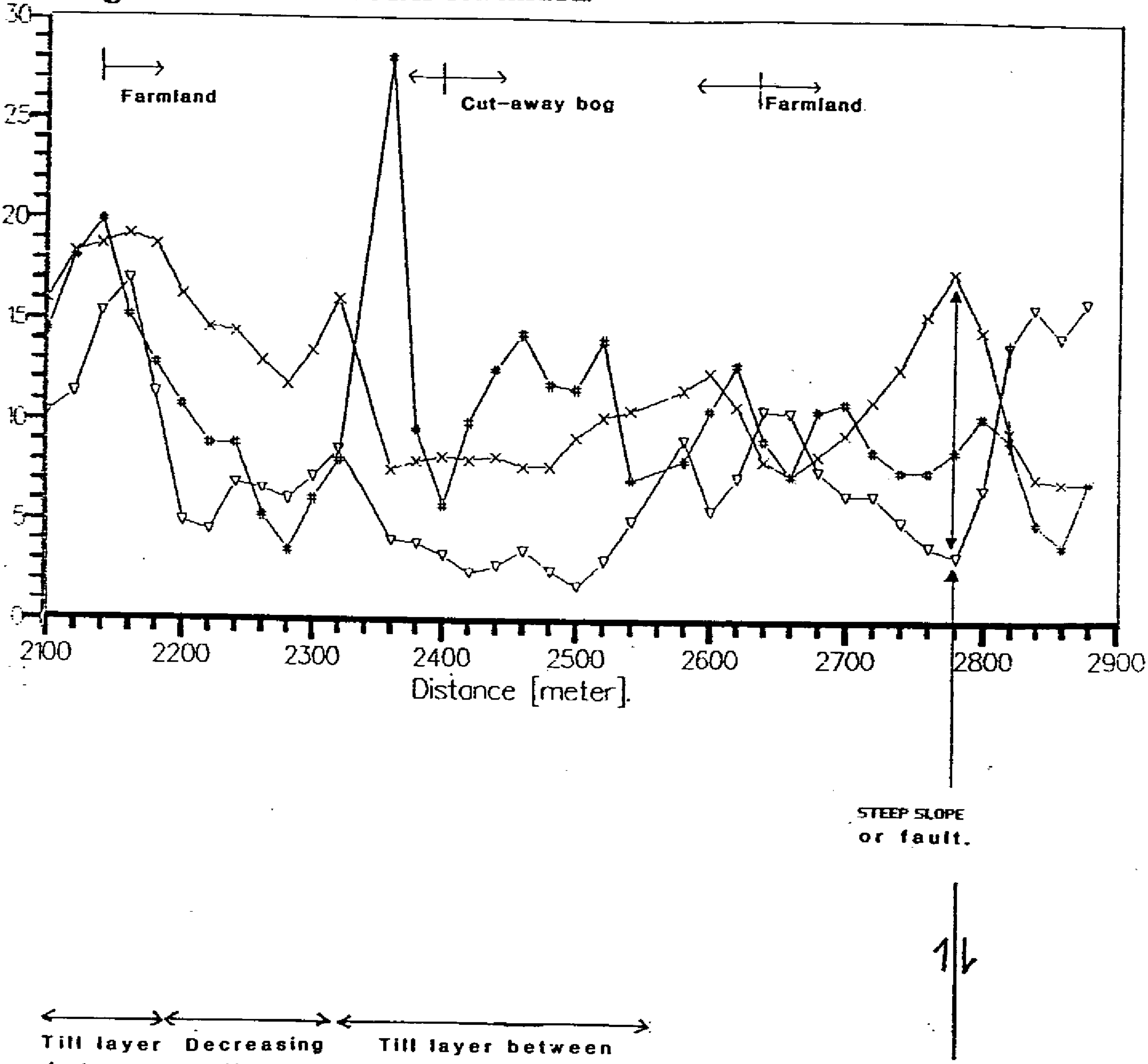
(Strong influence of)
Till layer between
7.0 and 20 meter

Increasing tickness of Till layer.

Till layer
between 4.0 and 20
meter

Limestone within
20 meter below surface.

Figure 23d. Line MA1 continued.



Till layer between ≤2 and ≥30 meter

Decreasing influence of Till layer.

Till layer between 5 and 15 meter

Limestone within 15 meter below surface.

Limestone within 20 meter below surface.

At 780-860 and 1720-1880 meter distance, the relative low conductivity values of CS20, VC and CS20, HC indicate limestone respectively within 15 and 20 meter below surface.
The other parts of the bog show, with respect to the conductivity values of CS20, HC and CS20, VC, limestone more than 20 meter below surface.

On the cut away bog, at 1900-2140 meter distance, very high (increasing) conductivity values of CS10, VC, CS20, VC, and CS20, HC indicate a strong influence of Till (fig. 23c-d). The Till layer will be present between 2 (high conductivity values of CS10, VC) and 30 meter (high conductivity values of CS20, VC and CS20, HC).

At 2140-2500 meter distance (farmingland and cut-away bog), the low conductivity values of CS20, HC indicate limestone "close" to the surface (fig. 23d).
At the Farmingland the thickness of Till will decrease, as the conductivity values of CS10, VC, CS20, VC and CS20, HC desreases.
At the cut-away bog the relative low conductivity values of CS10, VC show the presence of a peat layer. The maximum thickness of peat will be 7 meter, as the high conductivity values of CS20, VC indicate a (strong) influence of Till between 8-15 meter depth.

The conductivity values of CS10, VC, CS20, HC, and CS20, VC, at 2560 - 2900 meter distance (fig. 23d), are erratic, as a result of the very rapid lateral changes in resistivity arising from the (stony) Till material. At 2780 meter distance a steep slope in the layered earth or fault is present.

5.2.3.2. Resistivity soundings CLSVES01, 02, 03 and 04, along line MA1..

Four resistivity soundings were performed on line MA1, at 920 (CLSVES01), 1220 (CLSVES01/02), and 1520 (CLSVES04) meter distance (fig. 23b-c). Due to the limited number of soundings performed on line MA1, this information is inadequate to build up a general picture of the layered earth.

The thickness of the peat layer varies between 7.0 - 11.5 meter (resistivity soudings CLSVES01, 02, and 04). This is confirmed by the EM34-4 interpretation (paragraph 5.2.3.1.).

Resistivity soundings CLSVES01 and CLSVES04 show the presence of a Till layer, the layer thickness is respectively 18.4 (CLSVES01) and 10.4 (CLSVES04) meter. At 1220 meter, the Till layer is absent. Here sounding CLSVES02 and CLSVES03 show the presence of clay at 5.5-6.5 and 11.5-12.5 (CLSVES02), and at 16.1-17.1 (CLSVES03) meter depth. The presence of a (thick) Till layer at 1520 meter distance, as well as the absence of Till at 1220 meter distance is confirmed by the EM34-4 interpretation (paragraph 5.2.3.1.).

At CLSVES01, limestone bedrock can be found 29.3 meter below the surface, confirmed by the EM34-4 interpretation (paragraph 5.2.3.1.). At 1220 meter distance, the limestone bedrock is much closer to the surface, respectively 12.5 (CLSVES02) and 17.1 (CLSVES03) meter. CLSVES04 shows limestone bedrock at 17.4 meter below the surface.

TABLE 9. THE "SURFACE" MATERIAL AT THE ESKER-BOG TRAVERSED LINE.

LINE	ESKER	ESKER/BOG BORDER	BOG	COILSPACING/CONFIGURATION
3	0 - 170 METER	170 - 200 METER	200 - 400 M.	10 HC/VC
4	0 - 160 METER	160 - 190 METER	190 - 430 M.	10 HC/VC
6	0 - 130 METER	130 - 160 METER	160 - 300 M.	10 HC/VC
7	0 - 130 METER	130 - 170 METER	170 - 300 M.	10 HC/VC
1	0 - 200 METER	200 - 240 METER	240 - 1000 M	20 HC/VC

6. Conclusions.

6.1. Raheenmore bog.

The results of EM34-4 surveying are in general agreement with the Schlumberger resistivity soundings at Raheenmore bog.

At Raheenmore bog, most resistivity soundings show a four layered earth-model, respectively (surface) peat, peat, (gravelly clayey) Till, and limestone bedrock (RHSVES01, 04, 05, 09, 12, 13, and 14). This is conform to the EM34-4 conductivity measurements, wich indicate a three layered earth, respectively peat, (undivided) Till, and limestone bedrock (line A, B, C, D, E, F, G, and MS1).

Some resistivity soundings at Raheenmore bog show, at locations where the bedrock is deepest, the presence of a fifth layer, (gravelly sandy) Till, on top of the limestone bedrock or (gravelly clayey) Till layer (RHSVES03, 07, and 08).

On the field near the bog, resistivity soundings indicate a three (RHSVES06) and four (RHSVES08) layered earth-model, respectively 1). (surface) Till, (gravelly clayey) Till, and limestone bedrock, 2). (surface) Till, (gravelly clayey) Till, (gravelly sandy) Till, and limestone bedrock. This does not oppose the EM34-4 conductivity measurements which show a two layered earth; respectively (undivided) Till and limestone bedrock.

6.1.1. The peat layer.

At Raheenmore bog, it appears that in most cases, a (relative) thick peat layer is present. EM34-4 measurements reflect a homogeneous, both in depth and general configuration, peat layer of 10-15 meter thickness.

Although, from a Geological point of vieuw the thickness of peat is not likely to be over 15 meter, three soundings (RHSVES03, 04, and 05) at northeast of the bog show a exeptional thickness of peat between 18 and 22.7 meter. However in table 5 one can see that sandy Till and peat sometimes have the same resistivity.

In the West and southwest of Raheenmore bog, the peat thickness is varying between 6.2 and 15.8 meter. (sounding RSVES09, 10, 11, 12, and 13, and EM34-4 line D and F).

In general, one hundred meter before the bog/cut away bog or bog/field border, the peat layer thickness is varying between 5.0 and 7.5 meter. Thereafter, towards the edge of the bog, the thickness of the peat layer rapidly decreases to 1.0-3.0 meter.

6.1.2. The Till layer.

The thickness of the (gravelly clayey) Till layer at Raheenmore bog varies between 4 and 20 meter.

At northeast and southeast of Raheenmore bog, a strong influence of Till is measured (EM34-4 line A and C). The Till layer thickness is at least 15 meter. Conform to the resistivity soundings at the north (fig. 24 N(2)) and northeast of Raheenmore bog, which show (gravelly clayey) Till layer thicknesses of 20 meter (sounding RSVES01 and 04).

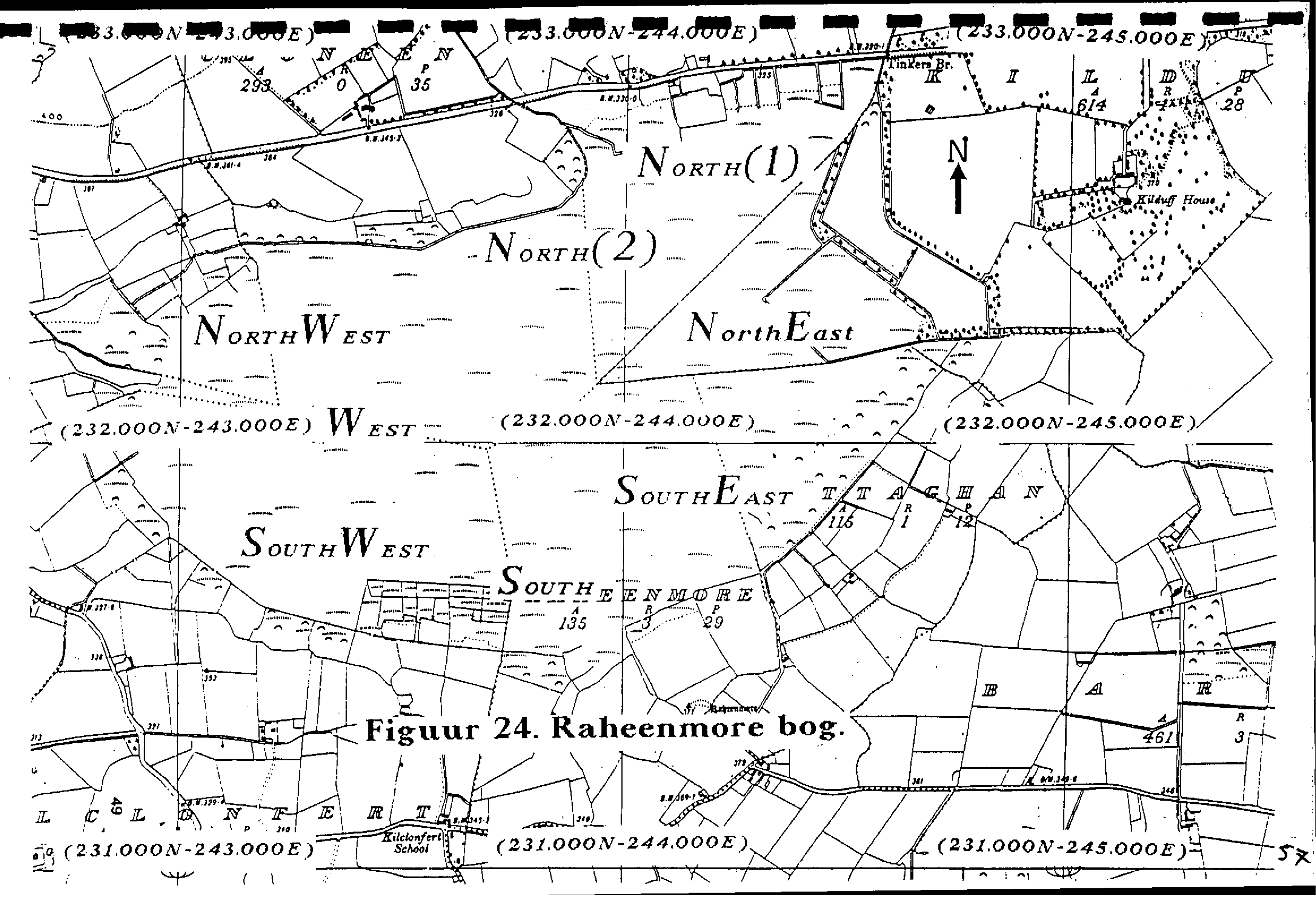
At these sides of Raheenmore bog, as well as on the Hart field at the north side of Raheenmore bog, a (gravelly sandy) Till layer is present on top of the (gravelly clayey) Till layer or limestone bedrock (sounding RHSVES03, 07, and 08).

The thickness of the (gravelly sandy) Till layer varies between 34 and 51 meter, and is found where the limestone bedrock is deepest.

At the northwest and west side of Raheenmore bog, EM34-4 line D, high conductivity values are found. The Till layer will be (also) at these sides of the bog relative thick; at least 15 meter. The thick Till layer is also at the northwest and west edge of the bog (fig. 17: EM34-4 contour map and sounding RHSVES09) and towards the centre of the bog (sounding RHSVES10) present.

At the south side, from 350 meter at the bog towards the edge of the bog, the Till layer rapidly decreases in thickness (fig 17: conductivity values respectively 9, 7, 5, and 3).

At southwest, south, and southeast side of Raheenmore bog, the thickness of the Till layer is at most



Figuur 24. Raheenmore bog.

9 meter. This is supported by the relative low conductivity values (fig. 17: 3 and 5 mS/m) and resistivity soundings RHSVES05, 11, 12, 13 and 14 (fig. 18).
On the field at the south side of Raheenmore bog, the thickness of Till is 3.9 meter (sounding RHSVES06).

6.1.3. The clay layer.

A thin clay layer is found at the north side of Raheenmore bog, as well as on the Hart field at the north side of Raheenmore bog. The layer is present, on top of (gravelly sandy) Till (RHSVES08), between the (gravelly sandy) Till (RHSVES07), and between two peat layers (RHSVES01 and 02). The clay layer thickness varies between 0.9 and 4.7 meter.
None of other resistivity soundings or EM34-4 measurements indicate the presence of a lacustrine deposit between Till and peat layer(s). There are three possible reasons for the absence of it:

1. The clay sedimentation only occured in certain parts under the surveyed area, depending on the location of depressions in the landscape and the possibilities of stagnation of rain and snowmelt-water in these depressions.
2. Due to the inadequate thickness of a clay layer it is impossible to determine lake marl with the used geophysical methods.
3. Due to the inadequate resistivity contrast between the clay layer (resistivity 45.0-50.0 Ohm.meter) and the (gravelly clayey) Till (resistivity 50 Ohm.meter) it is impossible to determine the lake marl with these methods.

6.1.4. Limestone bedrock.

At Raheenmore bog, the depth of limestone bedrock varies between 7.5 (EM34-4 line A and C, and fig. 17: conductivity value 3 mS/m) and 62.3 meter (sounding RHSVES03).
Most northwards of the bog (fig. 24 N(1)), a lower conductivity value is found, 5 mS/m, between higher values, 7 and 10 mS/m (fig. 17). This indicates a spherically shape ('hill') of the limestone at the north side (fig. 24 N(2)) of Raheenmore bog.

From the northwest to the southwest of Raheenmore bog, the depth of limestone bedrock decreases.
At the northwest and west side, limestone bedrock is found respectively 30 and 20 meter below surface. (fig. 17: conductivity values 9 and 7 mS/m, and soundings RHSVES09 and 10). -
At the southwest and south side, the depth of limestone bedrock varies between 15 and 18 meter (fig. 17: conductivity value 5 mS/m, and soundings RHSVES11, 12, 13, and 14 mS/m).

Resistivity soundings, as well as EM34-4 measurements reflect a very steep gradient of the limestone depth between the bog itself and the adjacient field area at the south side of Raheenmore bog.
Resistivity sounding RHSVES04, a two hundred meter before the bog/field border, shows limestone bedrock 15.4 meter below the surface. Thereafter, towards the edge of the bog, the depth of limestone bedrock rapidly decreases.
At the bog/field border, limestone bedrock is found within 7.5 meter below surface (EM34-4 line C: conductivity values 3-4 mS/m, and fig. 17: conductivity value 3).
Resistivity sounding RHSVES06, at C.Mallon fields, shows a very shallow depth of limestone, 3.9 meter below surface.

