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Regional Geophysics Research Group

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Further Geophysical Studies on the Basement Aquifer in Masvingo Province, Zimbabwe

I.F. Smith and M.G. Raines

July 1988

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CONTENTS

1. INTRODUCTION

1.1 Background

Geophysical studies were an integral part of a multidisciplinary investigation of the basement aquifer in Zimbabwe, carried out by British Geological Survey (BGS) and the Ministry of Energy and Water Resources and Development (MEWRD) of Zimbabwe, and funded by the Overseas Development Administration (ODA) of the British Government. The study was centred on Masvingo Province, in conjunction with the Provincial Water Engineer based in Masvingo as well as the Hydrogeology Department in Harare.

A geophysical study had been made in 1986 (Smith and Raines, 1987) of a number of key areas, which represented the range of major rock types, in a variety of different hydrological and hydrogeological settings. It was intended as an orientation study, to obtain additional data on a number of previous drilling exercises which had fully reported, but which had a proportion of unsuccessful boreholes. On the basis of this experience, it was hoped to apply methods which might enhance the success rate.

This second season's work represents the application of this experience to the identification of suitable drilling targets in conjunction with parallel hydrogeological, structural and geomorphological assessments. It was hoped that the drilling would improve our understanding of the structure and hydrogeological behavior of major linear features identifiable from aerial photography, as well as provide suitable sites for the installation of pumps for water supply.

Following the workshop on 'Groundwater Exploration and Development in Regions Underlain by Crystalline Basement Rocks' in Harare, Zimbabwe in June 1987, 2 geophysicists from BGS, accompanied by 2 counterpart hydrogeologists from MEWRD, spent 8 weeks in Masvingo Province. During this period some 16 sites were surveyed and at most of these sites borehole targets were identified and pegs were inserted to guide the drilling crews.

In addition to these sites, 2 areas were surveyed in the Gutu administrative area as potential sites for collector wells, the digging of which was to be funded by the German aid agency GTZ, through the Zimbabwean Commission for Agricultural and Rural Development (CARD).

Prof D.H. Griffiths of University of Birmingham, UK spent some 2 weeks in the area covering some of the critical sites with a prototype resistivity traversing system, based on a microprocessor-controlled electrode array. His results have been reported separately (Griffiths 1987).

This report presents the results obtained from the surveys, with an interpretation and brief assessment of the significance of the findings.

1.2 Geophysical Methods

The following methods were applied during our survey:

1. **Ground conductivity traversing**: The Geonics EM34-3 system was used for much of the survey work. The method is particularily applicable to the investigation of relatively conductive ground i.e. with a resistivity of less than say 100 ohm m (greater than 10 mmho/m or mS/m), and becomes progessively more sensitive to variations of conductance as the resistivity decreases.

The system is based on the principal of electromagnetic (EM) induction, whereby a primary alternating EM field of suitable frequency produced by the instrument transmitter induces a flow of electric current in conductors which it intersects. Such conductors may exist in the ground. These alternating 'eddy currents' themselves radiate a secondary EM field, which is measured at the instrument receiver, together with the primary field. Analysis of the received field allows certain characteristics of the conductor to be inferred.

The EM34 equipment allows the transmitter and receiver coils to be used either vertically or horizontally. This enables a measure of discrimination to be made between vertical and horizontal structures to be made. With coils held vertical and coplanar, the coupling of the primary field with horizontal structures is maximised, so that in this mode the instrument is sensitive to variations in thickness of conductive overburden (for example). With the coils 'horizontal' and coplanar the coupling with vertical structures is maximised, so that dyke-like bodies may be identified. Of course on sloping ground the coils cannot be held properly horizontal, so efforts are required to ensure the coplanarity of the coils: errors in this produce noisey results. Various coil spacings may be used to obtain a range of depths of investigation: in this survey we used exclusively 20 and 40m spacing.

We have used the cumbersome expression 'steep-sided conductive bodies' to describe targets which have been defined by horizontal coils. This is avoid a number of confusions and uncertainties: a) they are not necessarily dykes, which may or may not be conductive; b) they are unlikely to be the text-book parallel-sided prism infinite in the third dimension; c) the anomaly which they produce is characteristic in having a central minimum (less than 0 mmho/m), surrounded by 2 maxima (shoulders); c) although in many cases we have come to believe the anomalies are caused by fracture systems (which may be expressed on aerial photographs as lineaments), we are not sure that the fracture itself is sufficiently conductive to cause the anomaly. It may be that preferential weathering along the fractures has created extra thickness of conductive saprolite, which is bounded by steep contacts.

The Very Low Frequency (VLF) EM method was attempted using the Geonics EM16 equipment, which provides avery rapid method for acquiring ground conductivity data. However, despite a number of attempts, the signal strengths from transmitters at both Cutler, Maine (in the USA) and North Cape (Australia) were too low to provide a useable source.

2: **Vertical Electric Soundings (VES):** The widely used method of collecting depth estimates at a point was applied. We used the ABEM Terrameter 300B and either Schlumberger array or the offset Wenner array, the latter by means of the Barker Geophysical Soundings 256 cable and switch-box. When using the Schkumberger array, we used a progession of electrodes which provided 10 points per distance decade, so as to provide a minimum of redundant information but to ensure that a sufficiently detailed geo-electric section was collected.

When using the Schlumberger array successive M-N sections of the curve where adjusted to the minimum value, because it was judged that in general the inhomogeneity is likely to increase with the depth of saprolite, and thus the adjustments were made to the curve which sampled the most homogeneous material.

Interpretation was carried out in the field using curve matching methods. A field curve was matched against the 2-layer master curves and auxiliary curve of Mooney and Orellana (1967). Subsequently the computer program RESIST (Pedley, 1985) was used to generate a theoretical curve from a model earth to match against the field curve.

Two specific problems were identified. One the is importance of recognising equivilance in the H-type curve which are typical of this terrain. Equivilance means that there is a measure of ambiguity in any interpreted depth and resistivity solution, so that either a range of possible values should be suggested, or independant information should be sought to control the estimates. Another problem is the frequency with which the ascending part of the curve exceeds the theoretical maximum slope of 45^o. The reason for this possibly lies in the assumption of a horizontally layered earth, which clearly is invalid in this environment, yet attempts were made to minimise the error by careful siting of the VES centre and orientation.

3. **Seismic refraction profiling:** At a few sites seismic refraction profiles were surveyed. The ABEM Terralok seismic recorder was used with a 30kg weight drop energy source. This enabled energy to be received at a range of 230m in good conditions which offers the facility for exploring to a moderate depth without the necessity of explosives. Given that explosives and adequate drilling facilities were readily available, then such a source should be used - at least initially, but the weight drop can be used to obtain useful data for water exploration in this environment.

Whilst there is no doubt that seismic refraction is a most valuable tool, the results which derive may not be cost-effective for rural water supply, in that a large crew, with expensive and heavy equipment is required. The data are slow to acquire and the results require experience, skill and time to interprete. Finally, it is not particularily sensitive to steeply dipping structures such as fracture systems, although it responds well to flat lying layers.

4. **Microprocessor Resistivity Traversing (MRT)**: this novel approach to resistivity profiling and depth sounding as parallel methods has been developed in University of Birmingham by Prof D.H. Griffiths and his associates. The opportunity to apply the method in this environment was seen to be very interesting and Prof Griffiths was invited to make measurements over some sites where we had obtained a range of data. His report (Griffiths, 1987) contains the preliminary results of his work, although it is hoped that more detail and confidence will be possible when all the data are incorporated.

1.3. Acknowledgements

The two authors are grateful to Messrs. Andrew Mavurayi and Charles Muzimbaranda of MEWRD, Harare for their efforts in the field in carrying out the surveys. Mr R. Sothinathan, Acting Provincial Water Engineer in Masvingo, and his workshop staff provided assistance and advice when requested, which was essential to our ability to work. The staff of the Hydrogeology Branch in Harare, under Mr Peris Sinnett-Jones, were most helpful in providing equipment and support in some frustrating situations. Drs Wright, MacFarlane and Greenbaum provided invaluable background information and discussion whilst in the field, which allowed a greater insight into the geological problems under investigation. A number of knotty problems with Customs clearance were unravelled by officials of the British High Commission in Harare.

2. REPORTS ON AREAS STUDIED

Table 1 summarises the geophysical work carried out in 1987.

Table 1. Survey areas and geophysical methods employed.

site name	area	grid ref	report section	methods
Chibi	F	237 7751	2.6	EM VES
Chikofa	C	245 7722	2.1	EM VES
Chikore	C	254 7729	2.2	EM VES
Chinambire	F	245 7755	2.7	EM VES
Chinyika	Gutu	340-1 7842	2.14	EM VES seis MRT
Madangombe	E	218 7779	2.4	EM VES
Maramba	E	222 7768	2.5	EM VES
Matatire	G	278 7801	2.9	EM VES
Mhativa	F	249 7748	2.8	EM VES MRT
Nanwi	G	281 7797	2.10	EM VES VLF
Nemarundwe	G	282-3 7800-1	2.11	EM VES
Rungai	C	254 7721	2.3	EM VES seis MRT
Sarahuru	J	246 7677	2.13	EM VES MRT
Soti Source	Gutu	313 7846	2.15	EM VES MRT
Zimuto	G	273 7792	2.12	EM VES MRT

Methods are coded as follows:

EM	EM34 ground conductivity traverse
VES	vertical electrical sounding (resistivity)
seis	seismic refraction profile
MRT	micro-processor controlled resistivity traversing (Prof D.H. Griffiths)

Each area studied is reported under 4 sections, namely Introduction, Geophysical studies, Discussion and Conclusions. Diagrams, including location map, plots of the ground conductivty traverses and selected interpretations of the VES data, are included after each section.

2.1. **Chikofa School**

Area C

Map 2030 D1, grid reference 245 7722

2.1.1. Introduction

A borehole drilled in 1985 (EEC86) had not been providing an adequate yield, and a 4m deep hand-dug well at 2455 77225 was found to be dry in July. Lineaments had been identified running in a NW-SE direction, and a possible rock barrier crossed the vlei (Greenbaum and Wright personal communication).

2.1.2. Geophysical studies

Six ground conductivity traverses and 3 VES were measured over a vlei elevated above the main drainage system.

EM traverse no.1 ran across the vlei in a SW direction, from kjope to kjope, and crossing patches of outcrop. It also passed the hand-dug well at its NE extremity. The profile indicated that there was little thickness of regolith developed. A vertical sided conductivity anomaly was indicated at 280m, in an an area of relatively sparse outcrop. A VES was measured at this point and indicated significant lateral variation. Some 3m of regolith with apparent resistivity of 90 ohm m overlies perhaps 10m of saprock, at 400 ohm m.

EM traverse no 2 ran down the vlei towards the SSE, to intersect the proposed rock barrier. Very strong irregular anomalies were measured, as a result of working along the conductive body. Subsequently traverses 3, 4, 5 and 6 ran across the vlei in order to better define the anomalous feature, which lies close to the watershed. Traverses 3 and 6 clearly show it to be a classic 'dyke-like' anomaly, although it is less well defined on 3 and 4, and show irregular curves. Two VES were sited to investigate the regolith thickness along the valley bottom. No. 2 show 15m of regolith at around 30 ohm m, overlying bedrock, and no.3 indicate great lateral variation and probably only 1-2m of regolith.

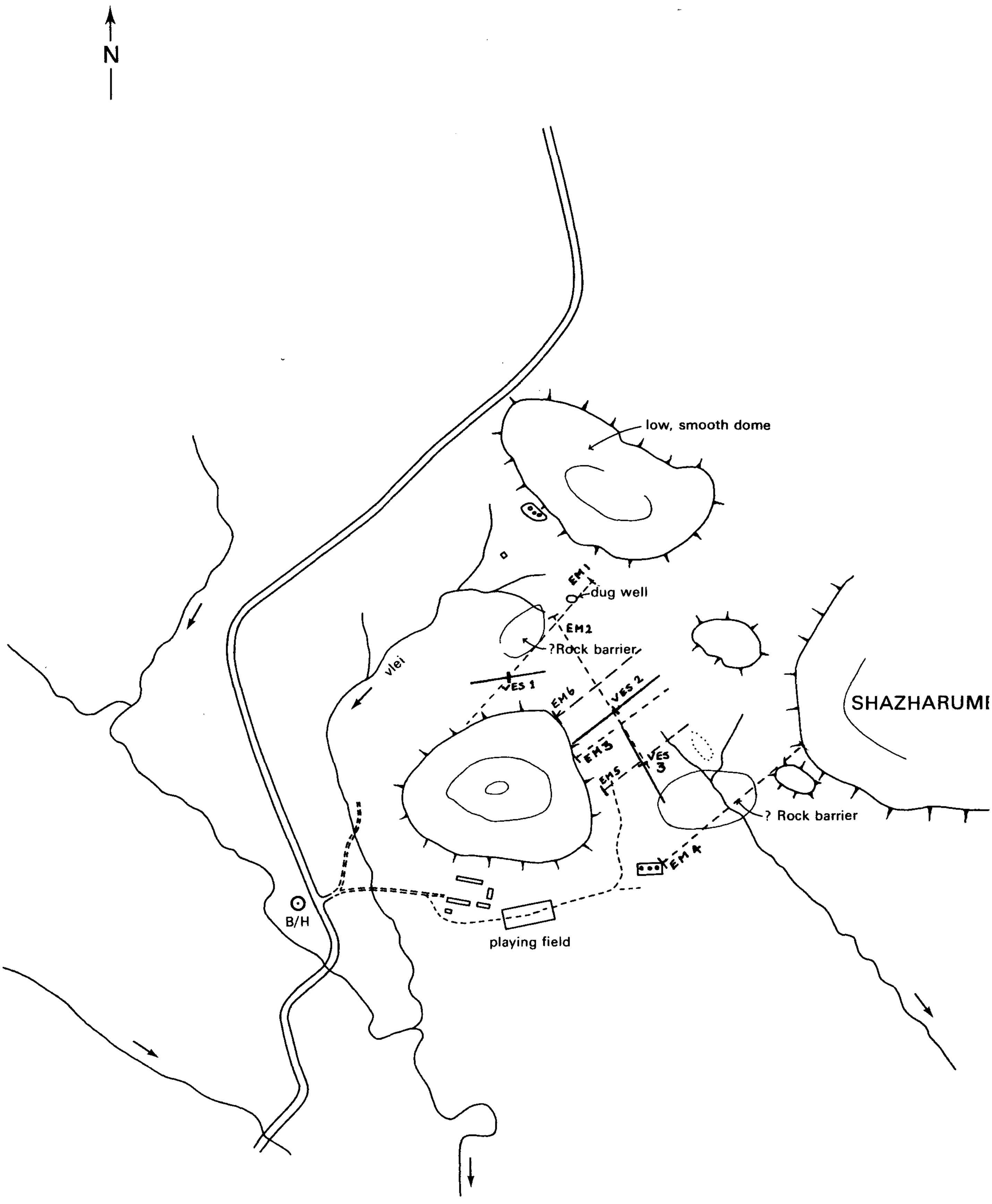
2.1.3. Discussion

The conductivity anomaly investigated with traverses 2-6 is a well-developed linear feature, although whether it links to the anomaly on traverse 1 is not clear. Near the water-shed, it becomes particularily strong, suggesting a local development of weathering in a narrow zone, with a thickening of regolith and/or increase of conductivity. This is also indicated on the VES, although the lateral variation would of course, be large. There is strong evidence from traverse 4 that the rock barrier does exist, and the vertical-sided anomaly is noted in an area in which there is plentiful reddish weathered quartz at the surface. In this area there is no evidence of a thickening in the regolith.

2.1.4 Conclusion

It is concluded that this is evidence of a linear fracture system, maybe containing conductive clay-rich regolith, running along the length of the vlei. A peg was fixed to indicate the maximum development of the anomaly, so that a vertical borehole might investigate the fracture system. The maximum thickness (or conductivity) of the regolith would be found 20m to the NE.

CHIKOFA SCHOOL: AREA C: MAP 2030 D1



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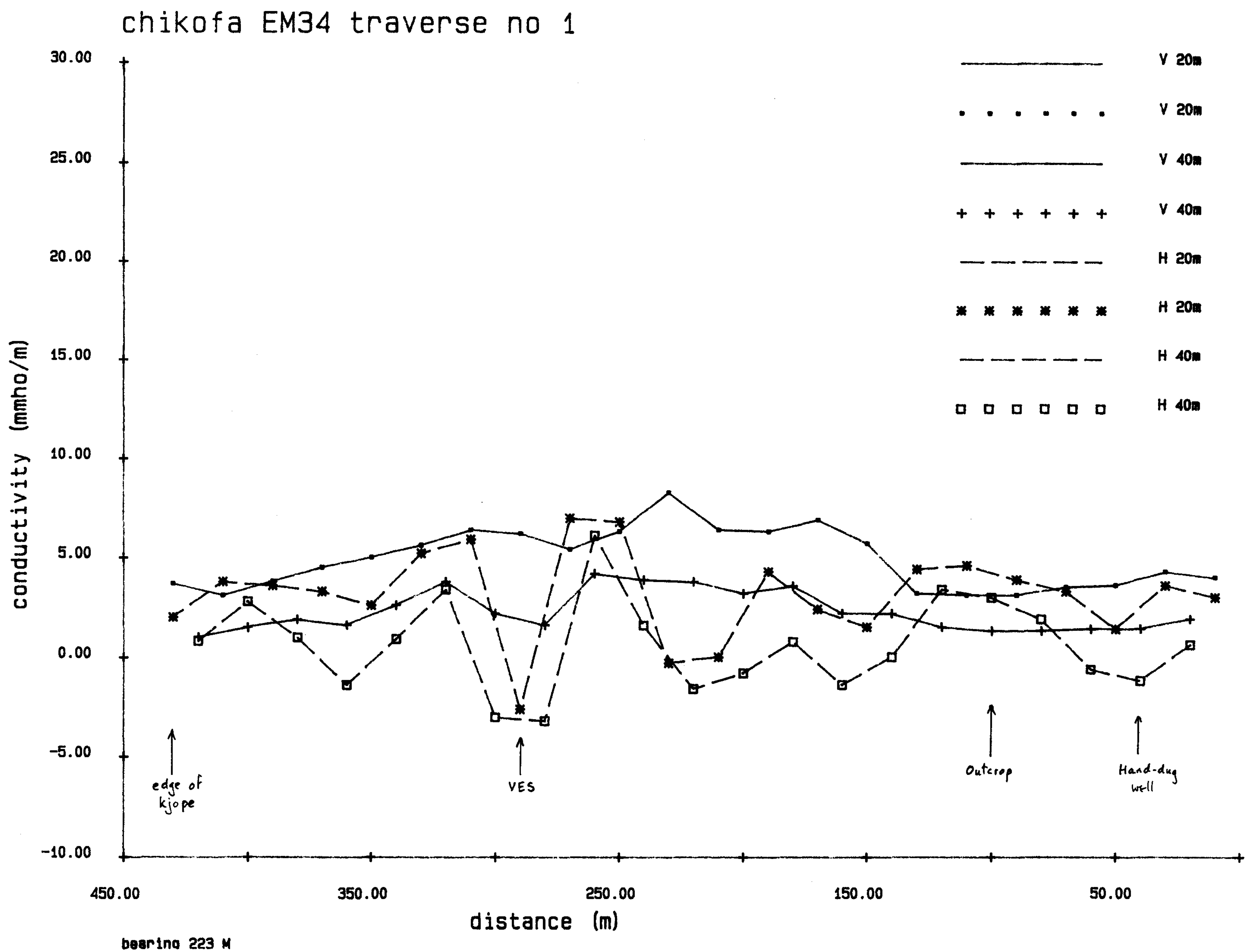
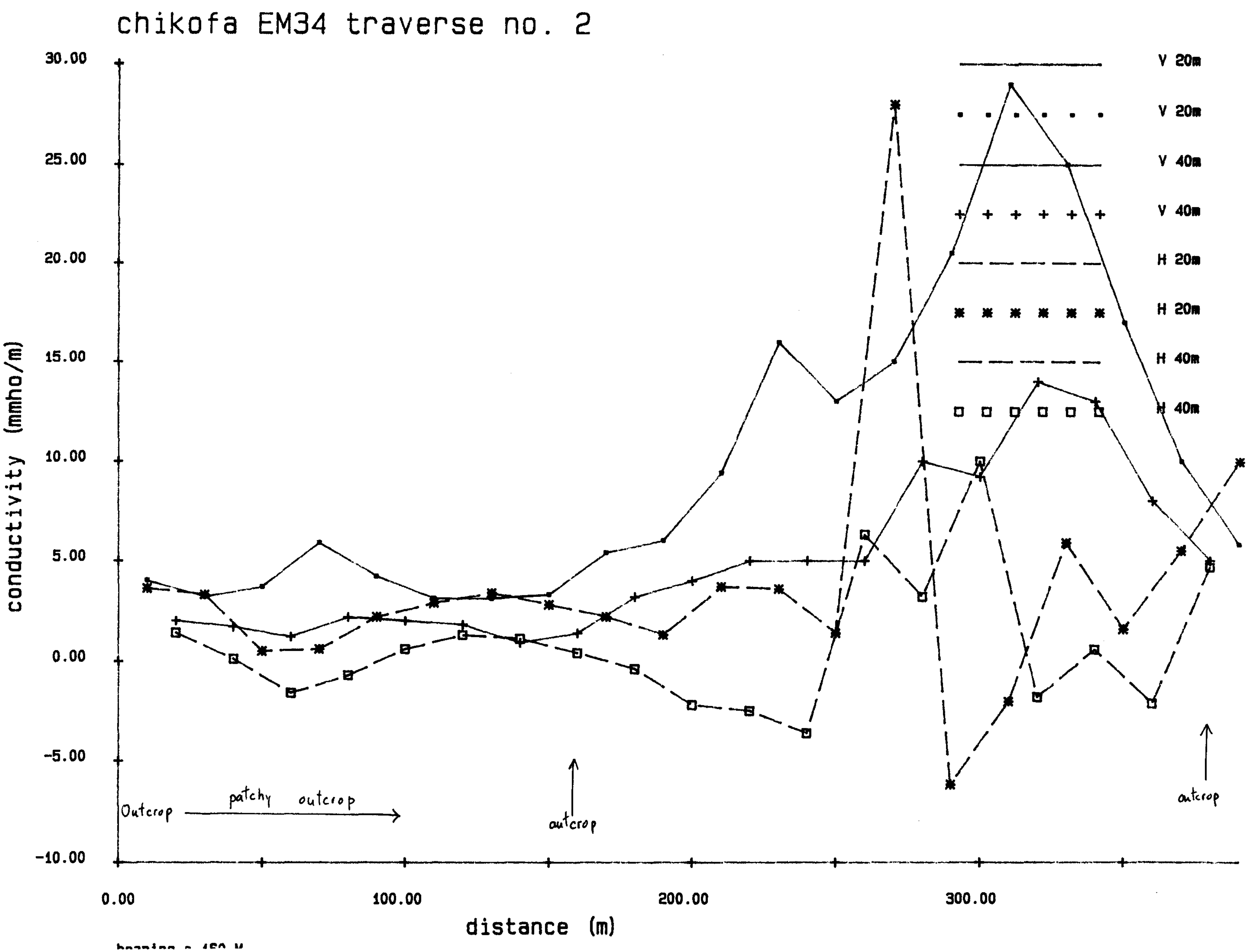
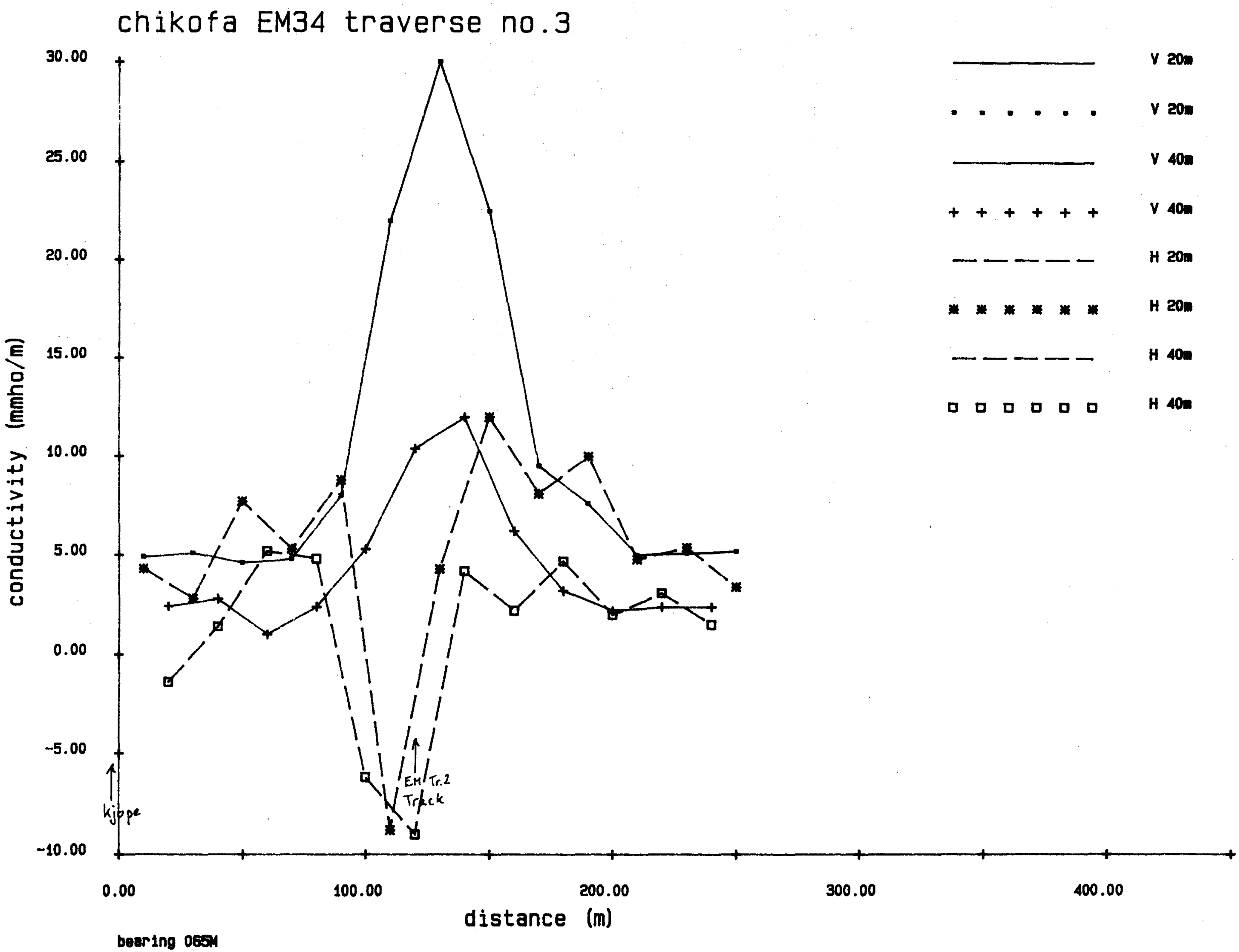
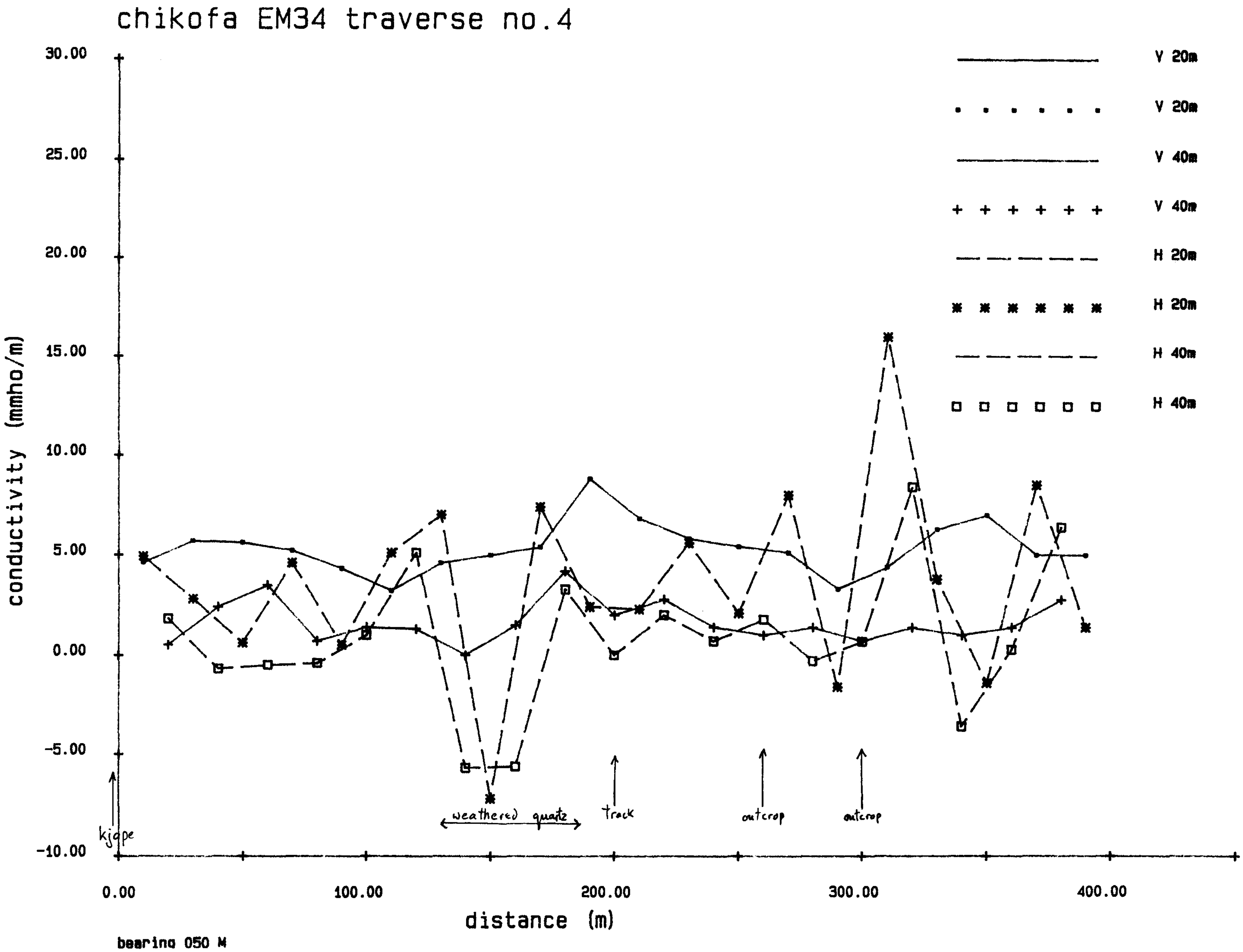
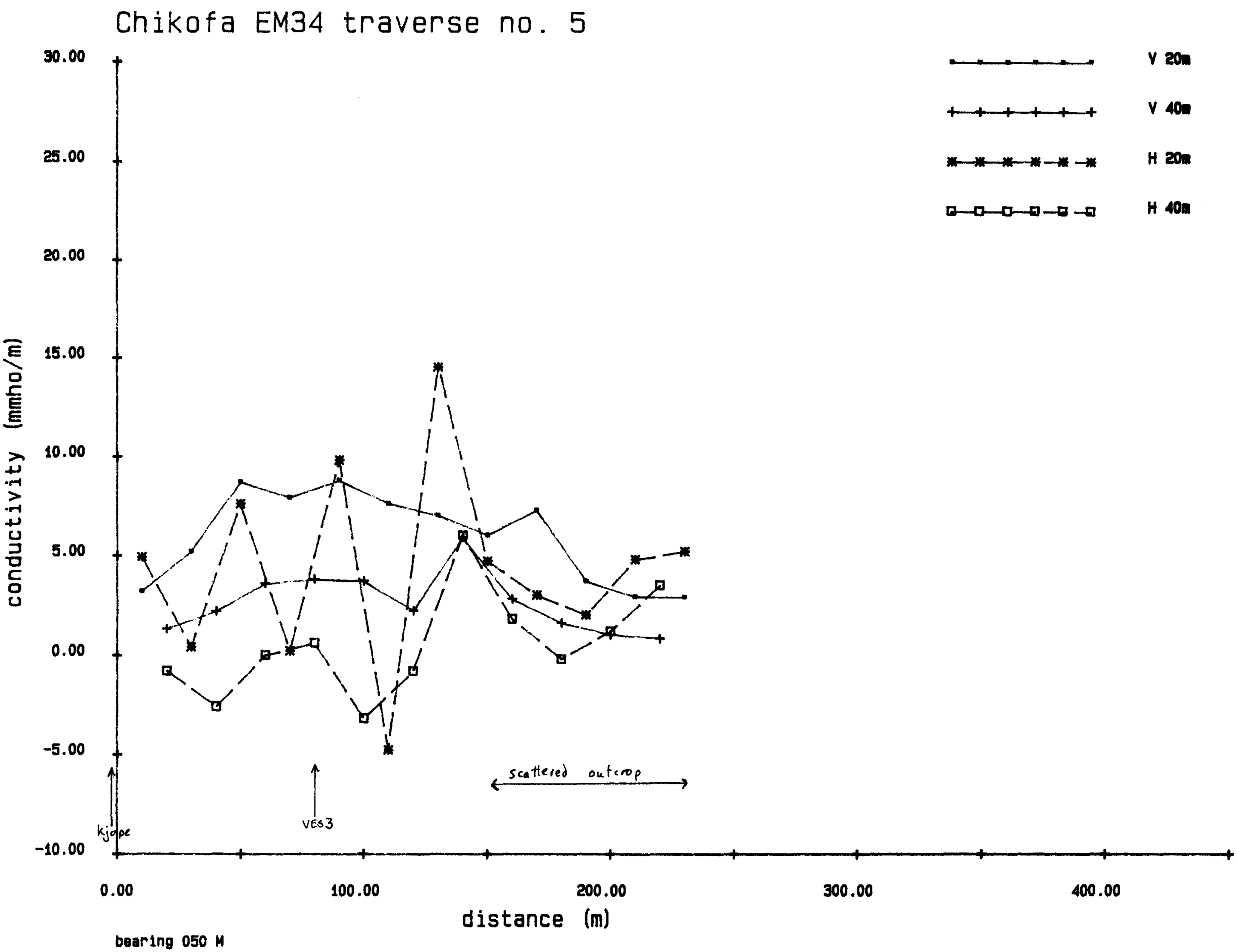


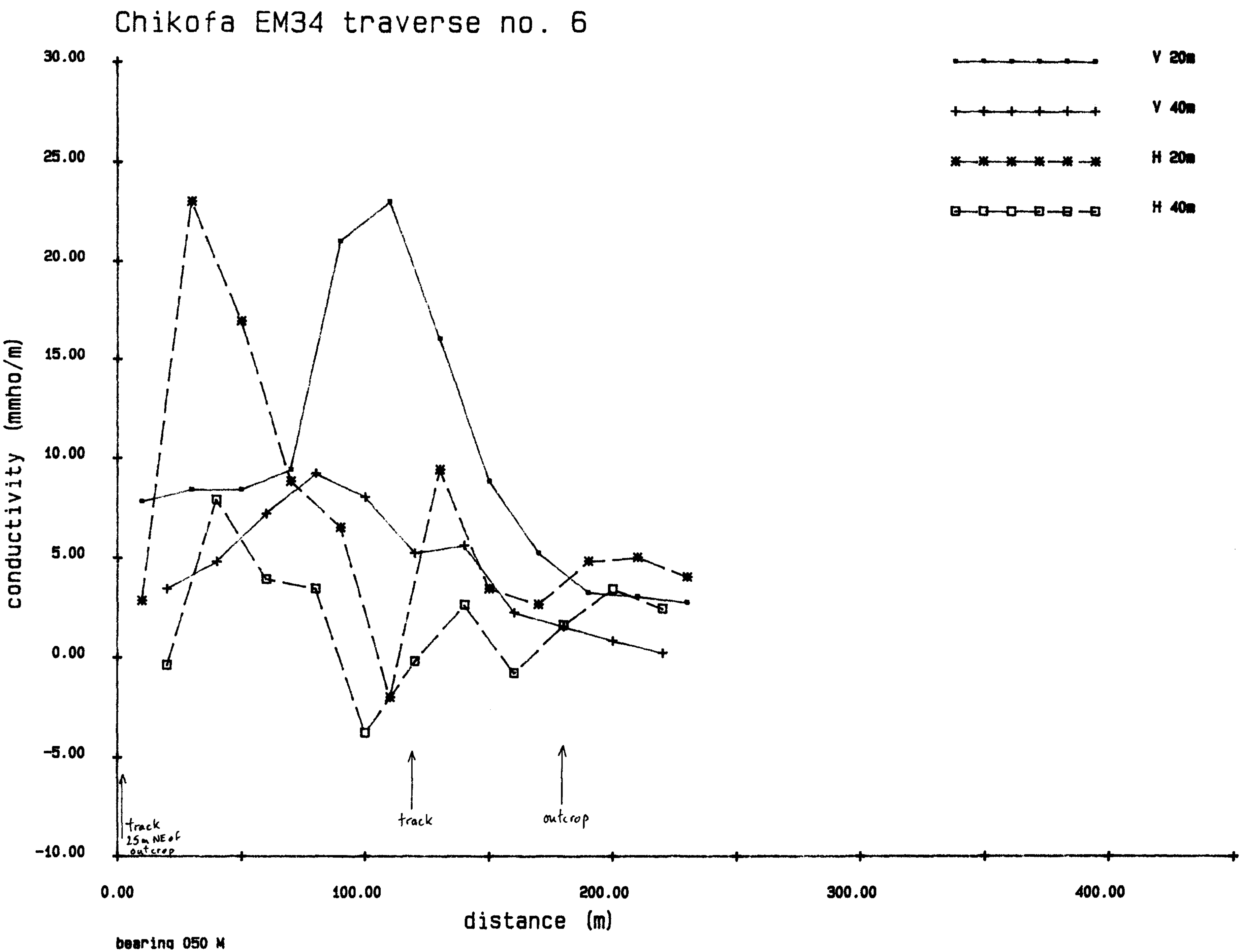
chikofa EM34 traverse no 1
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
edge of kjope
VES
Outcrop
Hand-dug well
450.00
350.00
250.00
150.00
50.00
distance (m)
bearing 223 M


chikofa EM34 traverse no. 2
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
0.00
100.00
200.00
300.00
distance (m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
Outcrop
patchy outcrop
outcrop
outcrop