North(2) and Northeast of Raheenmore bog, as well as on the Hart field at the north side of Raheenmore bog, limestone is interpreted at least 25 meter below surface (fig. 17 conductivity values > 9 mS/m, and sounding RHSVES01, 03, 04, and 07).
The exeptional depths of limestone found at the north, 46.6 (RHSVES07) and 54.5 meter (RHSVES08), and northeast side, 62.6 (RHSVES03) and 45.8 (RHSVES04) meter below surface, are in strong contrast to the limestone depths found at west side of Raheenmore bog. The variation in depth to bedrock might indicate a fault.
Also the difference in depth to bedrock at the northern end of the bog and the limestone outcrop occuring in the vicinity, found south of the Mullagharugh Hill, might indicate a fault or steep slope.

6.2. Clara bog.

6.2.1. The ridge near the soak.

The shape of the ridge near the soak can be explained by the dome-shaped limestone bedrock at this location. The crest of the dome-shaped bedrock is at a depth of approximately 12 meter below surface (CLSVES09 and 10).

The crest of the dome-shaped bedrock has a small variation along the longitudinal axis of the ridge (EM34-4 line R3). A Till or clay layer is found, between peat and Limestone bedrock, where bedrock is at least 12 meter below surface. If Limestone bedrock gets shallower in relation to the ground surface the Till or clay layer is absent

A strong influence of Till is measured at the west and east sides of the ridge. At the bog towards the top of the ridge the thickness of Till decreases. Half-way the slope the influence of Till isabsent, as towards the top of the ridge, EM34-4 line R1 and R2 indicate, a two-layered earth model: a peat layer and limestone bedrock.

6.2.2. The Esker to the north of the bog.

On the slope of the Esker, EM34-4 survey shows unsaturated Esker material upto (at least) 15 meter below surface (line 1, 3, 4, 6, and 7).

At 40 meter - from the top of the Esker - downwards, the depth of limestone bedrock is at least 25.4 meter below surface, as sounding CLSVES05 shows unsaturated Esker material upto (at least) 25.4 meter below surface.

The one-layered earth model is found as far as 70 meter - from the top of the Esker - downwards (line 6 and 7).

Further - on the slope of the Esker - downwards, EM34-4 survey shows a two-layered earth model, respectivily Esker material and Till, or an increase in clay content of the Esker material in the layered earth.

Conform to sounding CLSVES06, at 60 meter before the Esker/bog border, which reflects Till or a clay layer. The layer has a thickness of 3.8 meter. The Till or clay is found between Esker material, with a thickness of 4.6 meter, and Limestone bedrock, which is found 8.4 meter below surface. The limestone bedrock slopes steeply downwards, towards the Esker/bog border.

At comparable distance, 80-100 meter before the Esker/bog border, a very steep slope in the layered earth or a fault is present, as EM34-4 line 1 shows two negative (conductivity) values.

On the slope of the Esker, towards the Esker/bog border, and at Clara bog, the strong influence of Till remains. At Clara bog, 20 to 70 meter from the Esker/bog border, the Till layer thickness is respectively 5.1 (CLSVES07) and 8.4 (CLSVES08) meter.

At the Esker/bog border towards Clara bog, the peat layer increase slightly in thickness. At 20 meter from the Esker/bog border, the peat layer has a thickness of 5.3 meter (CLSVES07). At 70 meter from the Esker/bog border, the peat layer thickness is 6.2 meter.

6.2.3. Line MA1.

Line MA1 runs parallel to the westside of the road. The line starts in the 'Esker Associated Sand & Gravel area', and is crossing the Esker and the bog towards the south. At Clara bog, four soundings were carried out on line MA1. Line MA1 ends in the 'Sandy-loamy stony Till' associated area.

6.2.3.1. The Esker on MA1.

The conductivity values of EM34-4 survey on the slope of the Esker are erratic, as a result of the very rapid lateral changes in resistivity arising from the sand and gravel material.

At 180 meter distance a steep slope in the layered earth or a fault is present. At the south side, the low conductivity values, indicate a relative uplift of limestone bedrock. At this side limestone is found within 20 meter below surface.

6.2.3.2. The bog.

At Clara bog, with respect to the EM34-4 conductivity values of the traversed line, the thickness of the peat layer varies between 5 and 12 meter, conform to soundings CLSVES01, 02, 03, and 04, which indicate peat layer thicknesses of 7.0 to 11.5 meter.

On the traversed line, a (strong) influence of Till in the layered earth is largely absent, as EM34-4 conductivity values of CS20,HC and CS20,VS are relatively low. At this part of Clara bog, the Till layer will be very thin or absent. Conform to sounding CLSVES02 and 03, which show (only) a clay of 1 meter thickness, between the peat layer and limestone bedrock.
At 1060-1200 and 1420-1640 meter distance, the high conductivity values of CS20,VC indicate a strong influence of Till. The Till layer is found between 7.0 and 20.0 meter. Conform to sounding CLSVES04, wich shows a Till layer at 7.0-17.4 meter below surface.

On the traversed line, with respect to the EM34-4 conductivity values of the traversed line, limestone bedrock is largely found at least 20 meter below surface. Conform to sounding CLSVES01, where limestone is found 29.2 meter below surface.
At 780-860 and 1720-1880 meter distance the bedrock is shallower in relation to the ground surface, within 15-20 meter below surface.
Sounding CLSVES 02, 03, and 04 indicate limestone bedrock at respectively 12.5, 17.1 and 17.4 meter below the surface.

6.2.3.3. Cut away bog and field area.

On the (first) cut away bog area, at 1900-2140 meter distance, a Till layer is found between 2 and 30 meter, as EM34-4 survey reflects very high (increasing) conductivity values. The peat layer has a thickness of (at most) 2 meter.

On the (first) farmland, at 2140-2400 meter distance, the thickness of Till decreases, as the EM34-4 conductivity values decreasing. Limestone bedrock gets shallower - within 15 meter - in relation to the ground surface.

On the (second) cut away bog area, the peat layer has a thickness of (at most) 7 meter. On the (second) cut away bog area, high conductivity values of CS20,VC indicate a strong influence of Till. The Till layer is found between 8.0 and 20.0 meter. Limestone bedrock is found within 20 meter below surface.

On the (second) farmland, the EM34-4 conductivity values are erratic, as a result of the very rapid lateral changes in resistivity arising from the stony Till material.

7. Discussion and recommendations.

7.1. Raheenmore.

Most attention is given to EM34-4 survey with the 20 meter intercoilspacing, horizontal coils. Altough interpretation has result in a (reliable) contour map of the electrical conductivity of the layered earth at Raheenmore bog, the grid size of the traversed lines is too course to give a detailed information on the centre of Raheenmore bog.

Continuation of EM34-4 surveys on the bog itself is usefull, altough if the measurements are taken with 20 meter intercoilspacing horizontal and vertical coils.
First, this data can be used for specific information on a traversed line in areas of interest, as these coilconfigurations give an accurate impression of the influence of the Till layer, and the depth of the Limestone bedrock.
Second, a more closer grid size will result in a more accurate contour map of the electrical conductivity at Raheenmore bog.

The 10 and 40 meter intercoilspacing have given less information because:

1. Using the 10 meter intercoilspacing vertical coils, it is only possible to measure the influence of the peat layer (exploration depth 7.5 meter).
2. Using the 10 meter intercoilspacing horizontal coils, the influence of the peat layer is to strong.
3. Using the 10 meter intercoilspacing, strong extreem fluctuating values at one measurement station or between measurement stations reduce the utility of these values for interpertation.

Therefore, further EM34-4 survey with 10 or 40 meter intercoilspacing is not advisable.

Continuation of Schlumberger resistivity soundings at Raheenmore bog is advisable. Between the eastwards and westwards (fig. 12b.) traversed lines, two more (parrallel) traverse lines should be made.

First, to determine the nature of the changes in depth of the bedrock going from West to East and from the North to South. Second, to obtain information of the layered earth at the centre of Raheenmore bog.
Further soundings are also necessary on the total outline field area, and on the rim and outher reaches of Raheenmore bog. This, to obtain information of the interaction of the layered earth, between the bog and the surrounding area.

Drilling operations with resistivity and gamma logging are advisable at specific areas of interest:

1. At the north (fig. 24 N(2)) side of Raheenmore bog, as well as on fields at the north side of Raheenmore bog, to determine location, nature and thickness of the (sandy clay) Till.

2. At the northeast side of Raheenmore bog, close to sounding RHSVES03, 04, or 05, to determine the exeptional thickness of peat.

3. At the south side of Raheenmore bog, as well as on the fields at the south of Raheenmore bog.
   First, to determine the very steep gradient of limestone bedrock between the bog and the adjacient f field area. Second, to determine nature and depth - in relation to the ground surface - of limestone bedrock.

7.2. Clara bog.

Due to the limited number of resistivity soundings at Clara bog it is not yet possible to infer a complete picture of the structure of the bog.
A survey covering a much larger geographical area is needed to more accurately quantify the spaceform of Clara bog (Smyth, Farenhorst and Barton, 1990).

Drilling operations with resistivity and gamma logging are advisable at specific areas of interest:

1. On the ridge near the soak. First to determine the nature and thicknesses of the layered earth. Second, to determine the nature and depth - in relation to the ground surface - of limestone bedrock.

2. On the slope of the Esker, near the Esker/bog border. First, to determine the nature and thickness of Till between Esker material and Limestone bedrock. Second, to determine the nature and depth - in relation to the ground surface - of limestone bedrock.

7.3. Further recommendations.

Finally there are four practical recommendations which must be review to improve the usefulness of the the (new) data:

1. The number of times that the potential electrode distances are increased has to be kept as small as possible. So this has to happen only when the signal noise ratio becomes to small, and definitely not so often as has been done during this fieldwork. The measurement must be repeated only at the last A AB/2 value, to go back to smaller values of AB/2 is a waste of time.
   The number of times that the distance between potential electrodes has to increase can also be reduced by using the ABEM with a power booster; the new potential electrode distance = AB/3, so lo longer MN caibles are necessary.

2. The instruments should only be used in (relative) dry weather-conditions. Damp will affect the instruments, resulting in unreliable data.

3. The height of the centres of all soundings should be levelled in to provide accurate data on the depth of each layer in relation to a common datum (Smyth, Farenhorst and Barton, 1990).

4. Using the Schlumberger areas, it is essential to have three persons available with three walkie talkies. This will treble the speed of the data collection.

5. To perform a reinterpretation of the Schlumberger soundings when there are enough resistivity loggings available for Clara bog as well as Raheenmore bog.

6. Reinterpretation of EM34-4 lines measured with two or three coilspacings with EMIX 34.

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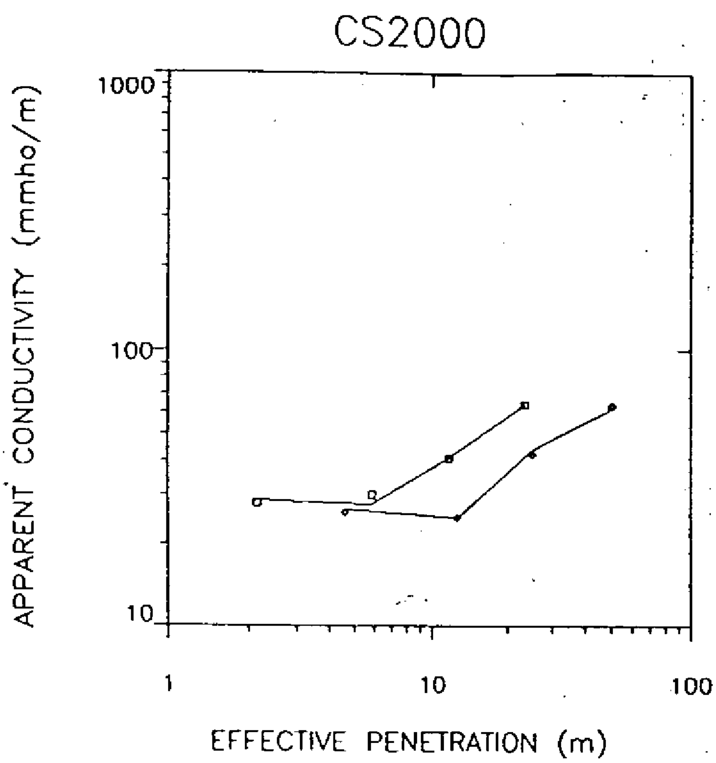
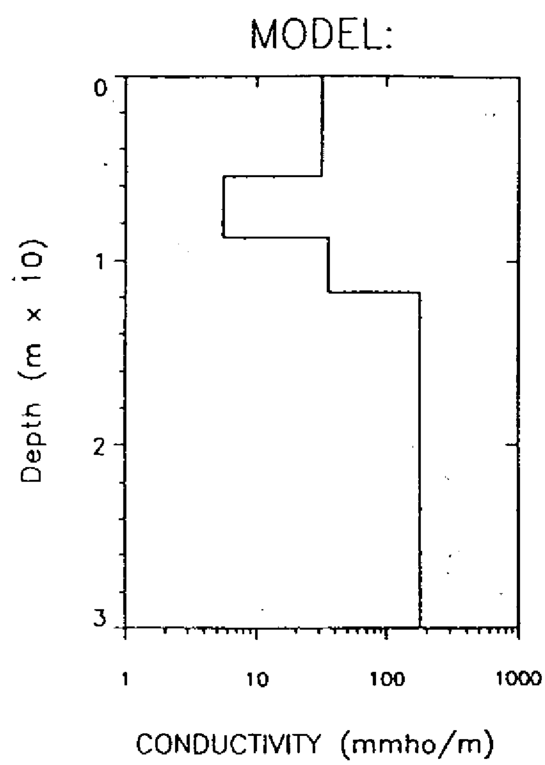


Depth Sounding Interpretations for Geonics EM31 and EM34 Instruments



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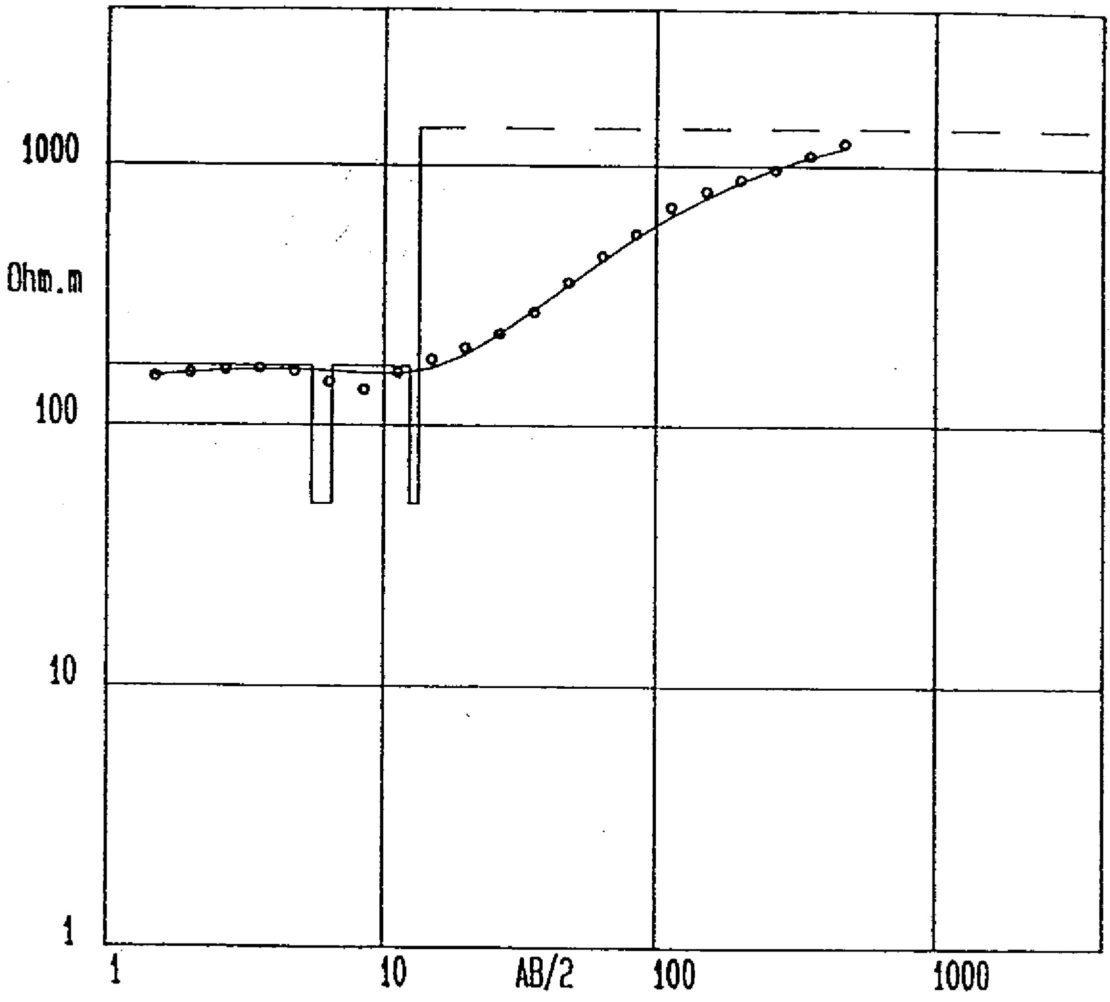
Appendix.