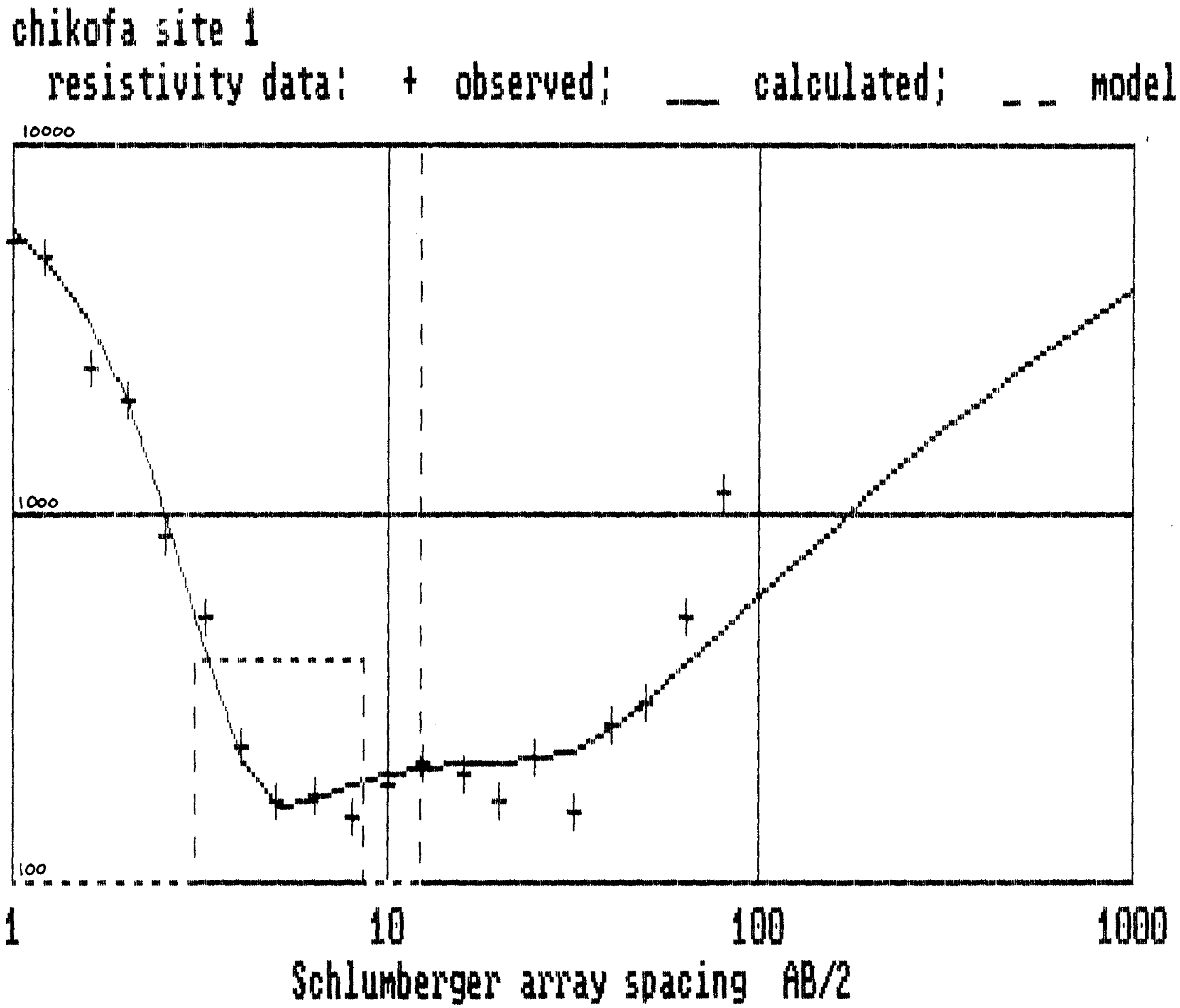

chikofa EM34 traverse no.3
conductivity (mmho/m)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
0.00
100.00
200.00
300.00
400.00
distance (m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
kjope
EM Tr.2
Track
bearing 065M


chikofa EM34 traverse no.4
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
weathered quartz
track
outcrop
outcrop
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 050 M


Chikofa EM34 traverse no. 5
V 20m
V 40m
H 20m
H 40m
conductivity (mmho/m)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
scattered outcrop
VES3
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 050 M



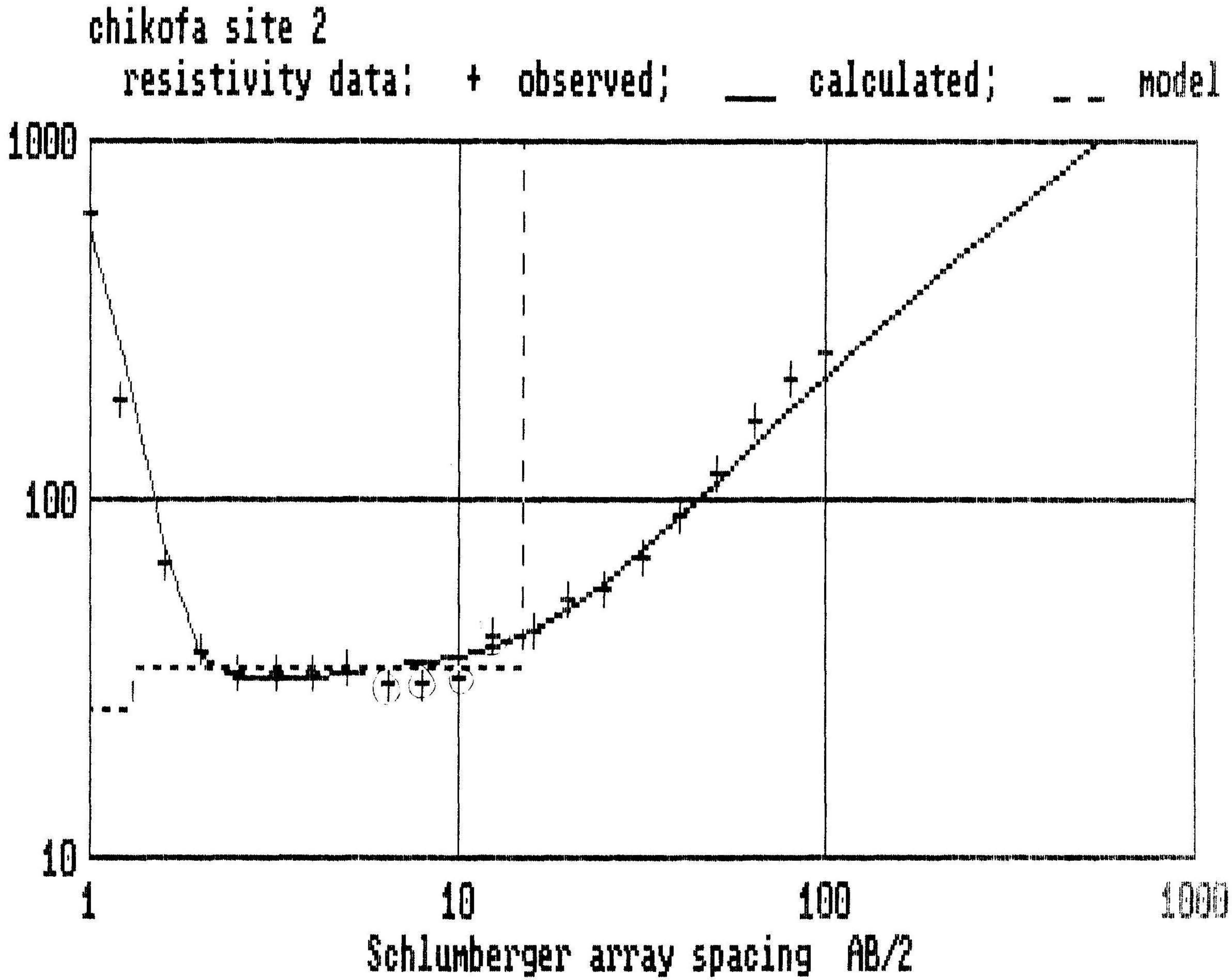
Chikofa EM34 traverse no. 6
V 20m
V 40m
H 20m
H 40m
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
0.00
100.00
200.00
300.00
400.00
distance (m)
track 25m NE of outcrop
track
outcrop
bearing 050 M



Model parameters for sites

chikofa site 1

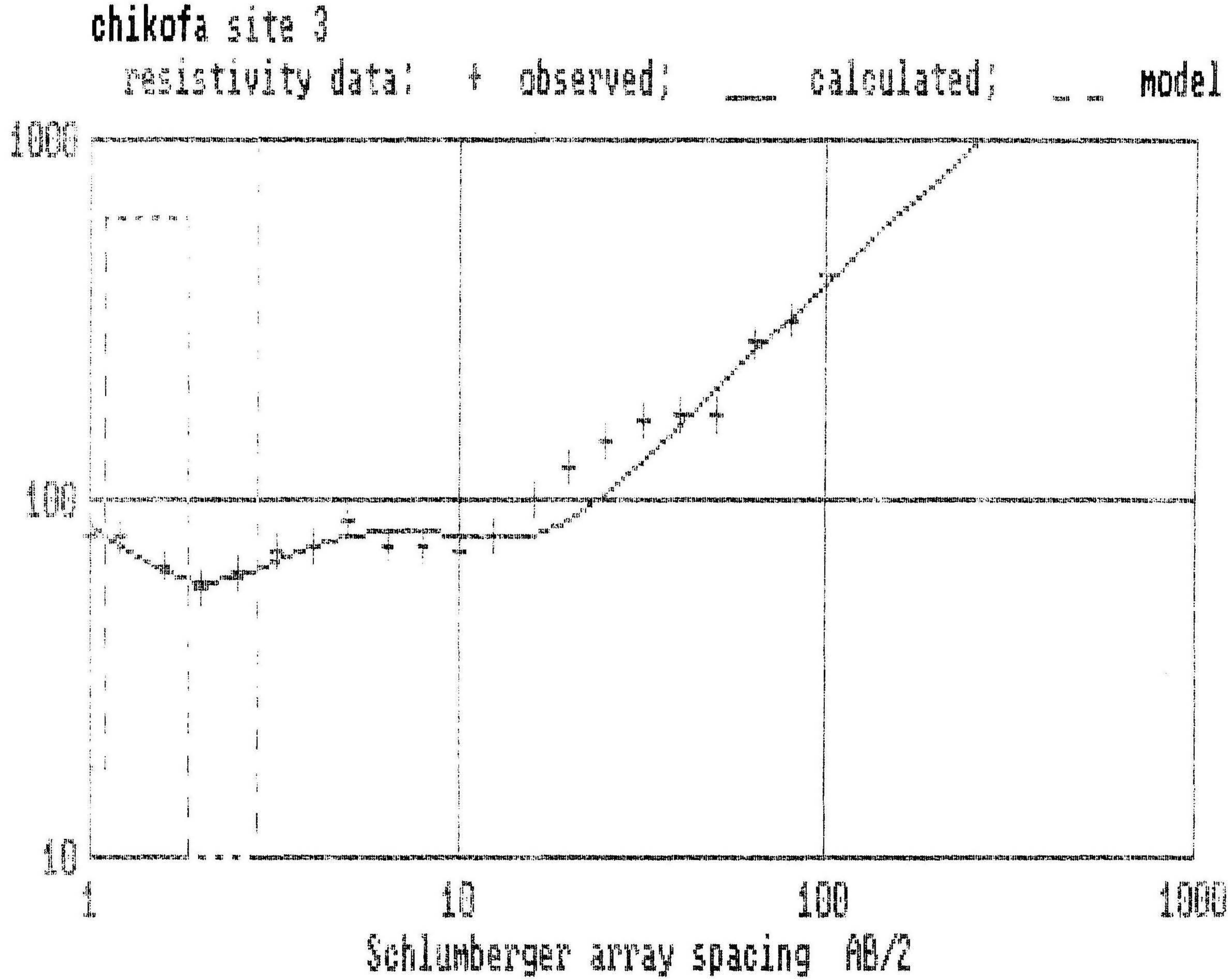
Layer	Thickns.	Restvty.	Depth
1	0.75	8250.00	0.75
2	2.25	90.00	3.00
3	5.65	400.00	8.65
4	3.65	30.00	12.30
Substrait		10000.00	*****



Model parameters for site:

chikofa site 2

Layer	Thickns.	Restvty.	Depth
1	0.28	6000.00	0.28
2	1.02	26.00	1.30
3	13.70	34.00	15.00
Substrait		5000.00	*****



Model parameters for site:
chikofa site 3

Layer	Thickns.	Restvty.	Depth
1	0.55	130.00	0.55
2	0.55	10.00	1.10
3	0.75	600.00	1.85
4	1.00	4.70	2.85
Substrait		20000.00	*****

2.2 Chikore School

Area C

Map 2030 D1, grid reference 254 7729

2.2.1. Introduction

The borehole (JP5458) serving the school had been shown to be dry. Another site close to the line of ironstone hills had been pegged but not drilled. A lineament had been proposed (Greenbaum personal communication), cutting the hills and running SSE beneath the stream, the reservoir and dam.

2.2.2. Geophysical study

Three parallel ground conductivity traverses were measured across the lineament above the reservoir and one below it. On each traverse a similar signature was seen, showing the anomaly deriving from a vertical sided conductivity contrast i.e. a 'dyke-like' body, probably representing a fracture zone.

VES no. 1 was measured on some reasonably flat ground with relatively little outcrop to the west of the upper reaches of the stream, in order to investigate the general regolith thickness. It showed very high values of apparent resistivity, and indicated moderate lateral variations. An unique interpretation is not feasible, but it is likely that a maximum of 2m of regolith is present in this area. A second VES was measured on the flat land adjacent to the reservoir. A reasonable solution is obtained from a depth of 8m to the base of the regolith, with a resistivity for the regolith of 34 ohm m. On the other hand a 25m layer of fractured bedrock with a resistivity of 200 ohm m can also be inserted, with similar results.

VES no. 3 at the borehole showed up to 17m of material with a resistivity of 300ohm m, which may represent saprock, or highly-fractured bedrock.

VES no. 4, below the dam site, indicated little lateral variation although the array crossed minor outcrops. The interpretation showed up to 7m of overburden, although as little as 3m of low resistivity regolith satisfied the observed curves.

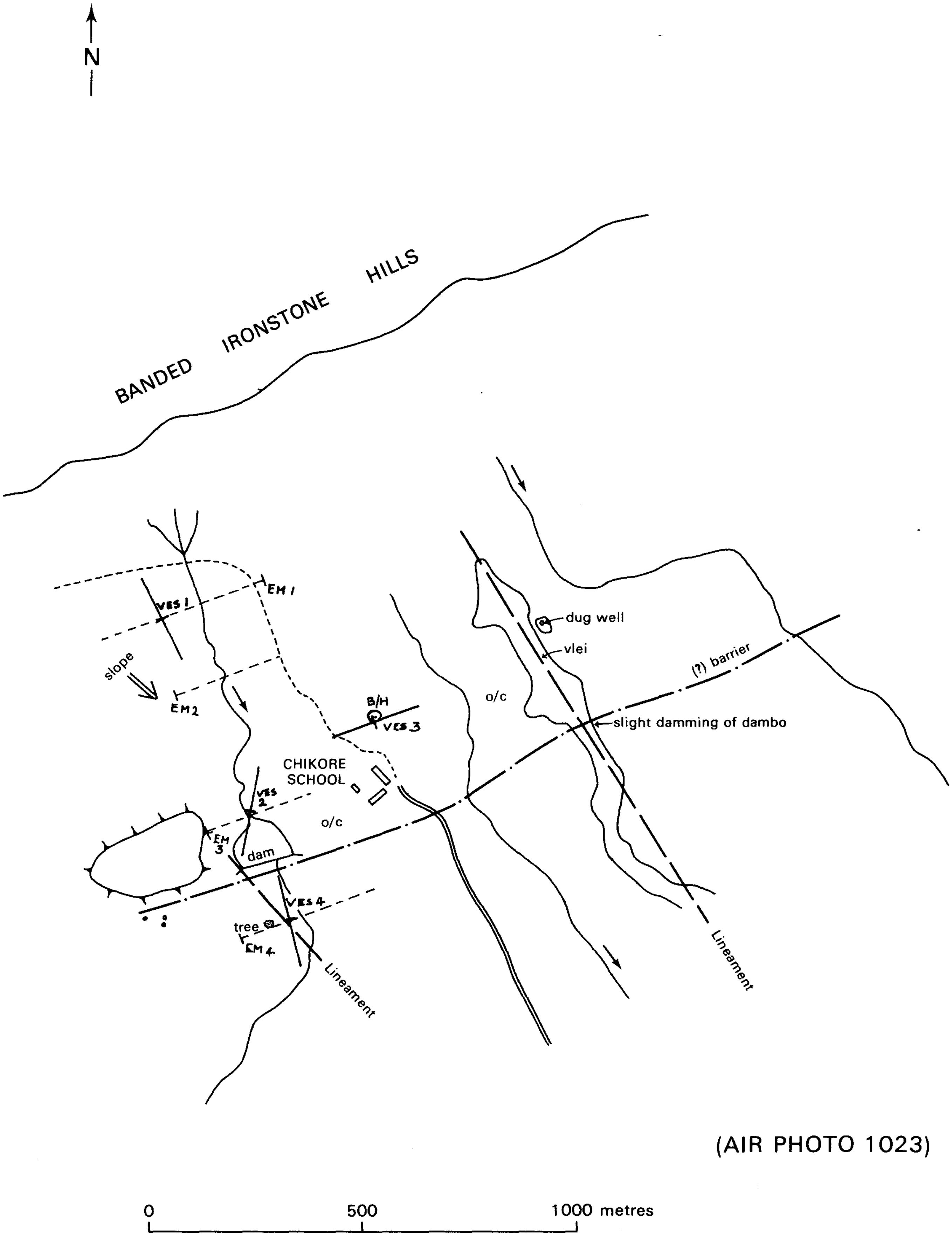
2.2.3. Discussion

In general this area of scattered outcrop shows only thin development of regolith, although there is reasonable evidence for a thicker section immediately behind the reservoir. There is strong correlation between the stream bed, the photo-lineament and the electromagnetic anomaly, indicating a fracture system running through the ironstone hills and parallelling another to the west at Makwaturi, investigated in 1986.

2.2.4. Conclusion

A peg was inserted on the line of a proposed fracture system as indicated by the ground conductivity traverse, close to the reservoir edge. At least 8m of regolith is estimated at that point. A borehole at that point should intersect the fracture and encounter water recharging from the reservoir and from the surrounding regolith via the fracture. edge of the reservoir, w

CHIKORE SCHOOL: AREA C: MAP 2030 D1



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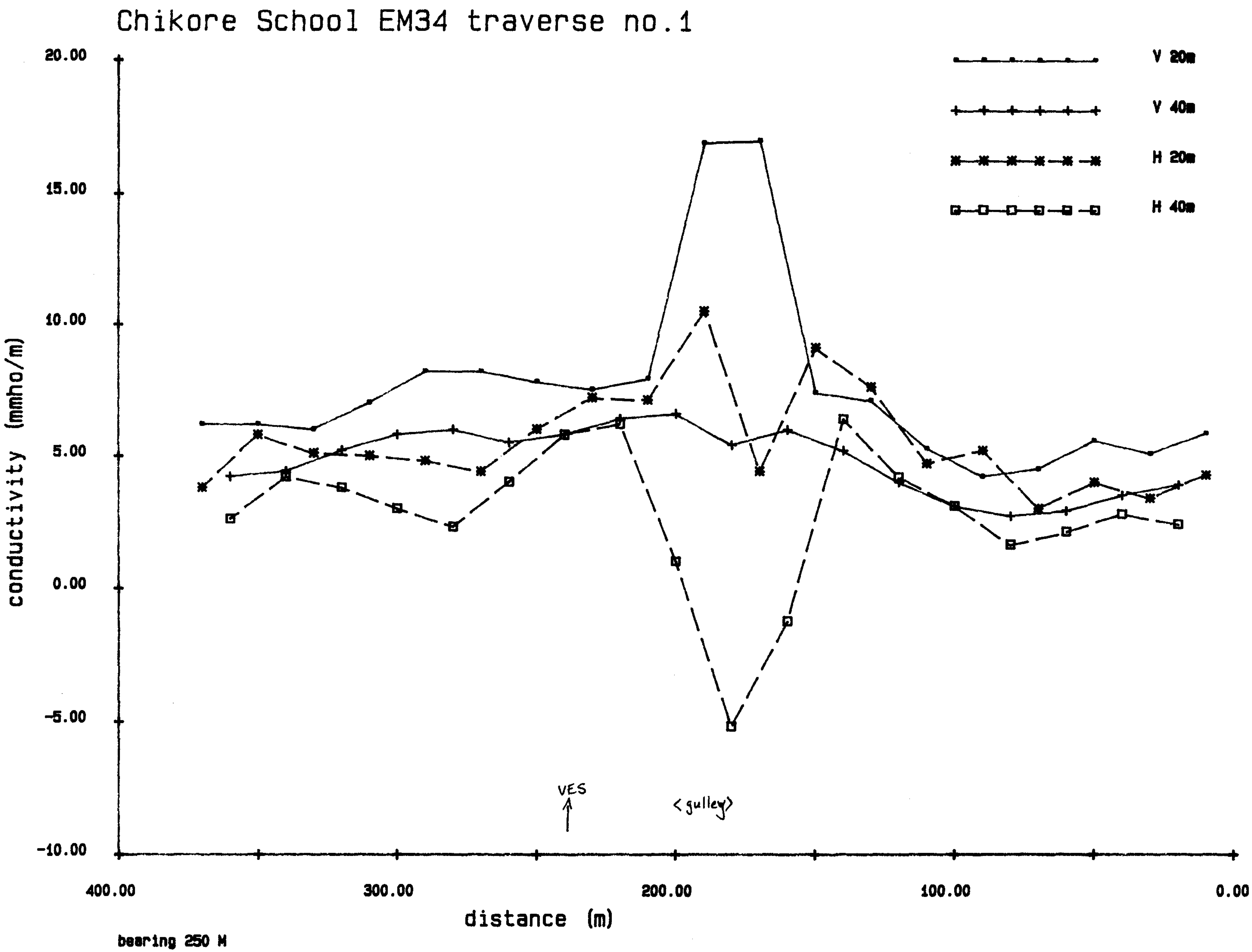
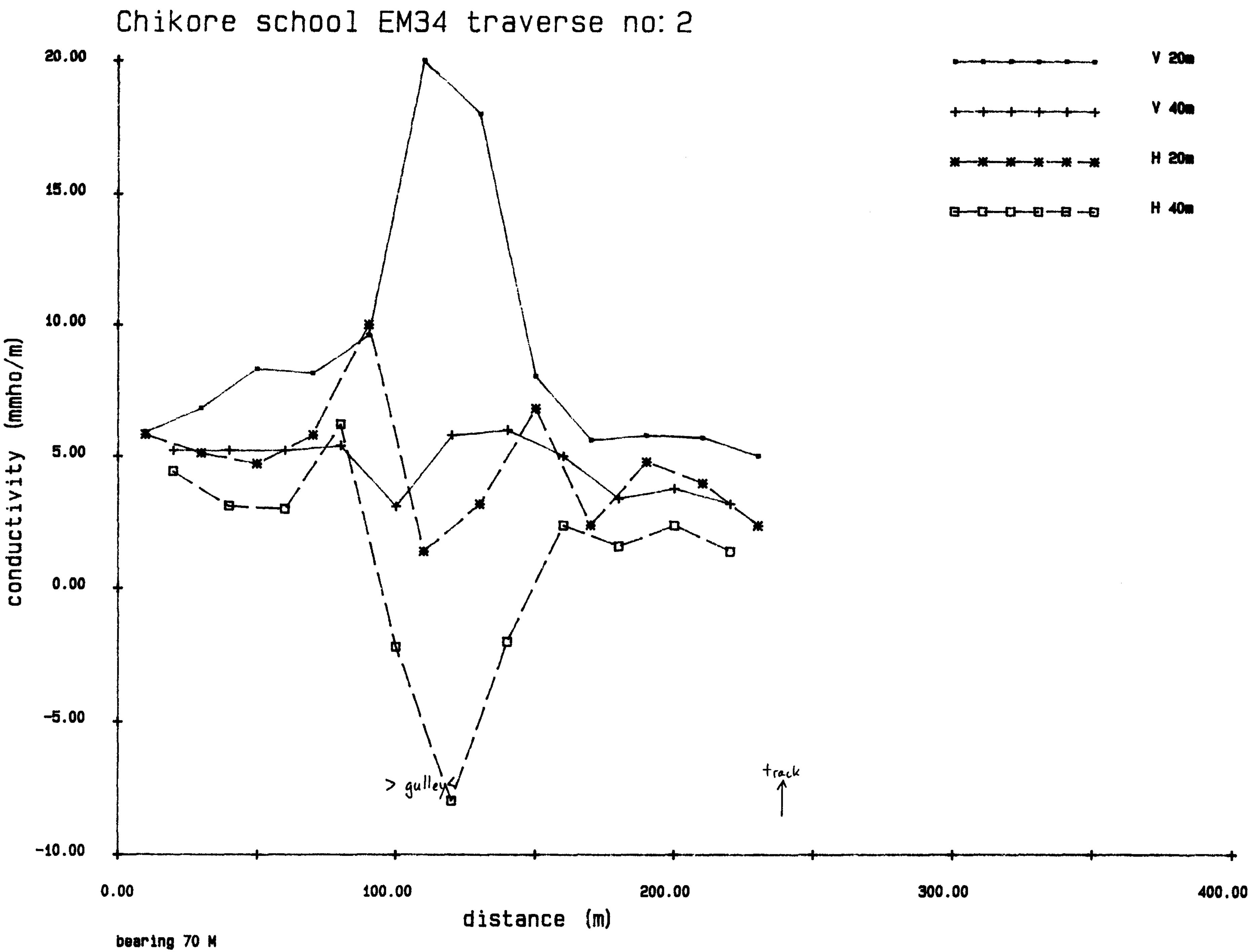
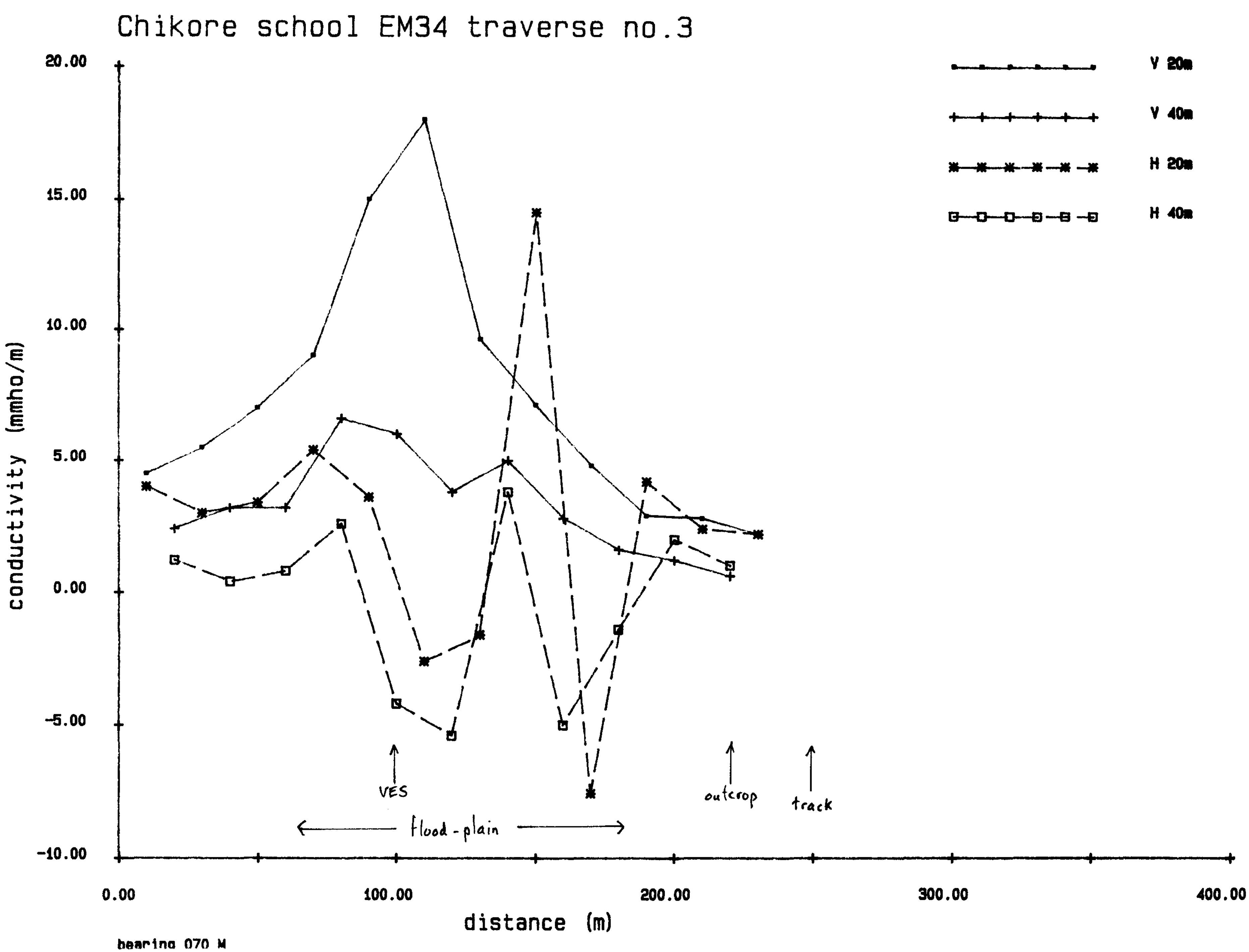
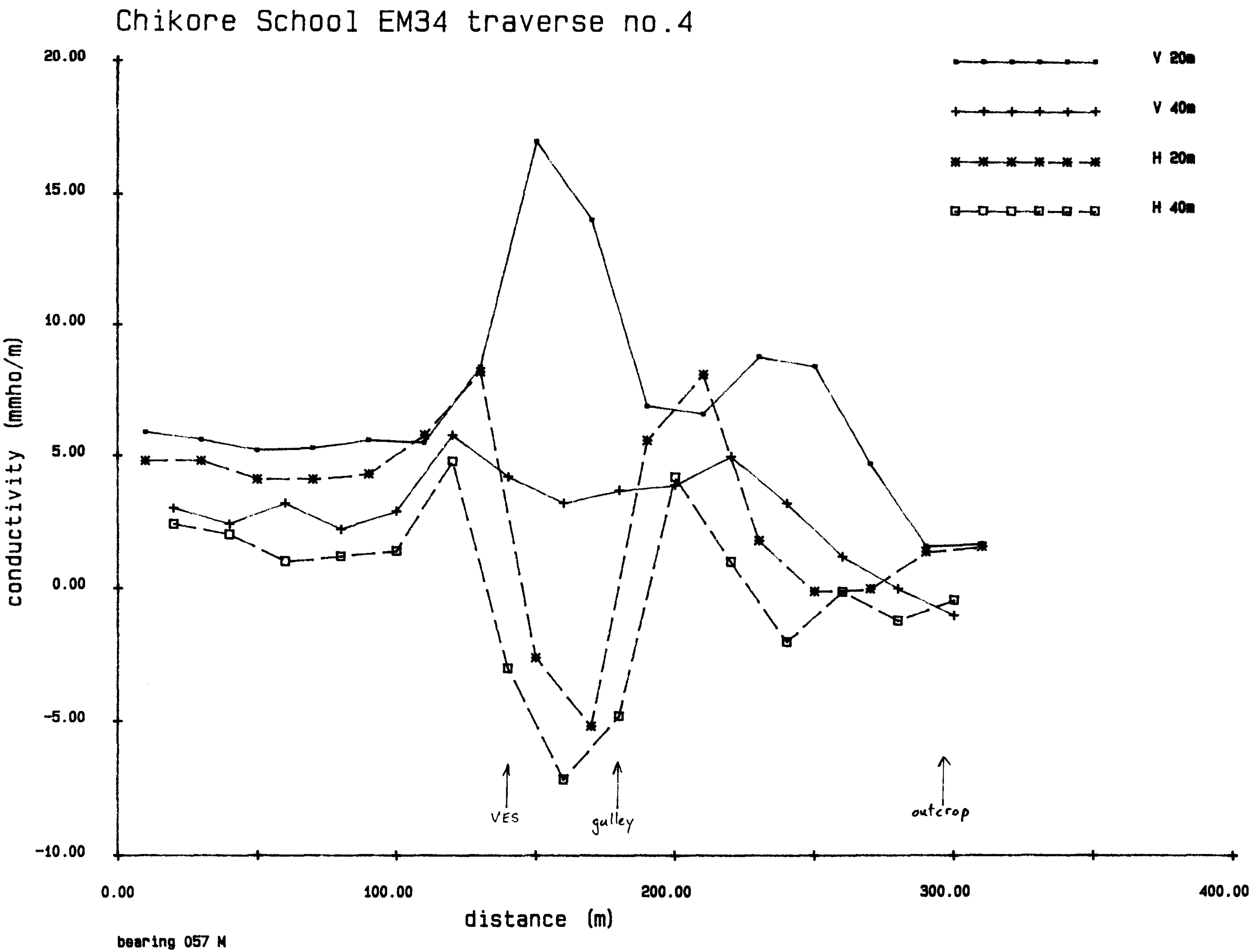
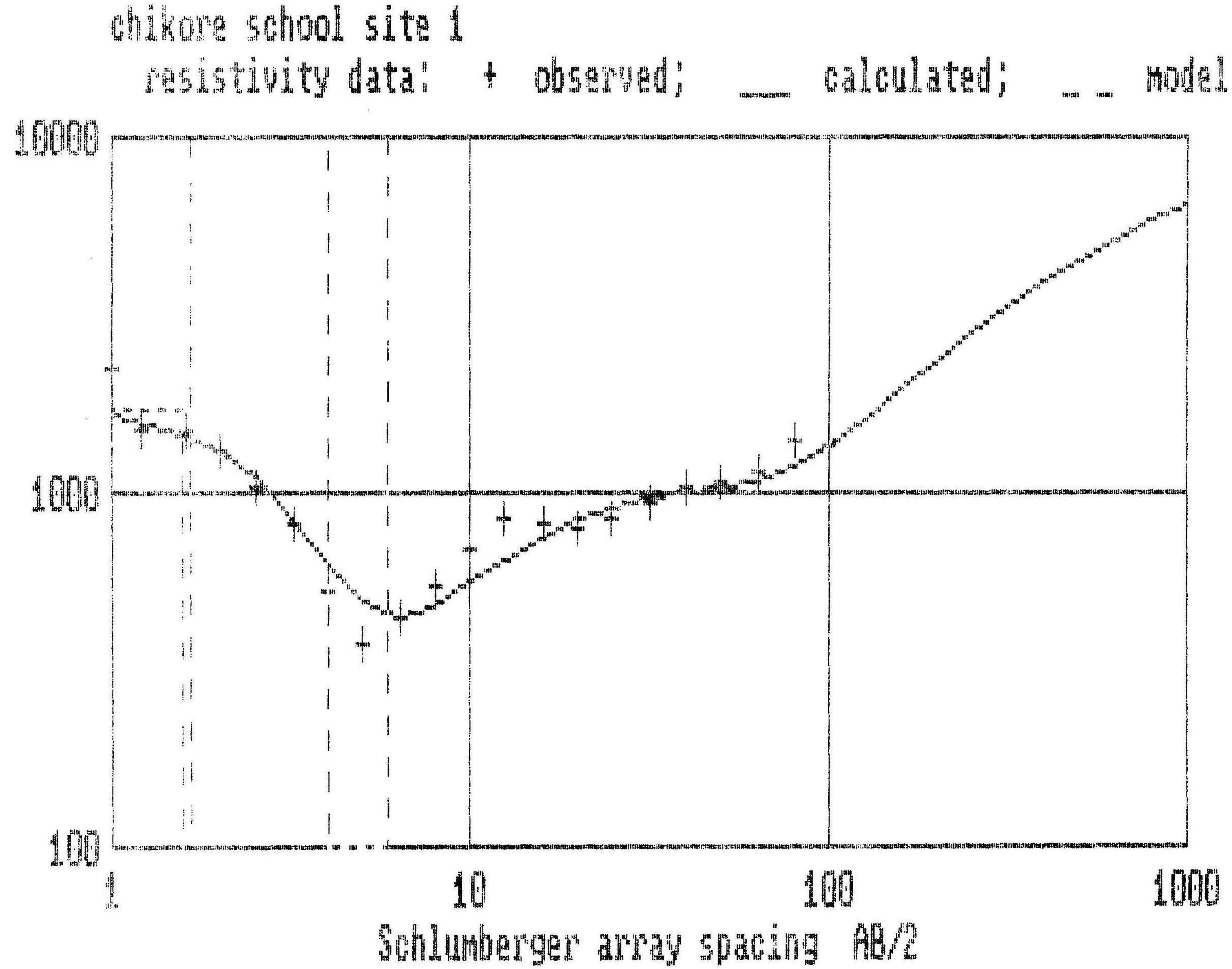


Chikore School EM34 traverse no.1
V 20m
V 40m
H 20m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
VES
<gulley>
400.00
300.00
200.00
100.00
0.00
distance (m)
bearing 250 M


Chikore school EM34 traverse no: 2
V 20m
V 40m
H 20m
H 40m
conductivity (mmho/m)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
0.00
100.00
200.00
300.00
400.00
distance (m)
> gulley <
track
bearing 70 M


Chikore school EM34 traverse no.3
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 40m
H 20m
H 40m
VES
outcrop
track
flood-plain
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 070 M


Chikore School EM34 traverse no.4
V 20m
V 40m
H 20m
H 40m
conductivity (mmho/m)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
0.00
100.00
200.00
300.00
400.00
distance (m)
VES
gulley
outcrop
bearing 057 M

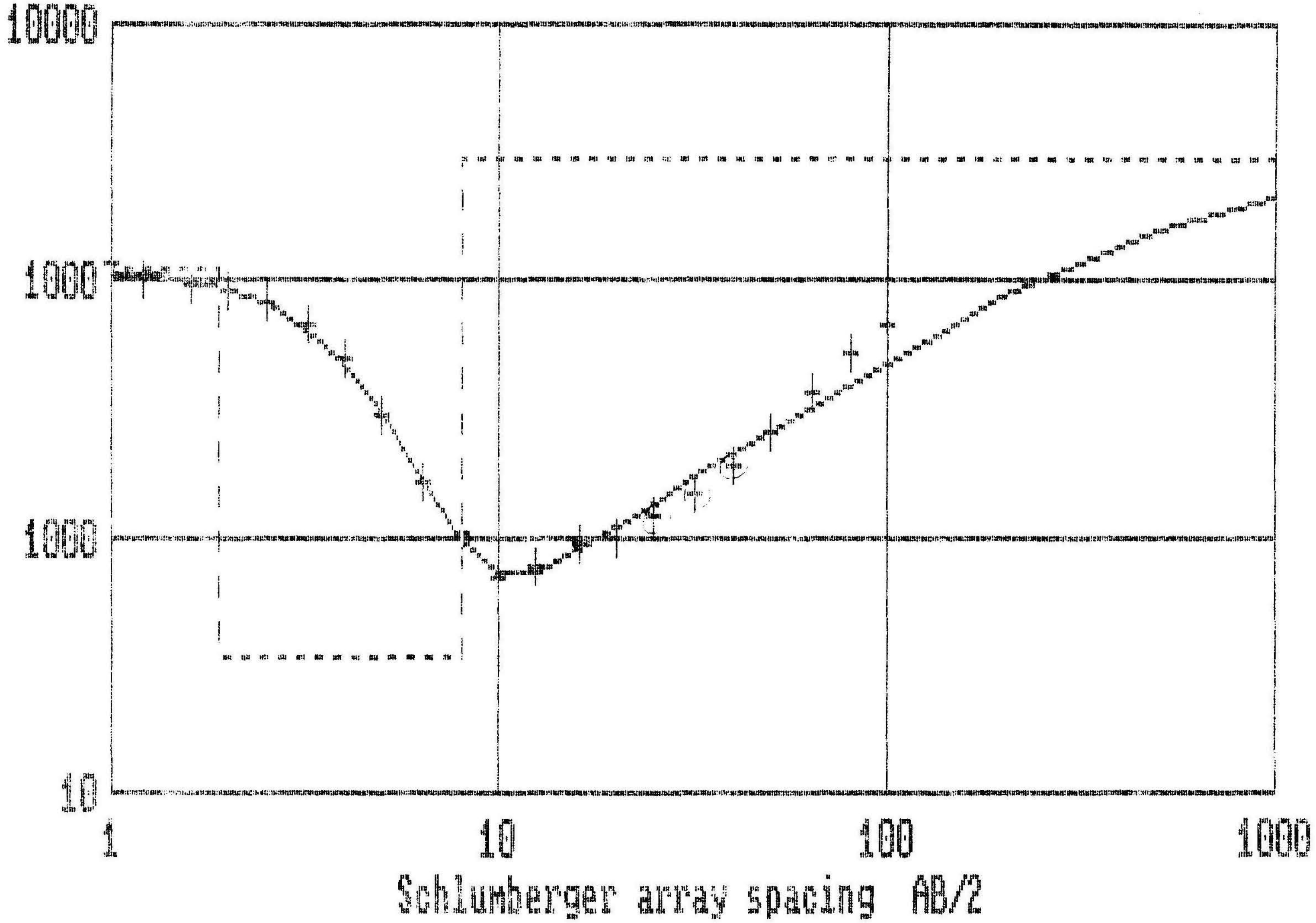


Model parameters for site:
chikore school site 1

Layer	Thickns.	Restvty.	Depth
1	1.55	1700.00	1.55
2	0.10	7.00	1.65
3	2.35	10000.00	4.00
4	1.85	35.00	5.85
Substrait		10000.00	*****

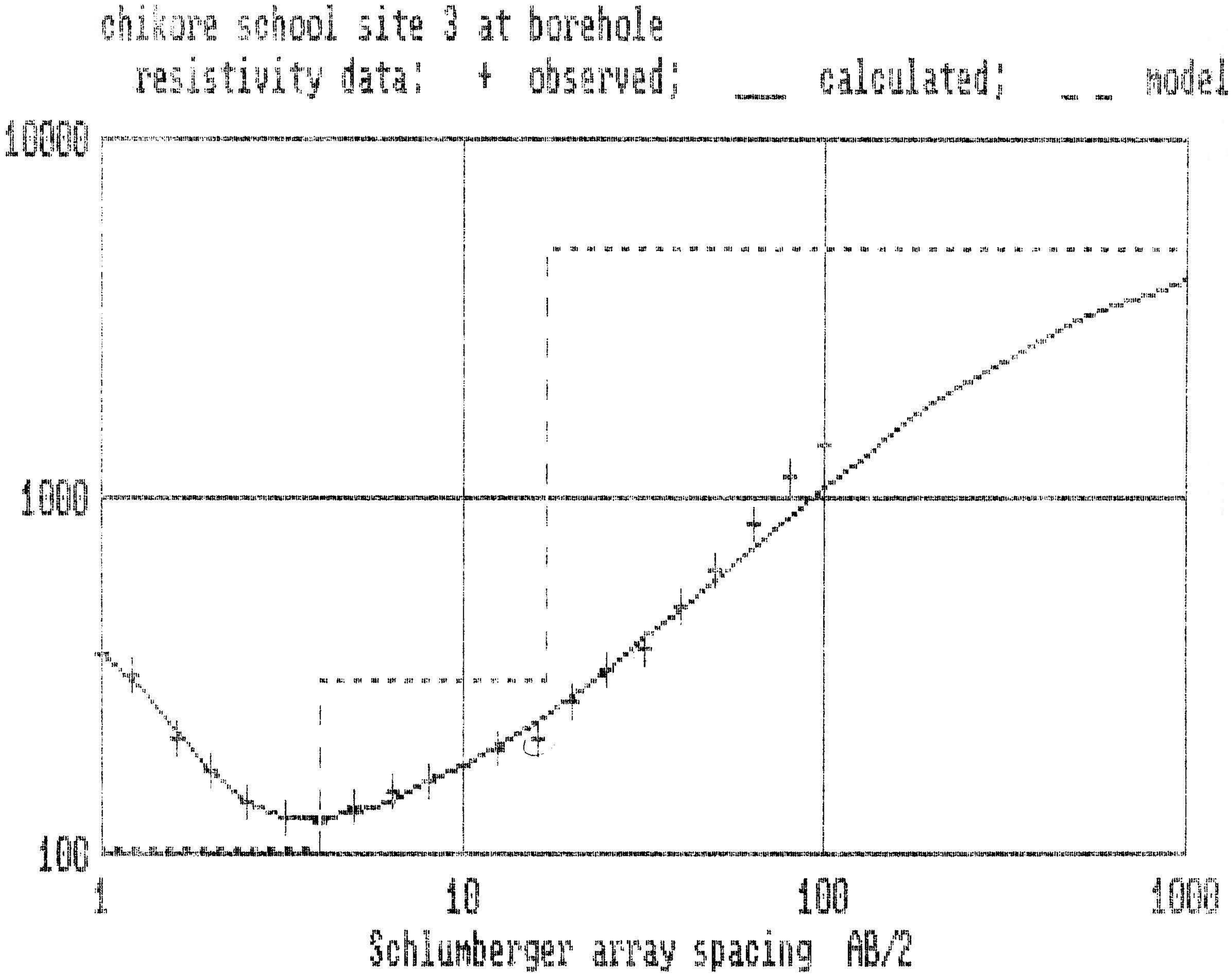
chikore school site 2 above dam

resistivity data: + observed; __ calculated; _ _ model



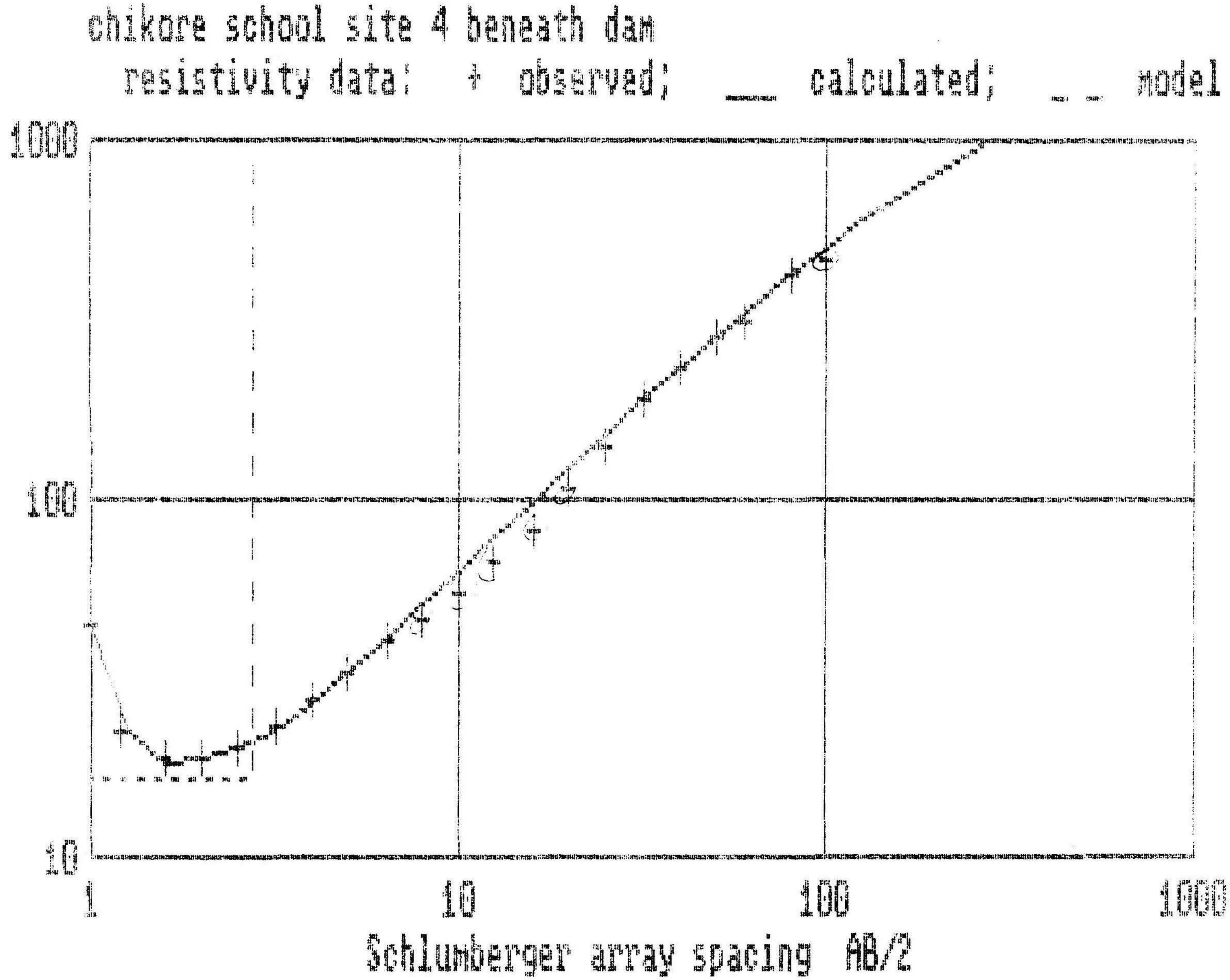
Model parameters for site:
chikore school site 2

Layer	Thickns.	Restvty.	Depth
1	1.90	1100.00	1.90
2	6.10	34.00	8.00
Substrait		3000.00	*****



Model parameters for site:
chikore school site 3

Layer	Thickns.	Restvty.	Depth
1	0.55	575.00	0.55
2	3.45	105.00	4.00
3	13.00	300.00	17.00
Substrait		5000.00	*****



Model parameters for site:
chikore school site 4

Layer	Thickns.	Restvty.	Depth
1	0.19	3000.00	0.19
2	2.37	16.30	2.76
Substrait		2000.00	*****

2.3. **Rungai**

Area C

Map 2030 D1, grid reference 254 7721

2.3.1. Introduction

Seismic refraction surveys in 1986 in the area of the school at Rungai found little evidence of thick regolith development. Currently water supply is from a private borehole at the business centre and a Lutheran World Federation hand-dug well nearby (although in July 1987 the pump was defective). In 1985 the EEC sunk 2 dry boreholes (EEC81A and 81B). Greenbaum and Wright (personal communication) identified 2 lineament which intersected in a vlei some 300m to the SW of the business centre, which provided drainage from a large catchment.

2.3.2. Geophysical studies

In the area of interest, 3 ground conductivity profiles were measured across the vlei so as to cover both proposed lineaments. On none of the profiles is there any clear systematic feature associated with the vlei, although there is a vertical-sided conductive anomaly type running NE-SW at about 100m to the south of the vlei.

Two VES were measured close by, one in the bottom of the rather narrow vlei (which might predictably lead to lateral effects), and the second on the side of the channel, about 90m to the SW of the first. In the first case, at least 11m of very conductive (<18 ohm m) regolith overlies bedrock. In the second site, the resistivity is even lower, being around 5 ohm m, and is between 8 and 11m in depth. In both cases the resistivity of the bedrock is not high (between 1000 and 2500 ohm m).

A 115m long seismic refraction profile was also run along the line of EM traverse no.3. Shots were made at 0, 17.5, 37.5, 57.5, and 77.5m. The results were rather inconclusive, because the results from crucial shots at 87.5 and 115m were lost due to battery failure, which prevented good 'plus-minus' interpretation to be pursued. However, good refracted arrivals were recorded and intercept methods provided some useful data. The upper layer velocity varied between 0.5km/s to 0.95km/s, the highest velocities being in the middle of the vlei. The velocity of the lower layer is about 3km/s, although this cannot be accurately determined. The evidence suggests that from 10 to 35m and 80 to 100m the interface dips from around 10m depth to around 15m towards the centre of the vlei: there is no data for the central part of the vlei.

The multi-electrode resistivity traversing (MRT) array was laid along the same line and the results are presented in Griffiths (1987). The results show general agreement with the seismic data.

In addition to the work on the vlei, the MRT array and EM34 traverses were measured along the 2 seismic profiles measured in 1986. A fracture-type anomaly was noted on EM traverse no.4, beneath the floor of the valley, associated with increased thickness of conductive regolith. On EM no.5 considerable variation is seen, with thickening high conductivity regolith being apparent in the area of the business centre and Lutheran well, in other words away from the influence of the bornharts.

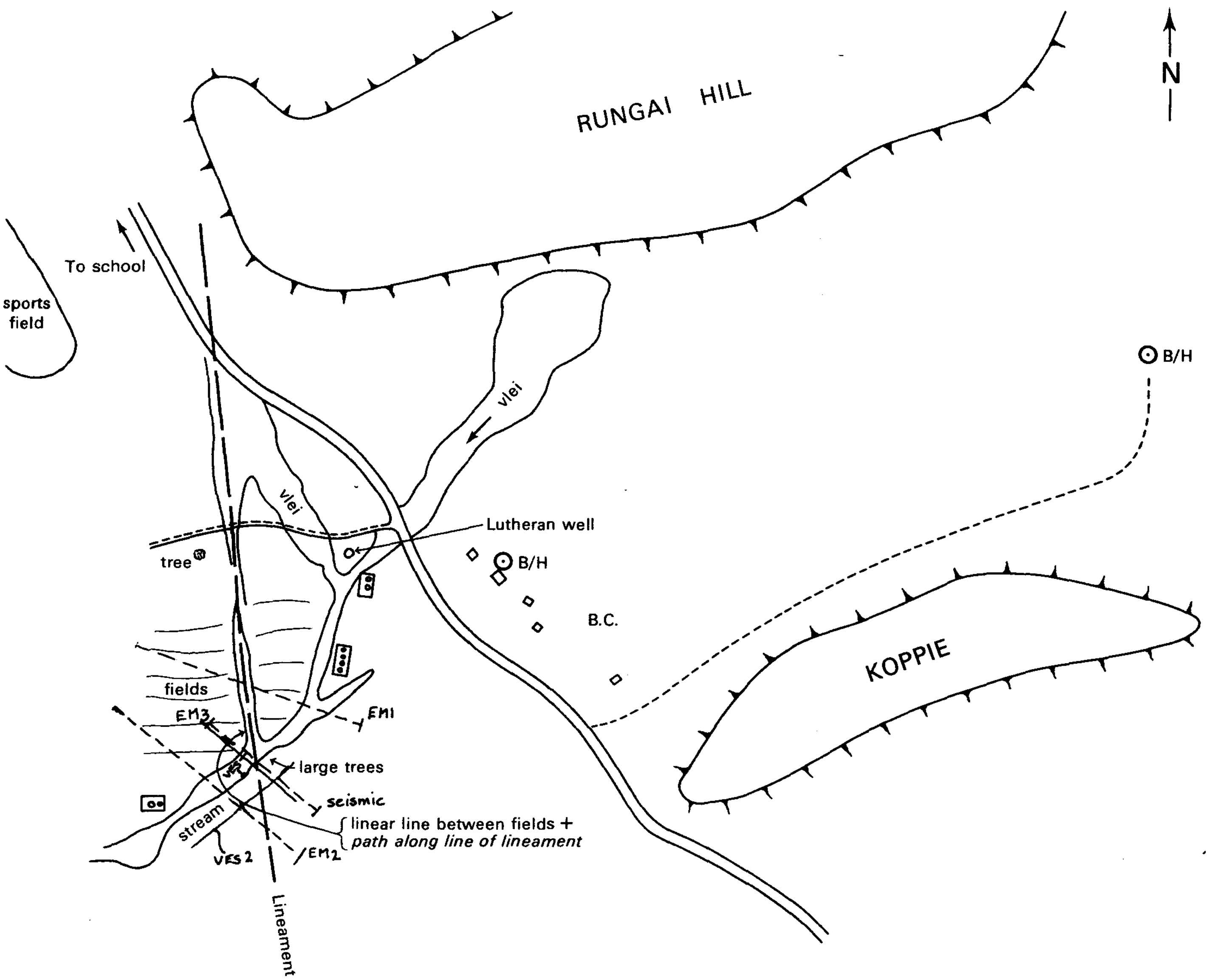
2.3.3. Discussion

In the target area, the vlei does not appear to have a direct relationship with the EM anomaly, which appears to indicate (with some uncertainty) a fracture running parallel to the vlei. The VES indicated over 10m of regolith in the vlei, although it is probably very clay-rich. The depth results is confirmed by the seismic refraction data. The bedrock has a relatively low seismic velocity and resistivity, and may prove to be rather fractured.

2.3.4. Conclusion

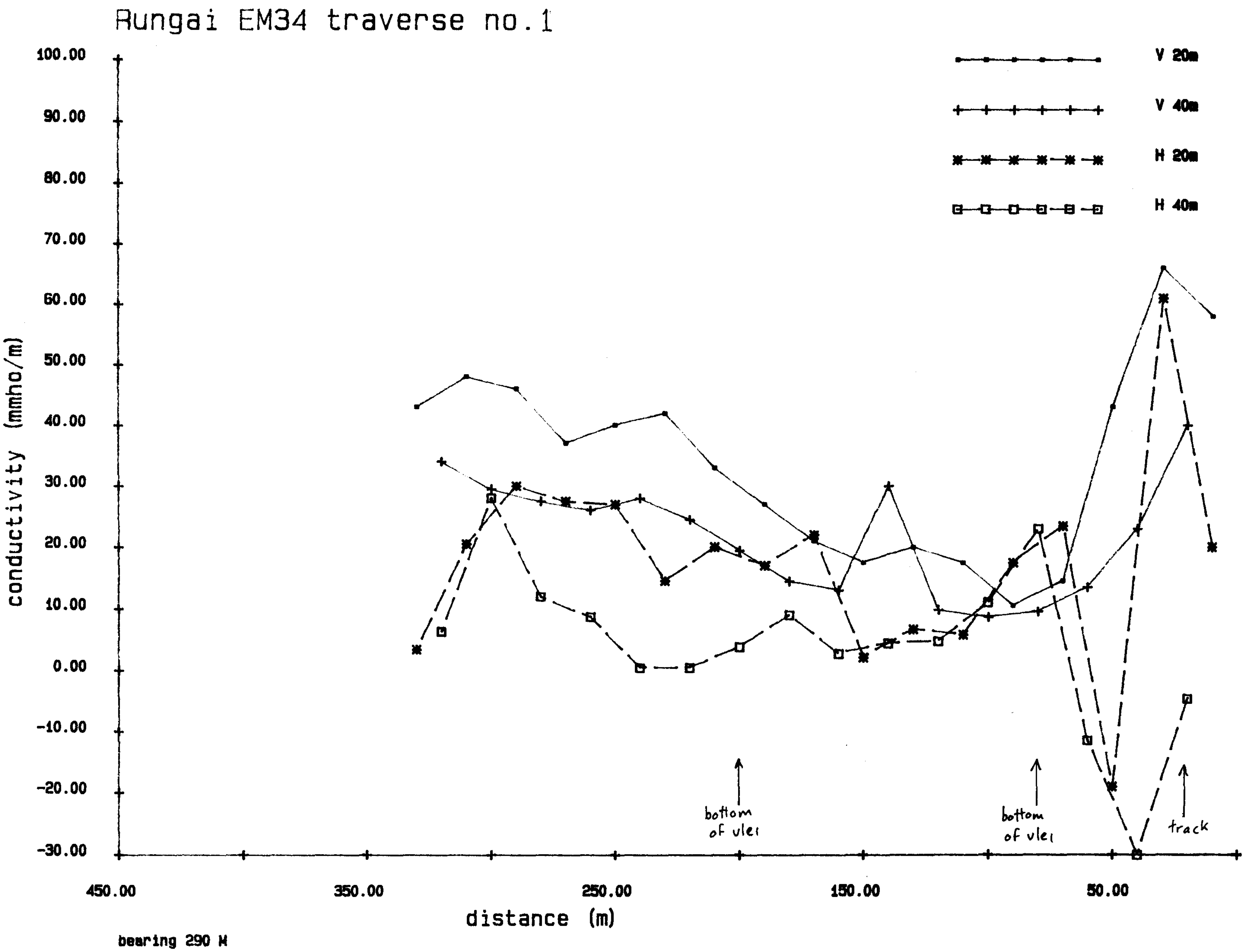
An intersection between two vleis does not appear to co-incide with a fracture system, which may run NE-SW a few tens of metres to the south of the vlei. The regolith, which is clay-rich, thickens from less than 10m on the flanks of the vlei, to up to 15m in the centre. Pegs were inserted on the line of the EM anomaly and on the site of the VES in the vlei bottom, with the recommendation that both sites could be drilled to provide useful data on the fracture and the vlei and their hydrogeology.

RUNGAI B.C.: AREA C: MAP 2030 D1

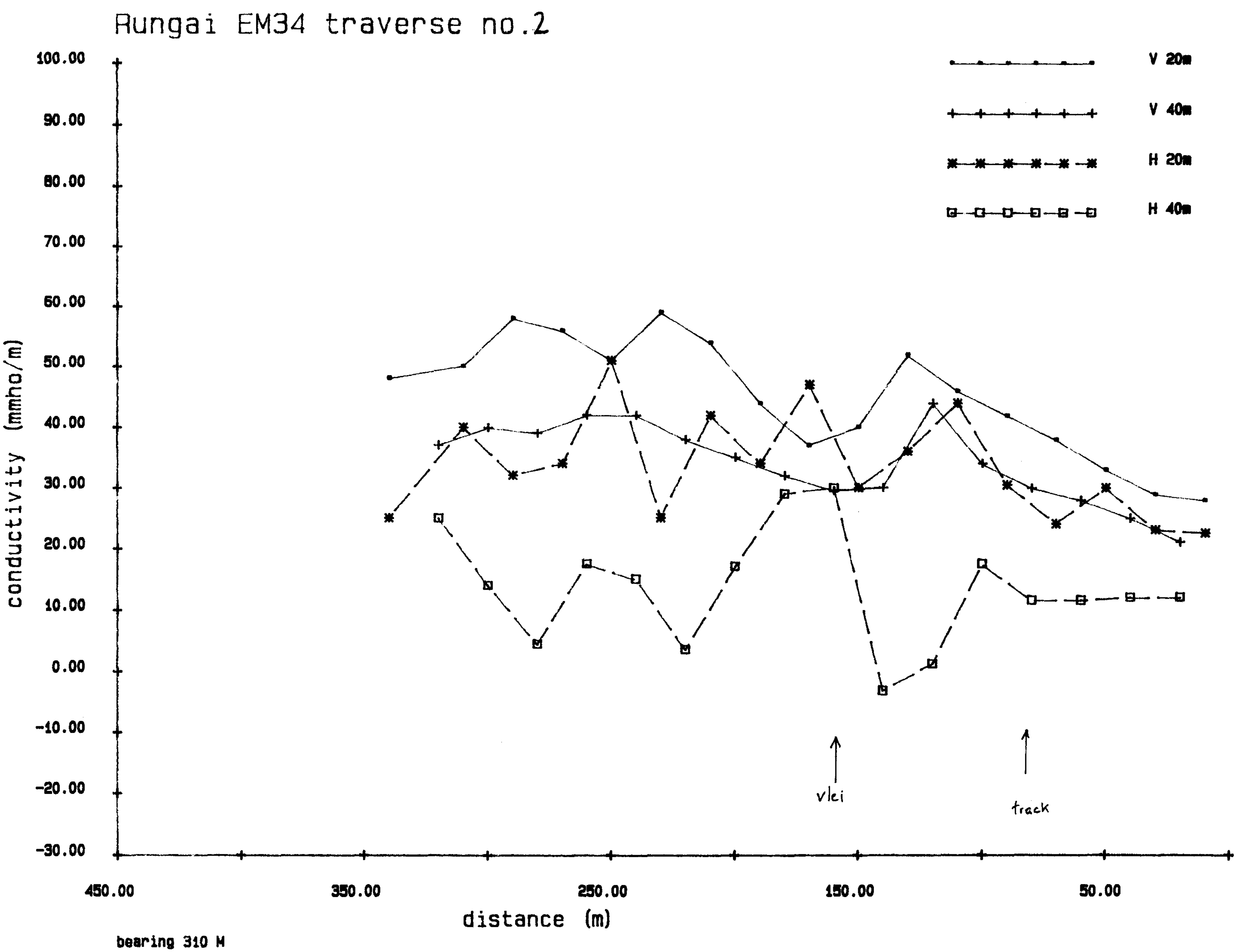


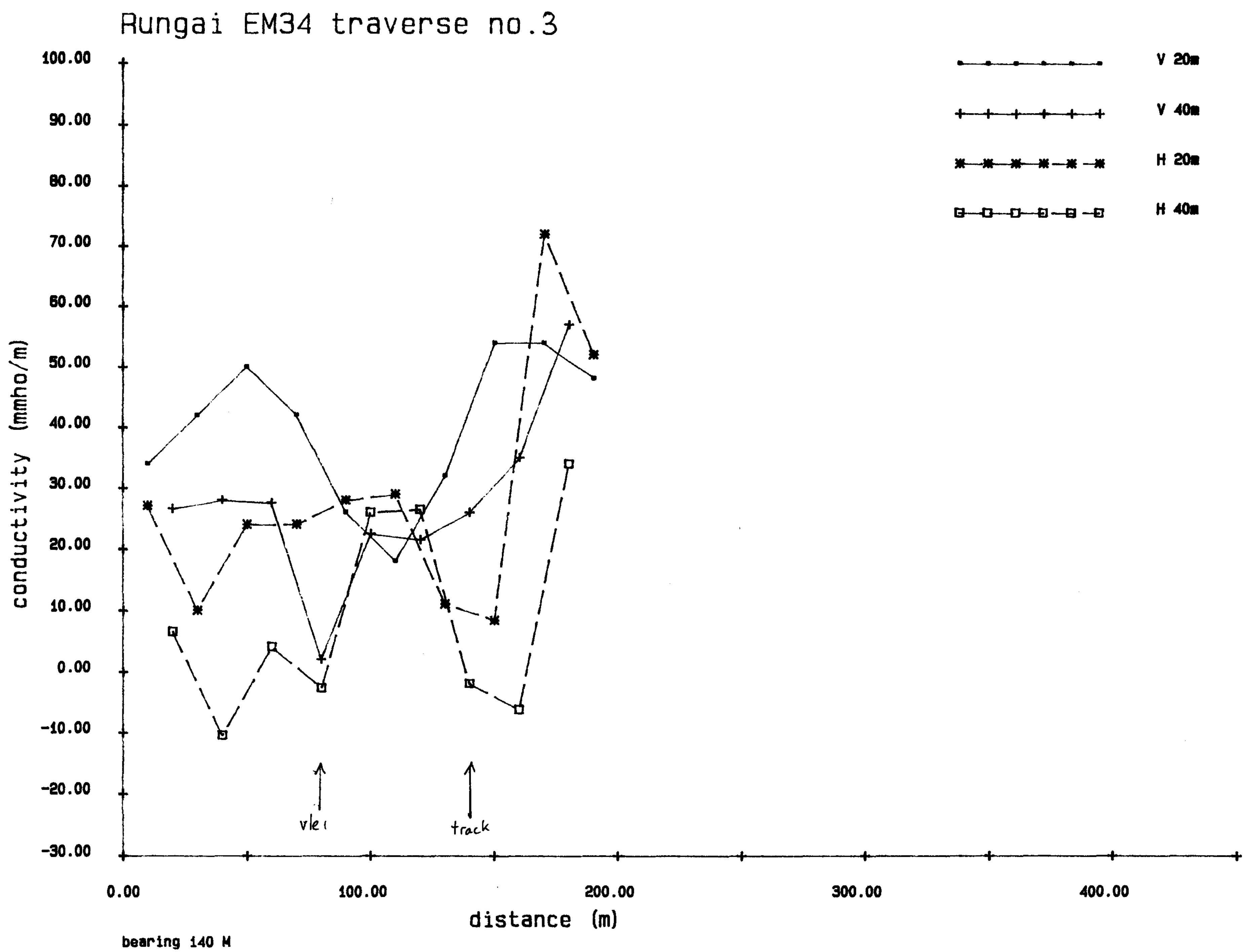
(AIR PHOTO 1177)

0 500 1000 metres



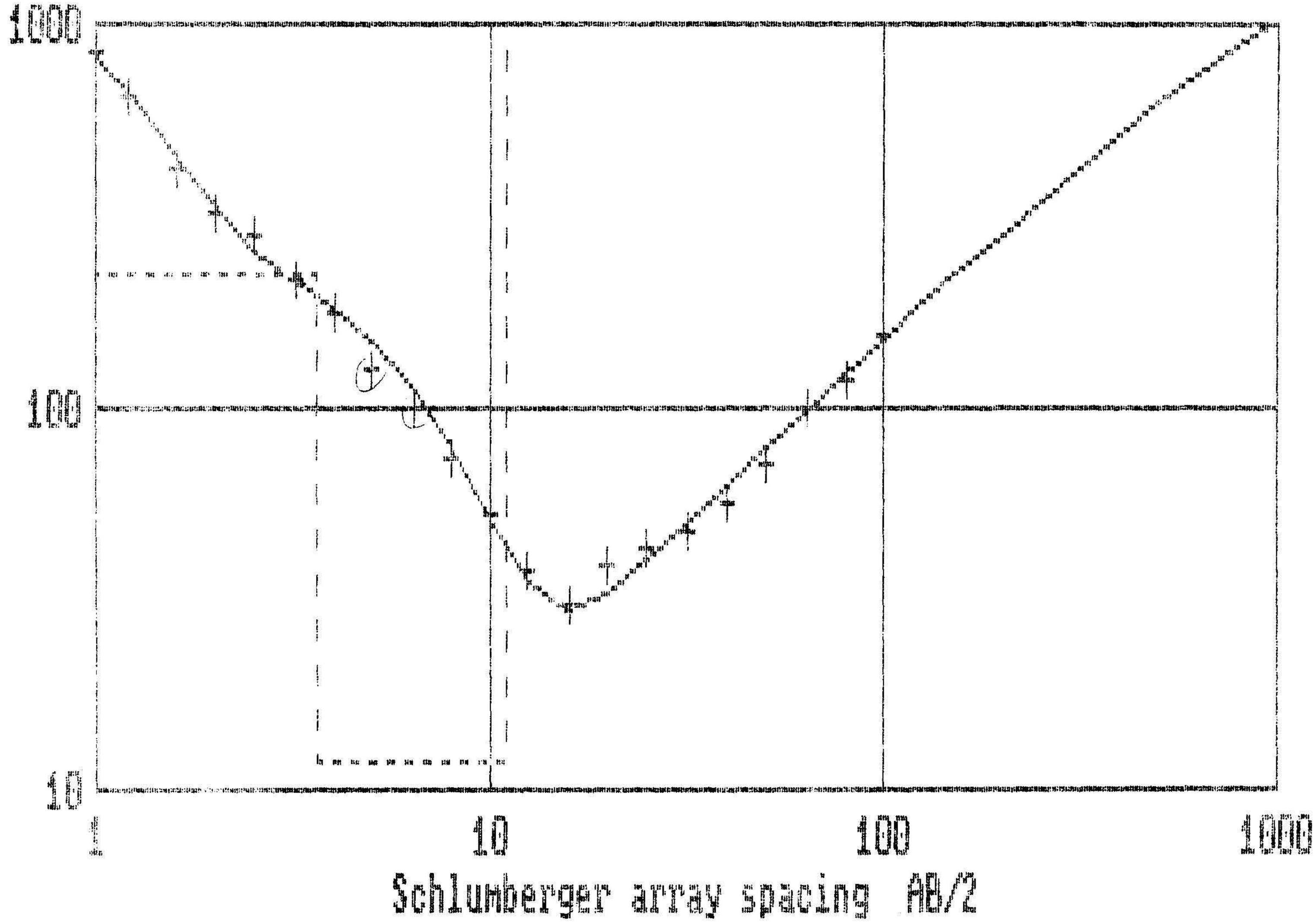
Rungai EM34 traverse no.1
V 20m
V 40m
H 20m
H 40m
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
conductivity (mmho/m)
bottom of vlei
bottom of vlei
track
450.00
350.00
250.00
150.00
50.00
distance (m)
bearing 290 M


Rungai EM34 traverse no.2
V 20m
V 40m
H 20m
H 40m
conductivity (mmho/m)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
vlei
track
450.00
350.00
250.00
150.00
50.00
distance (m)
bearing 310 M


Rungai EM34 traverse no.3
conductivity (mmho/m)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
V 20m
V 40m
H 20m
H 40m
vlei
track
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 140 M

rungai site 1 1987

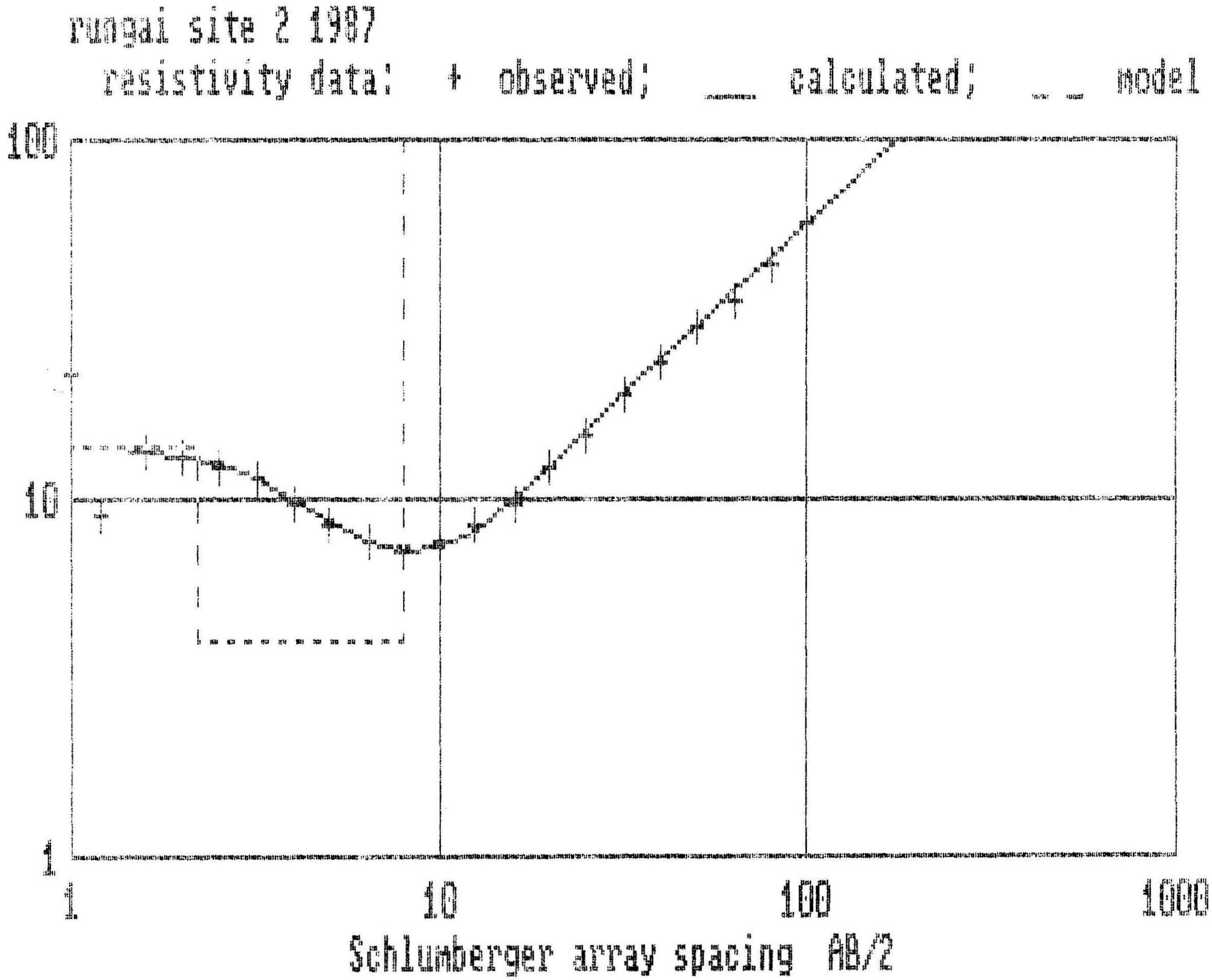
resistivity data: + observed; __ calculated; _ _ model



Model parameters for site:

rungai site 1

Layer	Thickns.	Restvty.	Depth
1	0.50	1500.00	0.50
2	3.10	220.00	3.60
3	7.40	12.00	11.00
Substrait		2500.00	*****



Model parameters for site:
rungai site 2

Layer	Thickns.	Restvty.	Depth
1	2.20	14.40	2.20
2	5.80	4.00	8.00
Substrait		1000.00	*****

2.4 Madangombe School

Area E

Map 2030 A2, grid reference 218 7779

2.4.1 Introduction

A marked linear feature (Greenbaum and Wright personal communication) runs from the borehole by the school (EEC77) to the NW, following a narrow discontinuous vlei. It passes a scattered kraal and gardens, which obtain a periodic water supply from a hand-dug well. A VES was measured at the borehole, in order to provide some background information on resistivities and depths and a number of EM profiles were run across the vlei to investigate the response of the lineament.