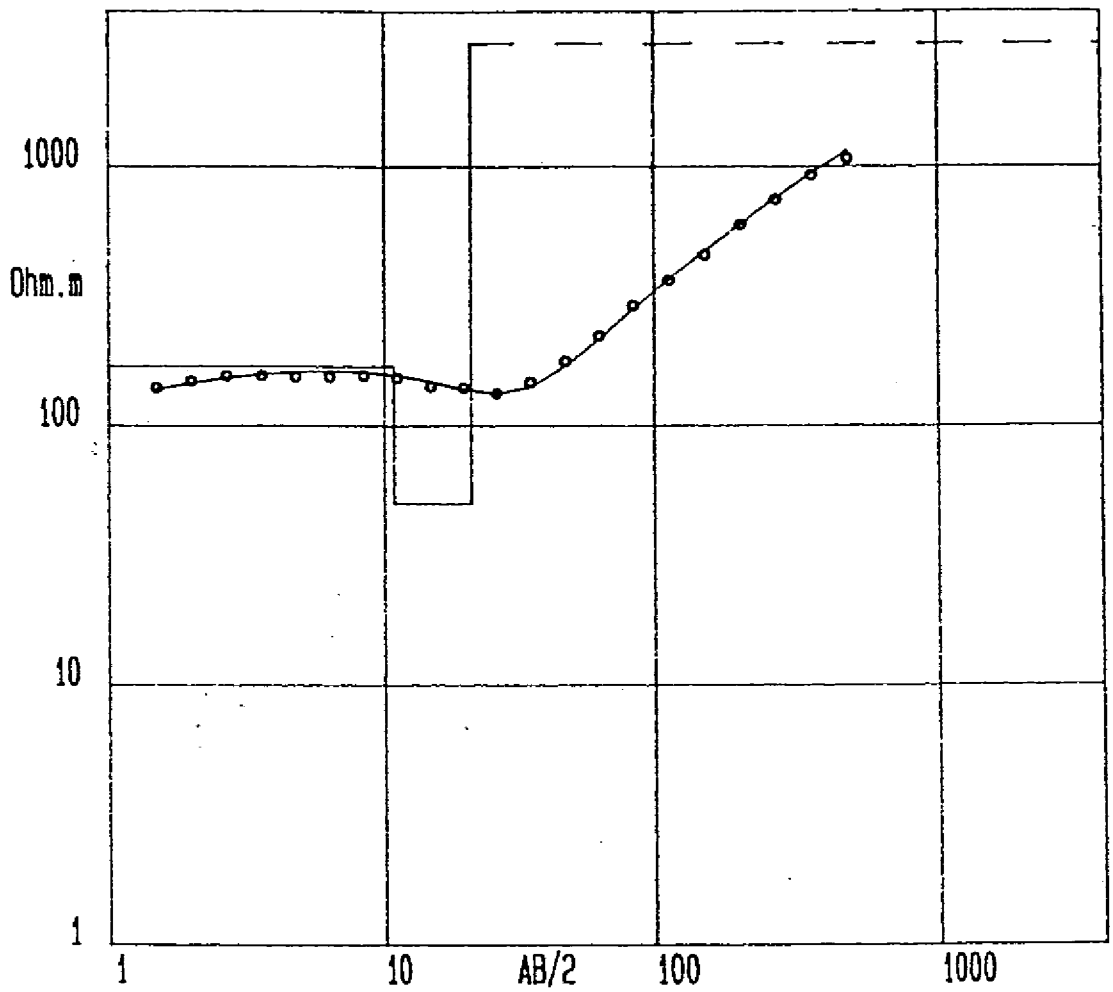
Date of the measurement	:	28/03/1990.
Location	:	CLARA BOG.
Map nr.	:	CLSVES02.
Measuring station nr.	:	CENTRE AT 224 710 E, 230 250 N.
Curve Fitting RMS Error	:	5.5 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.4	130.0	SURFACE LAYER.
2	5.1	170.0	PEAT LAYER.
3	1.0	50.0	CLAY LENS ?
4	6.0	170.0	PEAT LAYER.
5	1.0	50.0	TILL LAYER.
6	INF.	1400.0	LIMESTONE BEDROCK.

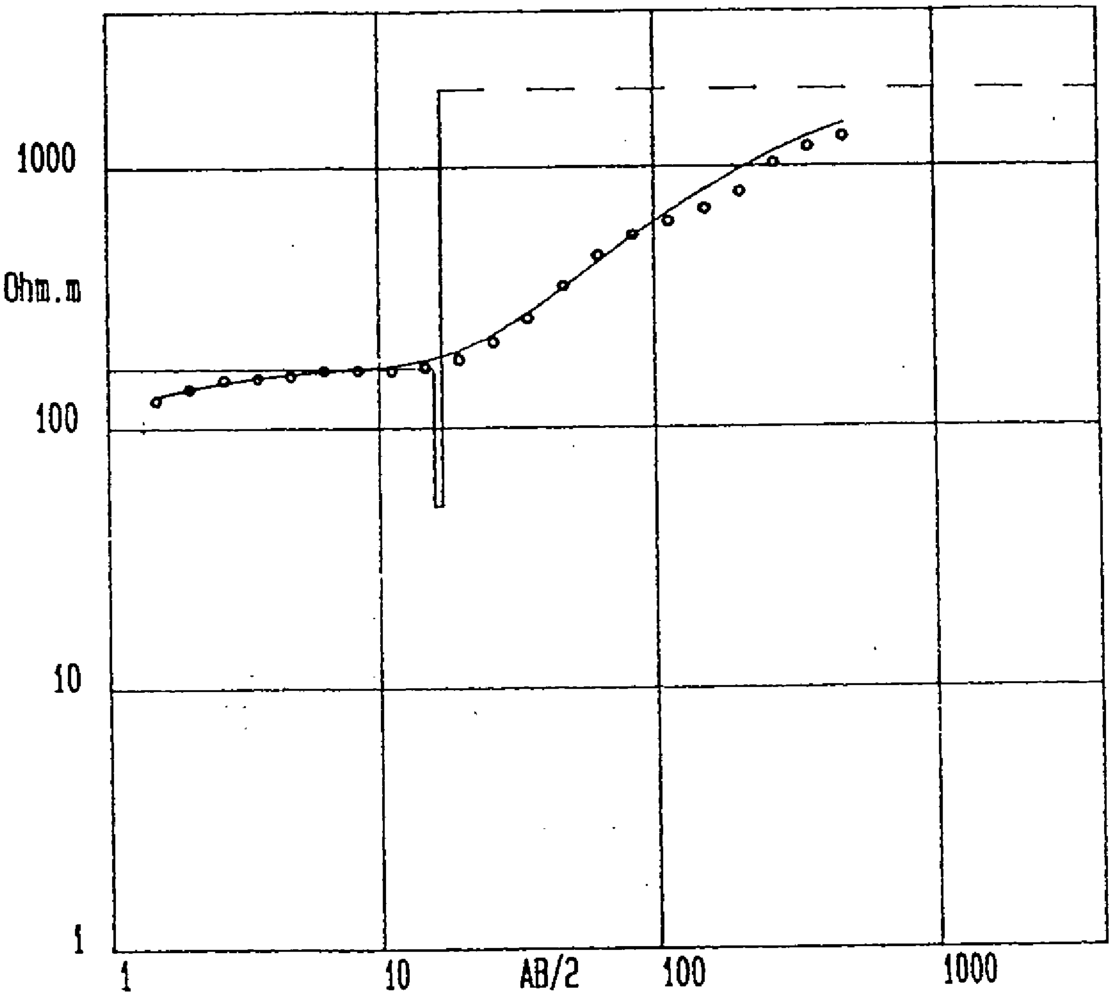
Date of the measurement	:	28/03/90
Location	:	CLARA BOG.
Map nr.	:	CLSVES01.
Measuring station nr.	:	CENTRE AT 224 800 E, 230 530 N.
Curve Fitting RMS Error	:	3.3 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	104.7	SURFACE (PEAT) LAYER.
2	10.4	170.0	PEAT LAYER.
3	10.3	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

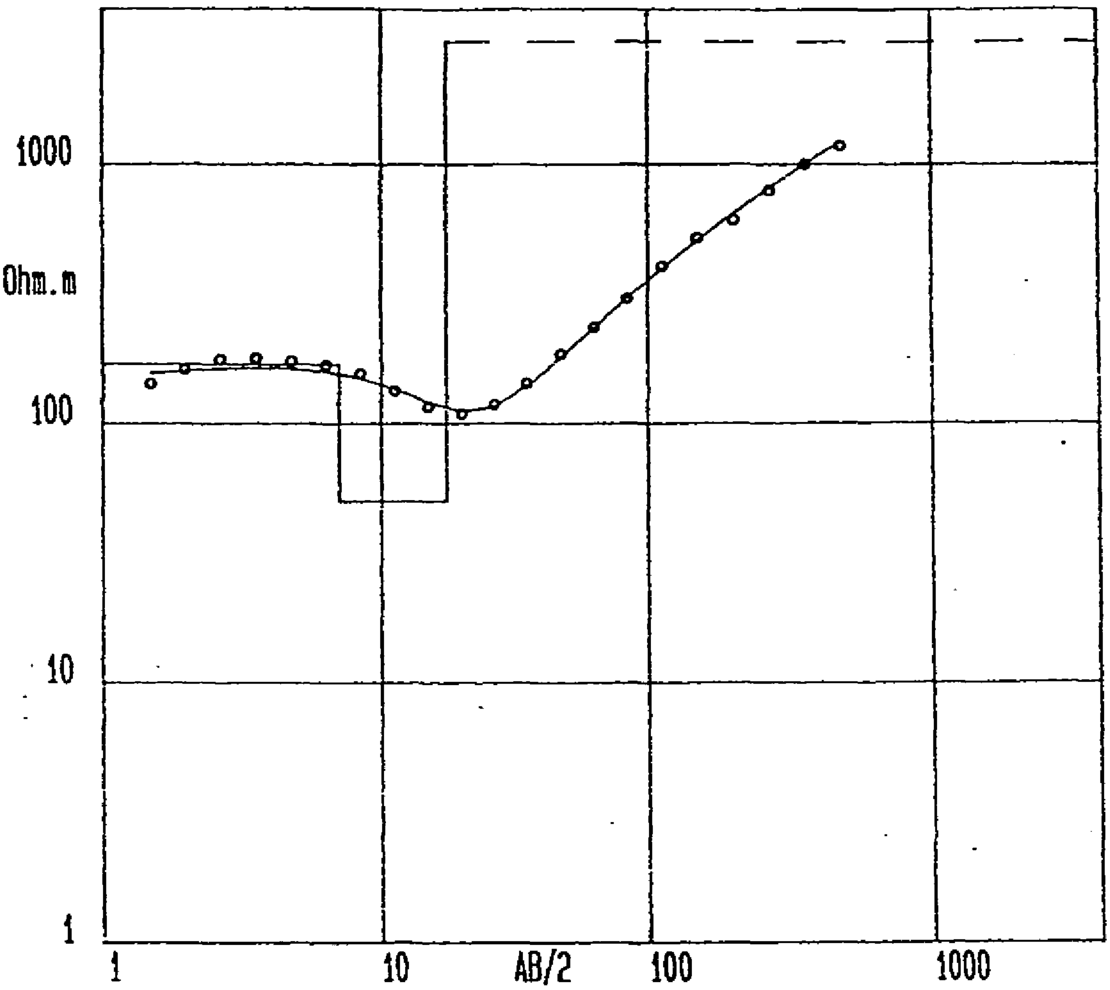
Date of the measurement	:	28/03/1990.
Location	:	CLARA BOG.
Map nr.	:	CLSVES03.
Measuring station nr.	:	CENTRE AT 224 710 E, 230 250 N.
Curve Fitting RMS Error	:	8.7 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	99.0	SURFACE (PEAT) LAYER.
2	15.6	170.0	PEAT LAYER.
3	1.1	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

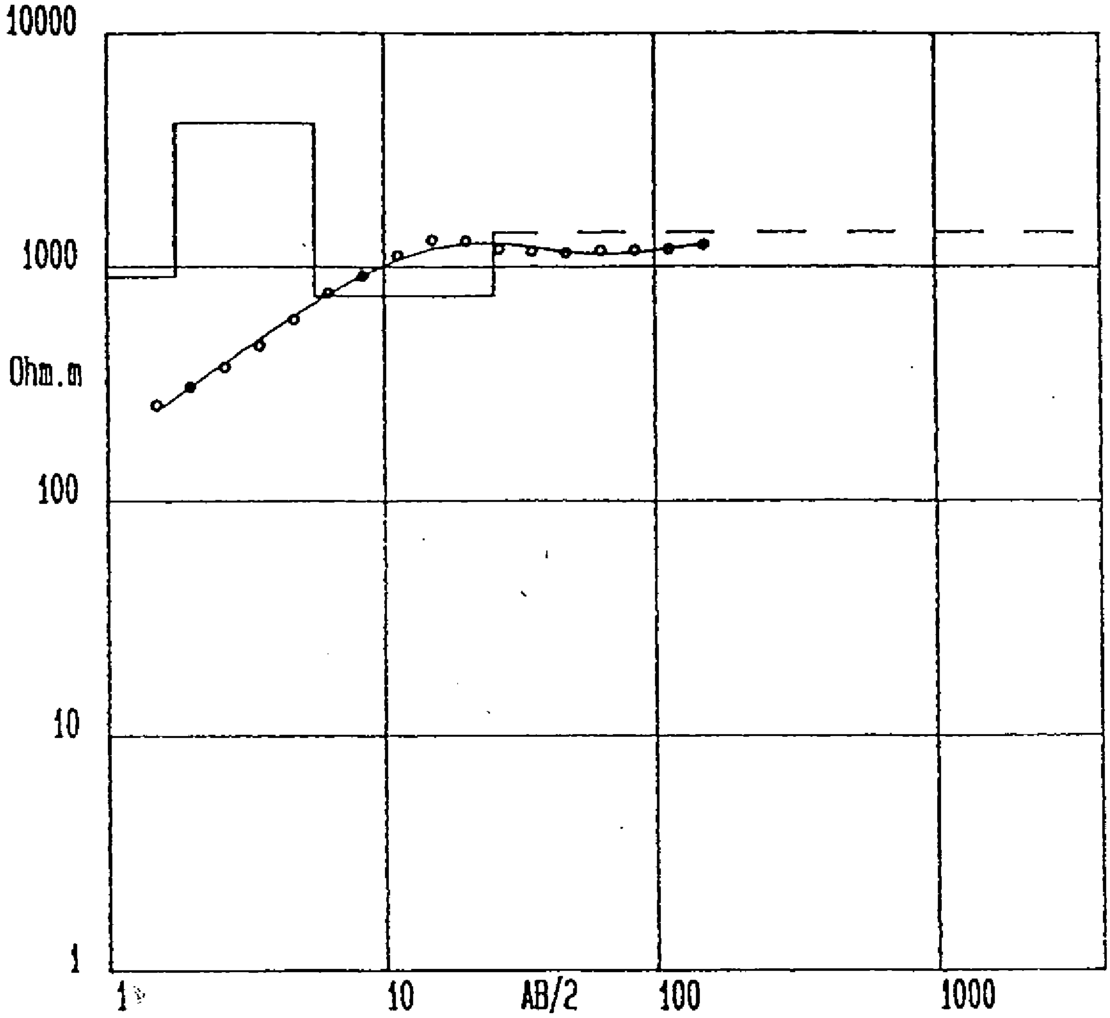
Date of the measurement	:	31/01/1990
Location	:	CLARA BOG.
Map nr.	:	CLSVES04.
Measuring station nr.	:	CENTRE AT 224 620 E, 229 960 N.
Curve Fitting RMS Error	:	4.5 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.3	122.9	SURFACE (PEAT) LAYER.
2	6.7	170.0	PEAT LAYER.
3	10.4	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

Date of the measurement : 29/03/1990.
Location : CLARA BOG, ESKER.
Map nr. : CLSVES05.
Measuring station nr. : CENTRE AT 224 240 E, 230 970 N.
Curve Fitting RMS Error : 4.1 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.3	64.0	SURFACE LAYER.
2	1.4	910.0	(UNSATURATED) ESKER MATERIAL.
3	3.9	4130.0	(UNSATURATED) ESKER MATERIAL.
4	19.8	750.0	(UNSATURATED) ESKER MATERIAL.
5	INF.	1410.0	(UNSATURATED) ESKER MATERIAL.

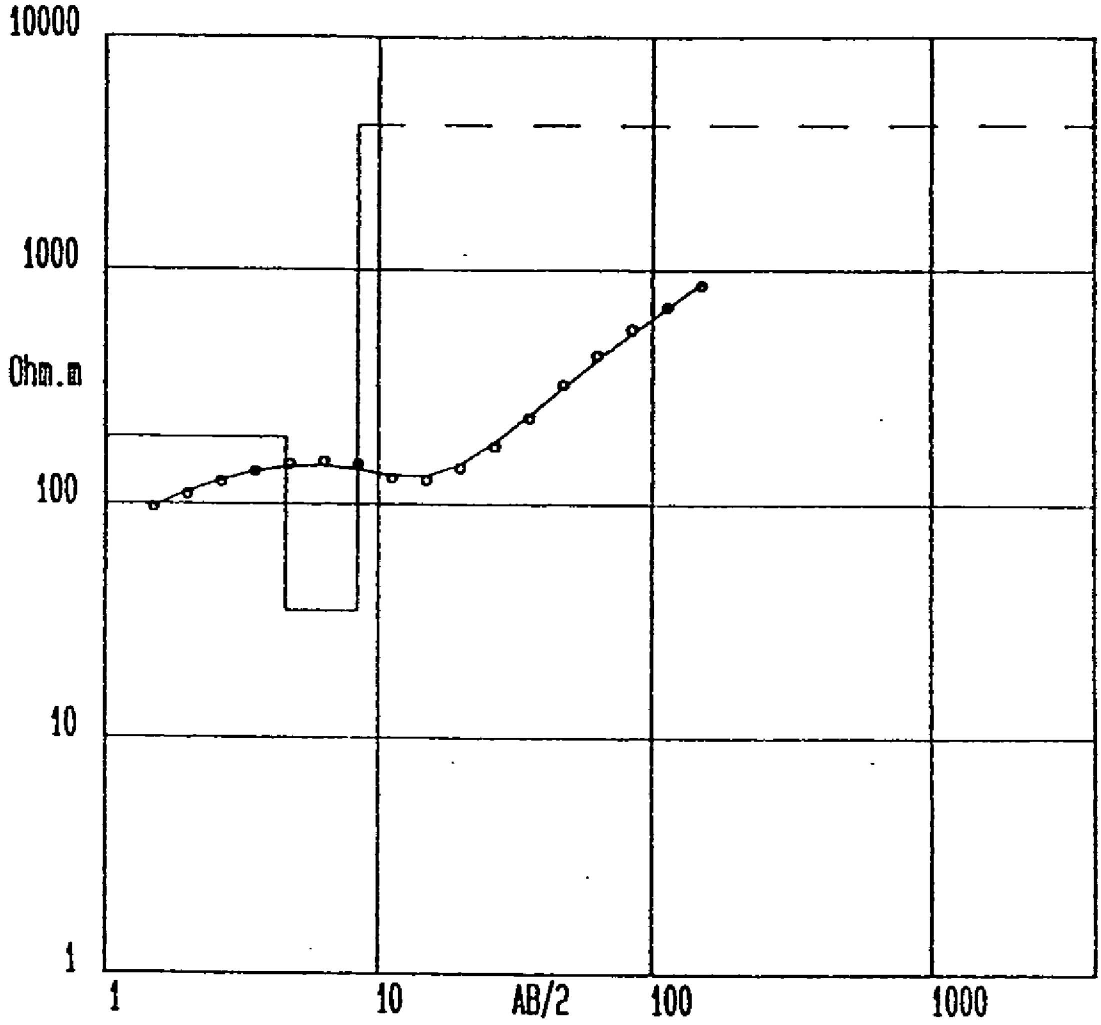
Date of the measurement : 29/03/1990

Location : CLARA BOG, ESKER

Map nr. : CENTRE AT 224 250 E, 230 920 N.