2.4.2. Geophysical studies

The VES at the borehole showed, as might have been predicted from the amount of outcrop nearby, a great lateral variation which invalidated any quantitative assessment below about 6m. To that depth the resistivity is determined to be 120 ohm m.

At the kraal site, 3 ground conductivity traverses were measured across the vlei, at the narrow part near the top, at the bottom, where it opens out and becomes poorly defined, and in the middle. In each case, a well-defined anomaly of the vertical-sided conductive type was demonstrated. On traverse no.1 the vlei and anomaly co-incide, but down-vlei the anomaly moves progressively onto the right bank. A thick development of regolith identified on traverse no.2 was further investigated with a VES, which showed around 14m of regolith with resistivity less than 110 ohm m, overlying relatively low resistivity (1200 ohm m) basement, which may indicate a moderate degree of fracturing.

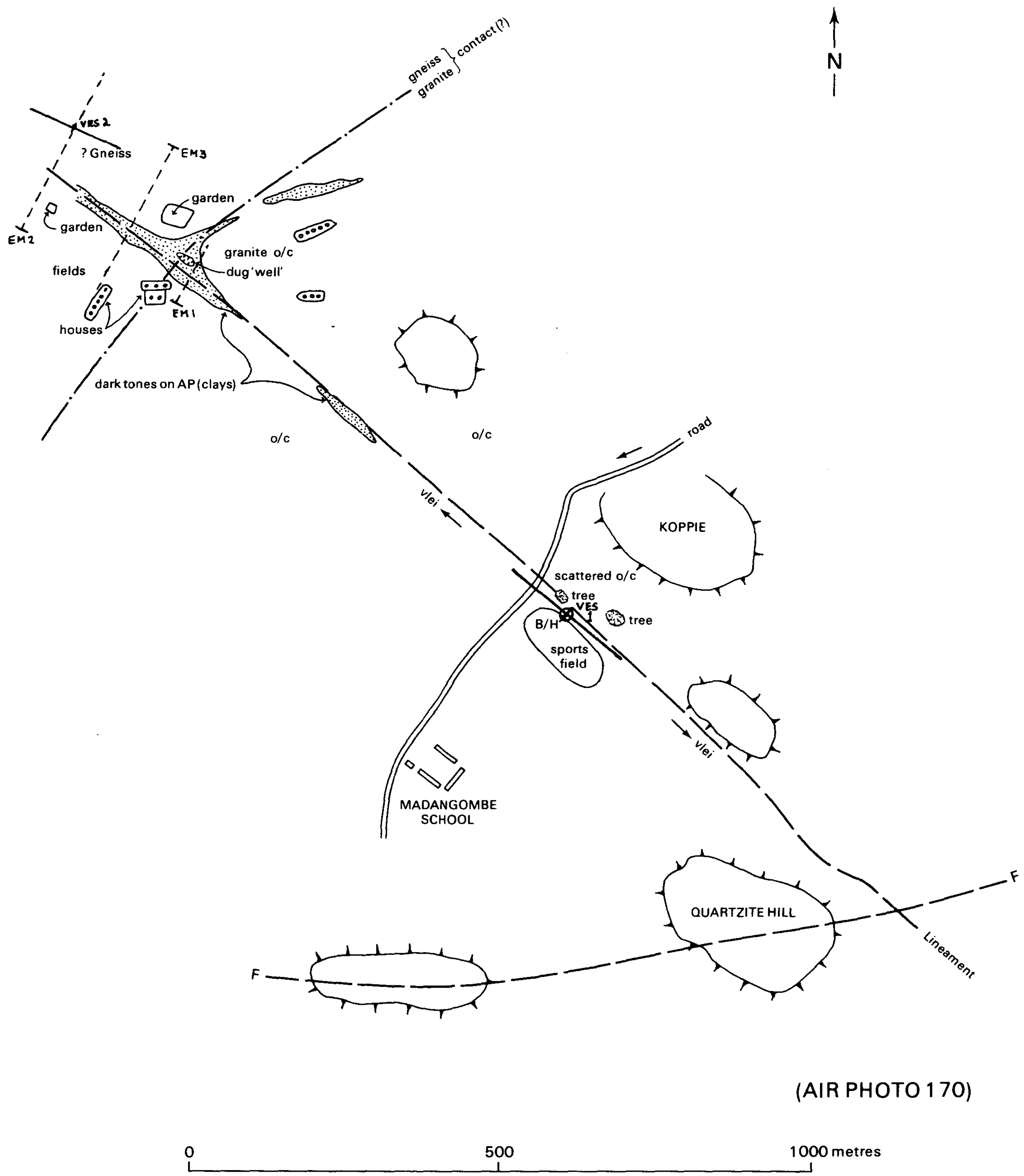
2.4.3. Discussion

There appears to be a strong case linking the lineament to the EM anomaly, which is very likely to be laterally continuous, and we assume that it represents a fracture in the bedrock beneath the saprolite. The anomaly on EM traverse no.3 was pegged, because it is close to the vlei bottom and the conductive saprolite is relatively extensive at this point, and might be expected to provide an improved recharge to the fracture. The saprolite, although not particularily thick has a high resistivty and might be clay-poor, with a consequent high permeability.

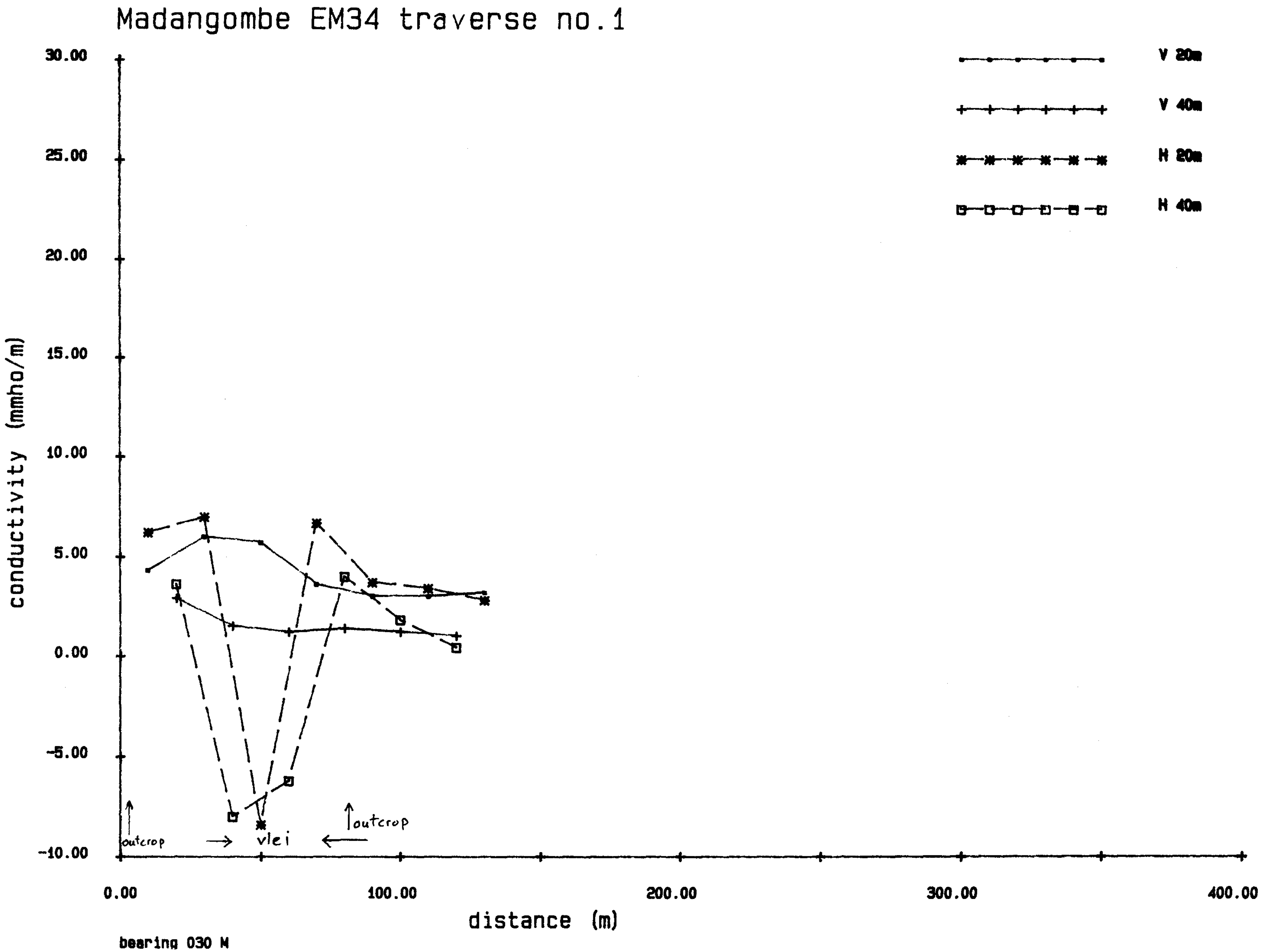
2.4.4. Conclusions

The ground conductivity provides good evidence of a fracture system a little offset from the vlei. From interpretation of the VES, the saprolite is suggested to reach a thickeness of 14m, with a useful permeability being possible. A peg was inserted to indicate the position of the fracture and a optimal thickness andextent of overburden.

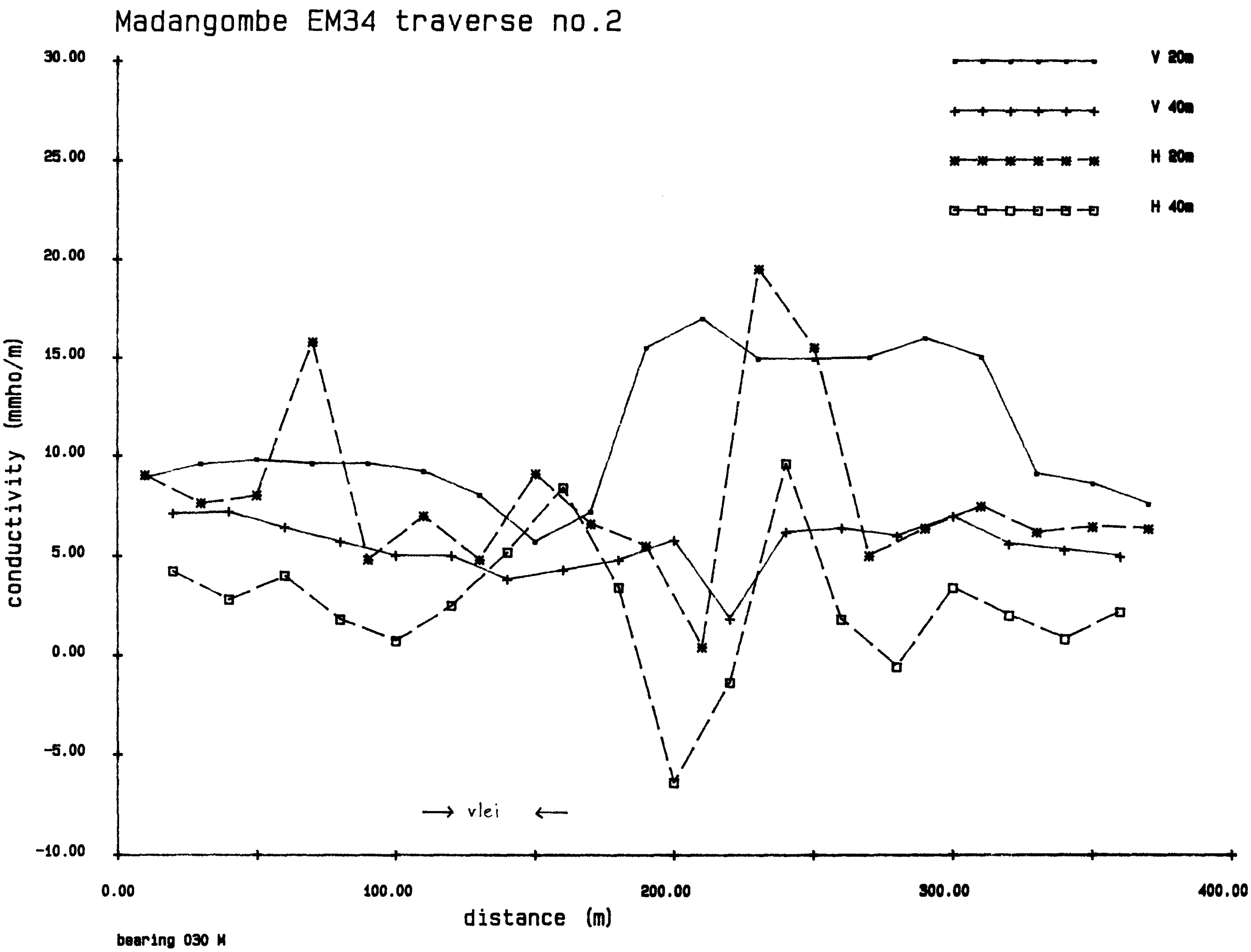
MADANGOMBE SCHOOL: AREA E: MAP 2030 A2 GR 219000/777900



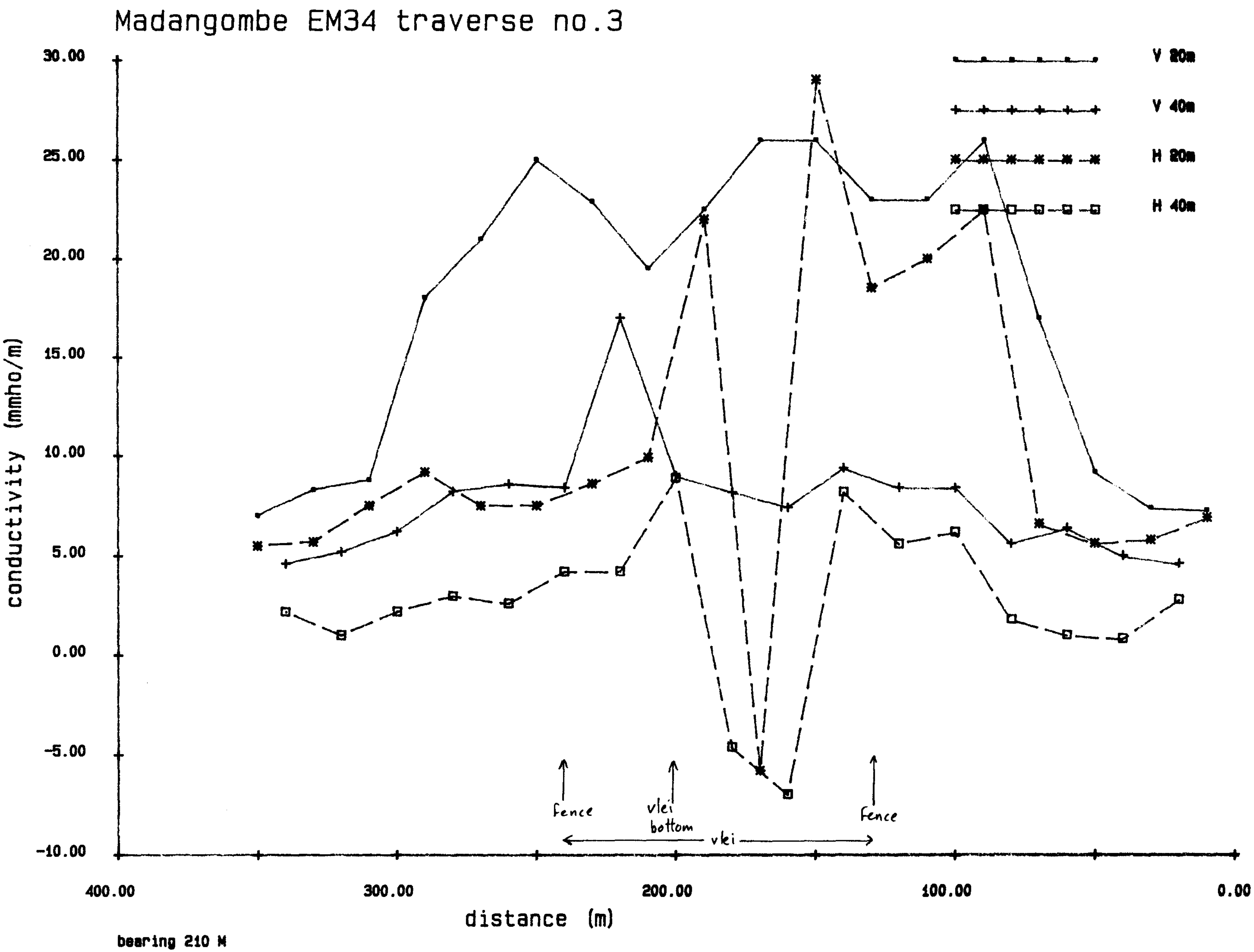
(AIR PHOTO 170)



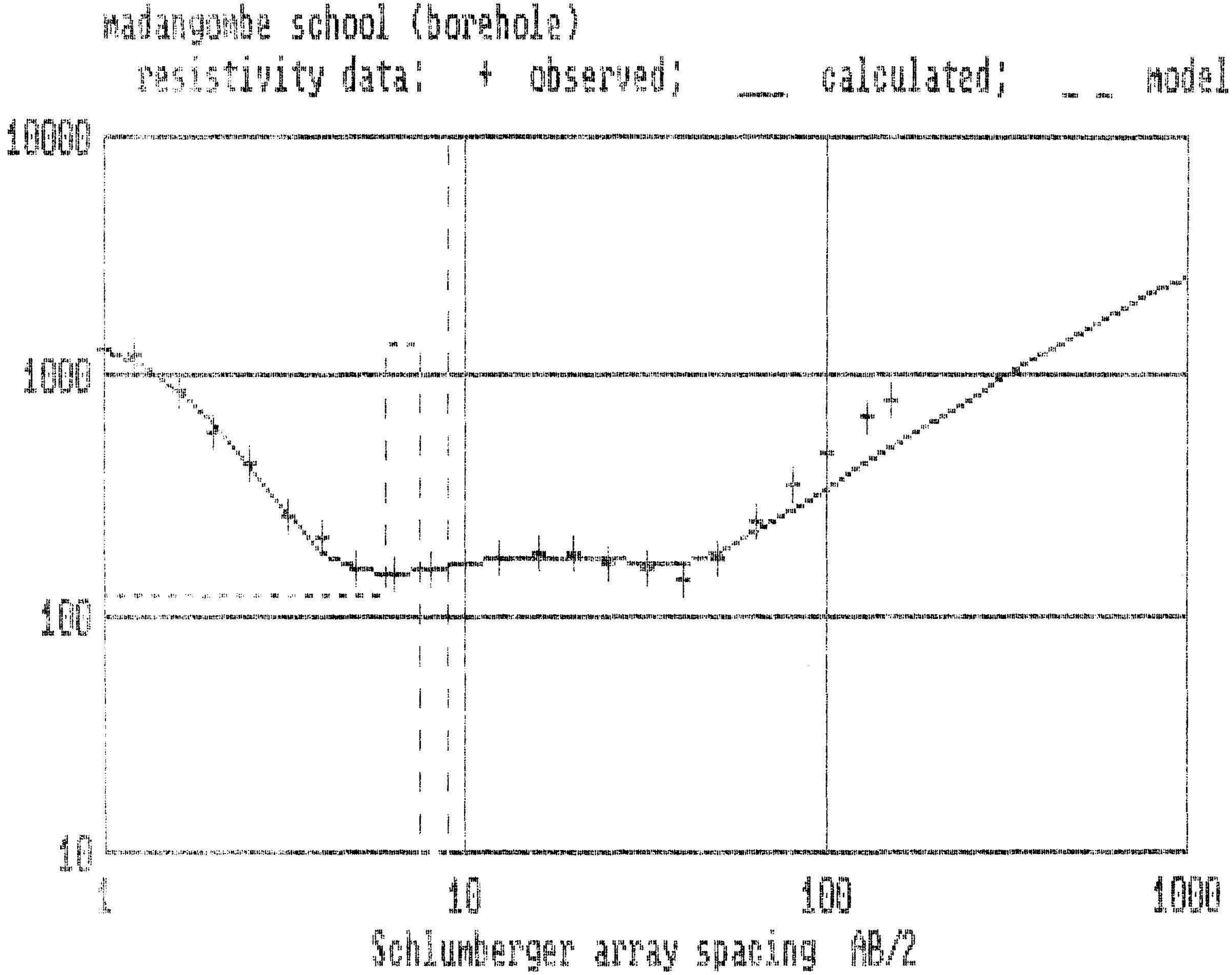
Madangombe EM34 traverse no.1
V 20m
V 40m
H 20m
H 40m
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
outcrop
vlei
outcrop
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 030 M



Madangombe EM34 traverse no.2
V 20m
V 40m
H 20m
H 40m
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
→ vlei ←
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 030 M

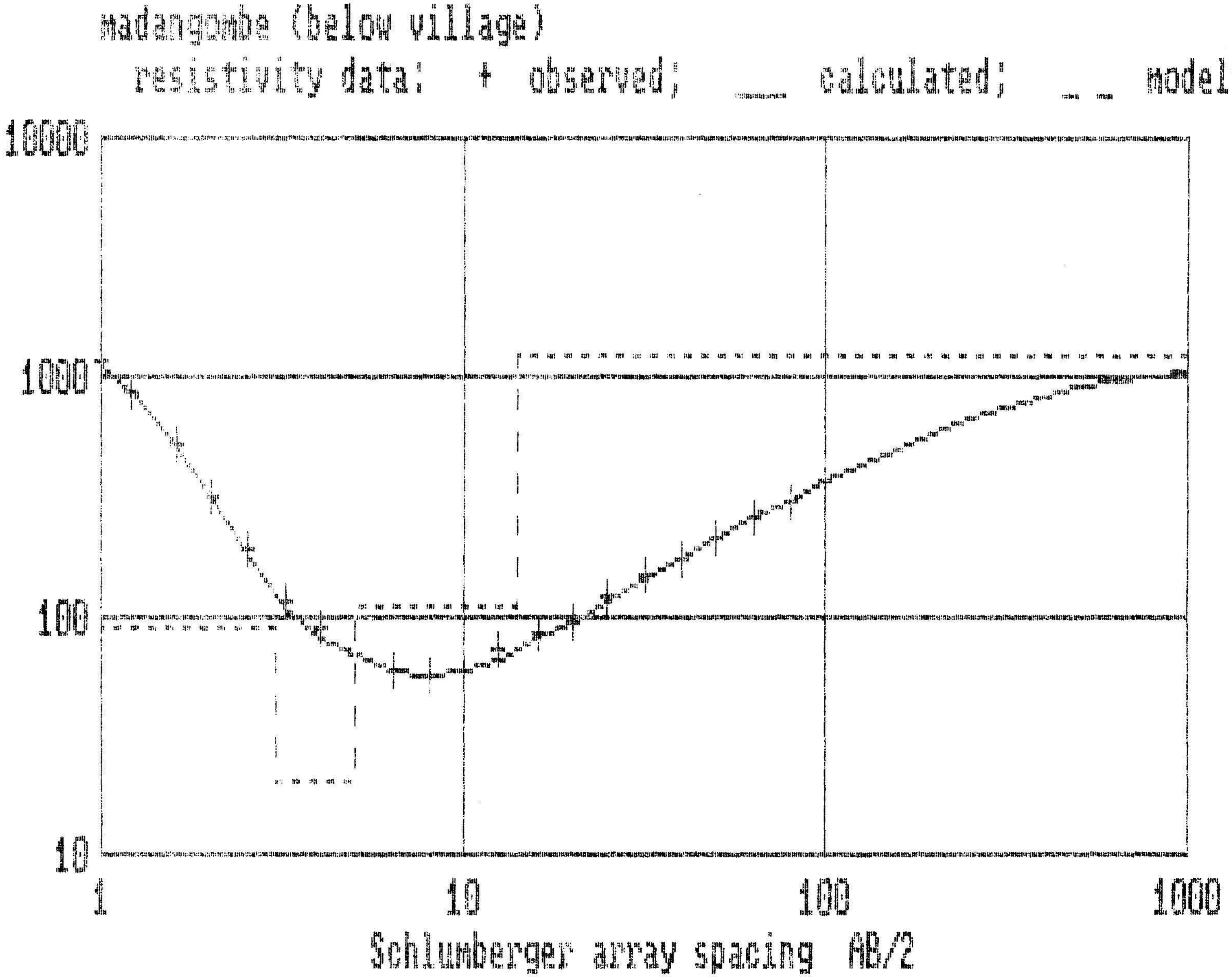


Madangombe EM34 traverse no.3
V 20m
V 40m
H 20m
H 40m
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
fence
vlei bottom
fence
vlei
400.00
300.00
200.00
100.00
0.00
distance (m)
bearing 210 M



Model parameters for site:
madangombe school

Layer	Thickns.	Restvty.	Depth
1	0.85	1600.00	0.85
2	5.15	120.00	6.00
3	1.50	1350.00	7.50
4	1.50	6.00	9.00
Substrait		1000.00	*****



Model parameters for site:
madangombe

Layer	Thickns.	Restvty.	Depth
1	0.60	1850.00	0.60
2	2.40	90.00	3.00
3	2.00	20.00	5.00
4	9.00	110.00	14.00
Substrait		1200.00	*****

2.5. **Maramba School**

Area E

Map 2030 A2, grid reference 222 7768

2.5.1. Introduction

Water supply for Maramba School was from a remote borehole (V2667), which apparently provided a reliable source. The possibility of a well closer to the school in this arid area had been investigated, with 2 pegs having been inserted and a LWF hand-dug well being constructed (July 1987). Ground inspections by Greenbaum and Wright (personal communication) revealed a broad shallow valley which intersected a massive quartz vein or quartzite 'reef', and an investigation of this feature as a potential barrier to sub-surface flow was recommended.

2.5.2. Geophysical studies

Two VES and 2 EM ground conductivity traverses were measured. One VES was sited at the borehole and indicated a total thickness of about 30m of saprolite, (with resistivity of between 27 and 53 ohm m), overlying bedrock.

The 2 EM profiles failed to cover the area of the quartz rock, because of operational errors, but indicated a zone of relatively low resistivity near-surface material in the vlei-bottom. This area was investigated with a VES, which showed 1-2m of low resistivity material, overlying rock with a resistivity of 90 ohm m to a depth of 7m. This overlay bedrock which had a resistivity of 550 ohm m.

2.5.3. Discussion

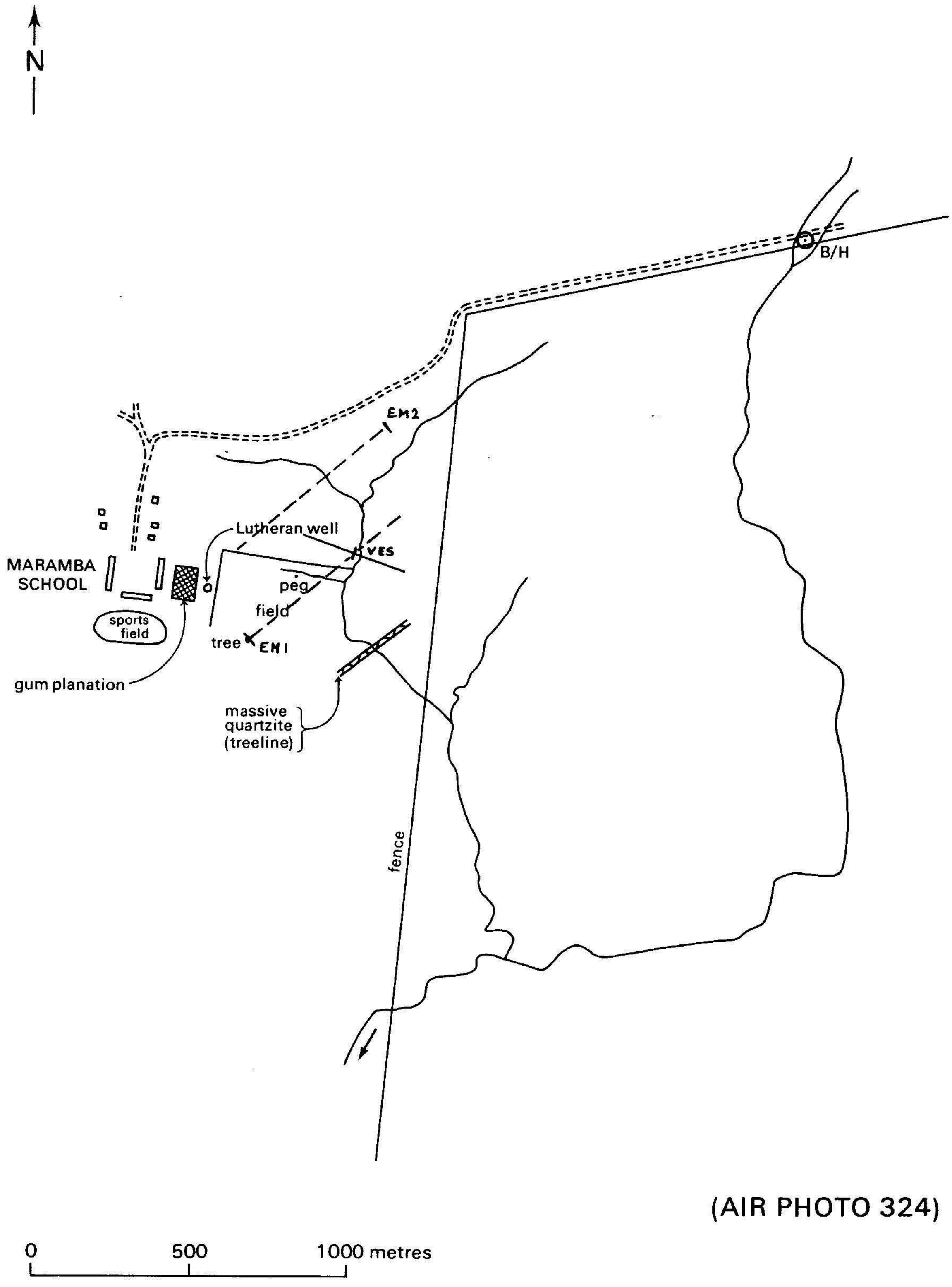
The borehole was sited where the saprolite appears to be sufficiently thick and to have a suitable resistivity to fulfill the 'Master Plan' criteria (Martinelli, 1984). In addition a mafic dyke ran across the nearby stream, which was probably the reason for the choice of site.

No clear vertical-sided conductivity anomaly was seen in the vlei area,in other words no evidence of a fracture system was noted. There is evidence on both profiles that the saprolite is more deeply weathered in the valley bottom, and this does not extend as far as the LWF well, in which unweathered speckled granite may be seen, beneath only a metre of saprolite. The VES was measured where the EM indicated that there was relatively little lateral variation. The bedrock resistivity is very low and must indicate a fair degree of fracturing, possibly justifying drilling into it as a possible storage medium, even though this is without the normally accepted criteria.

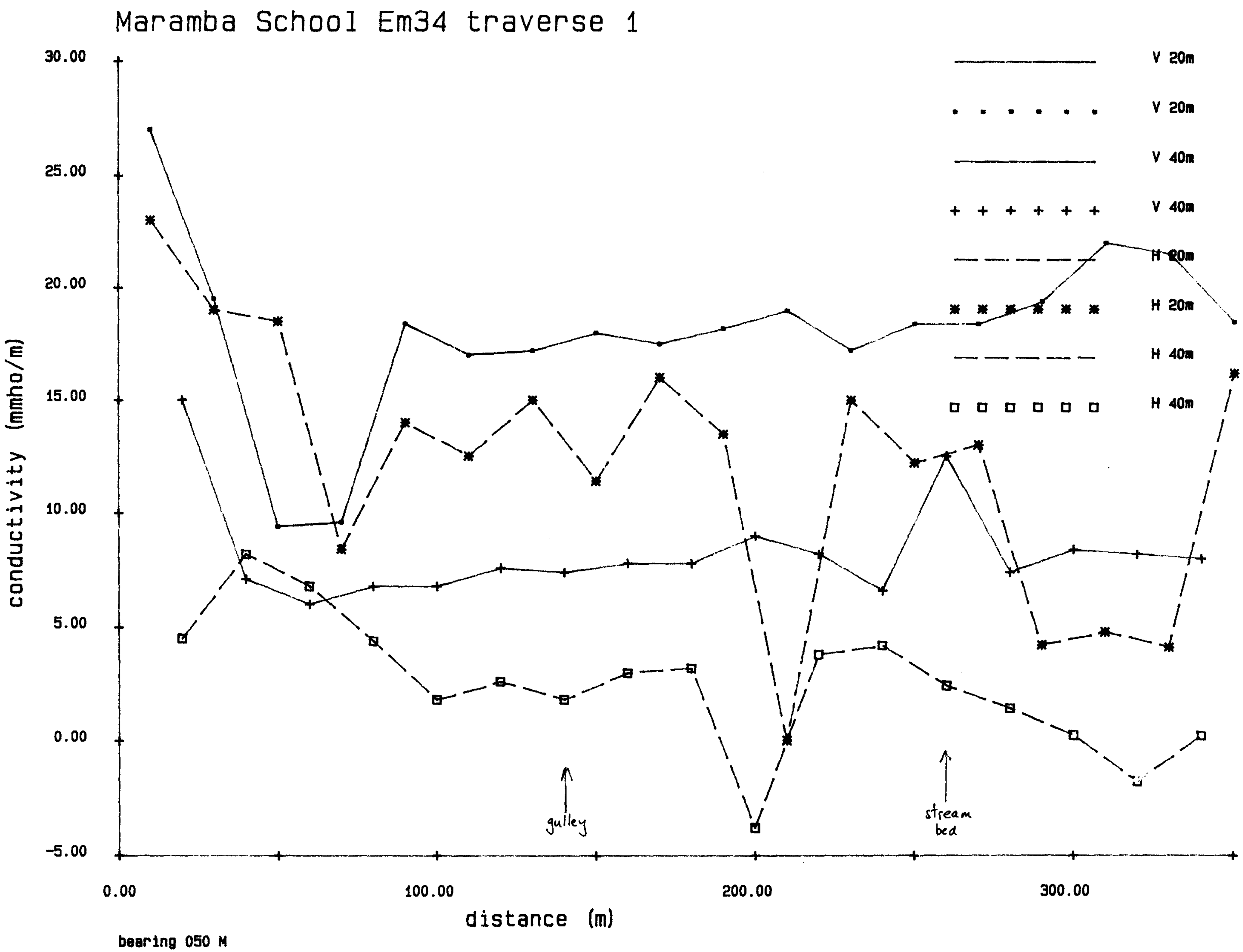
2.5.4. Conclusions

There is no evidence of a fracture system beneath the vlei at Maramba. An area of weathered rock is restricted to the valley bottom and overlies heavily fractured bedrock at a shallow depth. The co-incidence of the drainage channel and the fractured bedrock warrant investigation by drilling and the VES site was pegged to indicate a suitable position.

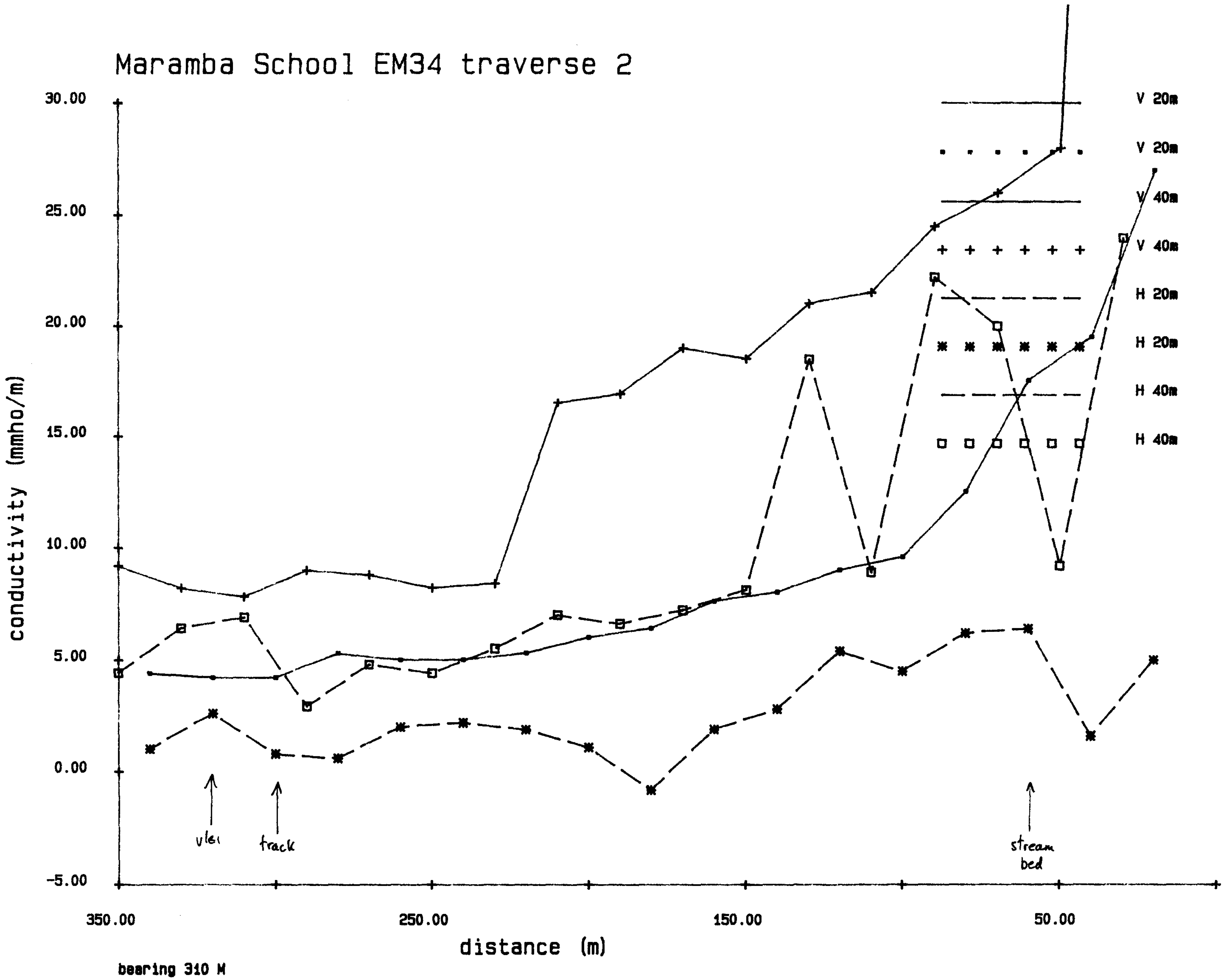
MARAMBA SCHOOL: AREA E: MAP 2030 A2 GR22270/776820

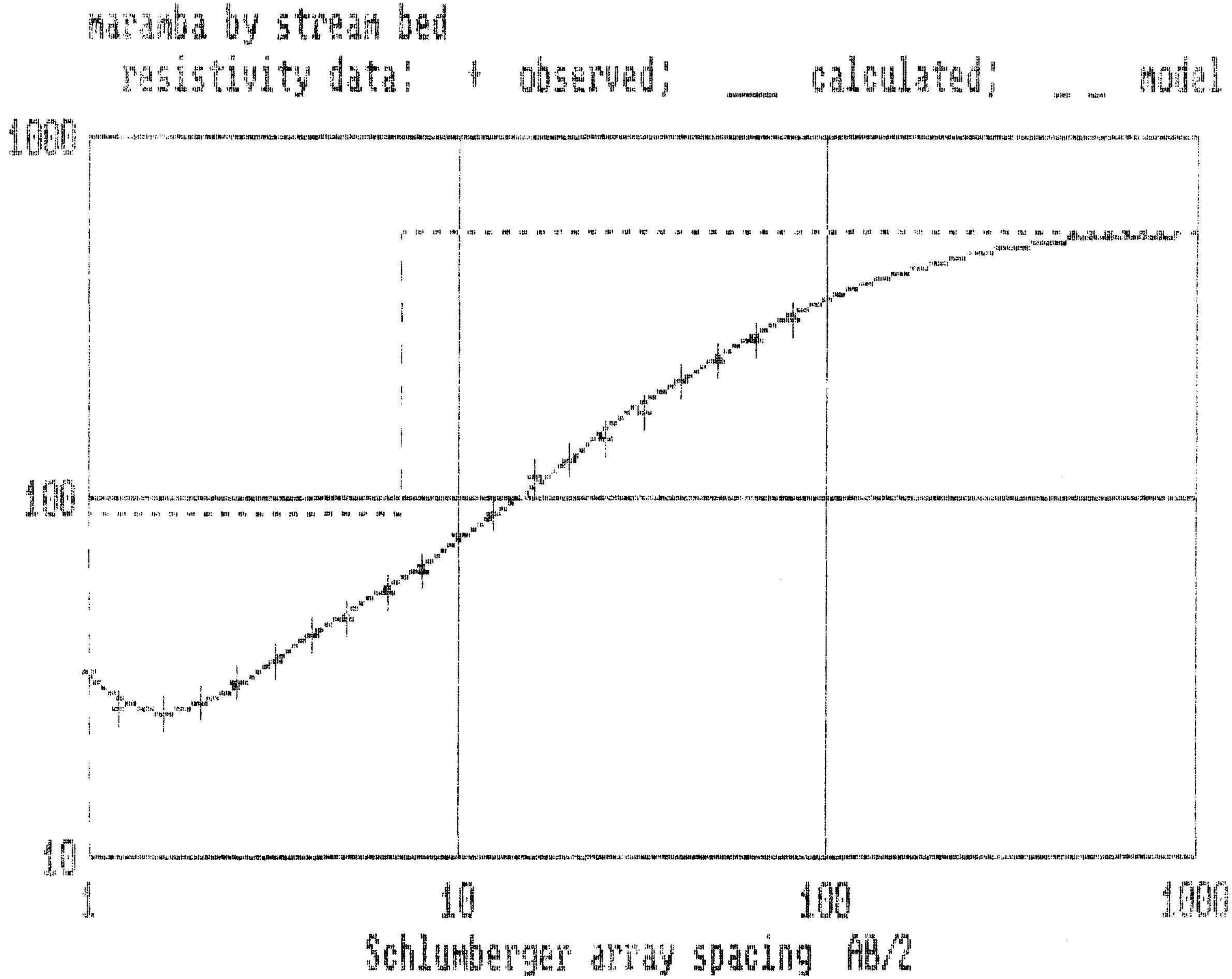


(AIR PHOTO 324)



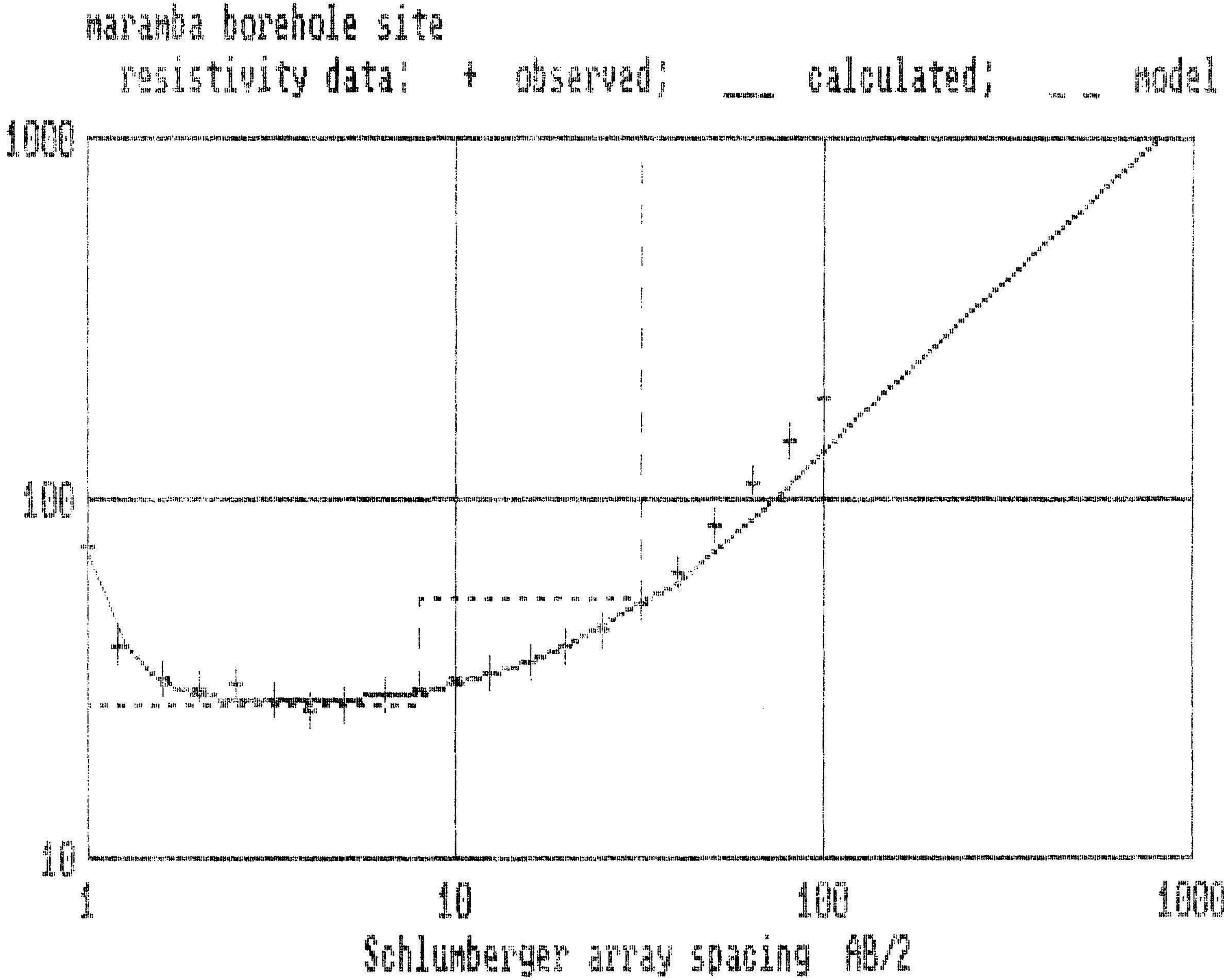
Maramba School Em34 traverse 1
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
gulley
stream bed
0.00
100.00
200.00
300.00
distance (m)
bearing 050 M


Maramba School EM34 traverse 2
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
vlei
track
stream bed
350.00
250.00
150.00
50.00
distance (m)
bearing 310 M



Model parameters for site:
maramba

Layer	Thickns.	Restvty.	Depth
1	0.40	65.00	0.40
2	0.60	10.50	1.00
3	6.00	90.00	7.00
Substrait		550.00	*****



Model parameters for site:
maramba

Layer	Thickns.	Restvty.	Depth
1	0.22	1500.00	0.22
2	7.76	27.00	6.00
3	24.00	53.00	32.00
Substrait		10000.00	*****

2.6. Chibi

Area F

Map 2030 A4, grid reference 237 7751

2.6.1. Introduction

About 1 km to the south-west of Chibi the road crosses a major vlei, occupying a valley linking into a complex of minor drainage basins in the hills overlooking Chibi from the south. Because of this connection it was felt that the vlei and a proposed underlying fracture system could provide substantial recharge. A rather similar situation was noted about 1.5km to the SE of Chibi, where a lush garden was irrigated from hand-dug wells, which provided a permanent and shallow supply. An attempt to carry out a VES at this second site provided uninterpretable results, because of the complexity of outcrop in the immediate vicinity and the consequent lateral inhomogeneity.

2.6.2. Geophysical studies

The area to the south of the road, immediately beneath the line of hills , was not conducive to geophysical investigations because of a network of wire fences and low voltage power lines, both of which were likely to create spurious conductive effects. To the north of the road, 2 ground conductivity traverses across the vlei and 1 VES on the left bank were measured.

Both traverses showed comparable results, with high values in all coil configurations. On the right band there is a wide variation in values for the configurations; on the left bank they are rather similar. In between the negative values in the 40m horizontal coil configuration may indicate the steep-sided conductivity contrast associated with a fracture system.

The VES shows a typical H-type result, with some very low apparent resistivity values. The interpretation shows considerable equivalence, but a reasonable solution indicates 8-10m of saprolite, with a resistivity between 35 and 4 ohm m. This is compatible with the EM results in the area.

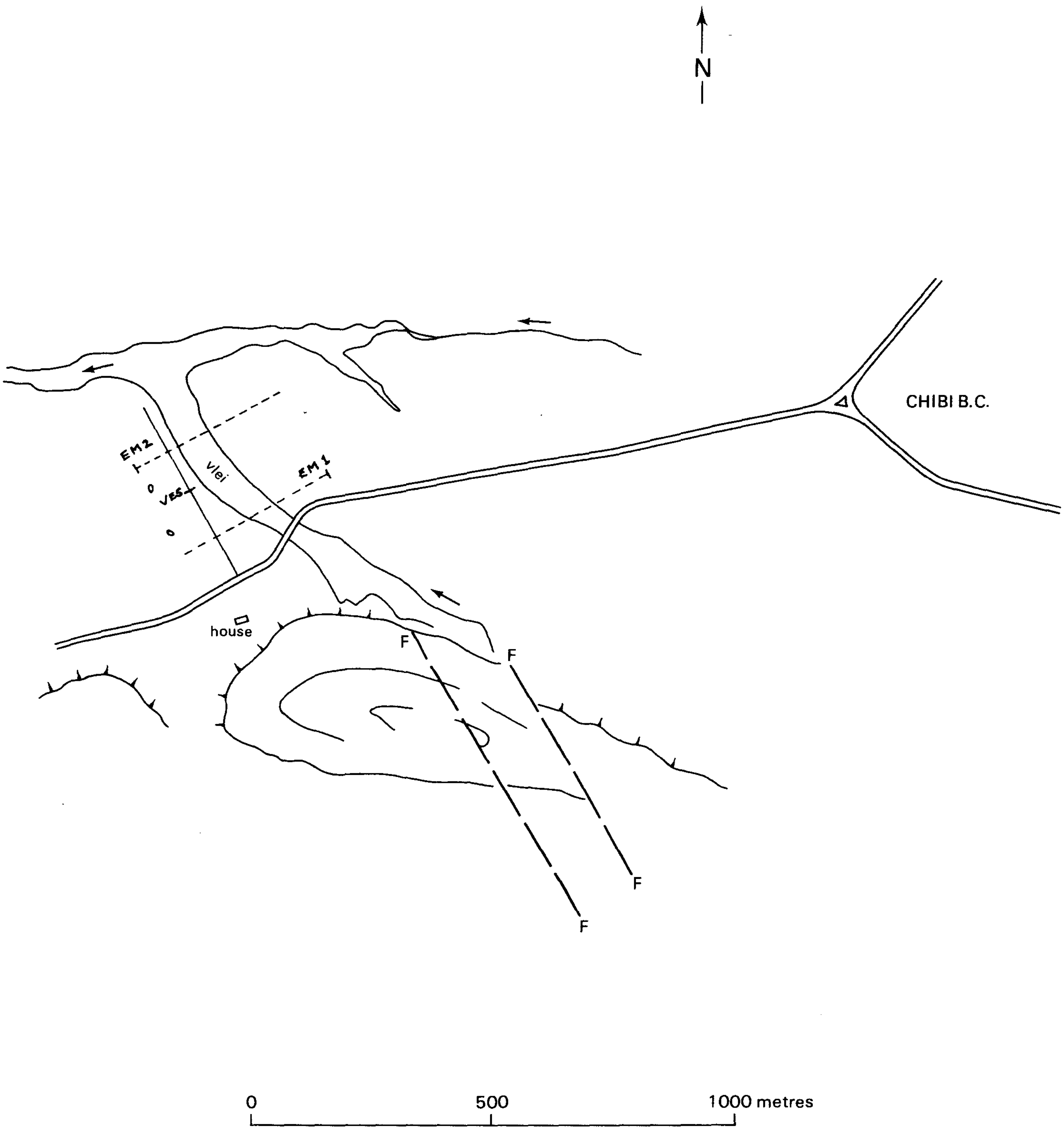
2.6.3. Discussion

There may be a structural discontinuity running along the vlei, as indicated by the negative EM values. A preliminary assessment would suggest that the overburden thickness would be greater on the left bank, where the VES was measured, although this conclusion might not accord with the topographic pattern. The low resistivity material is indicative of a high clay content, with a low permeability. Neither the thickness or the resistivity make this an attractive site for a borehole, unless the fracture system itself is transmissive.

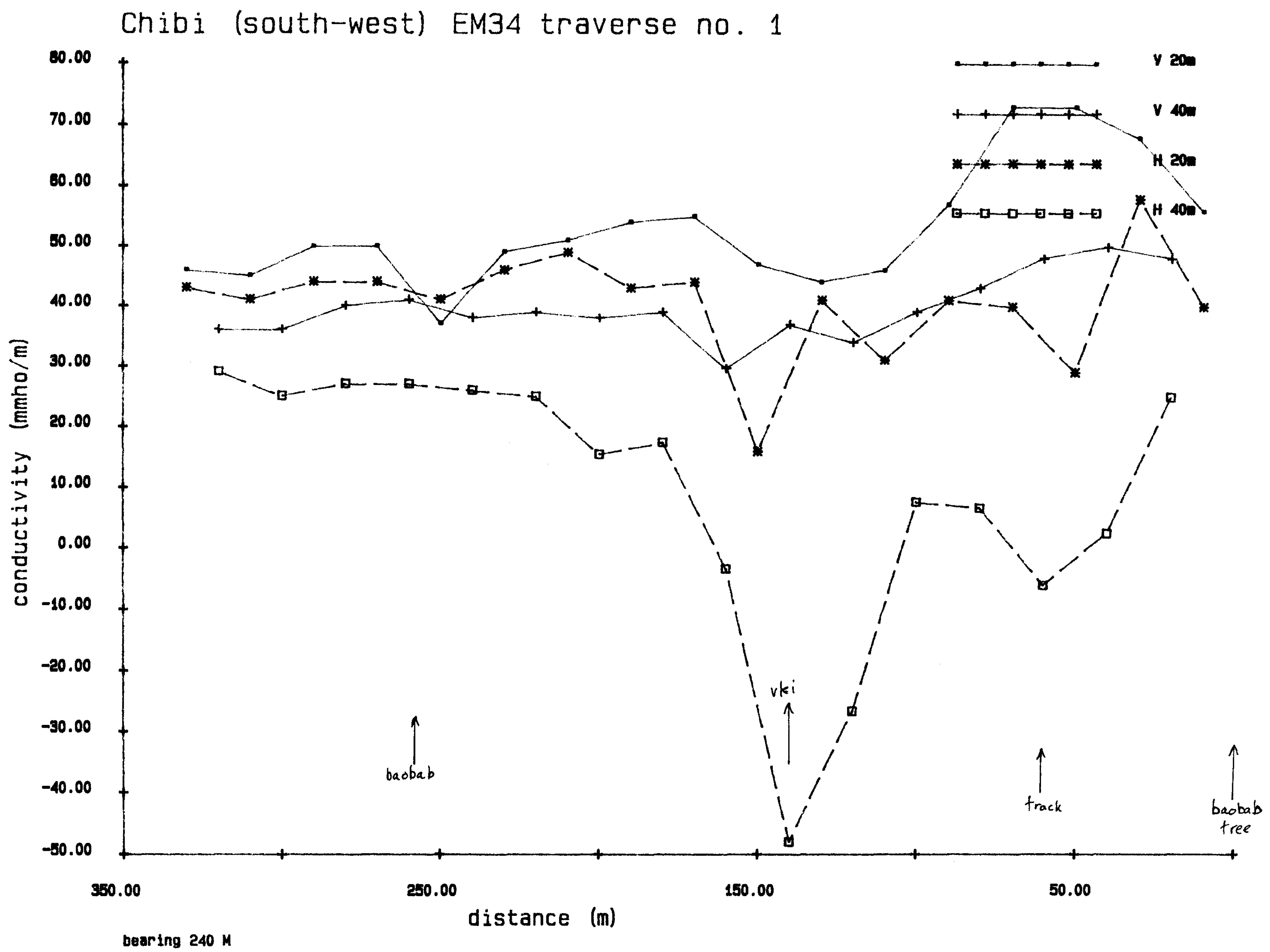
2.6.4. Conclusion

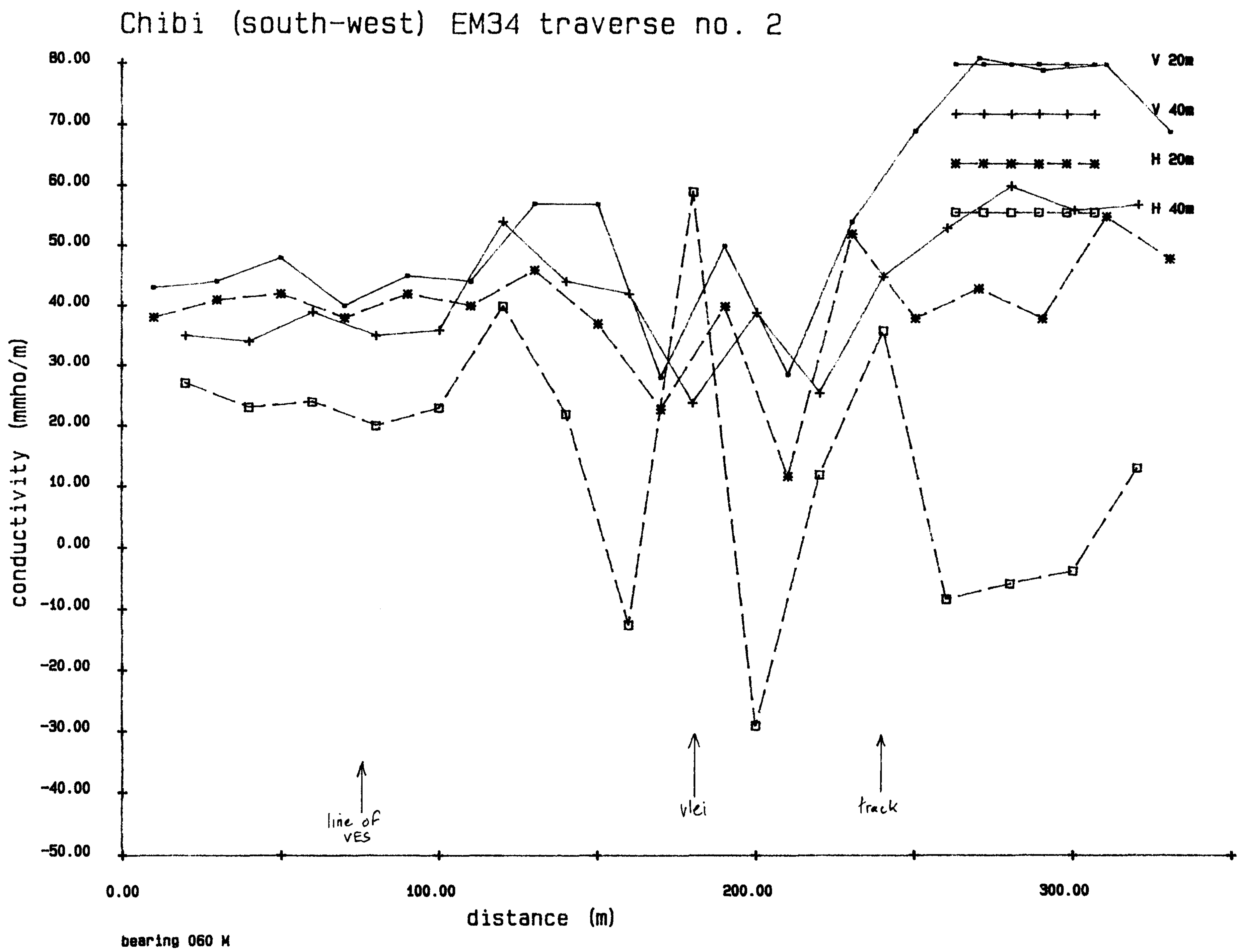
A possible fracture system underlies the vlei, but the saprolite is both thin and clay-rich. A borehole to intersect the fracture system would provide a valuable insight into its weathering profile and possible transmissivity.

CHIBI B.C.: AREA F



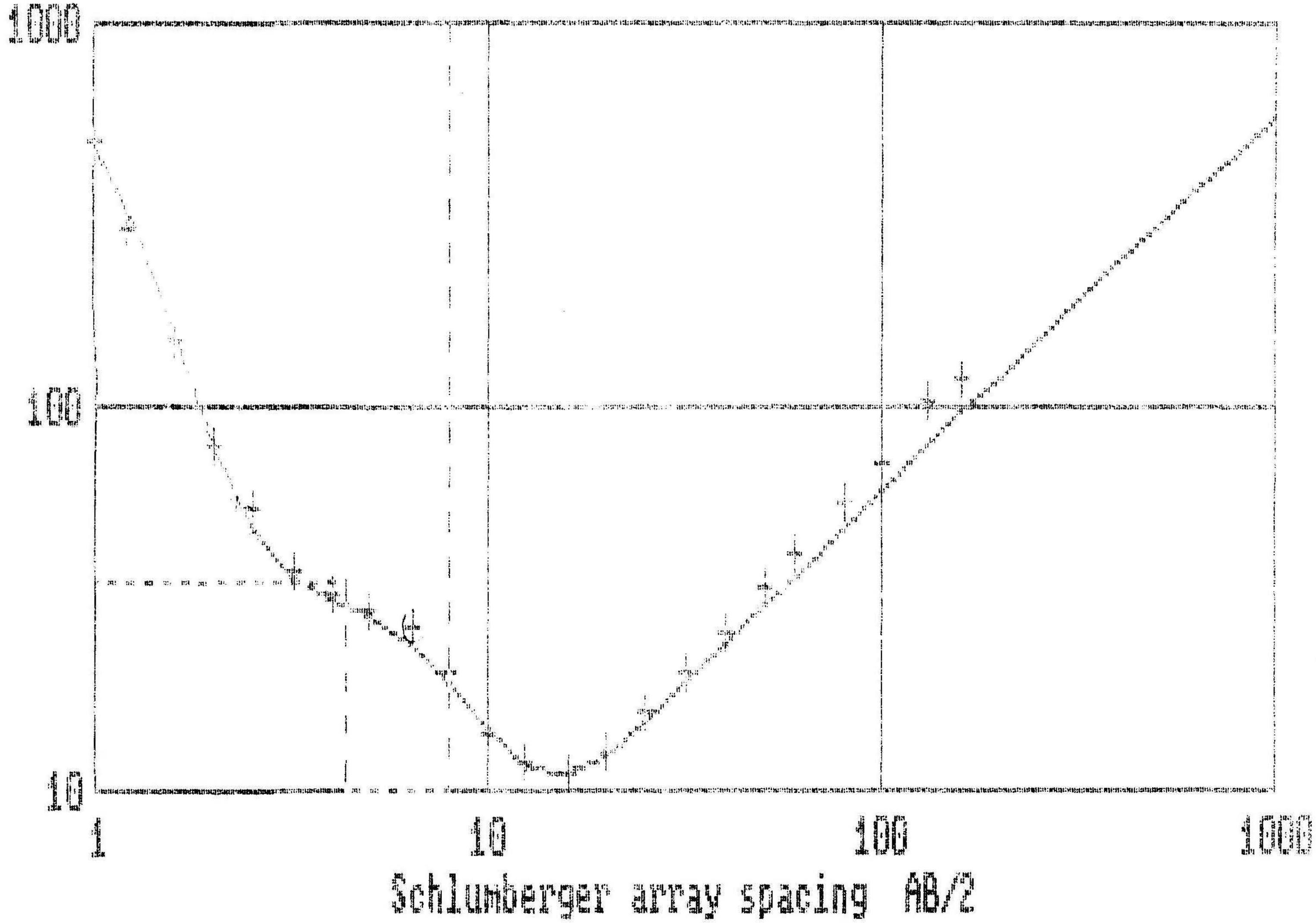
(AIR PHOTO 641)


Chibi (south-west) EM34 traverse no. 1
V 20m
V 40m
H 20m
H 40m
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
conductivity (mmho/m)
350.00
250.00
150.00
50.00
distance (m)
baobab
vlei
track
baobab tree
bearing 240 M


Chibi (south-west) EM34 traverse no. 2
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
conductivity (mmho/m)
0.00
100.00
200.00
300.00
distance (m)
V 20m
V 40m
H 20m
H 40m
line of VES
vlei
track
bearing 060 M

south-west chibi (vlei by large bungalow)

resistivity data; + observed; __ calculated; _ _ model



Model parameters for site:
south-west chibi

Layer	Thickns.	Restvty.	Depth
1	0.45	1200.00	0.45
2	3.90	35.00	4.35
3	3.65	2.35	8.00
Substrait		10000.00	*****

2.7. Chinambire School

Area F

Map 2030 B3, grid reference 245 7755

2.7.1 Introduction

Greenbaum and Wright (personal communication) identified a major lineament with a NW trend, following a narrow vlei,and which passed close to the borehole site (GEMS 3084). Restrictions in the width of the vlei caused a set of possible rock barriers which might locally raise the water table. Close to the water-shed, the lineament intersected a number of minor basic dykes, which might either provide storage or a sub-surface barrier. This area is one of limited saprolite thickness and only a limited area of catchment.

2.7.2. Geophysical studies

To the north of the school, close to the borehole site, 3 ground conductivity traverses were run across the vlei. On each there is indication of a steep-sided conductivity contrast over the centre of the vlei. On traverse no.1 the profile is rather irregular and the anomaly is not distinct, although the borehole is significantly off line of the feature.

Two VES were measured, the first close to the trace of the anomaly on traverse no.1 and the second in a widening in the vlei below the kjopes on either side. The first showed notable lateral variation, clearly arising from the many minor outcrops in the area. The saprolite is very thin (around 4m) with a resistivity of 8ohm m, which indicates a high clay concentration, and overlies bedrock. The second VES showed around 13m of saprolite of moderate resistivity, again overlying bedrock.

The EM traverse over the dyke and lineament intersection shows a confused profile withsome indication of steep-sided conductivity contrasts at 50 and 100m. The is a possibility that the saprolite may increase in thickness between 140 and 240m, although this could purely represent an increase in conductivity over the same interval. The VES close to the intersection showed some 2.5m of low resistivity saprolite overlying bedrock.

2.7.3. Discussion

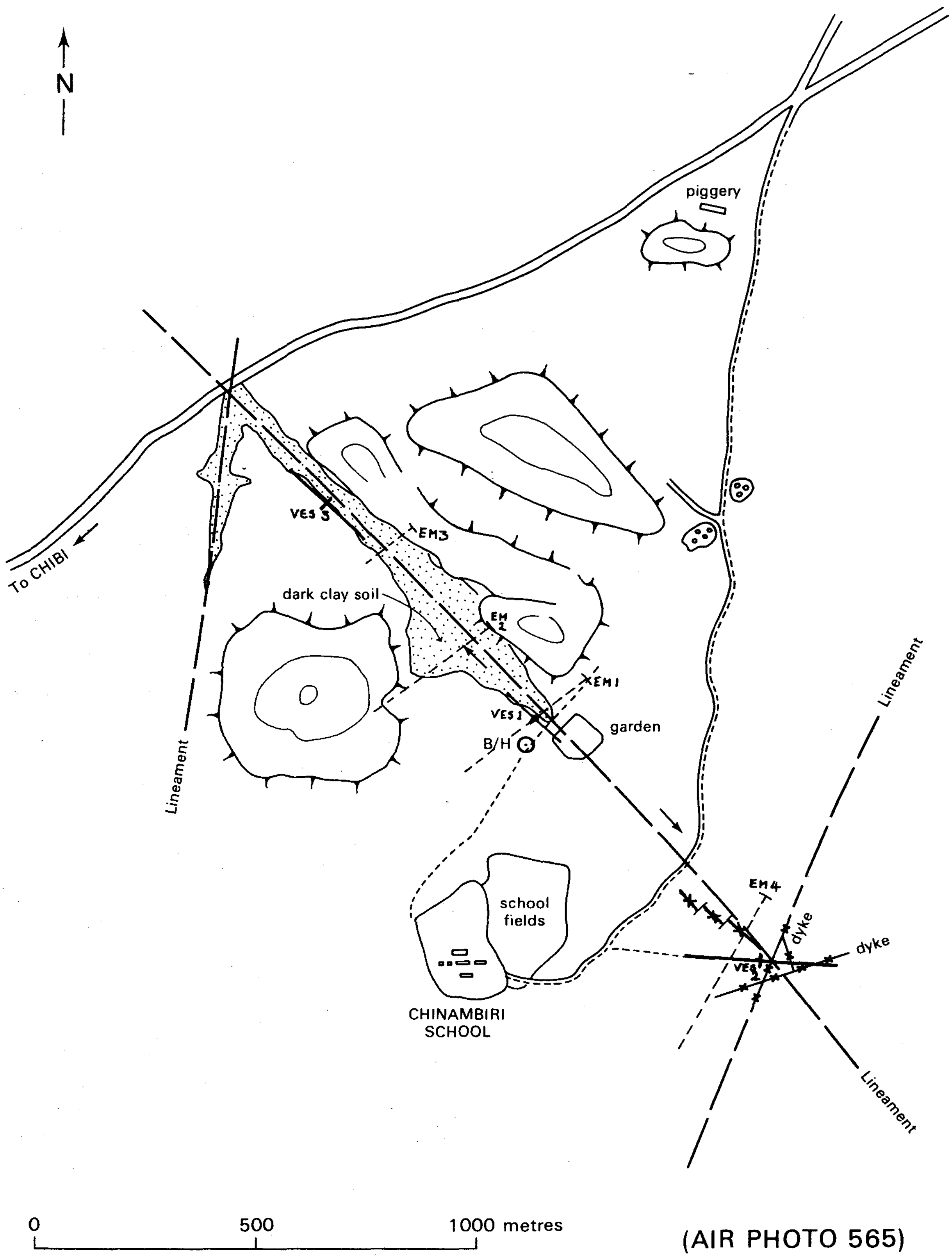
The geophysical evidence provides a good indication that the lineament represents the surface trace of a concealed fracture system, running beneath the vlei. It is clear that the existing borehole, which is surrounded by outcrop, is not on the fracture, but is offset some 50m. The VES confirms the thin development of saprolite in the area, although down-vlei it does become thicker and there are shallow hand-dug wells with moist clay indicating a shallower water table, possibly due to sub-surface barriers. At the 'dyke' site there is little saprolite development and only a uncertain observation of the fracture. To the west there does appear to be slightly more weathering but probably not adequate to justify a borehole test. Neither site has a great catchment area.

2.7.4. Conclusion

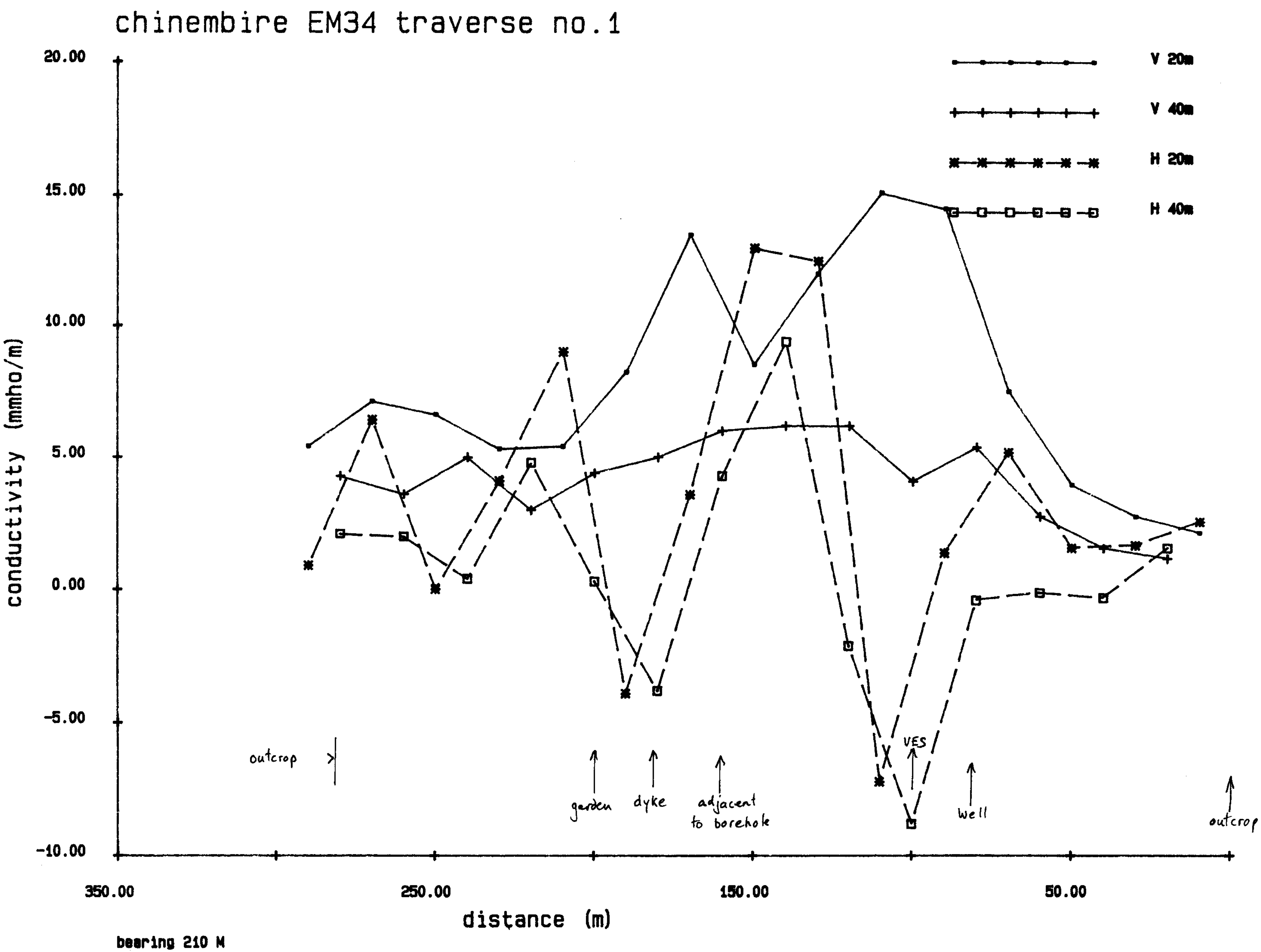
A fracture is identified beneath the vlei, which should be drilled. A suggested site has been pegged. Better thickness of regolith, sub-surface barriers and large recharge will be found further down-vlei.

To the east of the school the intersection of the fracture system with a number of dykes does not appear to provide a suitable site for a test borehole.