Measuring station nr. : CLSVES06.FDF

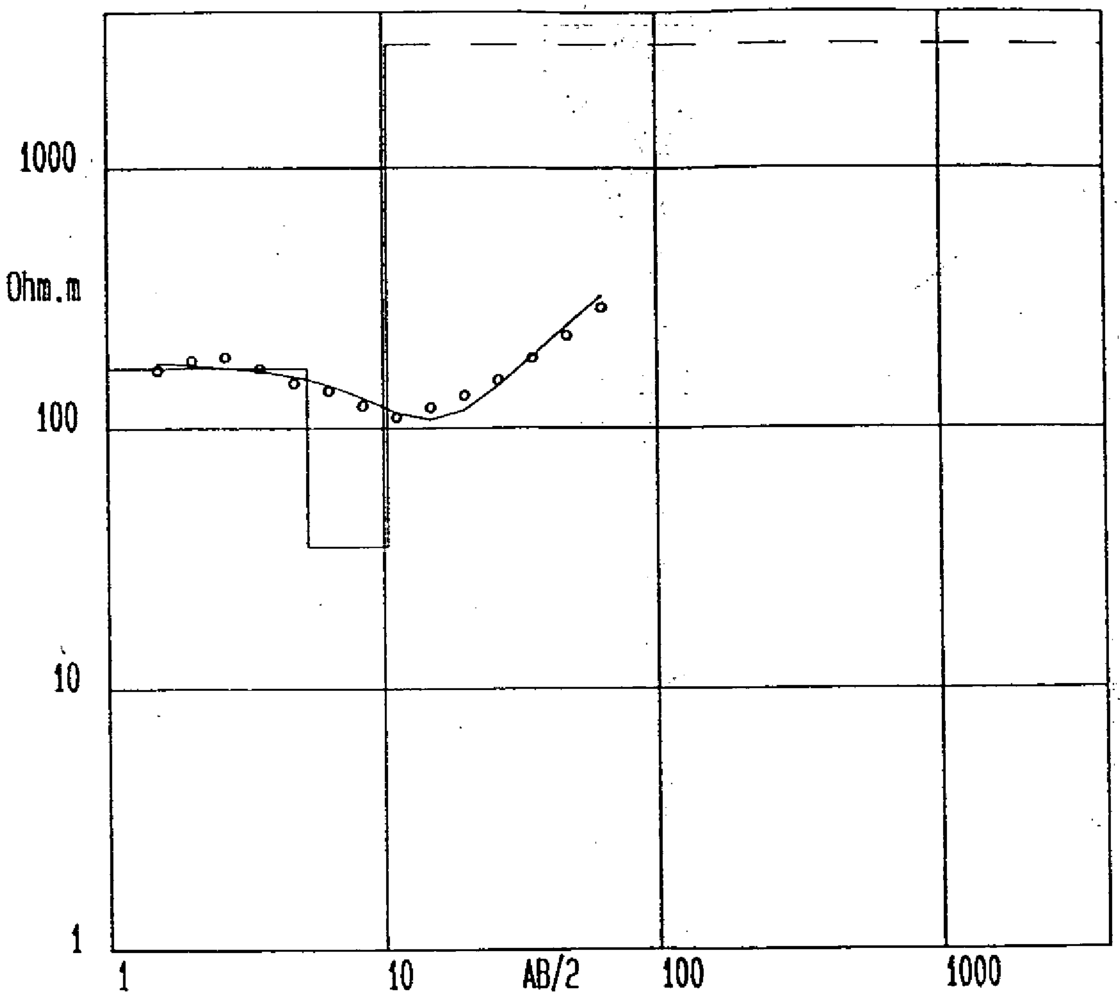
Curve Fitting RMS Error : 3.2 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	52.0	SURFACE LAYER
2	4.1	195.4	ESKER MATERIAL
3	3.8	35.0	TILL/CLAY
4	INF.	4182.1	BEDROCK

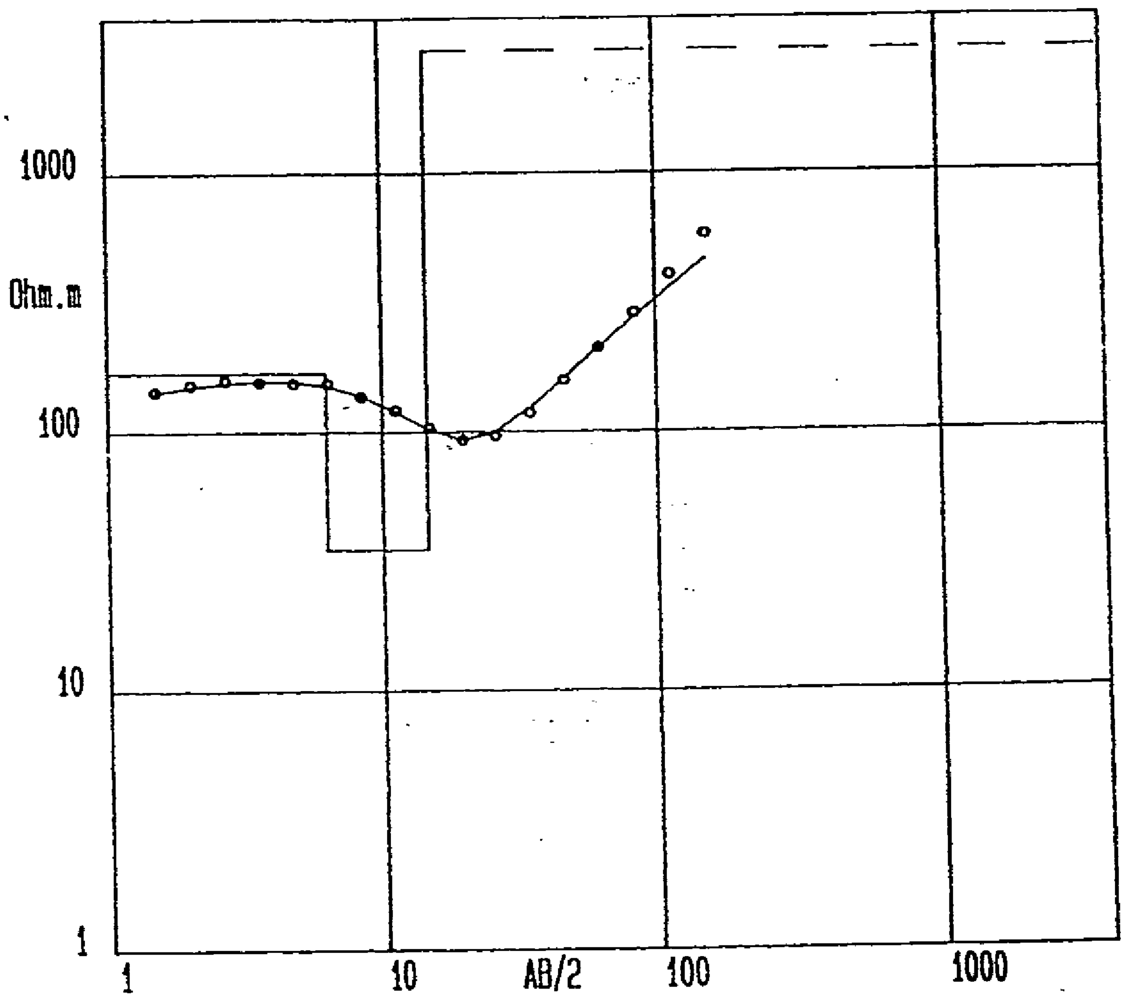
Date of the measurement : 29/03/1990.
Location : CLARA BOG, BOG-ESKER MARGIN.
Map nr. : CLSVES07.
Measuring station nr. : CENTRE AT 224 250 E, 330 890 N.
Curve Fitting RMS Error : 7.4 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	193.1	SURFACE (PEAT) LAYER.
2	4.8	170.0	PEAT LAYER
3	5.1	35.0	TILL LAYER
4	INF.	3000.0	LIMESTONE BEDROCK

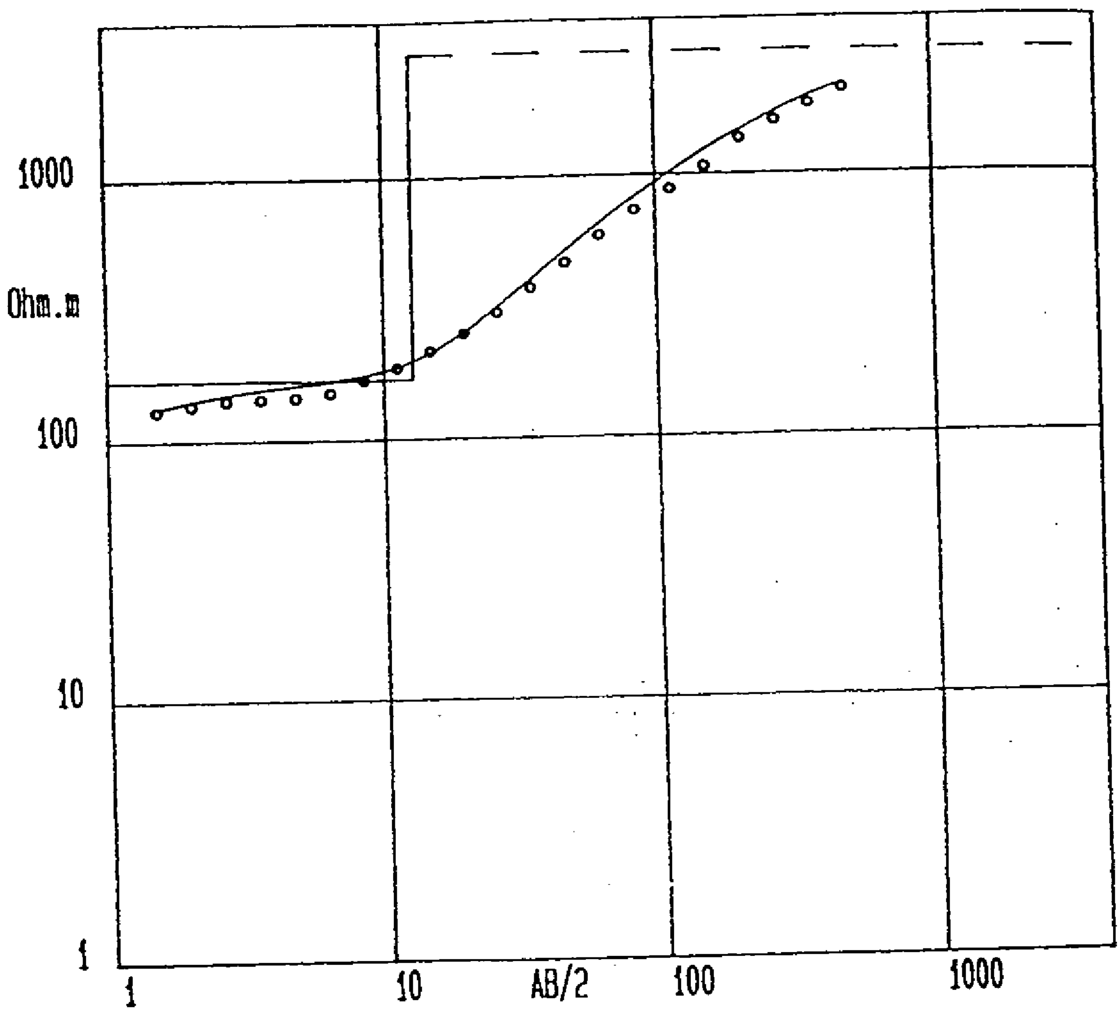
Date of the measurement : 29/03/1990.
Location : CLARA BOG.
Map nr. : CLSVES08.
Measuring station nr. : CENTRE AT 224 260 E, 230 860 N.
Curve Fitting RMS Error : 6.0 %



Model parameters in metres and Ohm.metres :

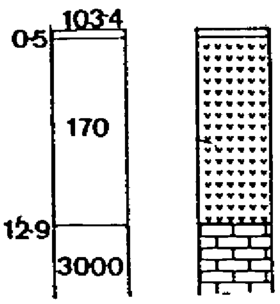
Layer	Thickness	Resistivity	Interpretation
1	0.4	111.2	SURFACE (PEAT) LAYER.
2	5.8	170.0	PEAT LAYER.
3	8.4	35.0	TiLL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

Date of the measurement : 31/03/1990.
Location : CLARA BOG, RIDGE.
Map nr. : CLSVES09.
Measuring station nr. : CENTRE AT 223 960 E, 229 960 N.
Curve Fitting RMS Error : 8.6 %

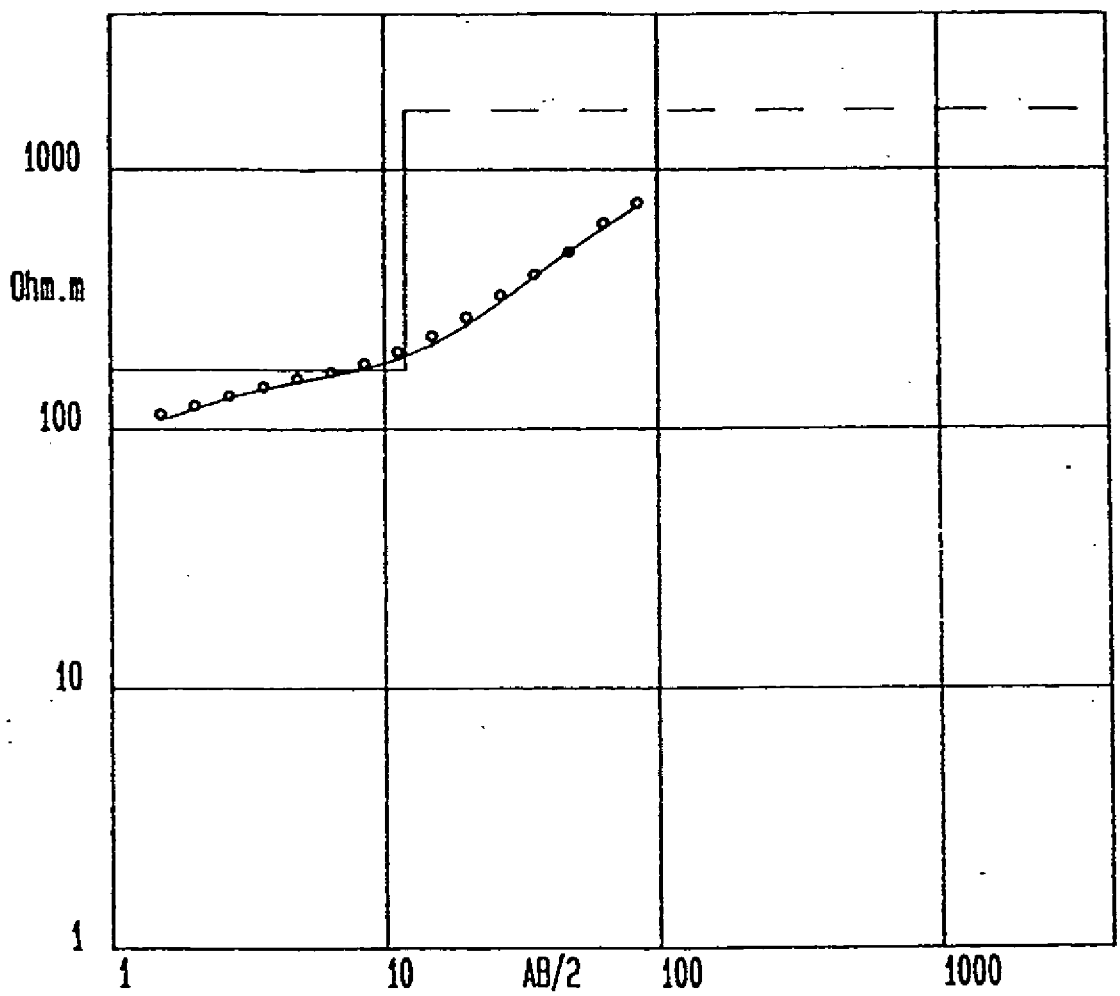


Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	103.4	SURFACE (PEAT) LAYER.
2	12.4	170.0	PEAT LAYER.
3	INF.	3000.0	LIMESTONE BEDROCK.