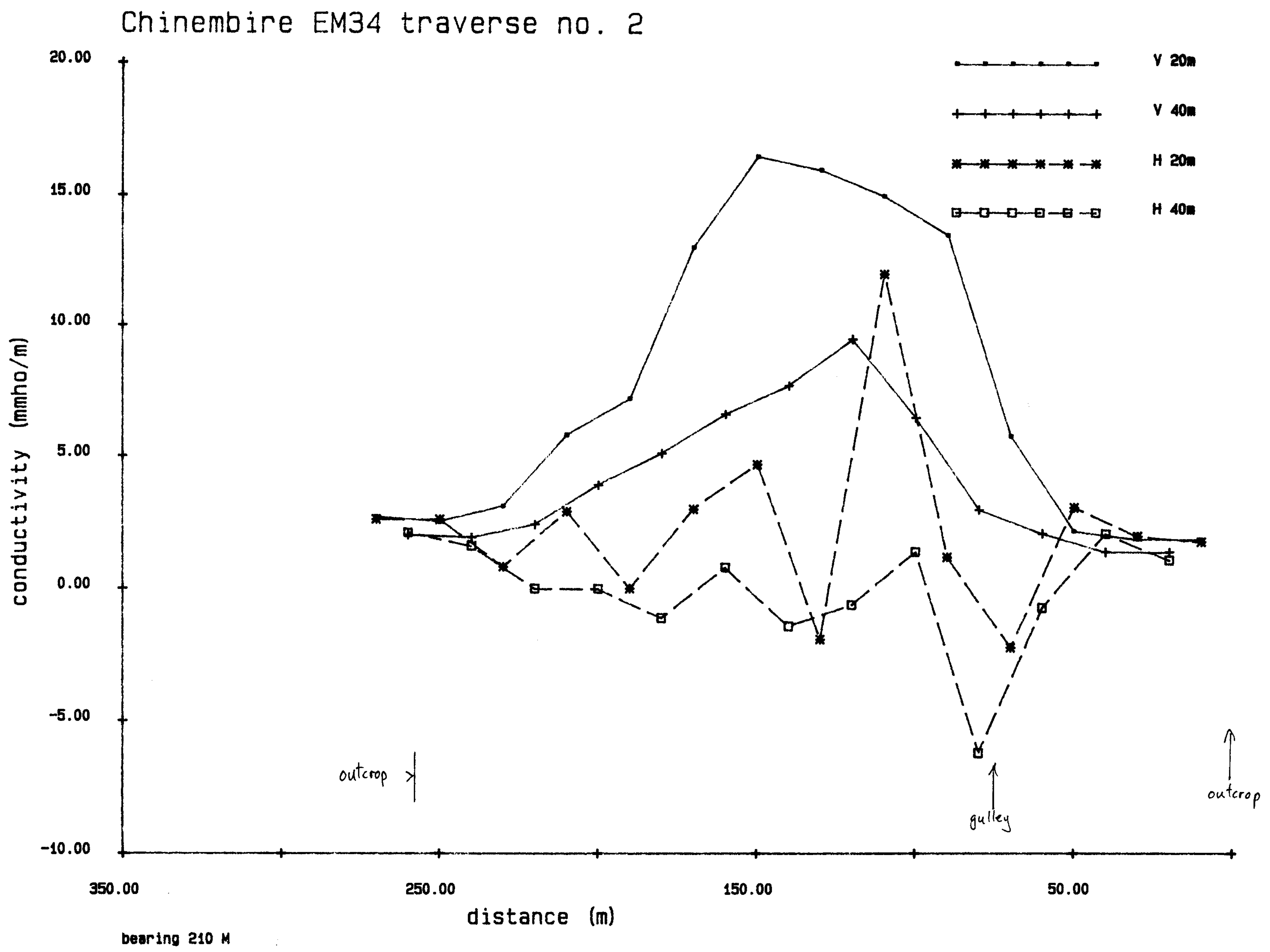
CHINAMBIRI SCHOOL: AREA F

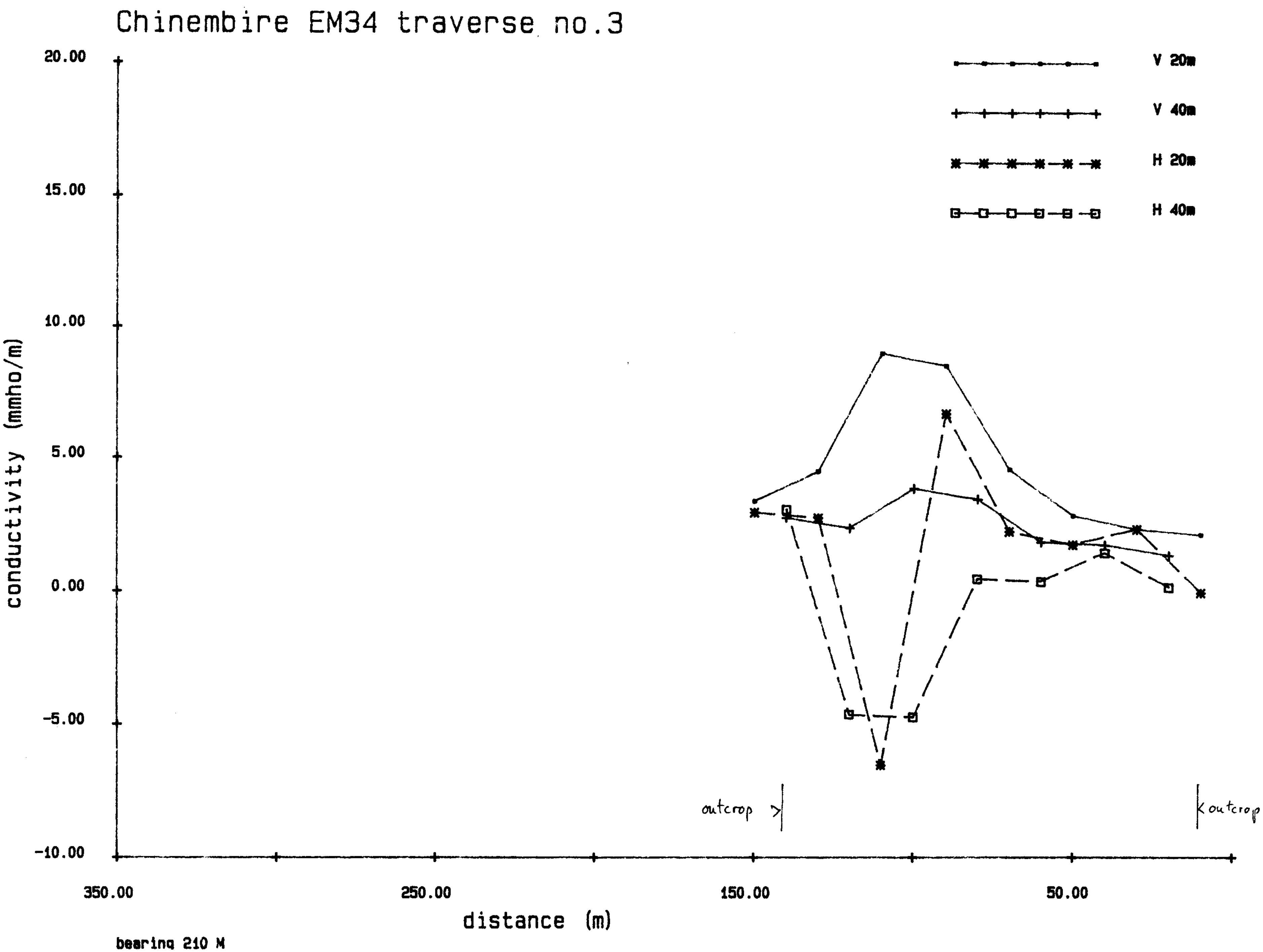


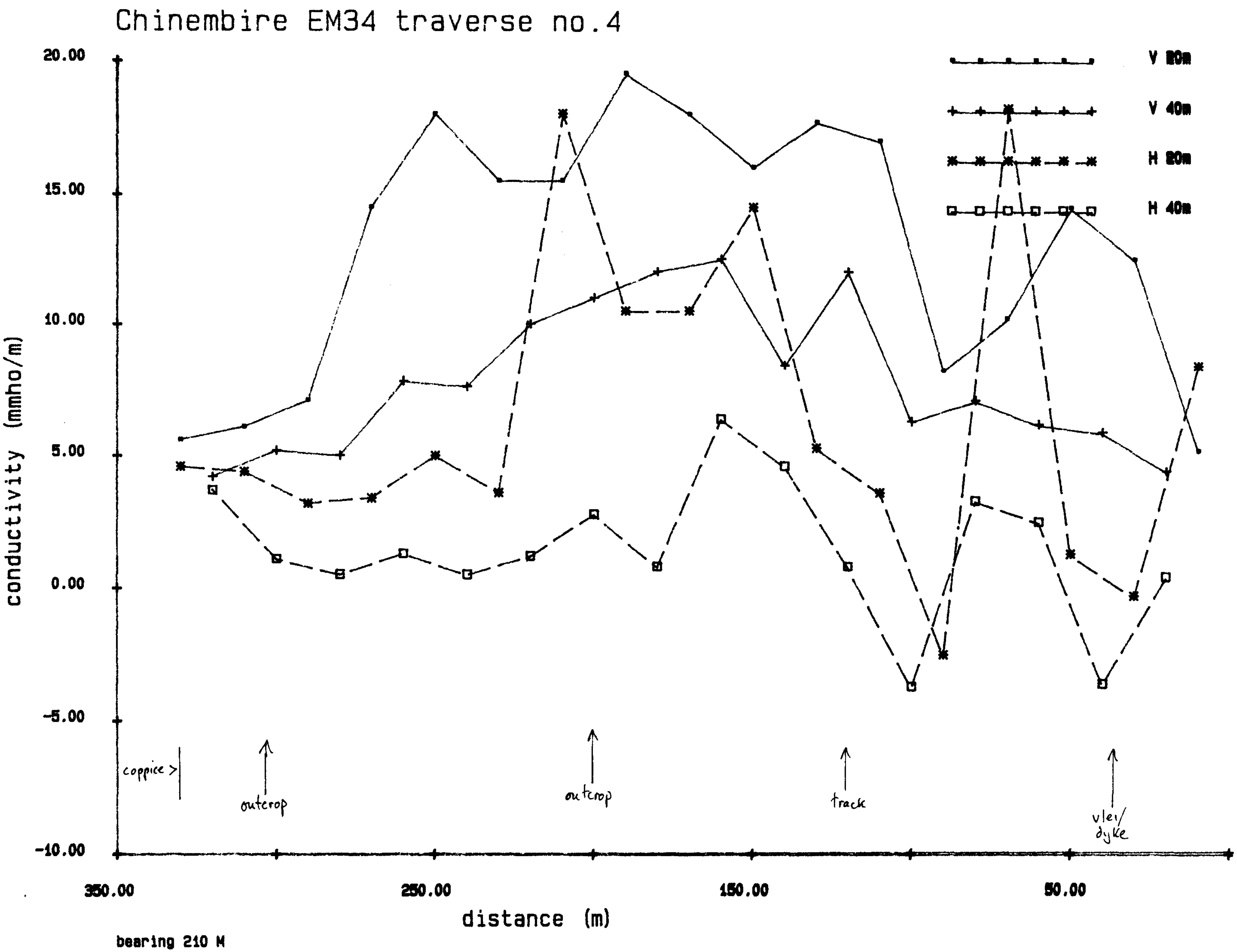
(AIR PHOTO 565)



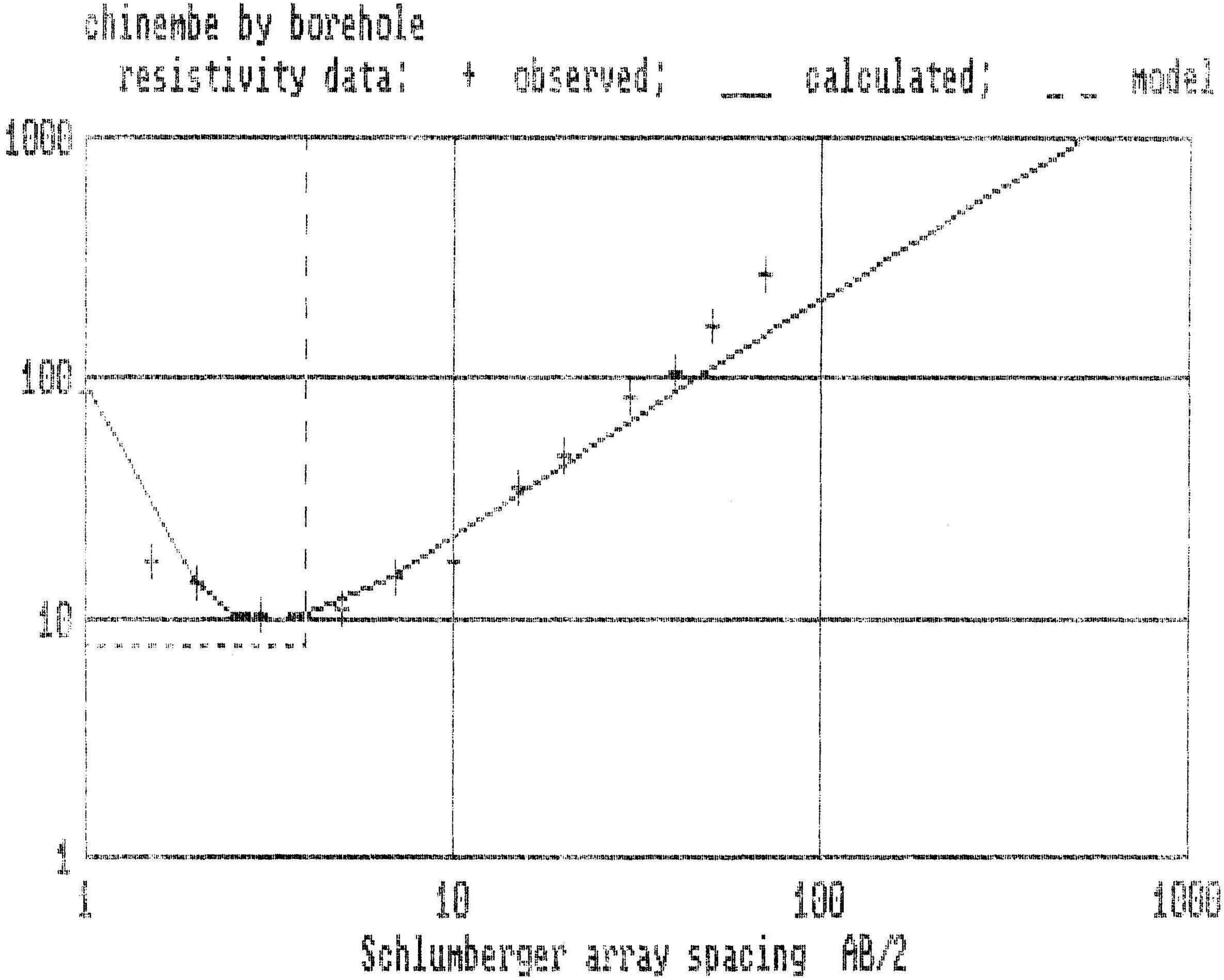
chinembire EM34 traverse no.1
V 20m
V 40m
H 20m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
outcrop
garden
dyke
adjacent to borehole
VES
well
outcrop
350.00
250.00
150.00
50.00
distance (m)
bearing 210 M


Chinembire EM34 traverse no. 2
V 20m
V 40m
H 20m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
outcrop
gulley
outcrop
350.00
250.00
150.00
50.00
distance (m)
bearing 210 M


Chinembire EM34 traverse no.3
V 20m
V 40m
H 20m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
outcrop >
< outcrop
350.00
250.00
150.00
50.00
distance (m)
bearing 210 M

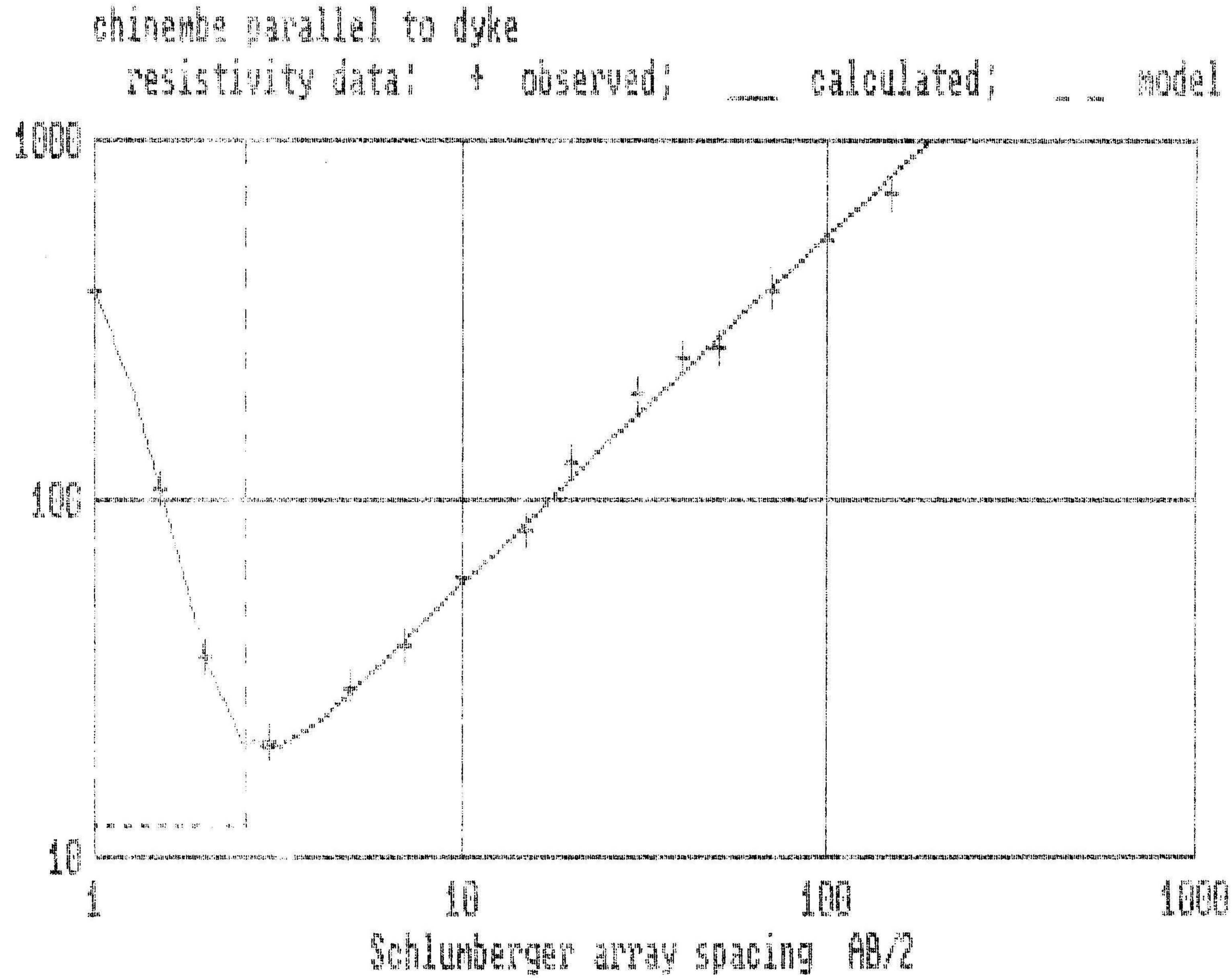


Chinembire EM34 traverse no.4
V 20m
V 40m
H 20m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
coppice >
outcrop
outcrop
track
vlei/
dyke
350.00
250.00
150.00
50.00
distance (m)
bearing 210 M



Model parameters for site:
chinembe

Layer	Thickns.	Restvty.	Depth
1	0.40	300.00	0.40
2	3.58	7.75	3.98
Substrait		10000.00	*****

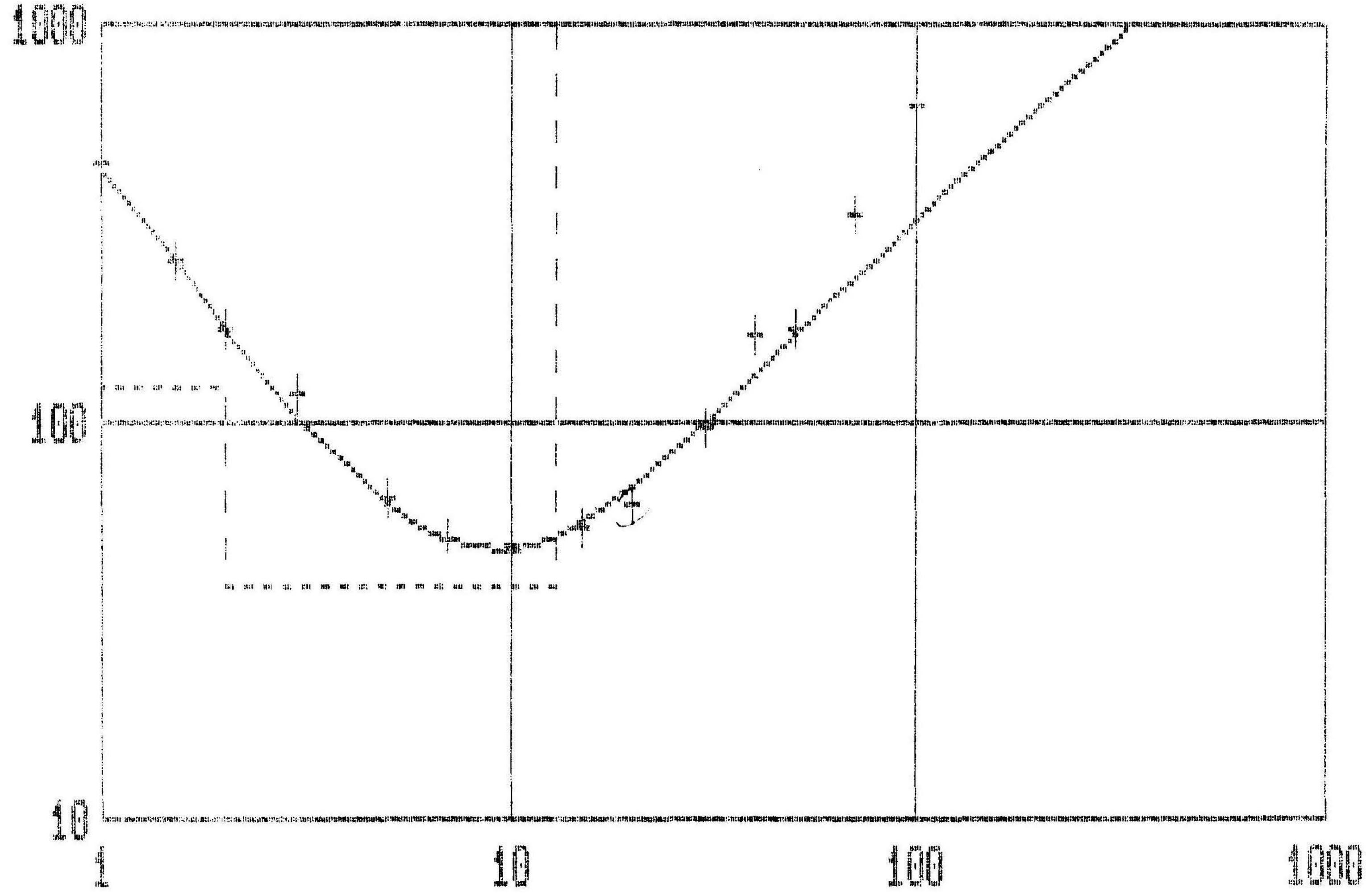


Model parameters for site: chinembe

Layer	Thickns.	Restvty.	Depth
1	0.40	1350.00	0.40
2	2.18	12.50	2.58
Substrait		10000.00	*****

chinembi below valley constriction

resistivity data: + observed; __ calculated; __ model



Schlumberger array spacing AB/2

Model parameters for site:

chinembe

Layer	Thickns.	Restvty.	Depth
1	0.50	780.00	0.50
2	1.50	120.00	2.00
3	11.00	38.00	13.00
Substrait		1000.00	*****

2.8. **Mhatiwa School**

Area F

Map 2030 B3, grid reference 249 7748

2.8.1. Introduction

Following work during the 1986 season (Smith and Raines, 1987), it was decided to continue investigation on the geophysically defined feature, which Greenbaum (1986) had recognised from aerial photography, in order to provide a alternative site for a borehole. Further investigation in 1987 (Greenbaum and Wright, personal communication) identified an intersecting lineament with a NW-SE trend and sub-surface barriers causing shallow water tables, which are currently being exploited as reliable hand-dug wells, which provide potable and horticultural water. The possibility of a borehole site close to these wells, or on the NW trending feature was also to be investigated.

2.8.2. Geophysical studies

Some 400m north of the existing borehole (JP 5849), below the confluence of a secondary valley, the combination of a VES and ground conductivity survey was measured. The EM showed a small thickness of saprolite, and evidence of a double fracture system, although the response is not strong. The VES indicated some 2m thickness of saprolite with a resistivity of 12 ohm m, but is probably to the west of the maximum development.

A second EM traverse runs from outcrop, past the hand-dug well and garden, and onto outcrop. It indicates steep-sided conductivity variations. The VES suggests at least 3m of rather low resistivity (25 ohm m) saprolite over bedrock. A greater thickness is probable some 50m to the east, as indicated on the EM traverse.

The third site on the NW-SE trending vlei was investigated, with an EM traverse and VES. There is evidence of a steep sided conductive anomaly at 70-80m, and an increase in saprolite thickness to the north-east. The VES was measured on the site of thickest overburden; a depth of 5m of saprolite with a resistivity of about 30 ohmm is demonstrated. This position was pegged.

Prof. Griffiths measured a MRT across the fracture at the borehole, and the results are shown in his progress report (Griffiths 1987).

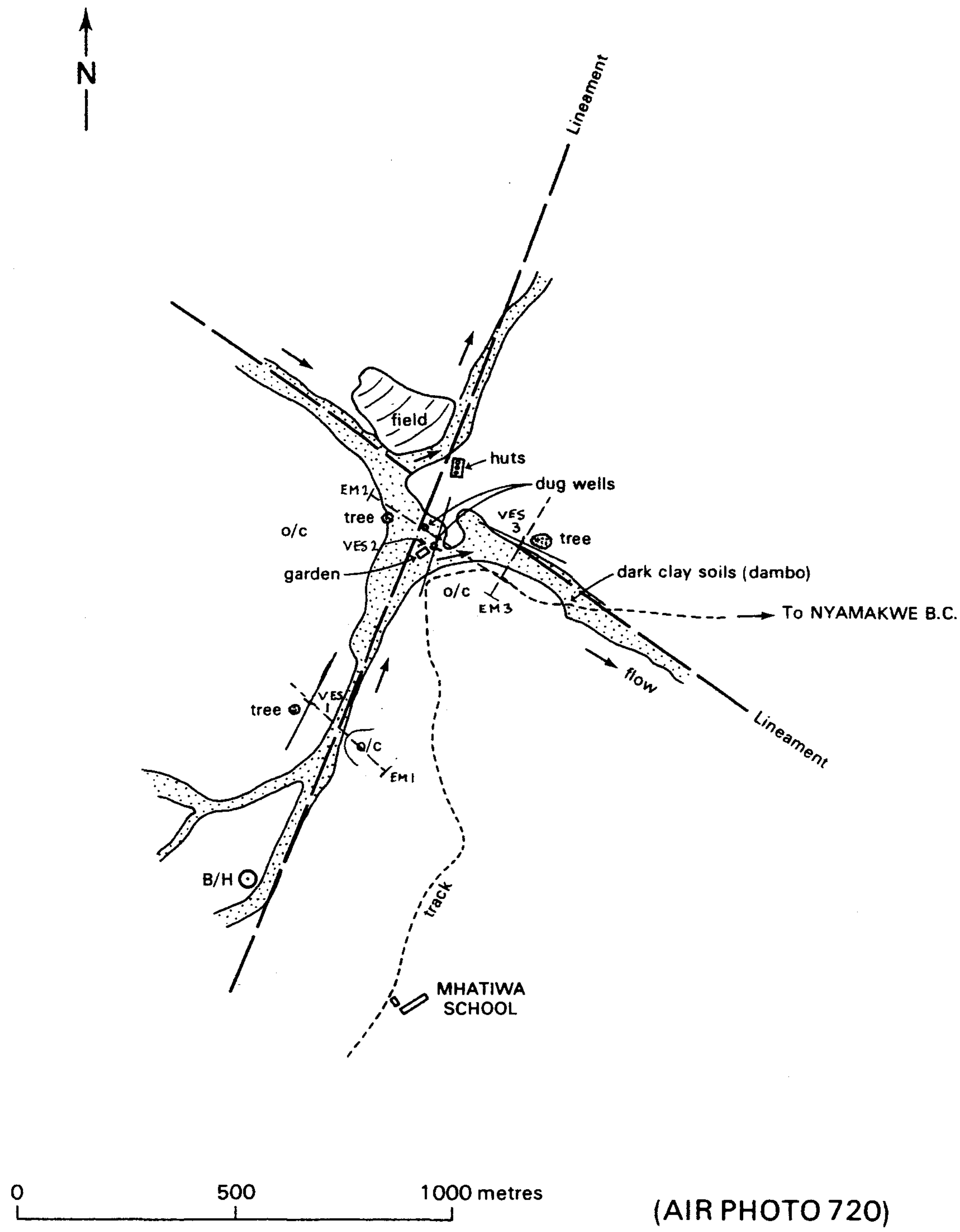
2.8.3. Discussion

All the EM traverses show suggestions of a fracture running beneath the vlei, although none are as clear as the results from the 1986 survey by the borehole. There is some evidence of a more complex fracture system (maybe a double) or perhaps the subsurface topography is more complex. Throughout this area the saprolite is thin, perhaps no more than 6m, and does not lie symmetrically across the vlei or the fractures. In general the resistivity of the saprolite is low, indicating a clay-rich type. Perhaps the hand-dug well might prove to be more effective in this environment than a borehole, even if the latter did intersect a fracture system.

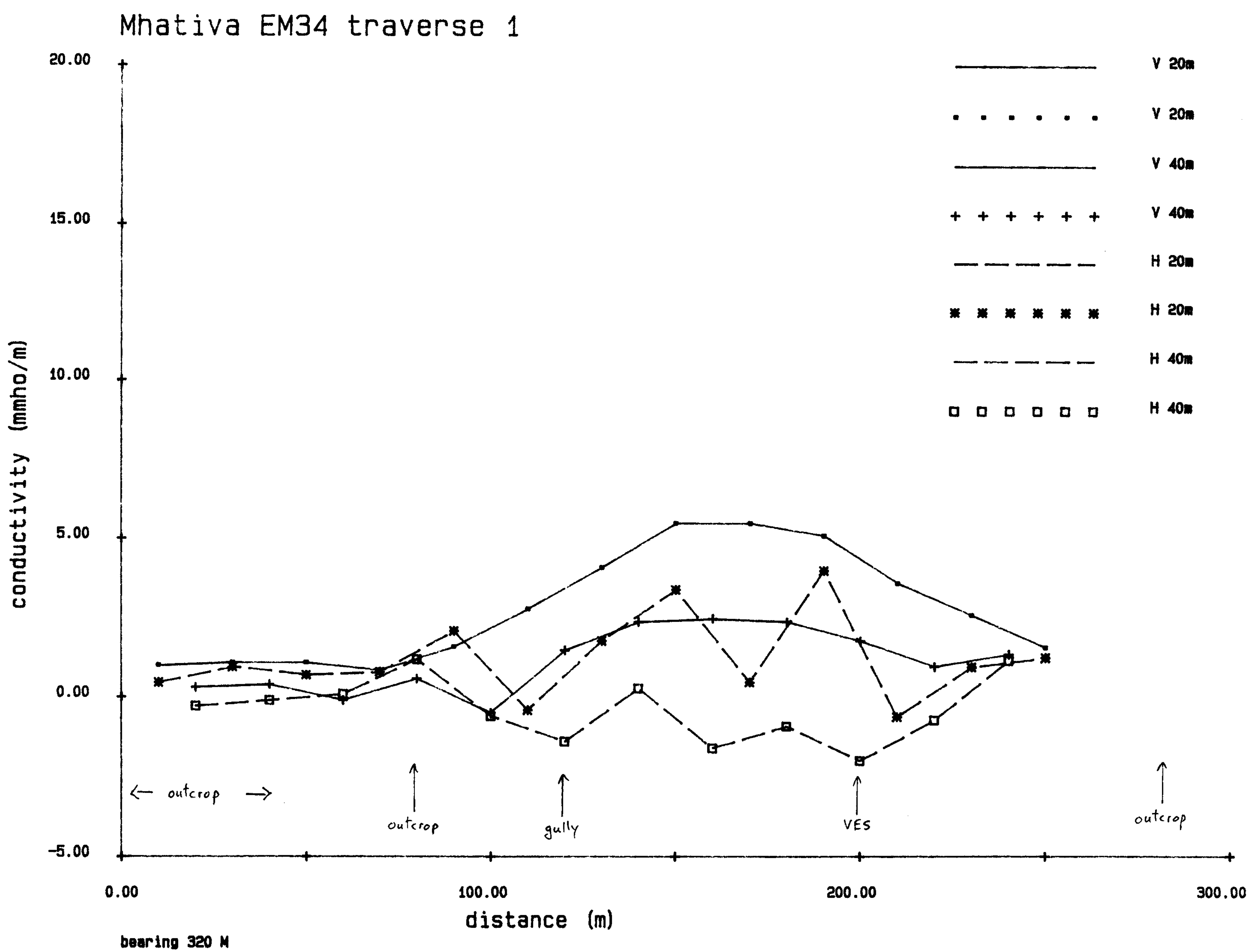
2.8.4. Conclusions

A well-defined fracture system is considered to continue from borehole JP5849 to the NE, although with a smaller response than identified at the borehole. Thickness of saprolite probably nowhere exceeds 6m, and the thickest development does not follow the lowest point of the vlei. A peg was inserted at the site of maximum development on the site below the hand-dug well, where a dug-well might provide an appropriate water supply.

MHATIWA SCHOOL: AREA F: MAP 2030 B3

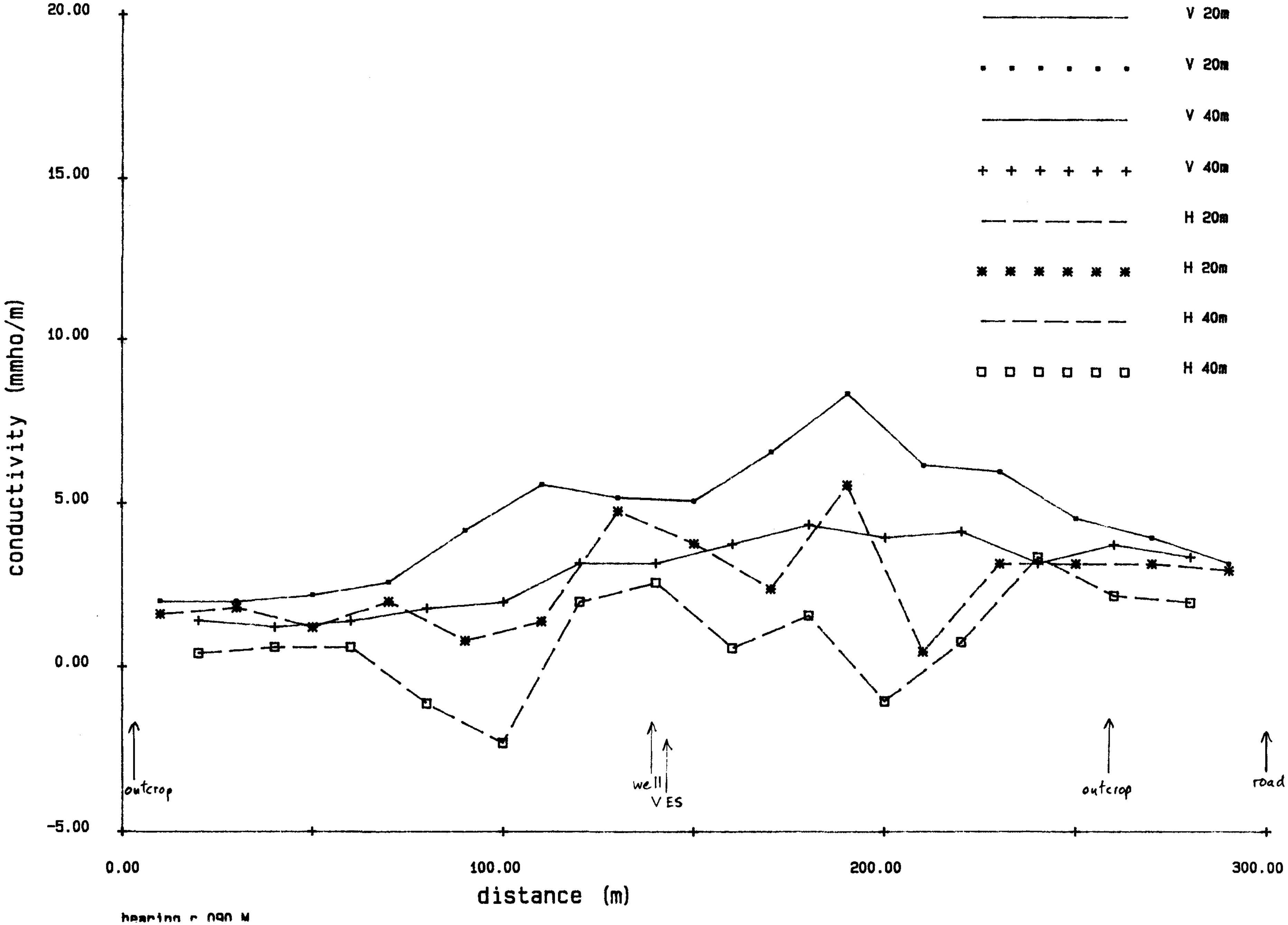


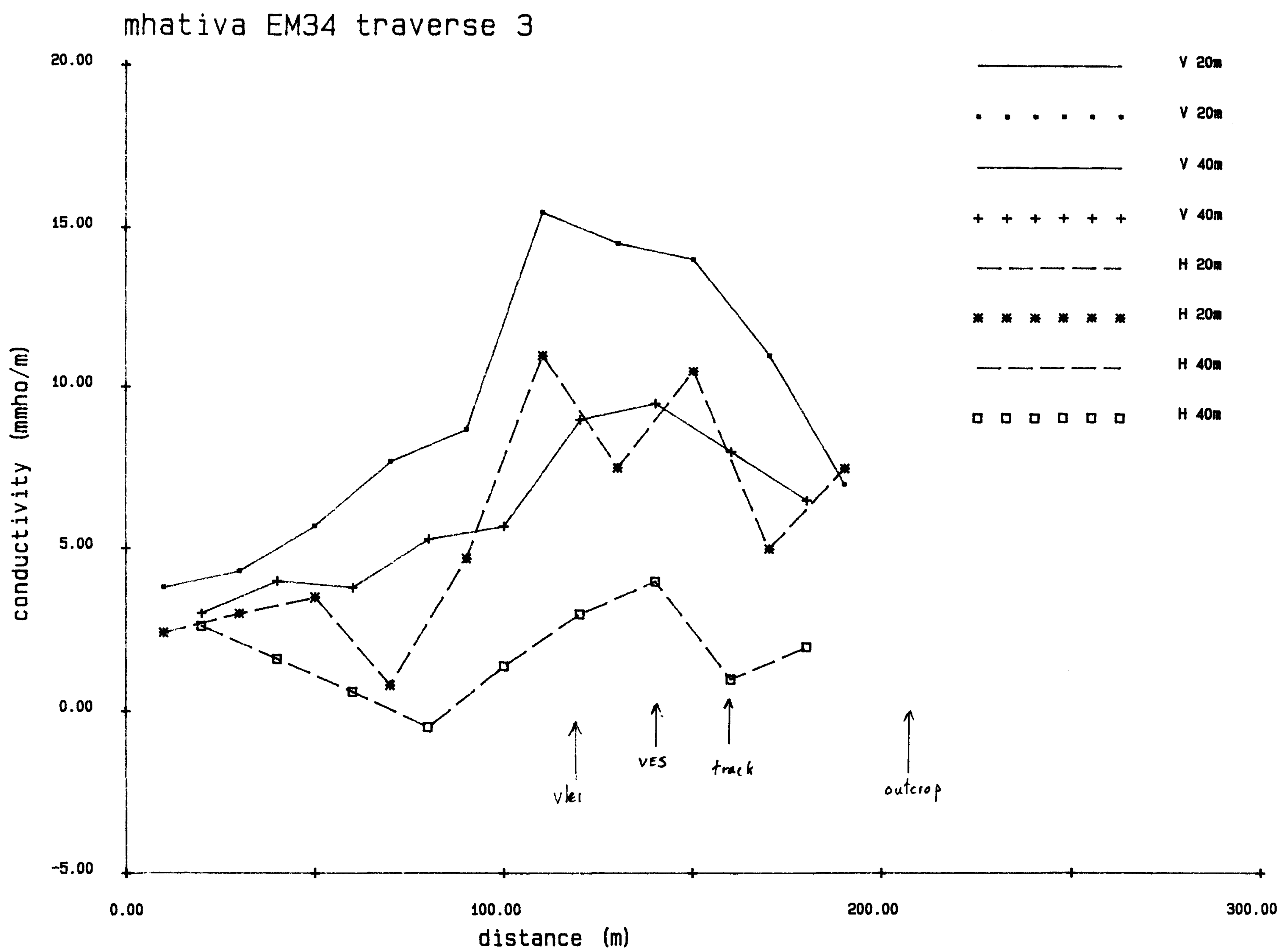
(AIR PHOTO 720)



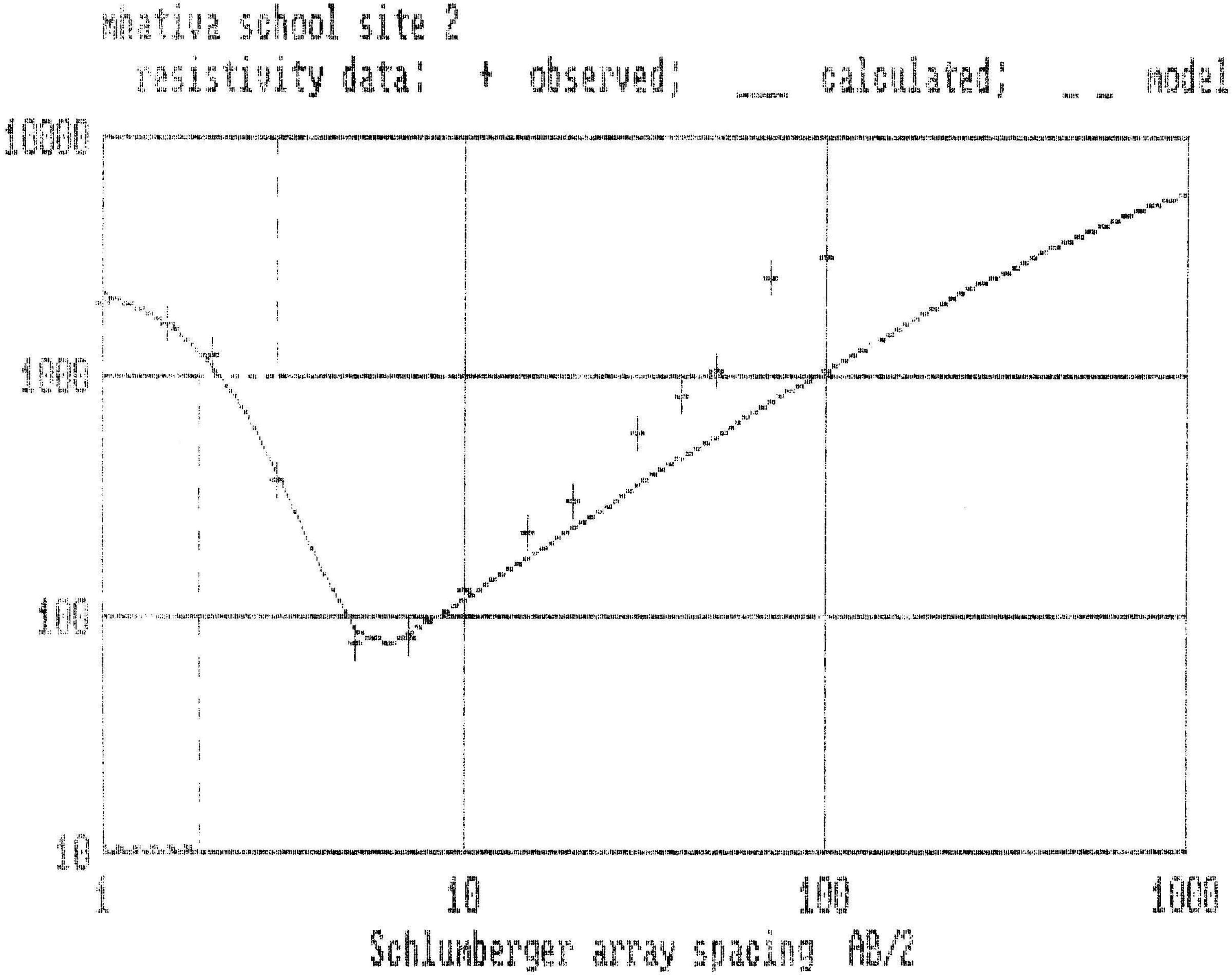
Mhativa EM34 traverse 1
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
outcrop
gully
VES
outcrop
0.00
100.00
200.00
300.00
distance (m)
bearing 320 M

Mhativa EM34 traverse 2



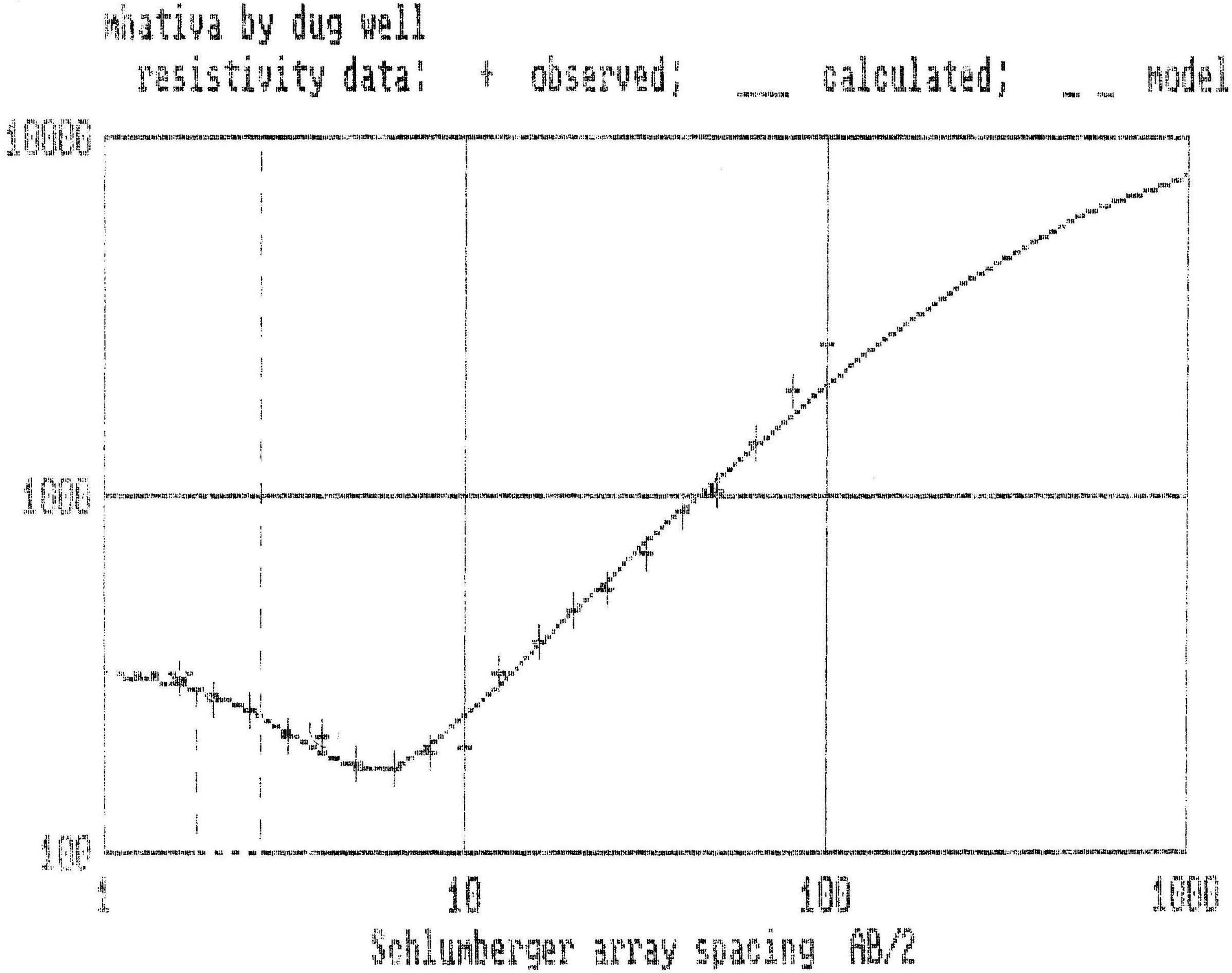


mhativa EM34 traverse 3
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
0.00
100.00
200.00
300.00
distance (m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
vlei
VES
track
outcrop



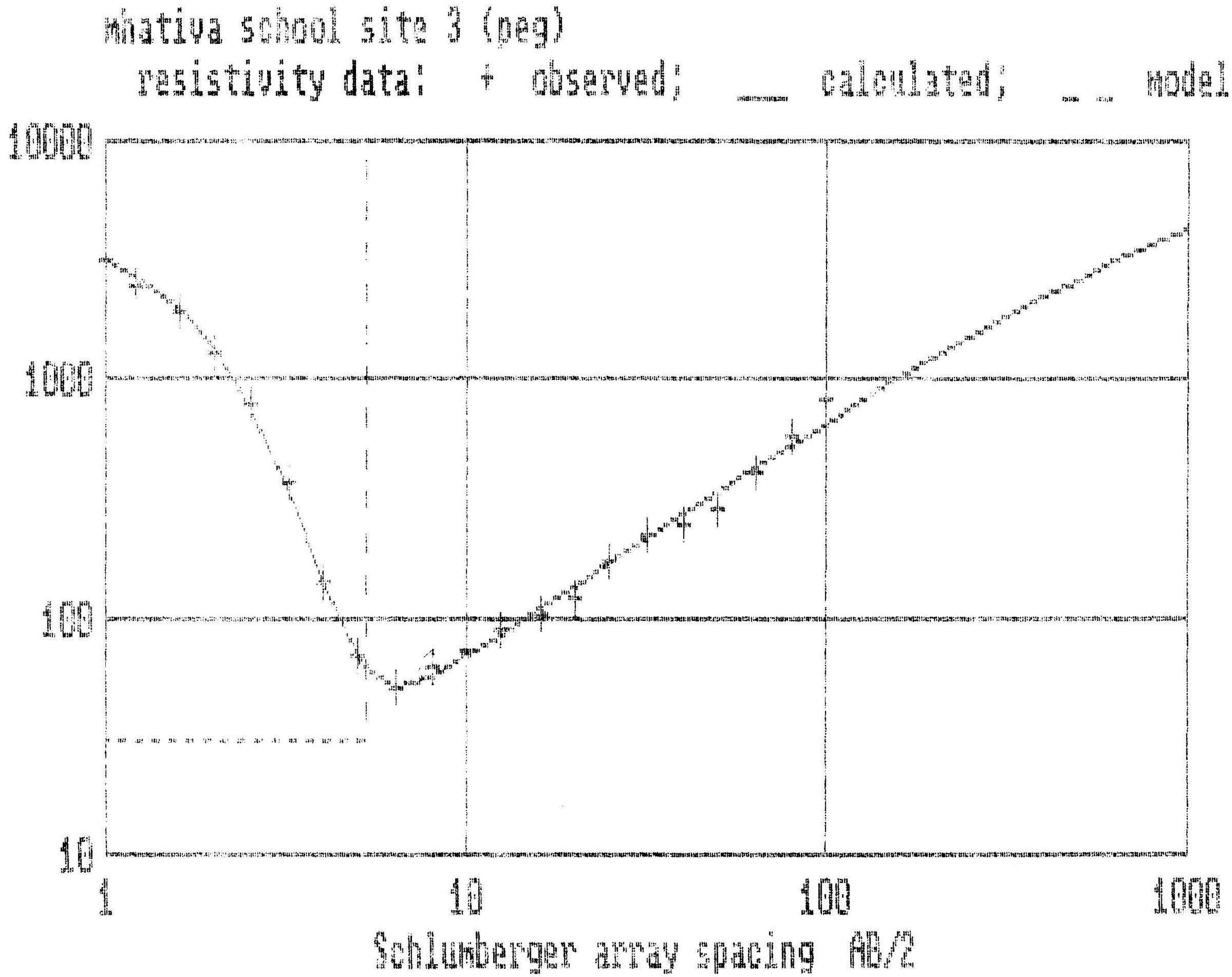
Model parameters for site:
mhativa school site 2

Layer	Thickns.	Restvty.	Depth
1	0.95	2700.00	0.95
2	0.90	10.65	1.85
3	1.15	1000.00	3.00
Substrait		1000.00	*****



Model parameters for site:
mhativa

Layer	Thickns.	Restvty.	Depth
1	1.60	320.00	1.60
2	0.90	25.50	2.70
Substrait		10000.00	*****



Model parameters for site:
mhativa school site 3

Layer	Thickns.	Restvty.	Depth
1	0.67	4000.00	0.67
2	4.38	30.00	5.25
Substrait		1000.00	*****

2.9. **Matatire School**

Area G

Map no. 1930 D4, grid reference 278 7801

2.9.1. Introduction

Greenbaum and Wright (personal communication) identified a lineament running NW-SE along a shallow vlei, and suggested that the water-table might be relatively shallow. Two hand-dug wells were identified, the one at the NW of the vlei containing standing water at a depth of about 1.5m (July), and the one on EM traverse no.1 was dry at about 1.5m.

2.9.2. Geophysical studies

2 EM traverses were run across the vlei to cross the proposed line of the lineament about 100m apart. On both a 'dyke-like' anomaly was seen, although the SE traverse (no.2) showed a rather complex pattern, probably arising from non-linear features. The minima in horizontal coils responses fell over the trace of the lineament in both cases. The VES was measured over the EM hoizontal coil minimum on traverse no.1 and indicated a minimum thickness of 5m of saprolite with a resistivity of 33 ohm m, ranging up to about 15 ohm m. The VES site was pegged.

2.9.3. Discussion

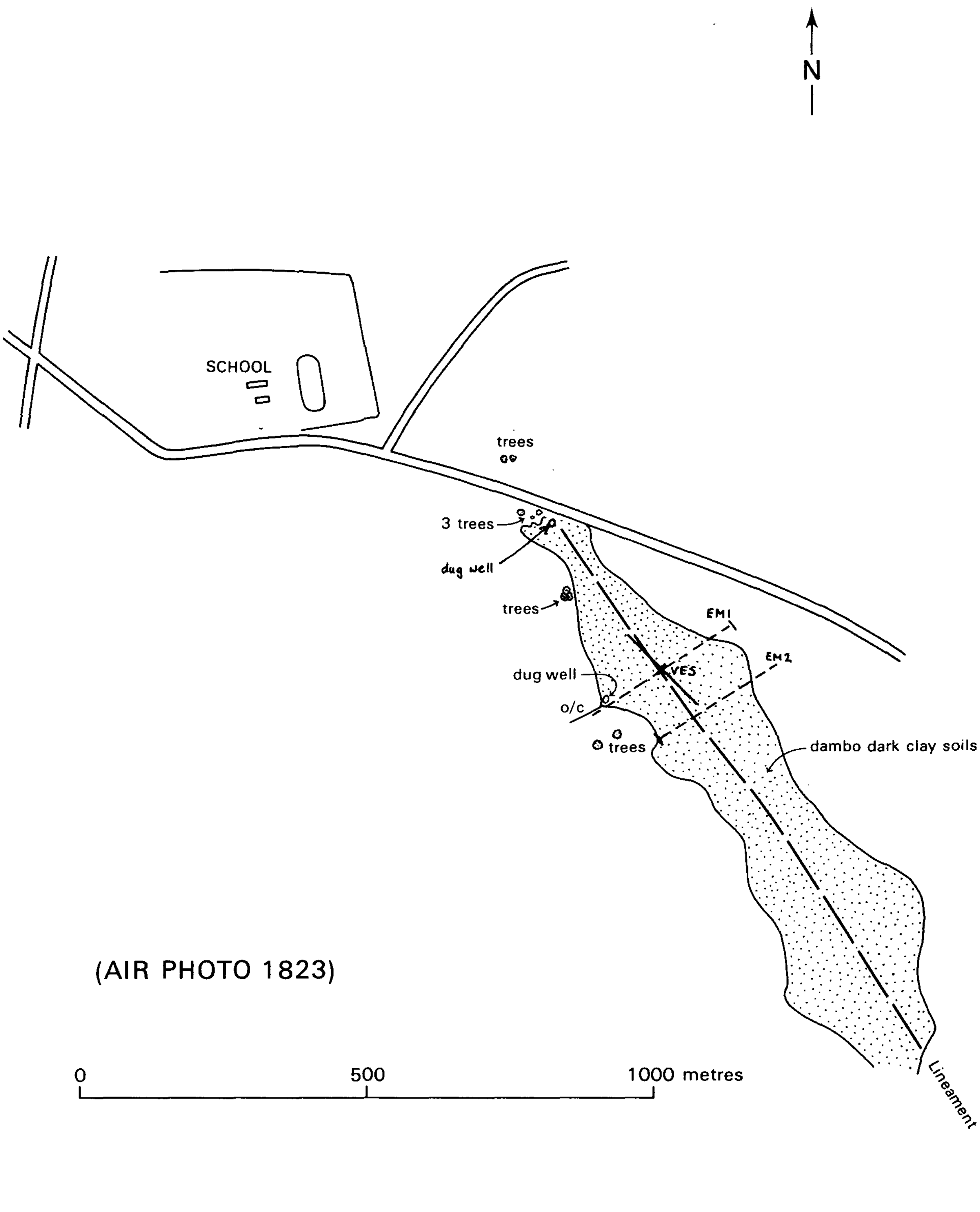
The EM traverses suggest a continuous steep-sided conductive feature runs along the valley bottom, although the anomaly is apparently modified by perhaps non-continuous cross cutting features, which give the surface expression of isolated blocky outcrops.

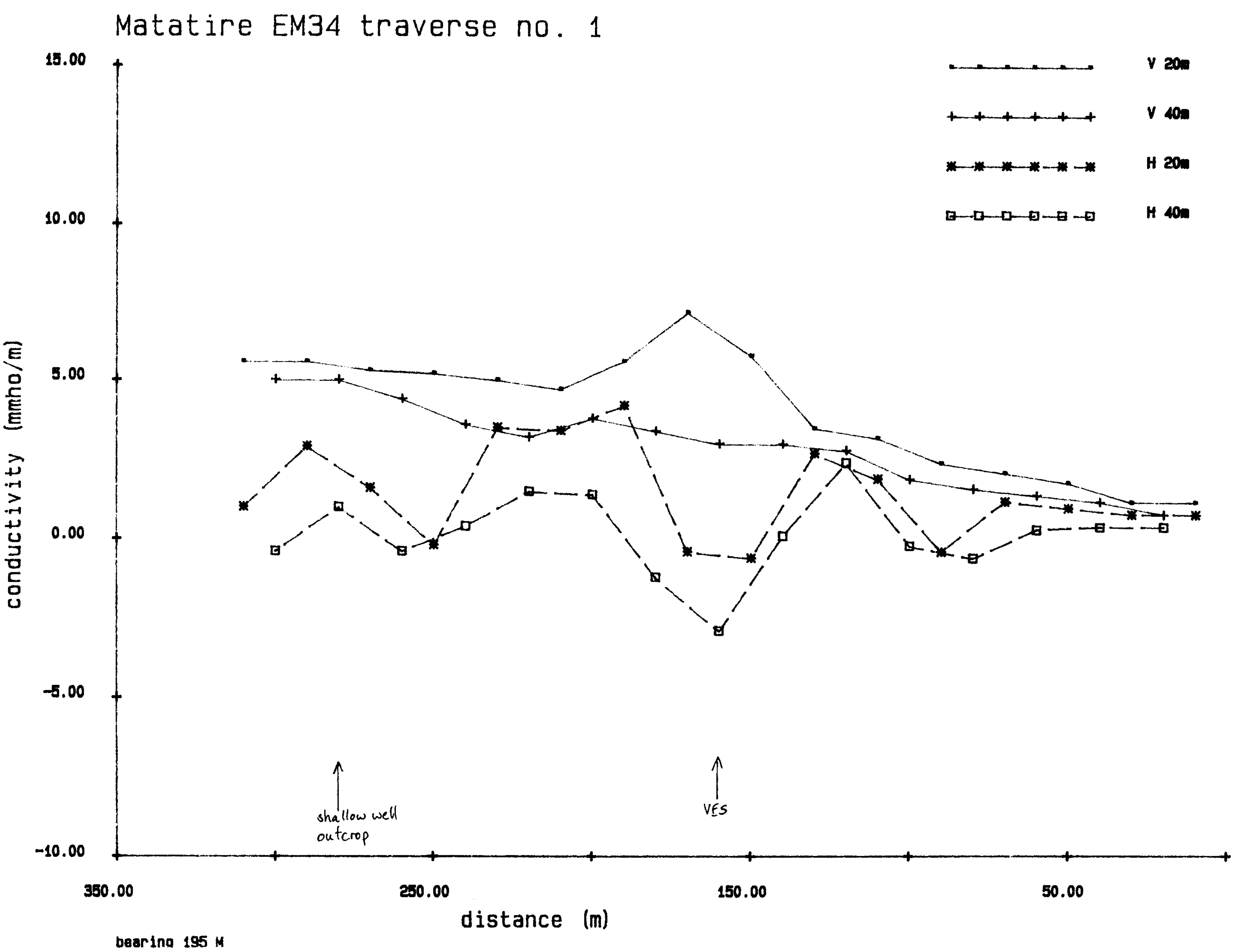
The VES identifies the mean thickness of the overburden beneath the array, rather than at a point, so the depth indicated from resistivity interpretation may not co-incide with any proposed borehole on the VES site.

2.9.4. Conclusion

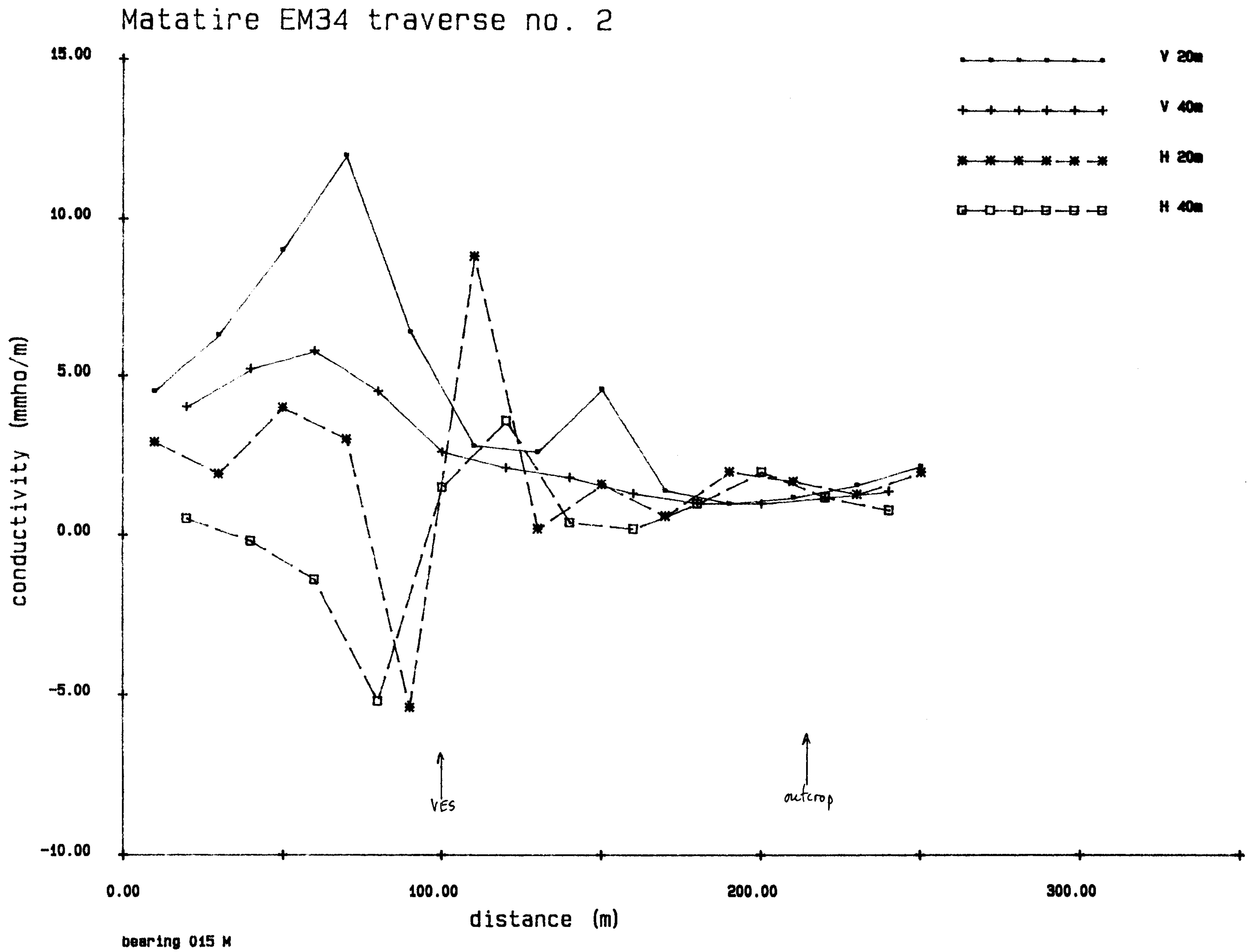
The EM traverses confirm the sub-surface expression of the lineament as a steep-sided conductivity feature, probably a fracture system. The VES suggests an average saprolite thickness for the vicinity of at least 5m, with a high clay content. Even if a borehole intersected a fracture, this might be a suitable site for a hand-dug/collector well.

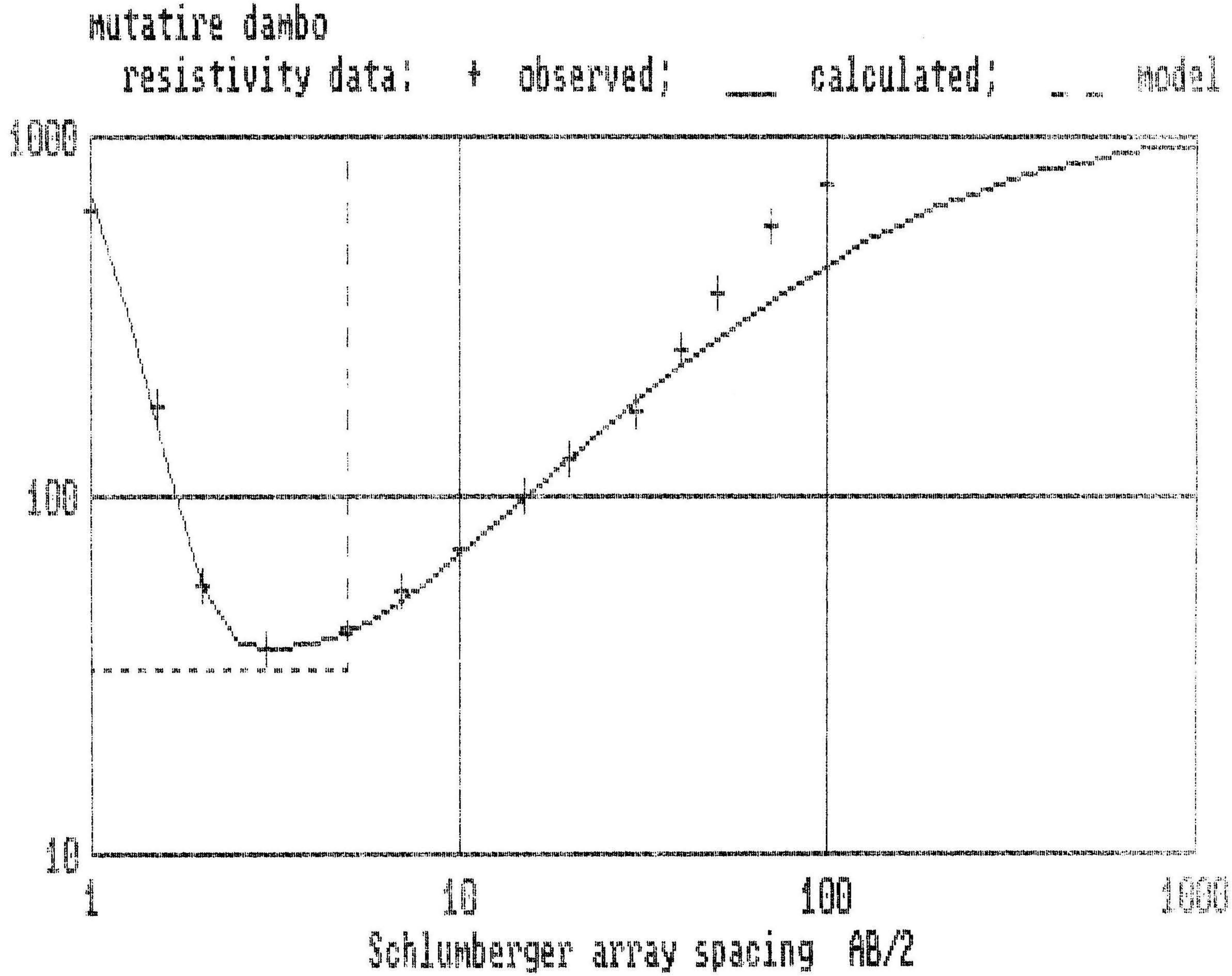
MATATIRE SCHOOL: AREA G: MAP 1930 D4





Matatire EM34 traverse no. 1
V 20m
V 40m
H 20m
H 40m
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
shallow well
outcrop
VES
350.00
250.00
150.00
50.00
distance (m)
bearing 195 M


Matatire EM34 traverse no. 2
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 40m
H 20m
H 40m
VES
outcrop
0.00
100.00
200.00
300.00
distance (m)
bearing 015 M



Model parameters for site:
mutatire dambo

Layer	Thickns.	Restvty.	Depth
1	0.34	3850.00	0.34
2	4.66	33.00	5.00
Substrait		1000.00	*****

2.10. Nanwi School

Area G

Map 1930 D4, grid reference 281 7797

2.10.1. Introduction

Greenbaum and Wright (personal communication) observed a lineament on aerial photography, which corresponded at one point wit a well-marked gully cutting through outcrop on either side. The reasonable suggestion was made that the gully was the surface expression of a fracture zone, also expressed as the lineament. A vlei ran from the gully in a SSE direction following the lineament. Ground conductivity surveys across the area should identify the geophysical expression of the lineament and its correlation with the gully.

A borehole (EEC54B) appears to be off the line of the vlei and the lineament, on a slight rise above the vlei.

2.10.2. Geophysical studies

Four ground conductivity traverses were measured across the vlei. The EM traverse no.1 crossed the gully and showed a negligible response in the vertical coil mode, indicating very thin saprolite, and only a minor response in the horizontal coil mode, with relatively negative values some 30-40m to the west of the gully.

EM traverse no.2 again indicated very thin regolith, even beneath the vlei, although there is an indication of steep-sided conductivity contrasts on the western side of the vlei, perhaps indicating a fracture system. EM traverse no.3 ran close to the borehole, and shows a stronger response in both coil modes. The greatest thickness of conductive saprolite is beneath the borehole, although a possible extension of the fracture system and lineament is marked by a duplex dyke-like anomaly across the vlei. The VES at the borehole cannot be uniquely interpreted, with a large amount of equivalence, but the depth to the base of the saprolite probably lies between 5 and 10m, and the saprolite resistivity may be about 80 ohm m.

EM no.4 ran across a subsidiary vlei, and indicates an increasing thickness of overburden towards the SE, and a fracture system in the environ of the vlei. At present we have no explanation of the very strong conductivity anomaly at the end of the profile, although further investigation proved its validity.

At several times during this survey, the Geonics EM16 (VLF receiver) was used, but as in previous experience, the signal strength was very weak, from both North Cape (Australia) and from Cutler, Maine (USA). Although a weak null could be obtained, perhaps verifying the presence of signal, it was not sufficiently precise to be used for survey purposes.

2.10.3. Discussion

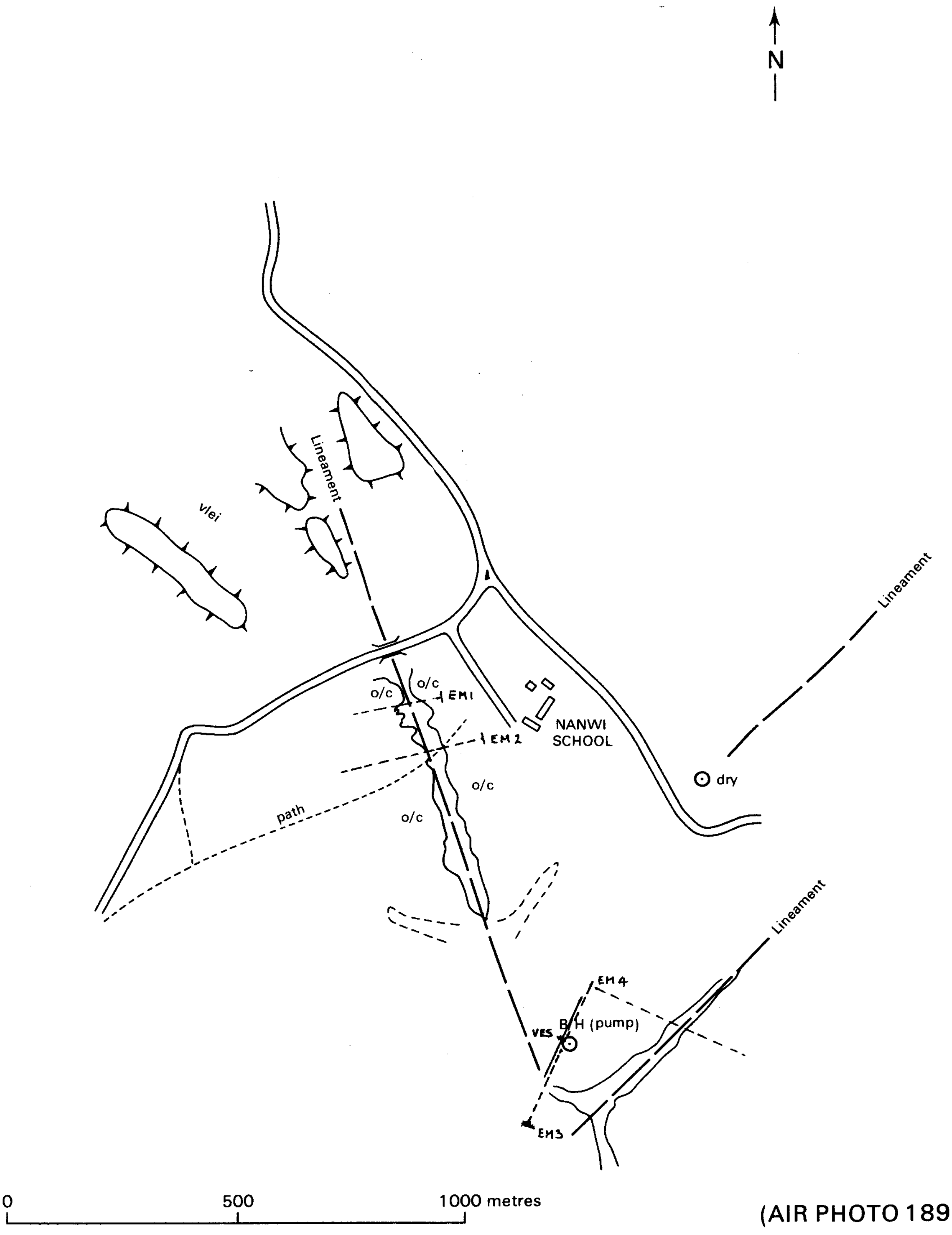
The EM results appear to demonstrate the existance of a fracture system running beneath the vlei, which also gives rise to the lineament on the aerial photography. However it seems likely that the gully crossed on traverse no.1 is not directly associated with the rather weak EM feature, which lies 40m to the west and passes beneath minor outcrops and broken ground. It will be most interesting to drill this feature and identify the correlation between the various aspects.