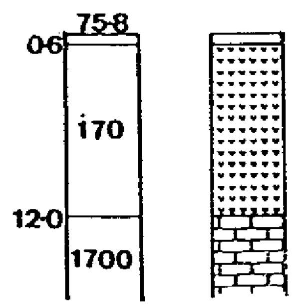


Date of the measurement : 29/03/1990.
Location : CLARA BOG, RIDGE.
Map nr. : CLSVES10.
Measuring station nr. : CENTRE AT 223 720 E, 230 000 N.
Curve Fitting RMS Error : 4.7 %

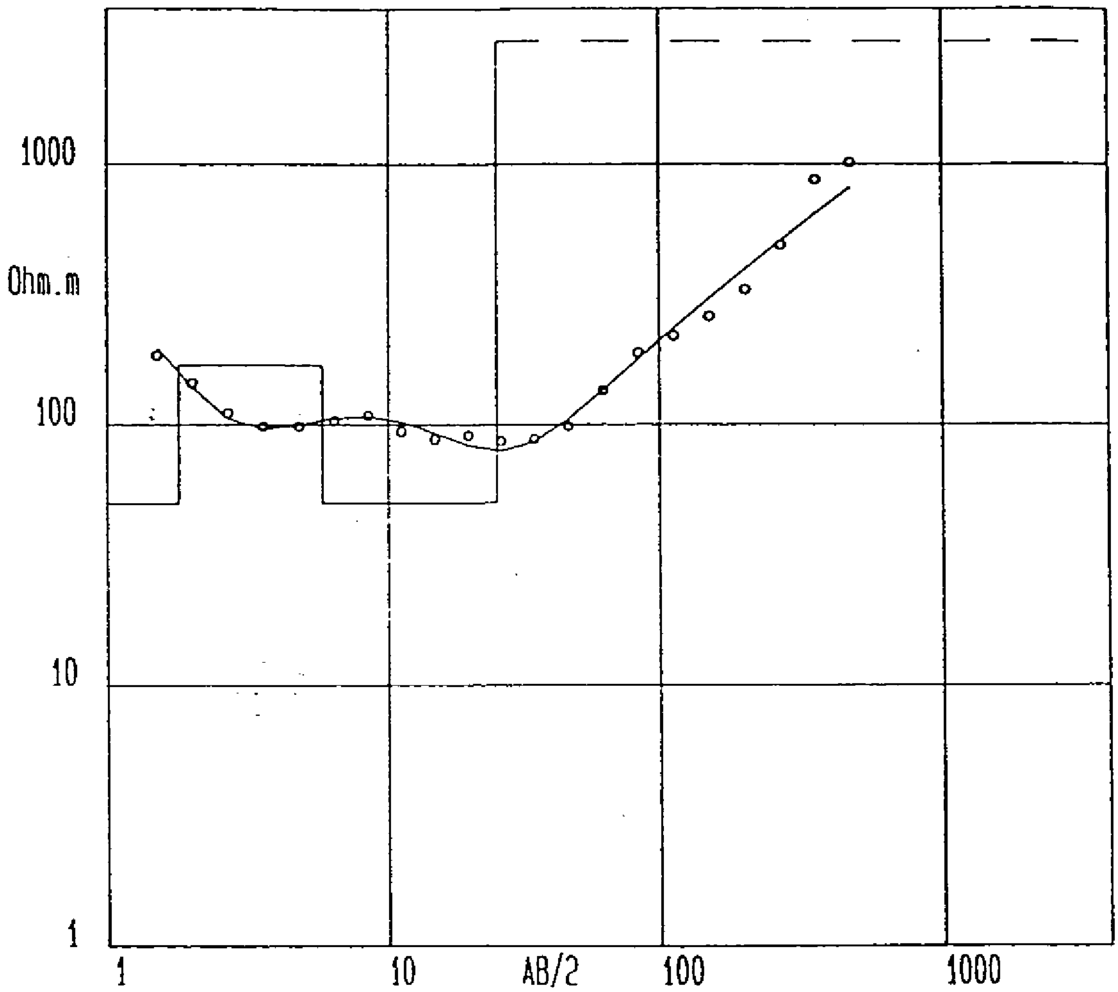


Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.6	75.8	SURFACE (PEAT) LAYER.
2	11.4	170.0	PEAT LAYER.
3	INF.	1700.0	LIMESTONE BEDROCK.



Date of the measurement	:	14/03/1990.
Location	:	RAHEENMORE.
Map nr.	:	RHSVES01
Measuring station nr.	:	CENTRE AT 243 910 E, 232 400 N.
Curve Fitting RMS Error	:	10.4 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.7	380.5	SURFACE LAYER.
2	1.1	49.7	CLAY LAYER.
3	3.9	170.0	PEAT LAYER.
4	19.9	50.0	TILL LAYER.
5	INF.	3000.0	LIMESTONE BEDROCK.

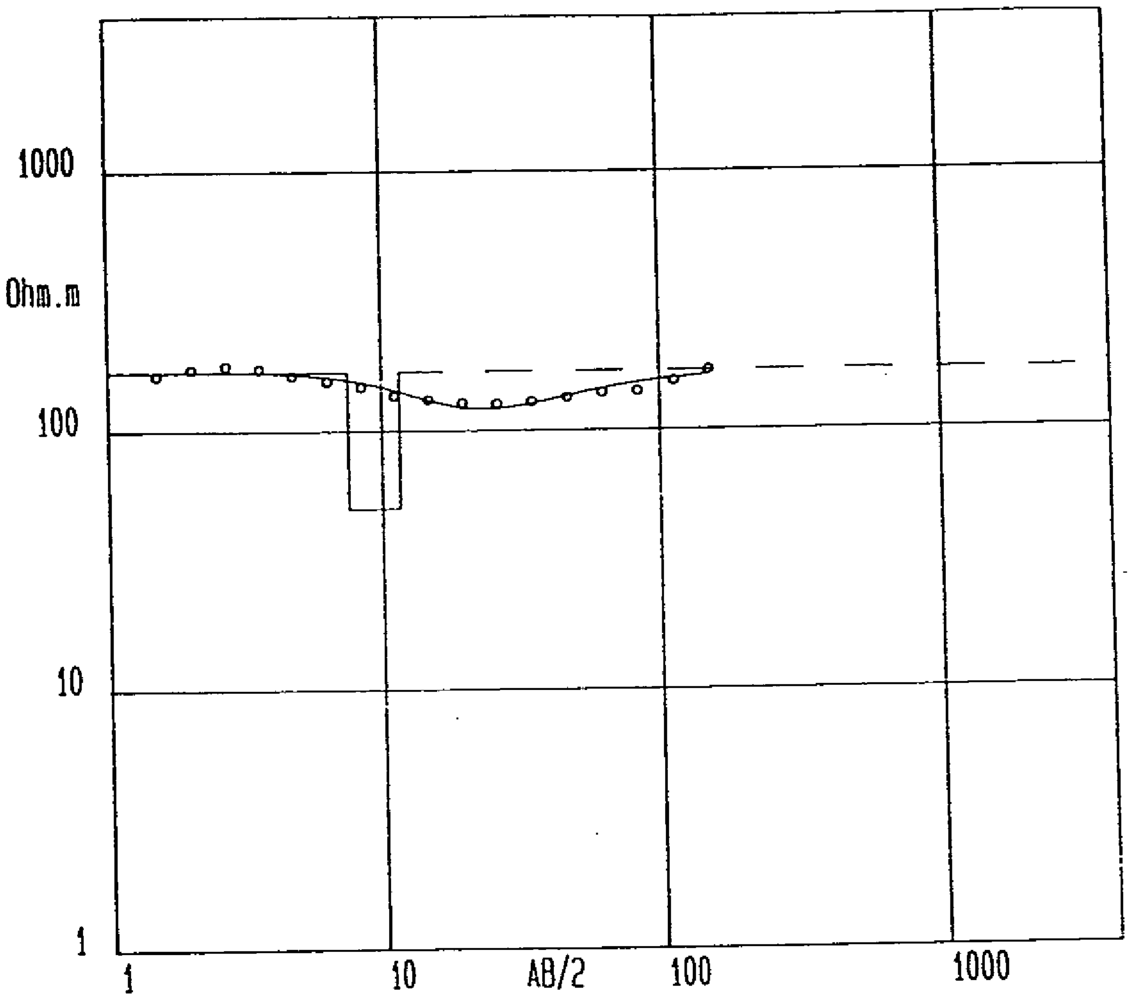
Date of the measurement : 15/03/90

Location : RAHEENMORE

Map nr. : RHSVES02

Measuring station nr. : CENTRE AT 243 910 E, 232 400 N.

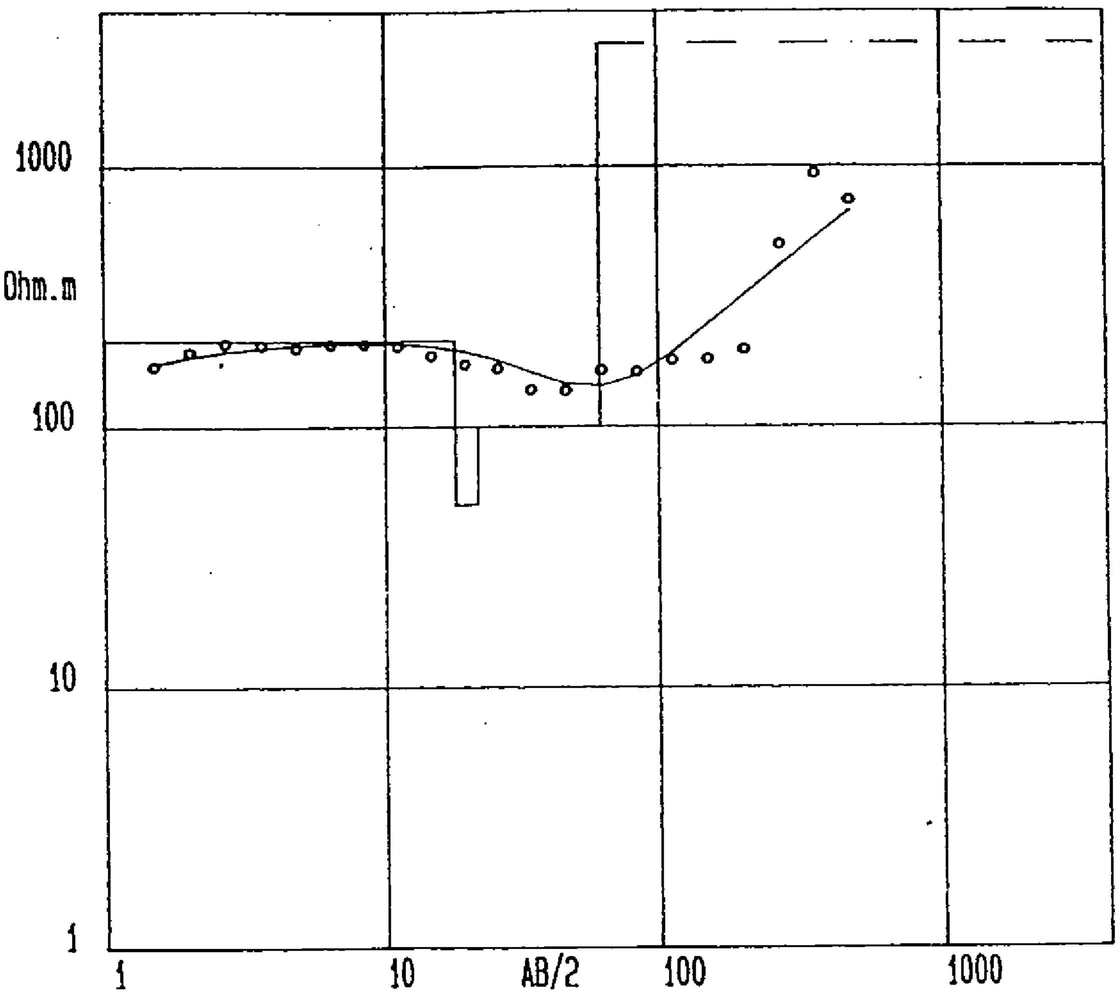
Curve Fitting RMS Error : 4.1 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.2	166.3	SURFACE LAYER.
2	7.3	170.0	PEAT LAYER.
3	4.2	50.0	CLAY LAYER.
4	INF.	170.0	PEAT LAYER.

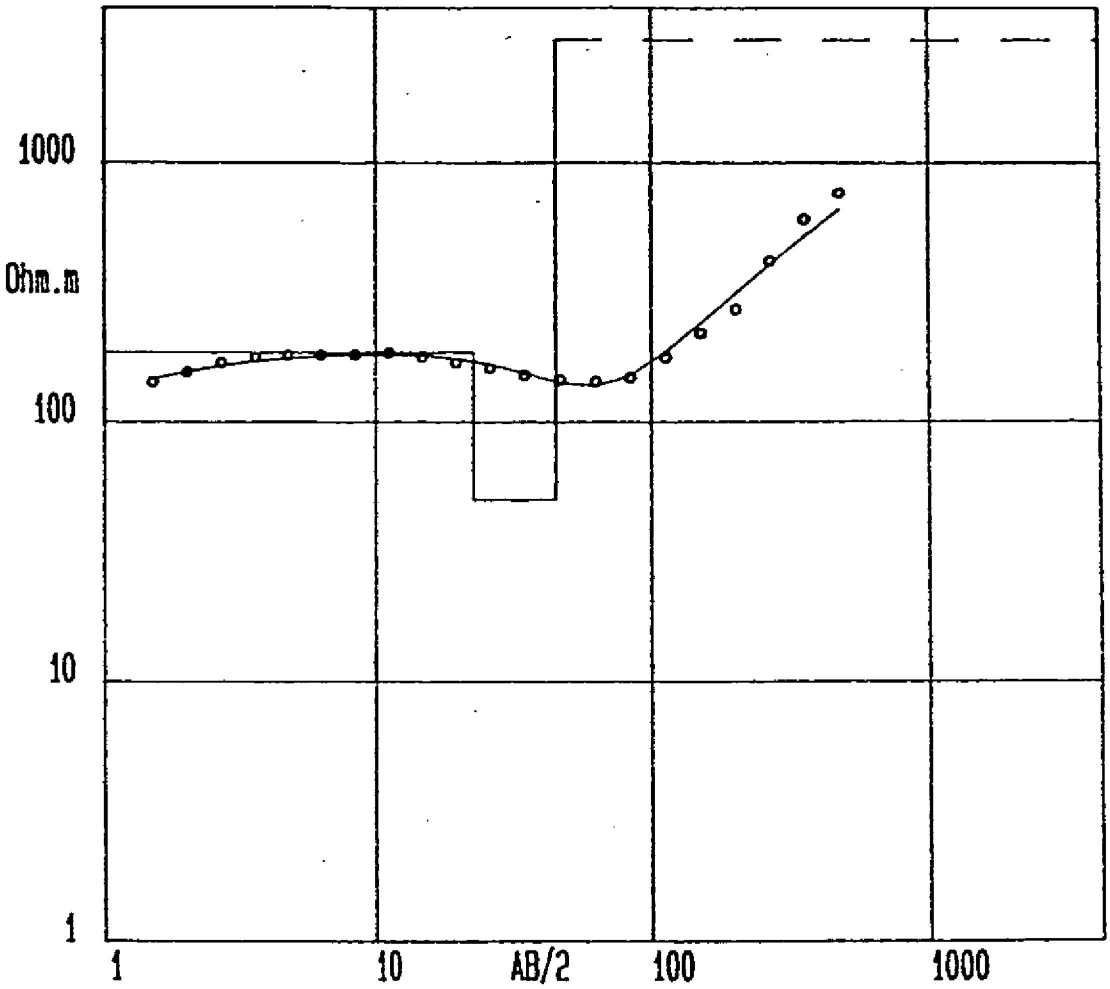
Date of the measurement : 15/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES03.
Measuring station nr. : CENTRE AT 244 020 E, 232 050 N.
Curve Fitting RMS Error : 19.9 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.3	100.0	SURFACE LAYER.
2	18.0	215.0	PEAT LAYER.
3	4.0	50.0	TILL LAYER.
4	40.0	100.0	? TILL LAYER.
5	INF.	3000.0	LIMESTONE BEDROCK.

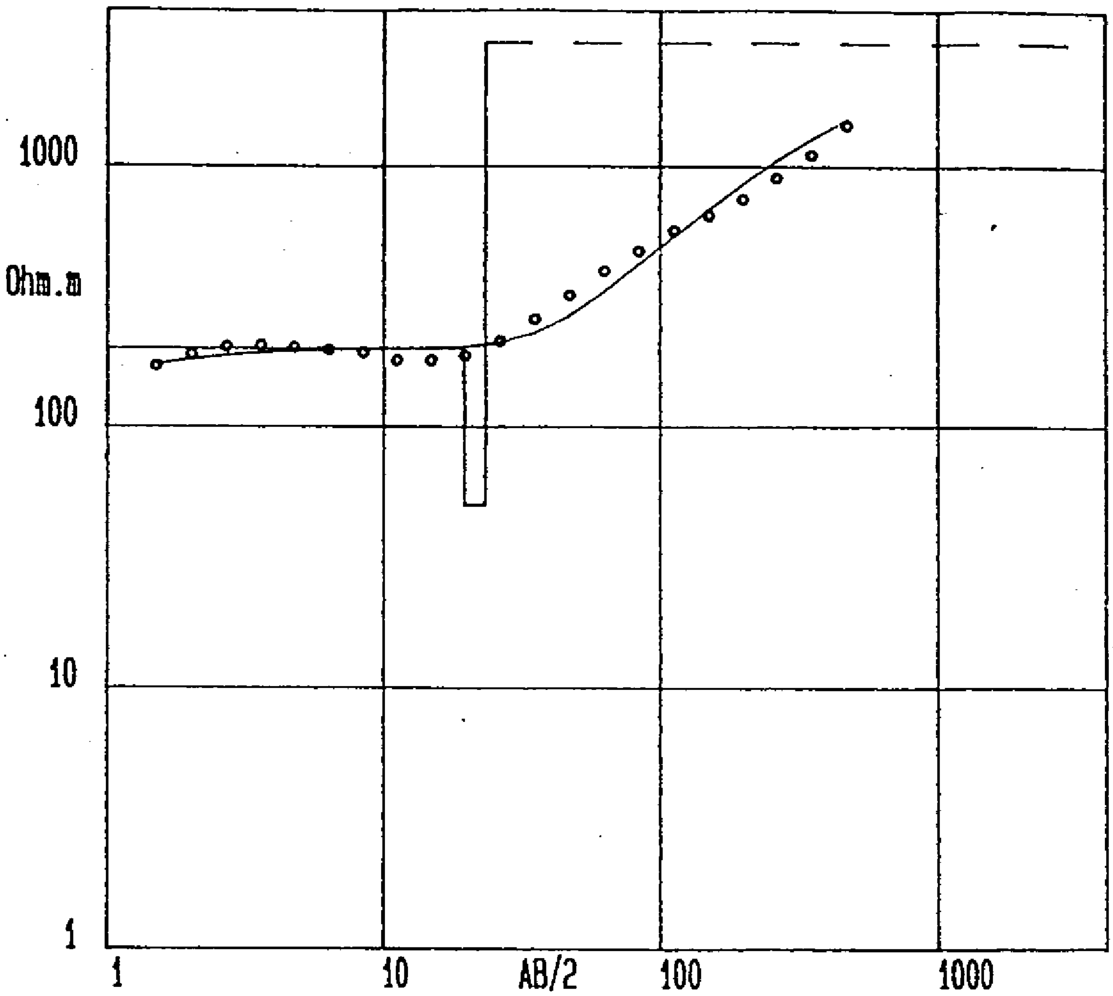
Date of the measurement : 16/03/90.
Location : RAHEENMORE.
Map nr. : RHSVES04.
Measuring station nr. : CENTRE AT 244 140E, 232 080 N.
Curve Fitting RMS Error : 6.3 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	112.3	SURFACE LAYER.
2	22.7	186.2	PEAT LAYER.
3	22.6	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

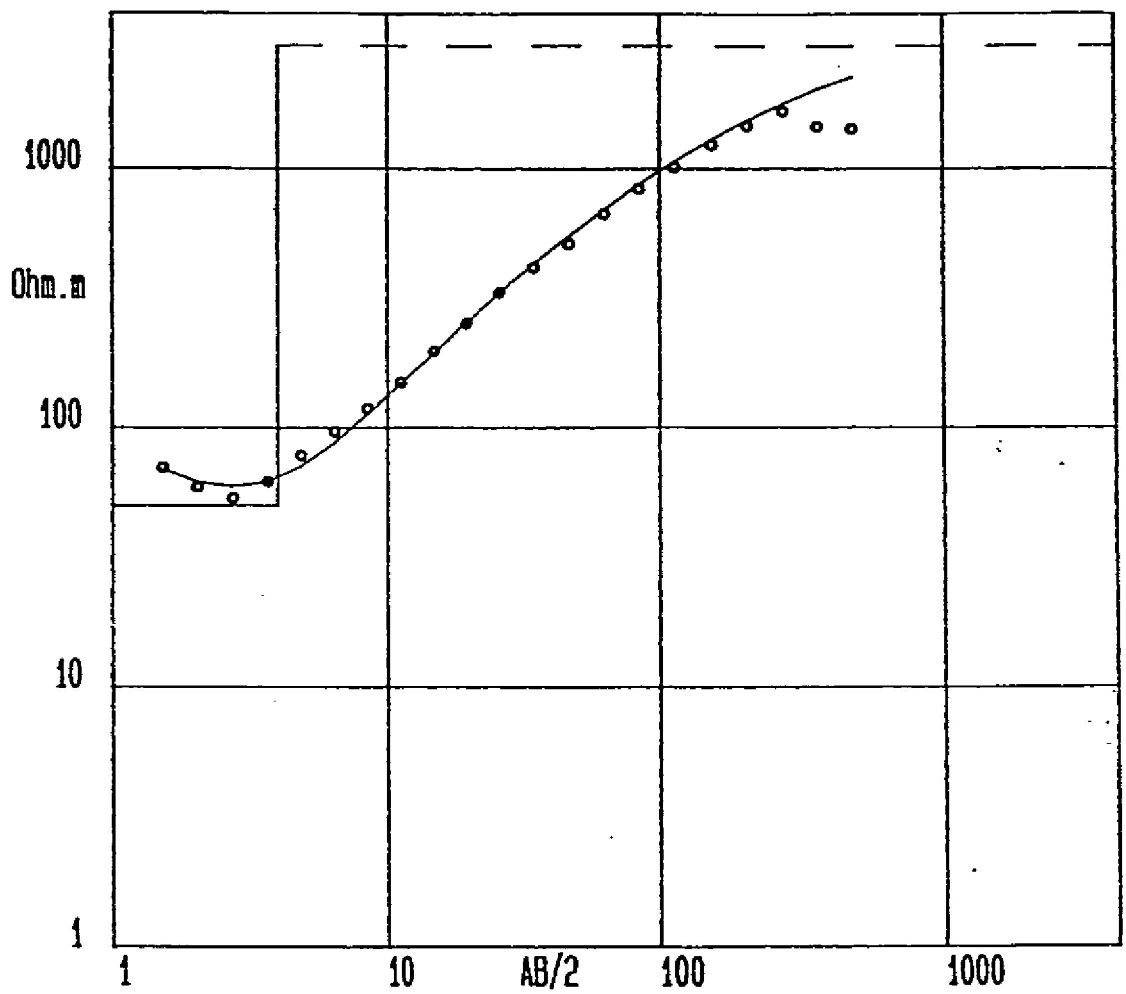
Date of the measurement : 16/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES05.
Measuring station nr. : CENTRE AT 244 230 E, 231 960 N.
Curve Fitting RMS Error : 9.9 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.3	113.8	SURFACE LAYER.
2	19.5	200.5	PEAT LAYER.
3	3.8	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

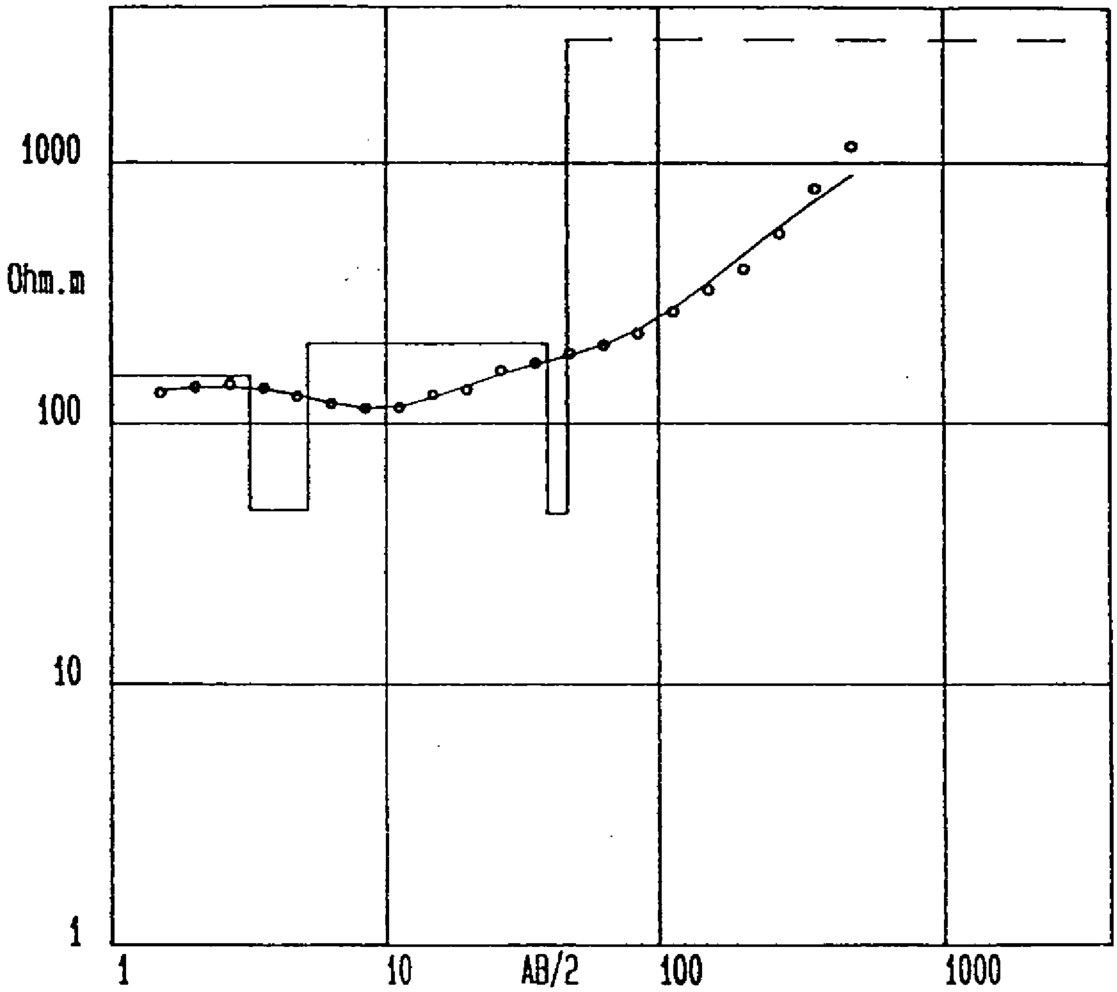
Date of the measurement : 19/03/1990.
Location : RAHEENMORE, C.MALLON FIELDS.
Map nr. : RHSVES06.
Measuring station nr. : CENTRE AT 243 810 E, 231 440 N.
Curve Fitting RMS Error : 16.4 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	115.3	SURFACE LAYER.
2	3.4	50.0	TILL LAYER.
3	INF.	3000.0	LIMESTONE BEDROCK.

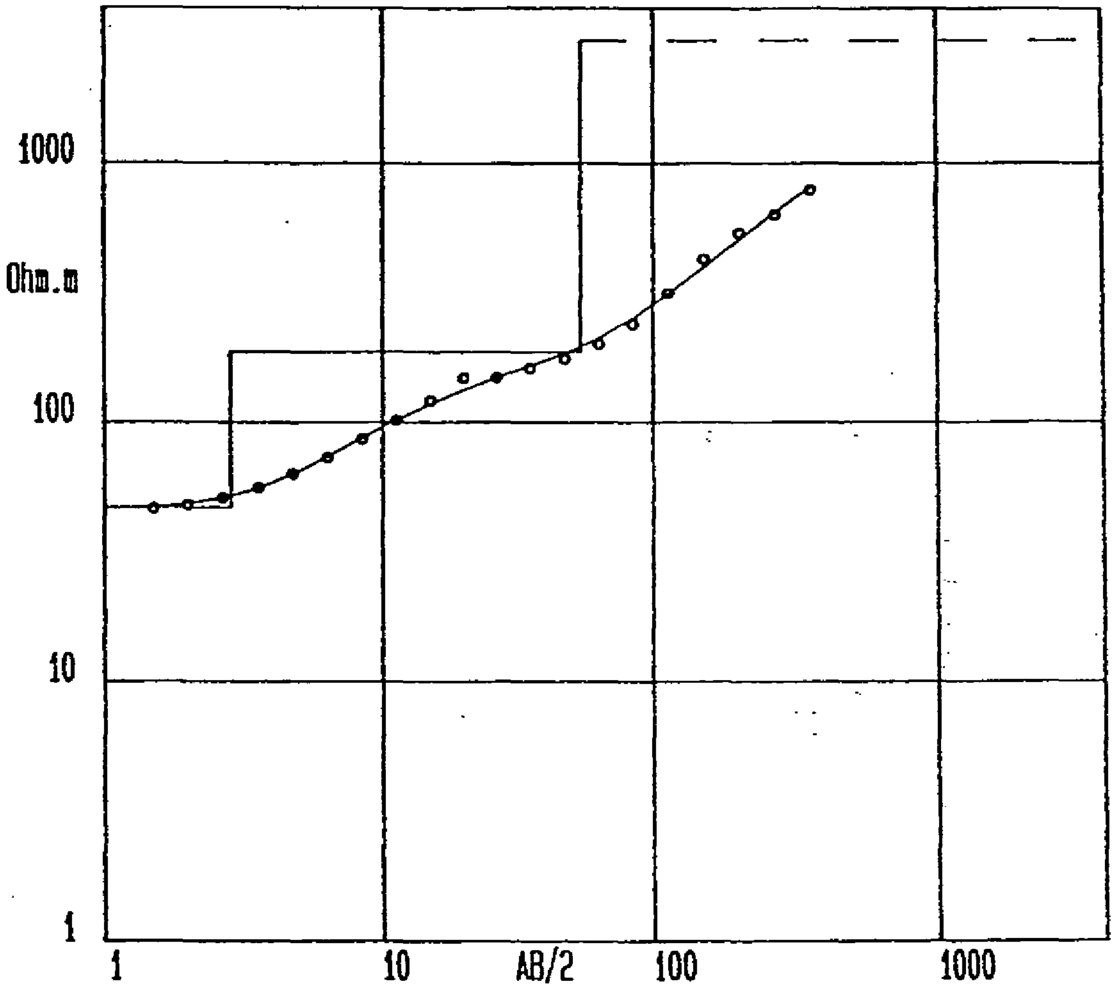
Date of the measurement : 20/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES07.
Measuring station nr. : CENTRE AT 243 790 E, 232 530 N.
Curve Fitting RMS Error : 6.7 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	116.4	SURFACE LAYER.
2	2.7	152.5	PEAT LAYER.
3	2.0	46.5	TILL OR CLAY LAYER.
4	34.2	203.6	? TILL LAYER.
5	7.2	45.0	TILL LAYER.
6	INF.	3000.0	LIMESTONE BEDROCK.

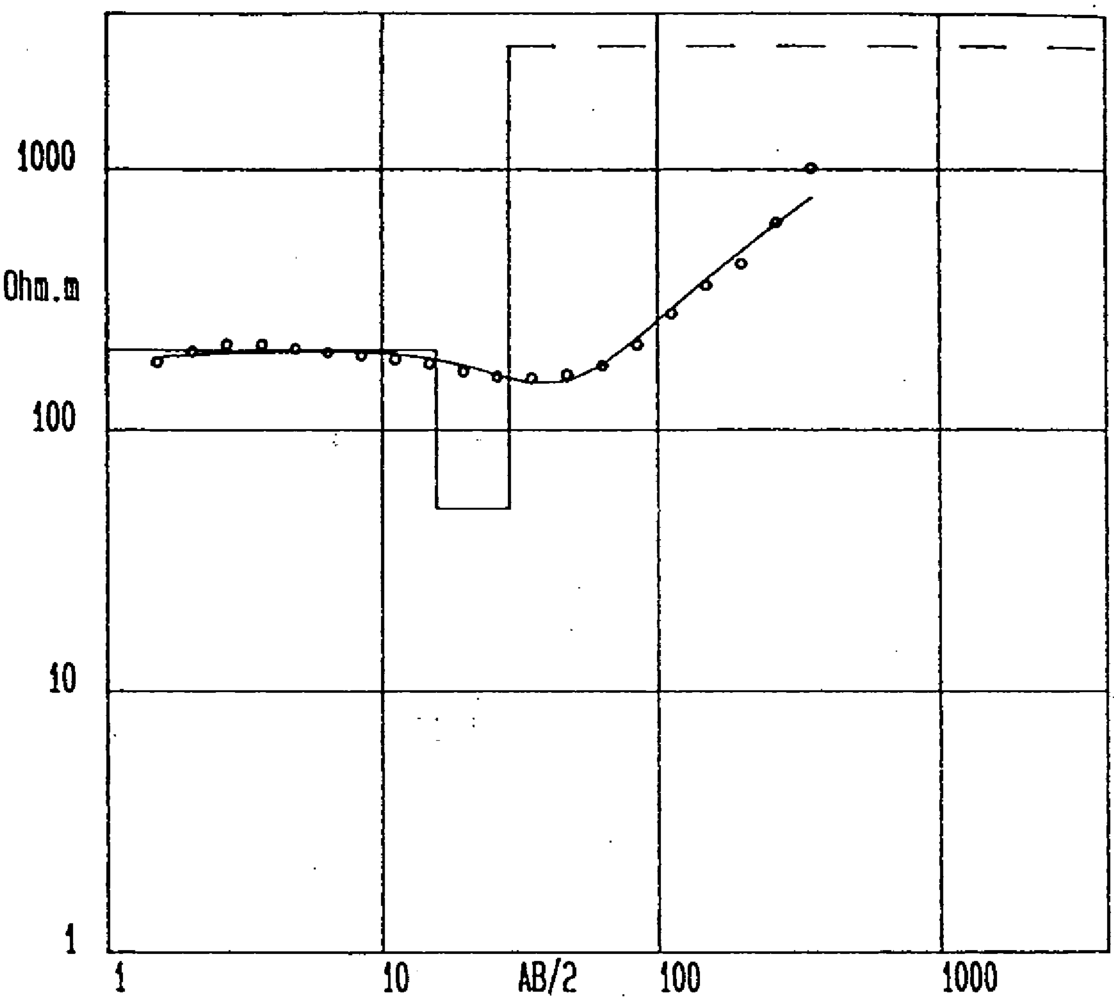
Date of the measurement : 20/03/1990.
Location : RAHEENMORE, HARTE FIELDS.
Map nr. : RHSVES08.
Measuring station nr. : CENTRE AT 243 420 E, 232 510 N.
Curve Fitting RMS Error : 3.8 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.1	29.8	SURFACE LAYER.
2	2.8	47.1	TILL OR CLAY LAYER.
3	51.5	187.5	? TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

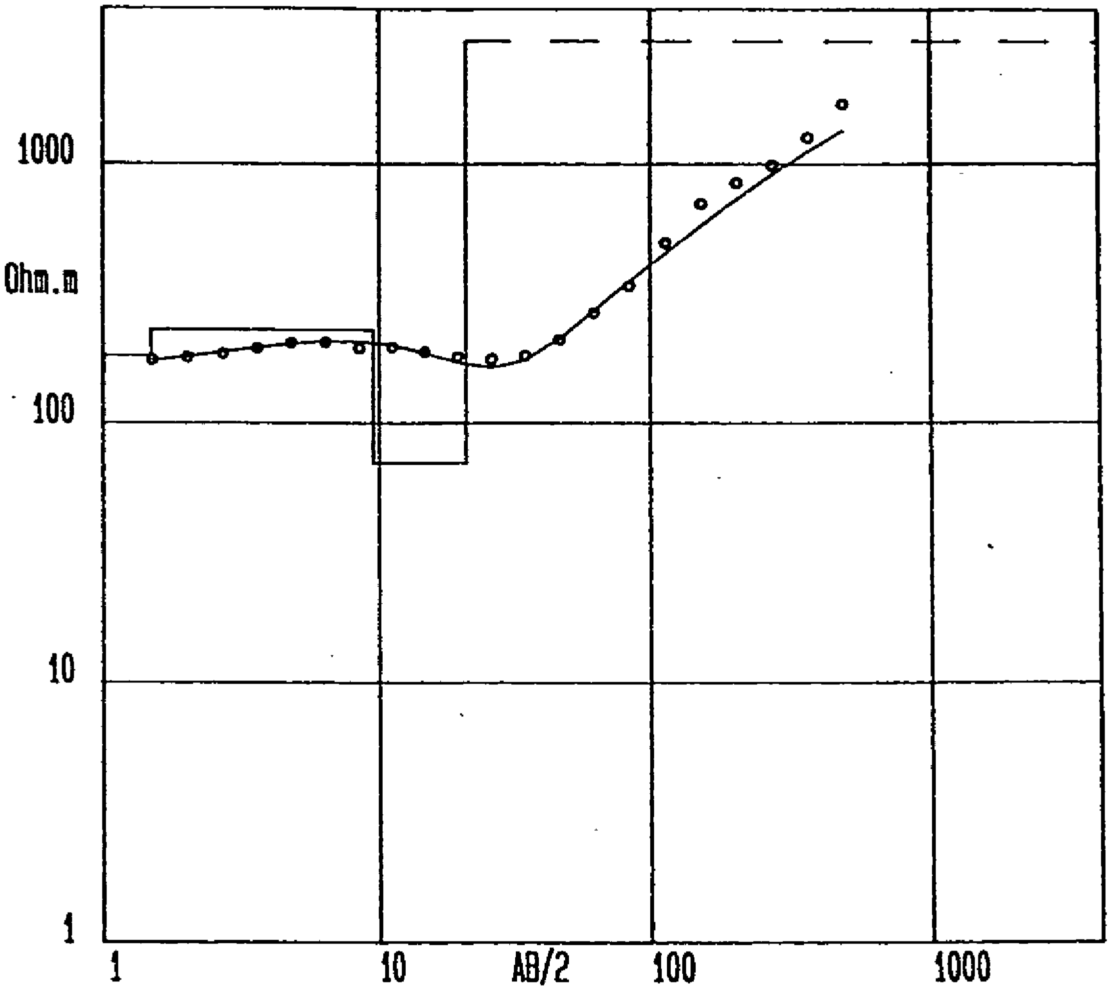
Date of the measurement : 21/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES09.
Measuring station nr. : CENTRE AT 243 280 E, 232 240 N.
Curve Fitting RMS Error : 7.2 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.4	170.1	SURFACE LAYER.
2	15.4	203.4	PEAT LAYER.
3	13.6	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

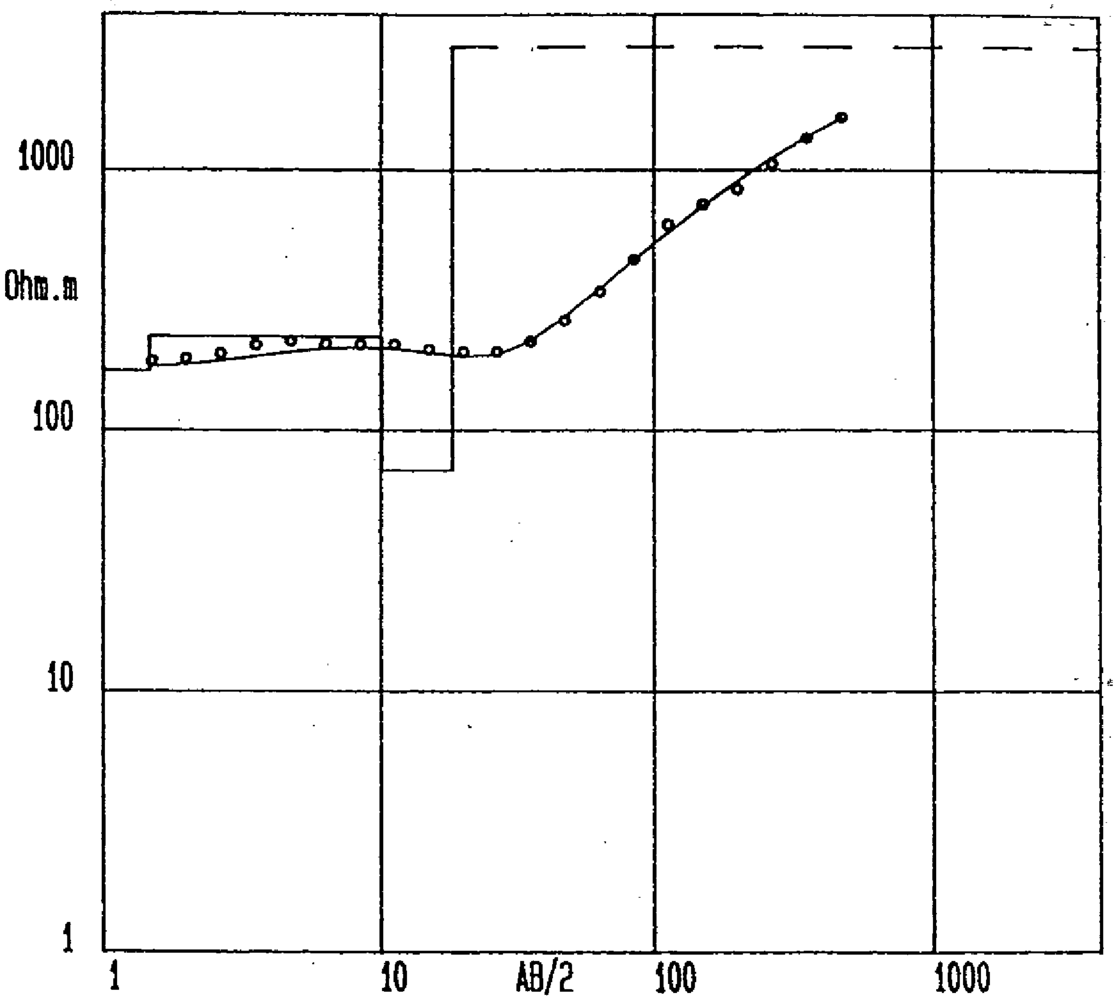
Date of the measurement : 22/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES10.
Measuring station nr. : CENTRE AT 243 370 E, 232 060 N.
Curve Fitting RMS Error : 8.2 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	158.0	SURFACE LAYER.
2	1.0	182.1	PEAT LAYER.
3	8.0	230.0	PEAT LAYER.
4	12.0	70.0	TILL LAYER.
5	INF.	3000.0	LIMESTONE BEDROCK.

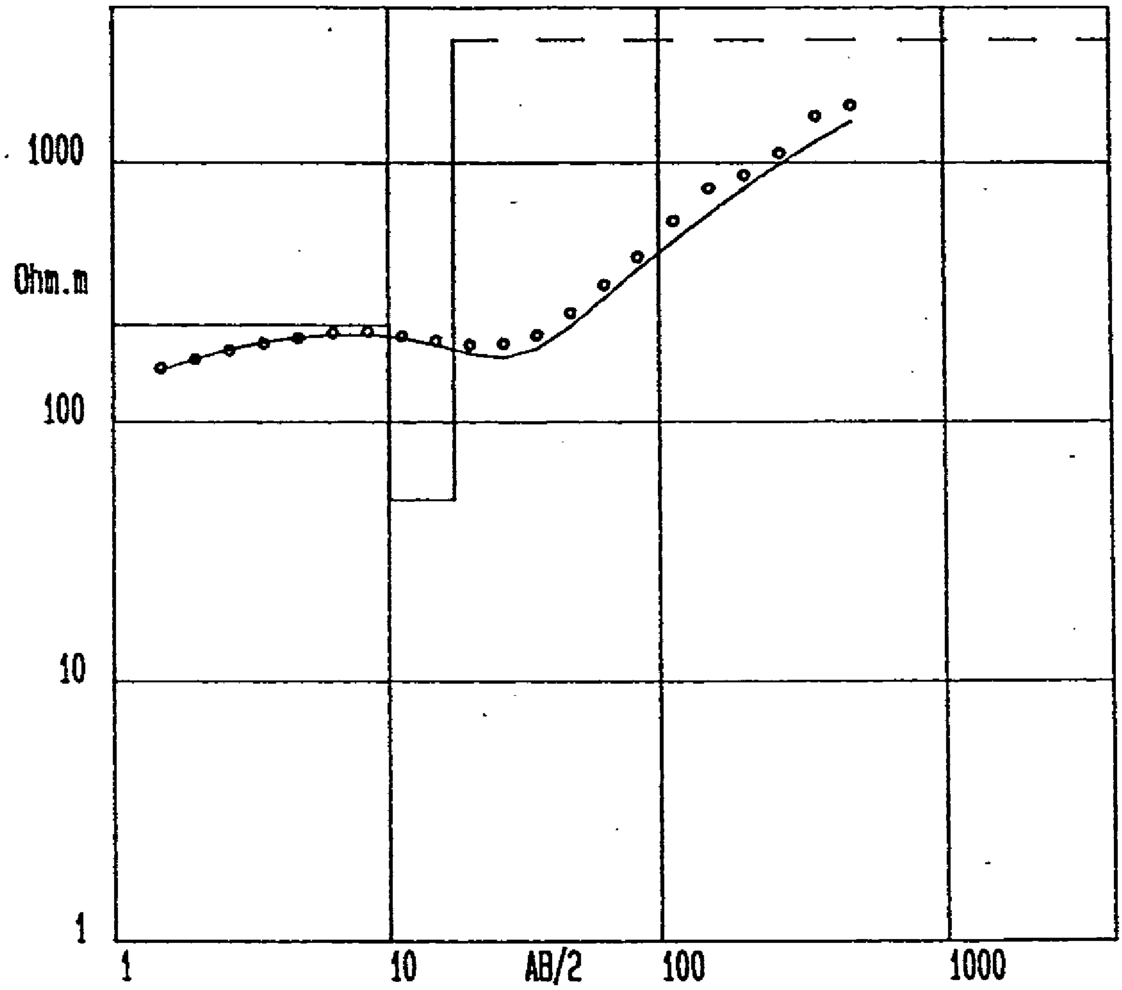
Date of the measurement : 22/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES11.
Measuring station nr. : CENTRE AT 243 470 E, 231 880 N.
Curve Fitting RMS Error : 4.8 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	174.4	SURFACE LAYER.
2	1.0	168.6	PEAT LAYER.
3	8.7	230.0	PEAT LAYER.
4	8.1	70.0	TILL LAYER.
5	INF.	3000.0	LIMESTONE BEDROCK.

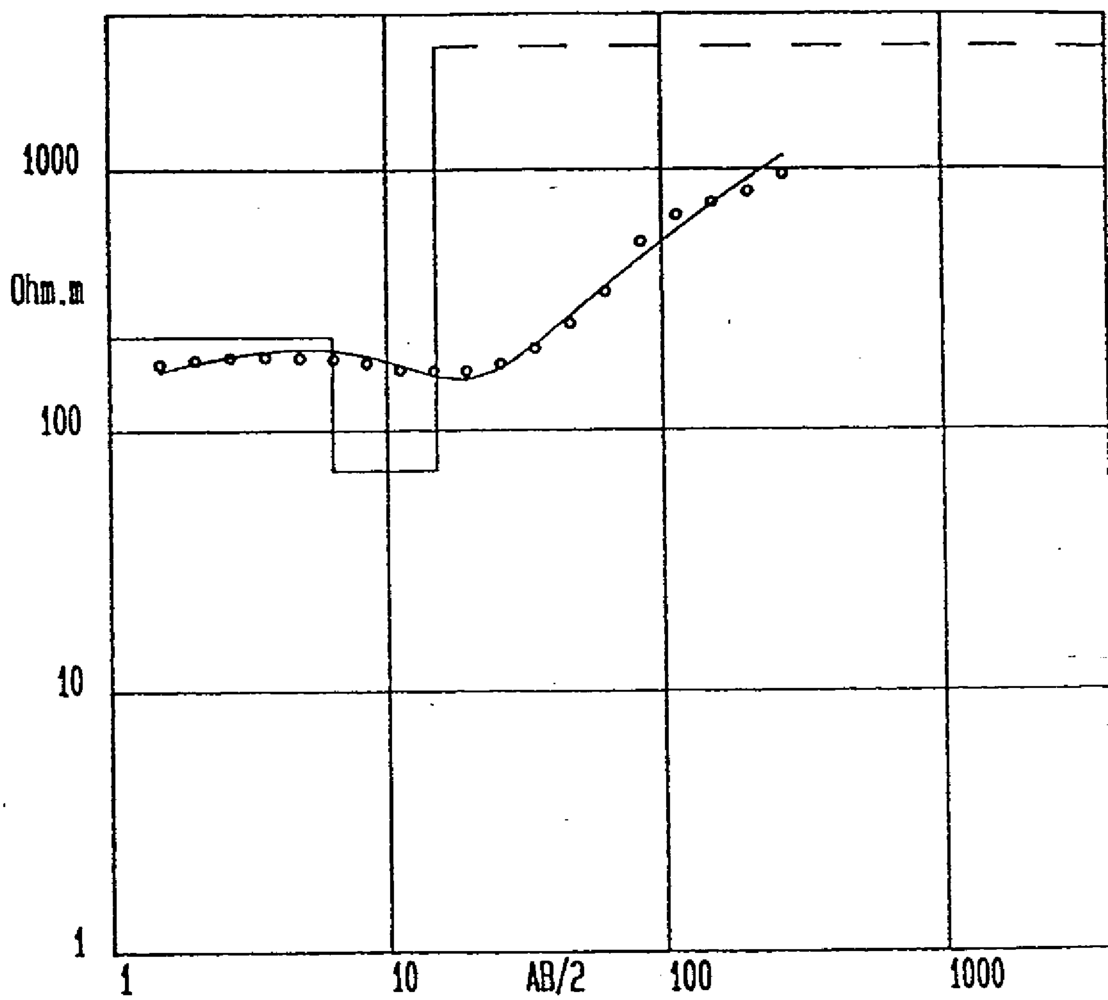
Date of the measurement : 23/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES12
Measuring station nr. : CENTRE AT 243 470 E, 231 880 N.
Curve Fitting RMS Error : 10.5 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	103.2	SURFACE LAYER.
2	9.6	237.8	PEAT LAYER.
3	7.4	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

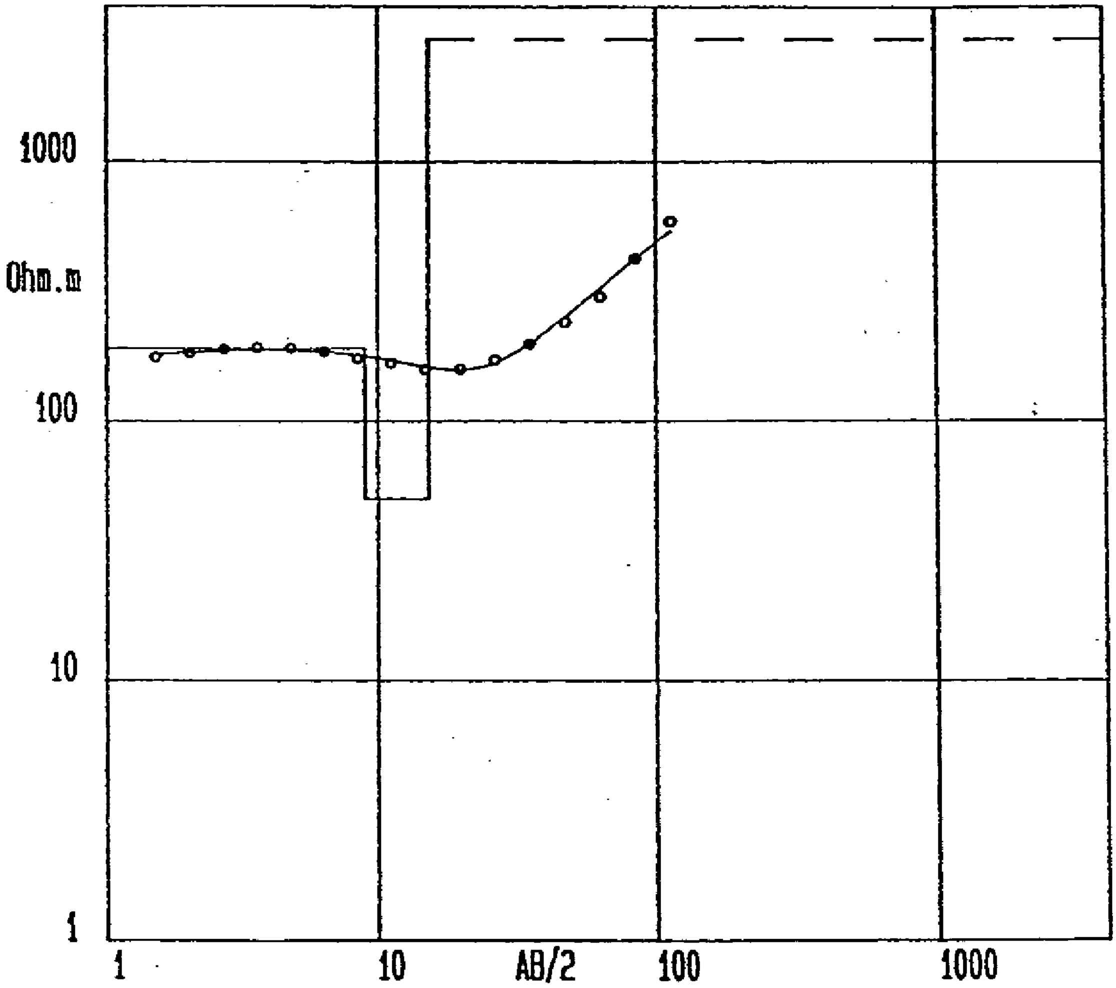
Date of the measurement : 27/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES13
Measuring station nr. : CENTRA AT 243 570 E, 231 710 N.
Curve Fitting RMS Error : 8.1 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.5	122.8	SURFACE LAYER.
2	5.7	230.0	PEAT LAYER.
3	9.1	70.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

Date of the measurement : 27/03/1990.
Location : RAHEENMORE.
Map nr. : RHSVES14
Measuring station nr. : CENTRE AT 243 670 E, 231 540 N.
Curve Fitting RMS Error : 3.7 %



Model parameters in metres and Ohm.metres :

Layer	Thickness	Resistivity	Interpretation
1	0.2	121.6	SURFACE LAYER.
2	8.8	191.5	PEAT LAYER.
3	6.4	50.0	TILL LAYER.
4	INF.	3000.0	LIMESTONE BEDROCK.

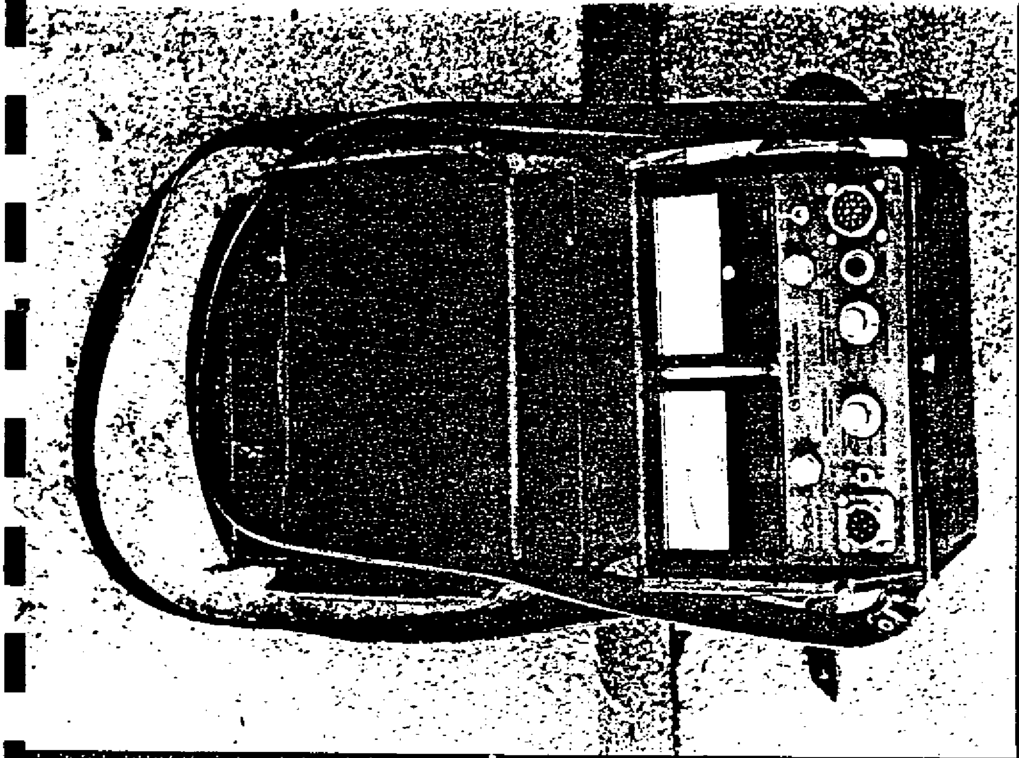


Photo 1.
EM34-4 receiver.

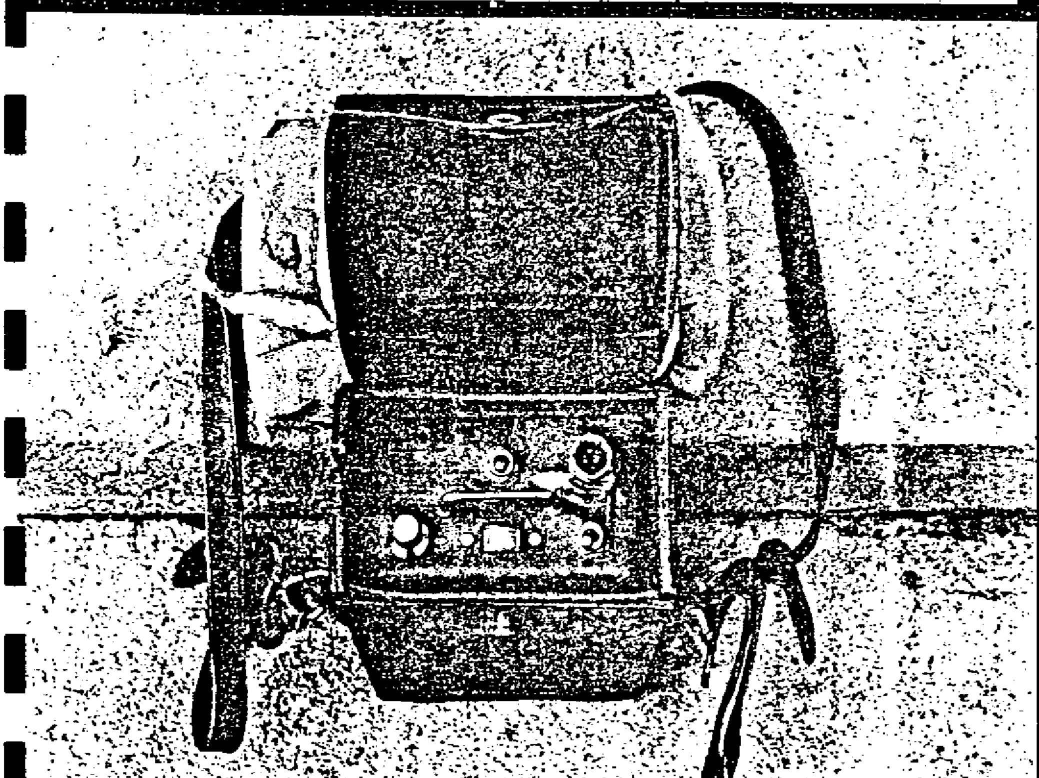


Photo 2.
EM34-4 transmitter

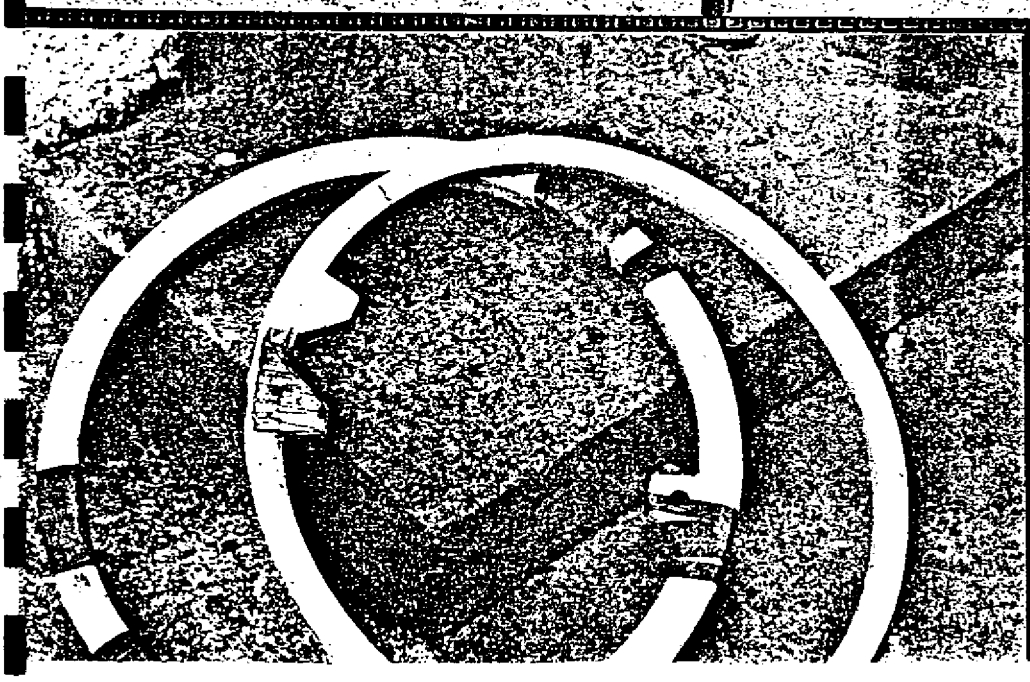


Photo 3.
EM34-4 coils.

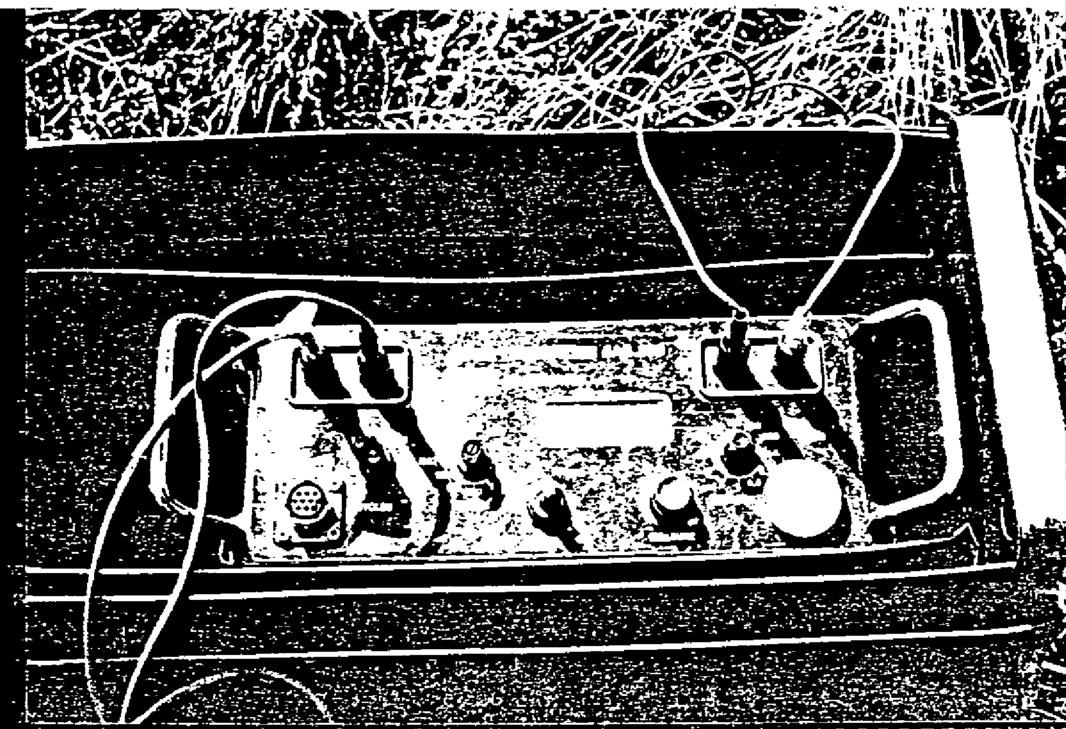


Photo 4.
ABEM Terrameter SAS 300.

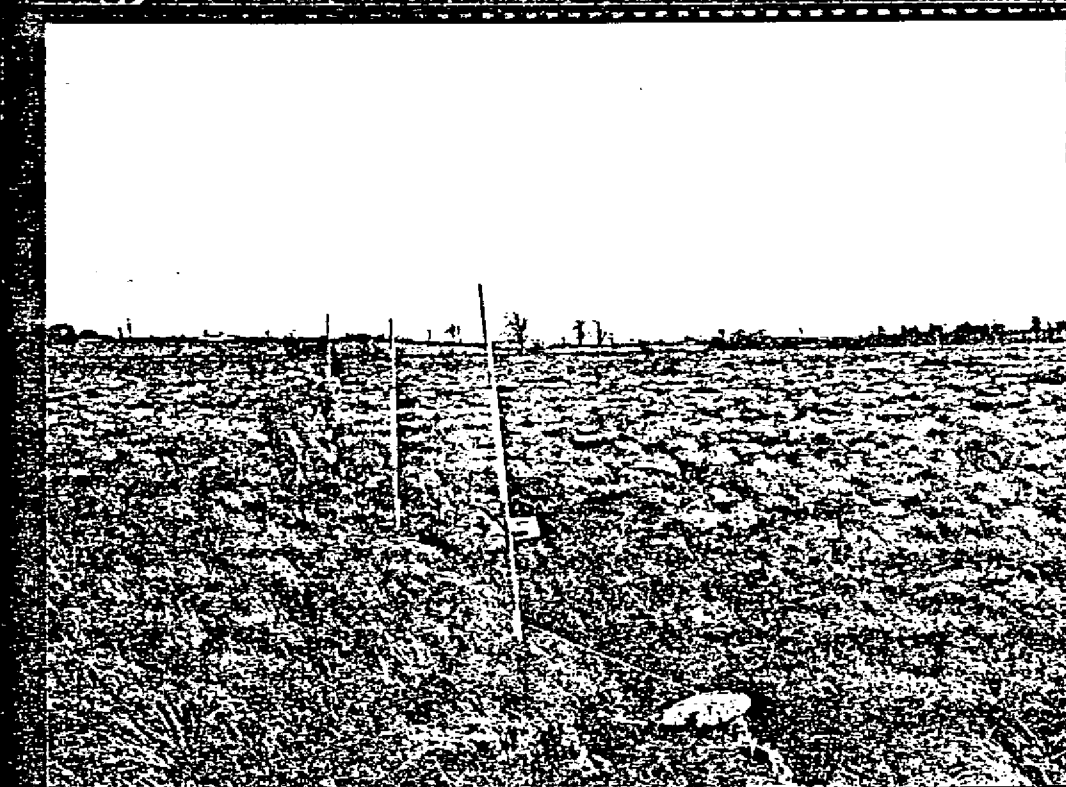


Photo 5.
Centre of a resistivity sounding at Raheenmore bog.

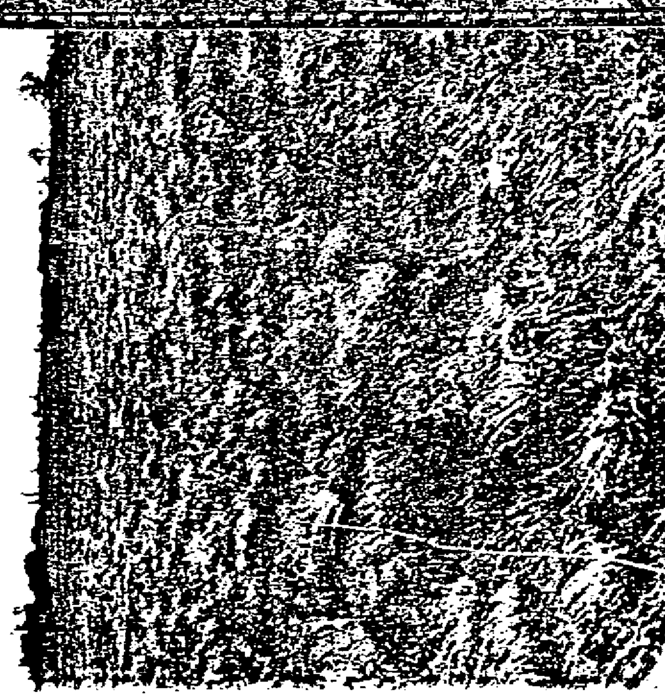


Photo 6.
Resistivity sounding at Raheenmore bog, AB/2=150 meter.

Photo 7.
Clara bog and the esker at the North-side of the bog.

Photo 8.
Raheenmore bog.

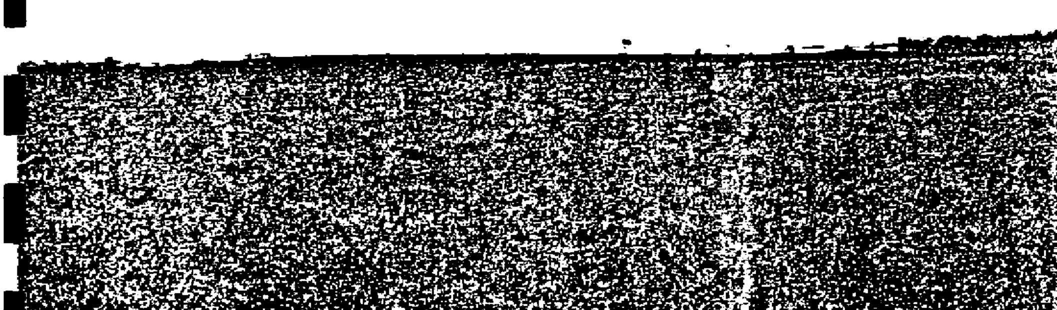


Photo 9.
The ridge near the soak at Clara bog.

IRISH - DUTCH

GEOHYDROLOGY AND ECOLOGY STUDY

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- Department of Nature Conservation, Environmental Protection and Wildlife Management, The Hague
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- National Forest Service, Utrecht

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University of Amsterdam
Nieuwe Prinsengracht 130
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