The borehole lies off the EM feature, and hence might not be benefitting from the possible fracture system. The VES suggests that the saprolite thickness is well below what is recommended by the Master Plan criteria for siting.

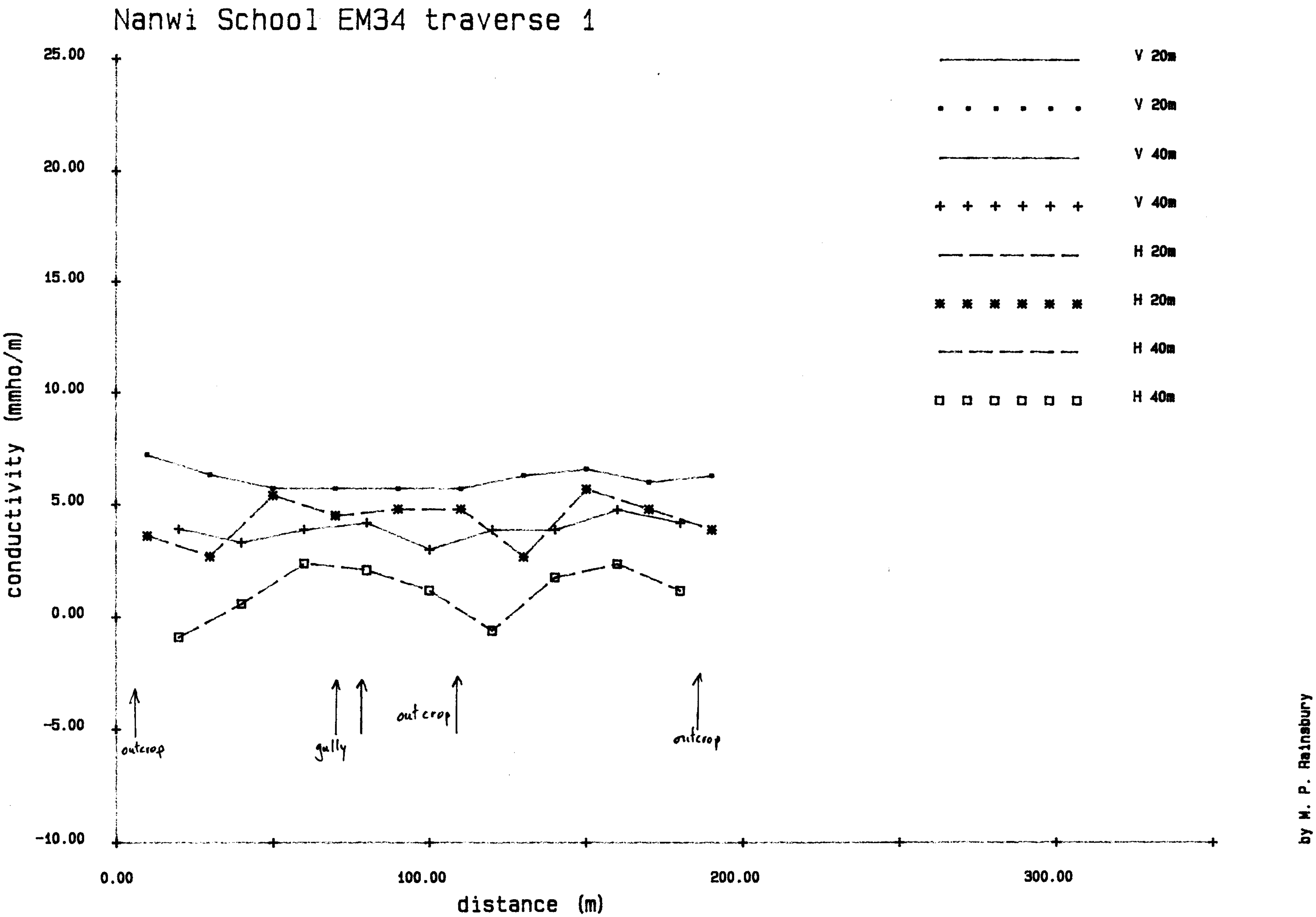
2.10.4. Conclusion

The correlation between a gully, lineament observed on aerial photography and EM anomaly should be investigated by an inclined borehole. Improved yield for the existing borehole might be achieved by drilling in the vlei to intersect the fracture system.

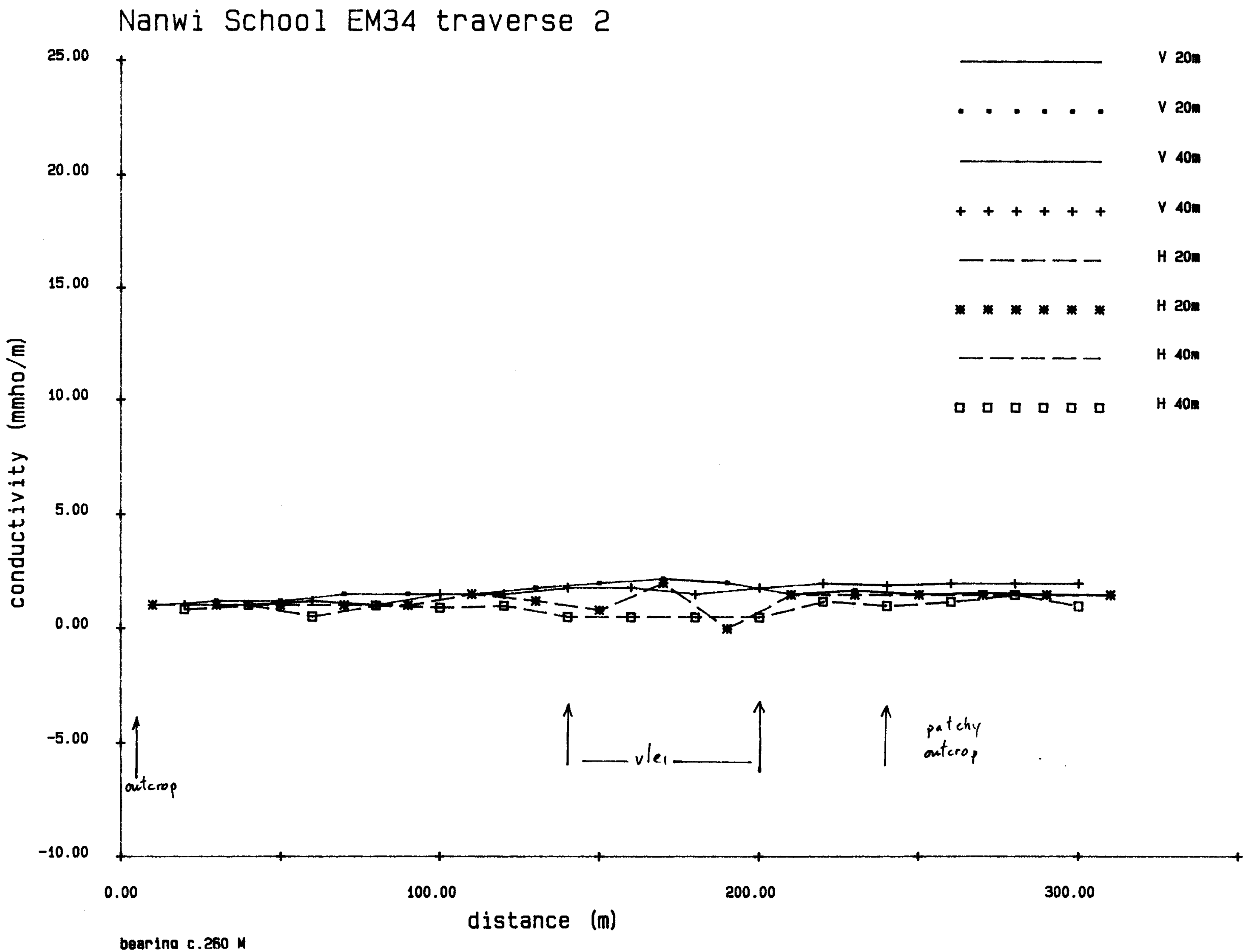
NANWI SCHOOL: AREA G: MAP 1930 D4

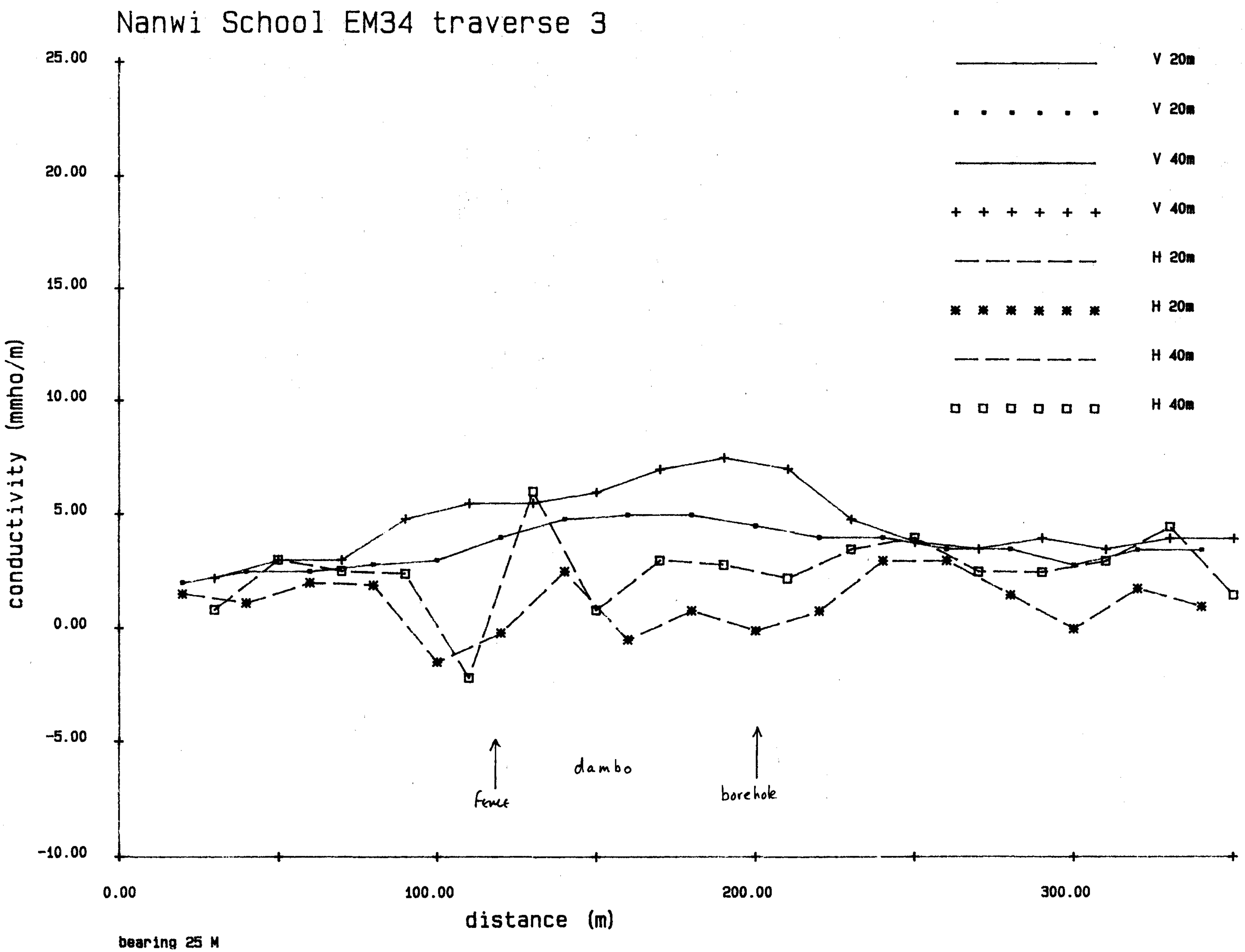


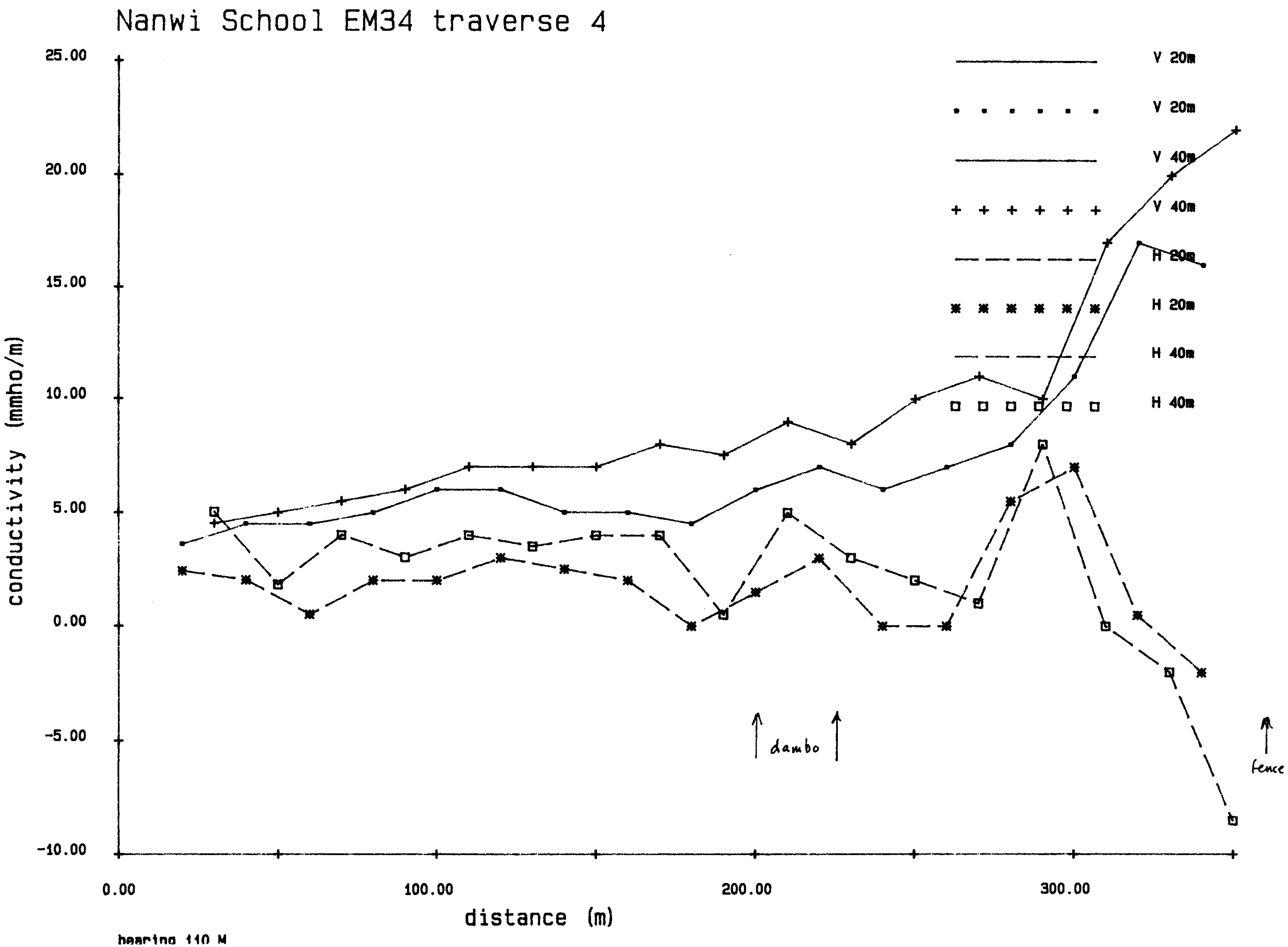
(AIR PHOTO 1899)



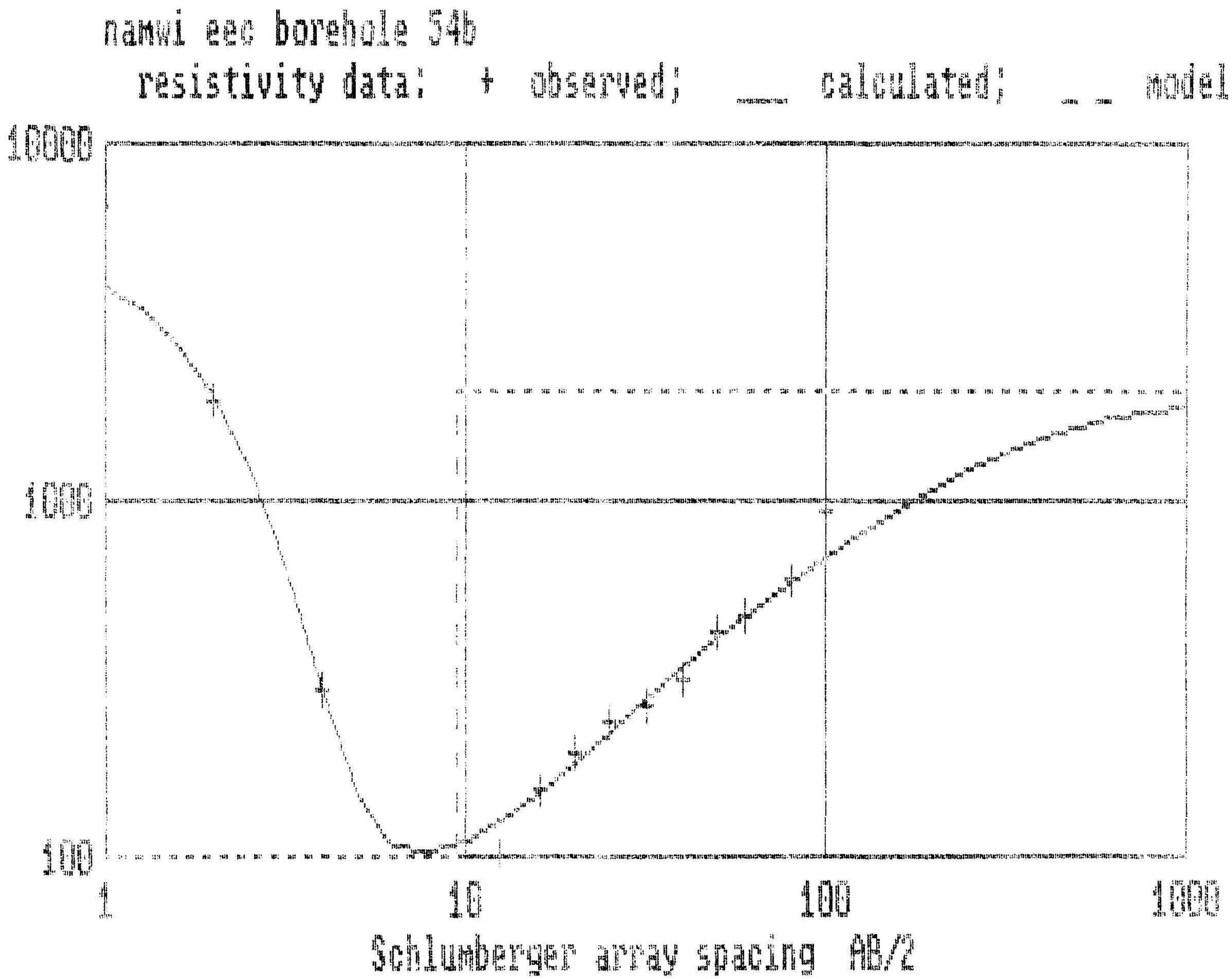
Nanwi School EM34 traverse 1
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
0.00
100.00
200.00
300.00
distance (m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
gully
outcrop
outcrop
by M. P. Rainsbury


Nanwi School EM34 traverse 2
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
vlei
patchy outcrop
0.00
100.00
200.00
300.00
distance (m)
bearing c.260 M


Nanwi School EM34 traverse 3
conductivity (mmho/m)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
0.00
100.00
200.00
300.00
distance (m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
fence
dambo
borehole
bearing 25 M



Nanwi School EM34 traverse 4
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
dambo
fence
0.00
100.00
200.00
300.00
distance (m)
bearing 110 M



Model parameters for site:
namwi

Layer	Thickns.	Restvty.	Depth
1	0.95	4900.00	0.95
2	8.55	85.00	9.50
Substrait		2000.00	*****

2.11 Nemarundwe Schools

Area G

Map 1930 D4, grid reference 282-3 7800-1

2.11.1. Introduction

Following the identification of a strong lineament (Greenbaum 1986), two reconnaissance surveys were carried out in this area in 1986 and the results were reported in Smith and Raines (1987). Small features on the EM traverses across the lineament south-east of the primary school were tentatively presumed to be geological noise rather than related to the lineament, but subsequent discussion suggested that further traverses down-vlei might prove interesting.

The yield from a hand-dug well to the south of the secondary school was proving inadequate for the school. The well was reported (local sources) to be 32 feet (c.10m) deep with the rest water level at 2m (following a 2 month period when the pump had broken down). A geophysical inspection of the site was suggested might yield some information on the structure of the broad vlei, which ran from the well to the south-east.

2.11.2. Geophysical studies

Vlei site
Two EM traverses were measured across the vlei and down the valley parallel to those from the 1986 survey. A VES was measured at the banana garden on the line of EM traverse no.1.

The 2 EM traverses showed significant conductivity anomalies in both coil modes, in contrast with the 1986 results which had weak, insignificant features. The anomalies indicate a steep sided conductivity contrast, associated with the lineament, and an increased thickness of the saprolite across the zone. The VES indicated a depth to the base of the weathered layer of up to 8.5m, the maximum being shown by including a 6.6m layer of saprock (resistivity 600 ohm m) beneath 2m of saprolite, with a resistivity of 30 ohm m.

Hand-dig well site
At this site south of the secondary school, a VES was measured at the well and a ground conductivity traverse was run across the vlei, also past the well. The VES has been interpreted to show 3m of saprolite overlying saprock to a depth of 5m, which might not accord well with the reported depth of the well, which presumably did not penetrate the bedrock. The EM traverse shows little thickness of conductive saprolite, which reaches a local maximum some 50m to the SW of the present position. There is a clear but weak anomaly in the horizontal coil modes at this same point, which might indicate the existance of a fracture system.

2.11.3. Discussion

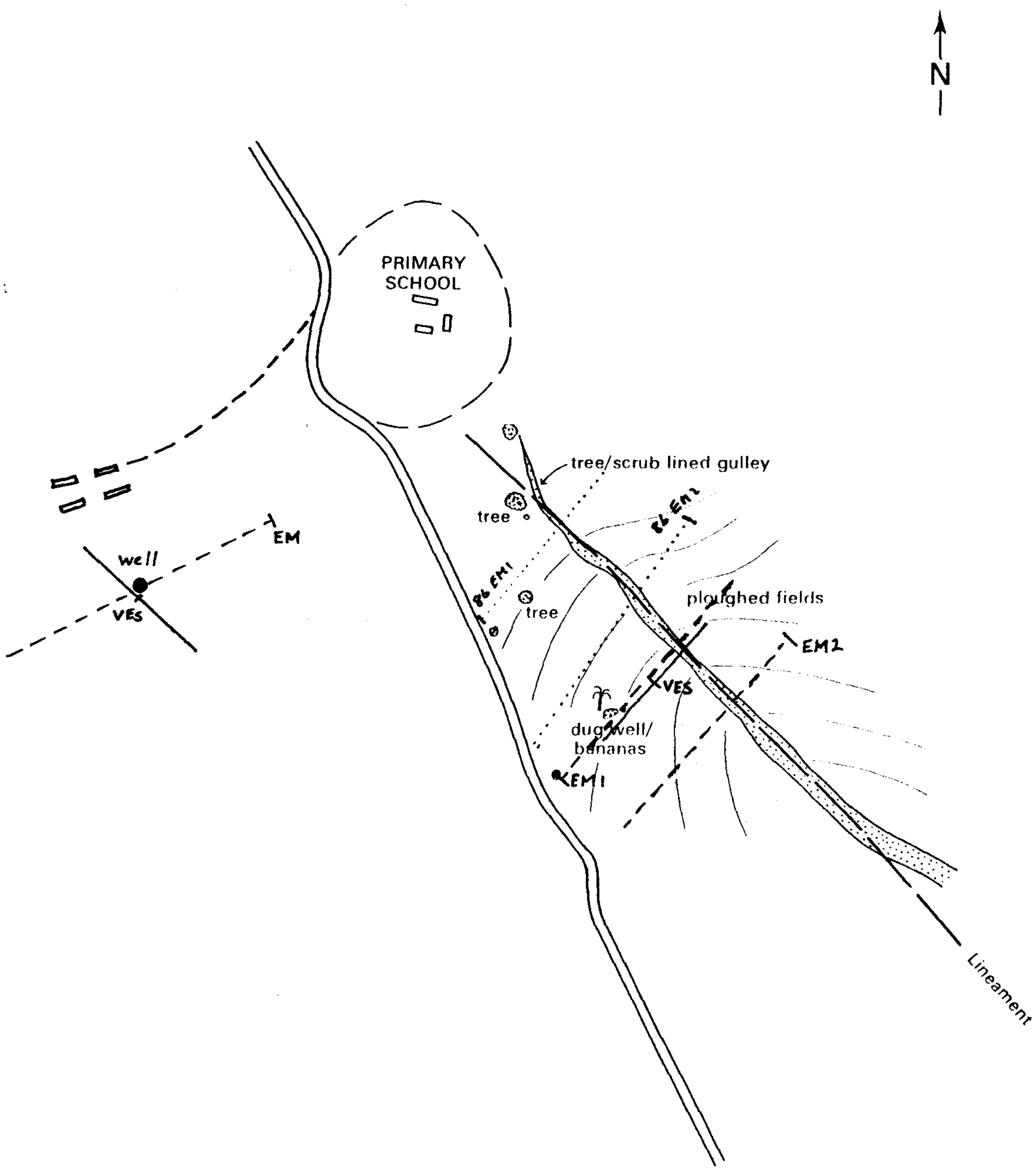
The results from the 1987 EM survey indicates that the anomaly magnitude has increased down-vlei (assuming that ground conductivity is not grossly different at depth at the times of the surveys). This would indicate that the weathering along the fracture is greater, perhaps because of the increased catchment and water flow. The thickness of saprolite nevertheless is generally quite thin throughout the area, as both the EM and VES results confirm.

2.11.4. Conclusions

There are strong indications of a vertical-sided conductivity contrast, related to a fracture system to the SE of the banana garden and a peg was inserted on EM traverse no.2 indicating the maximum anomaly. The overall thickness of saprolite in the vlei is thin, perhaps little more than 5m, although saprock may be developed beneath.

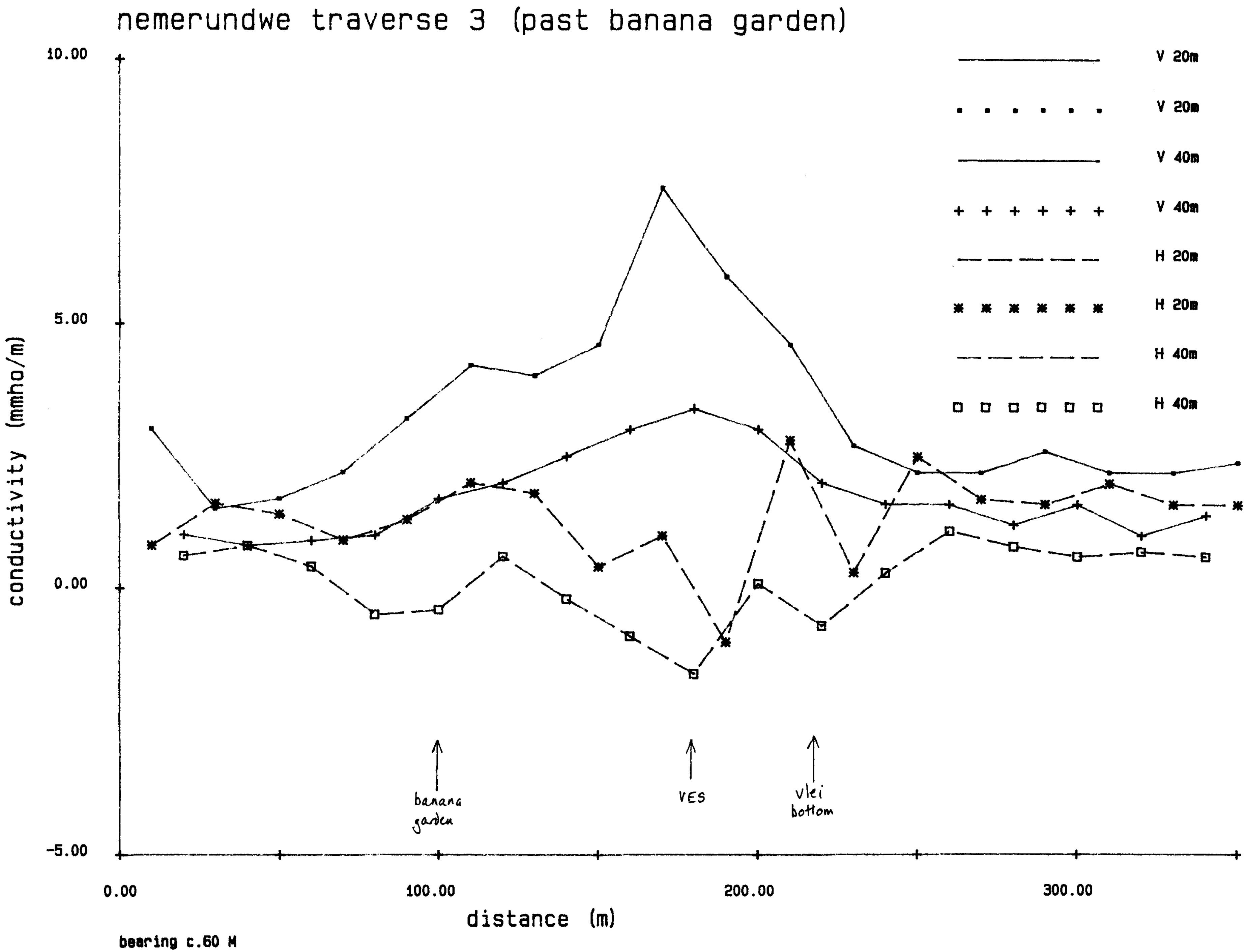
At the dug-well, the saprolite is also thin, but saprock may be present beneath. A greater thickness of weathered material might be intersected some 50m to the SW of the well, with the possibility of a fracture system running beneath.

NEMARUNDWE SCHOOLS: AREA G: MAP 1930 D4

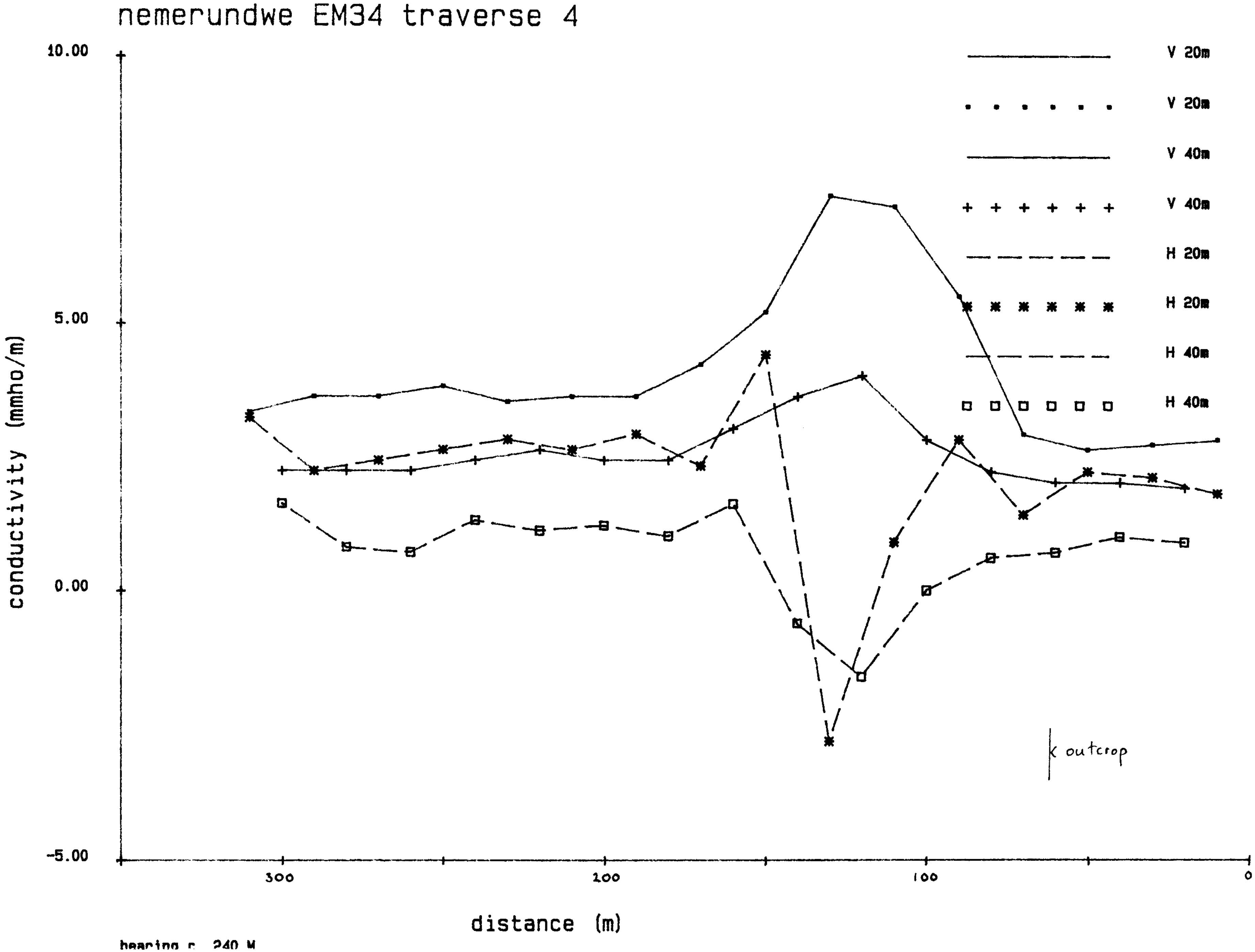


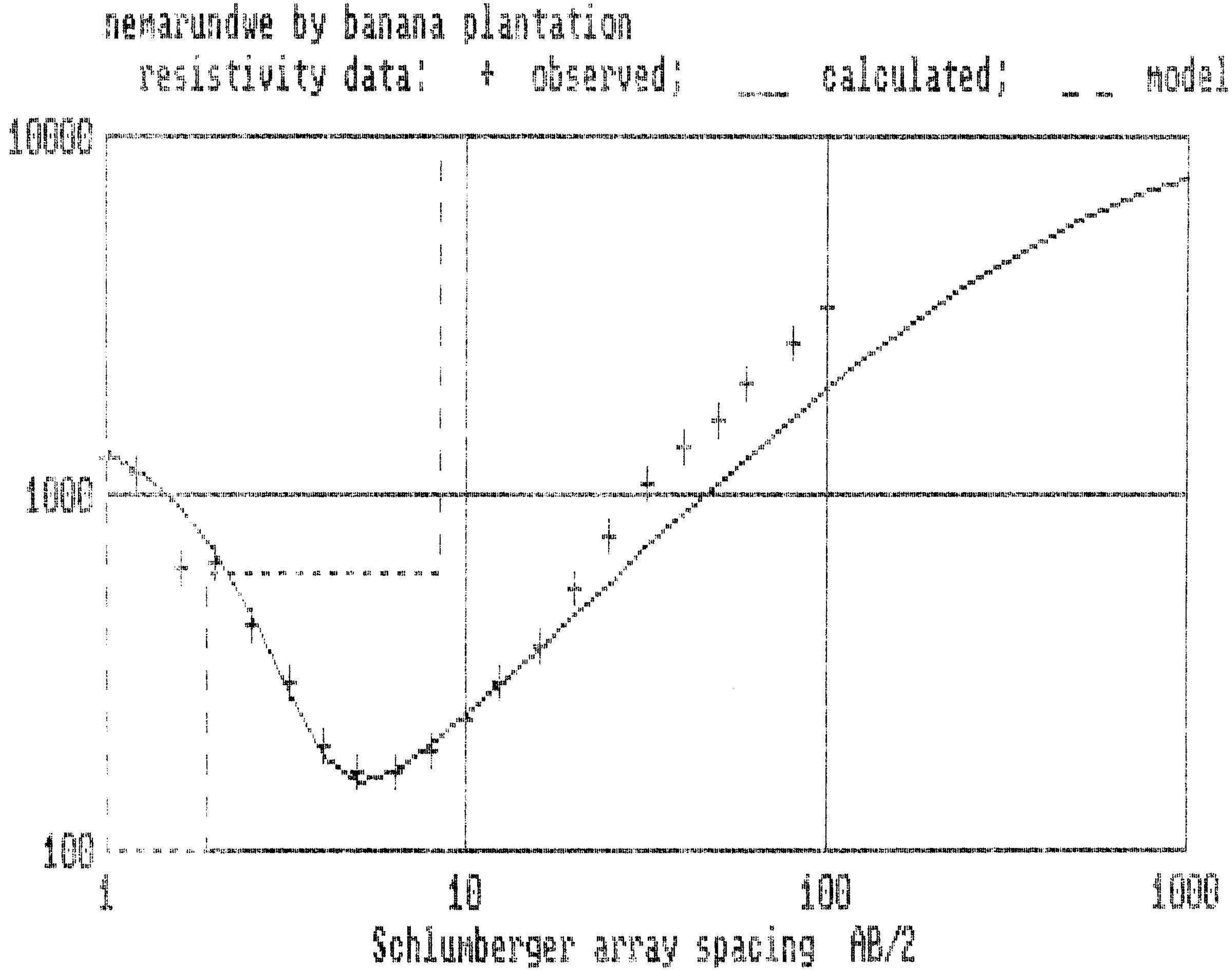
(AIR PHOTO 1825)

0 500 1000 metres



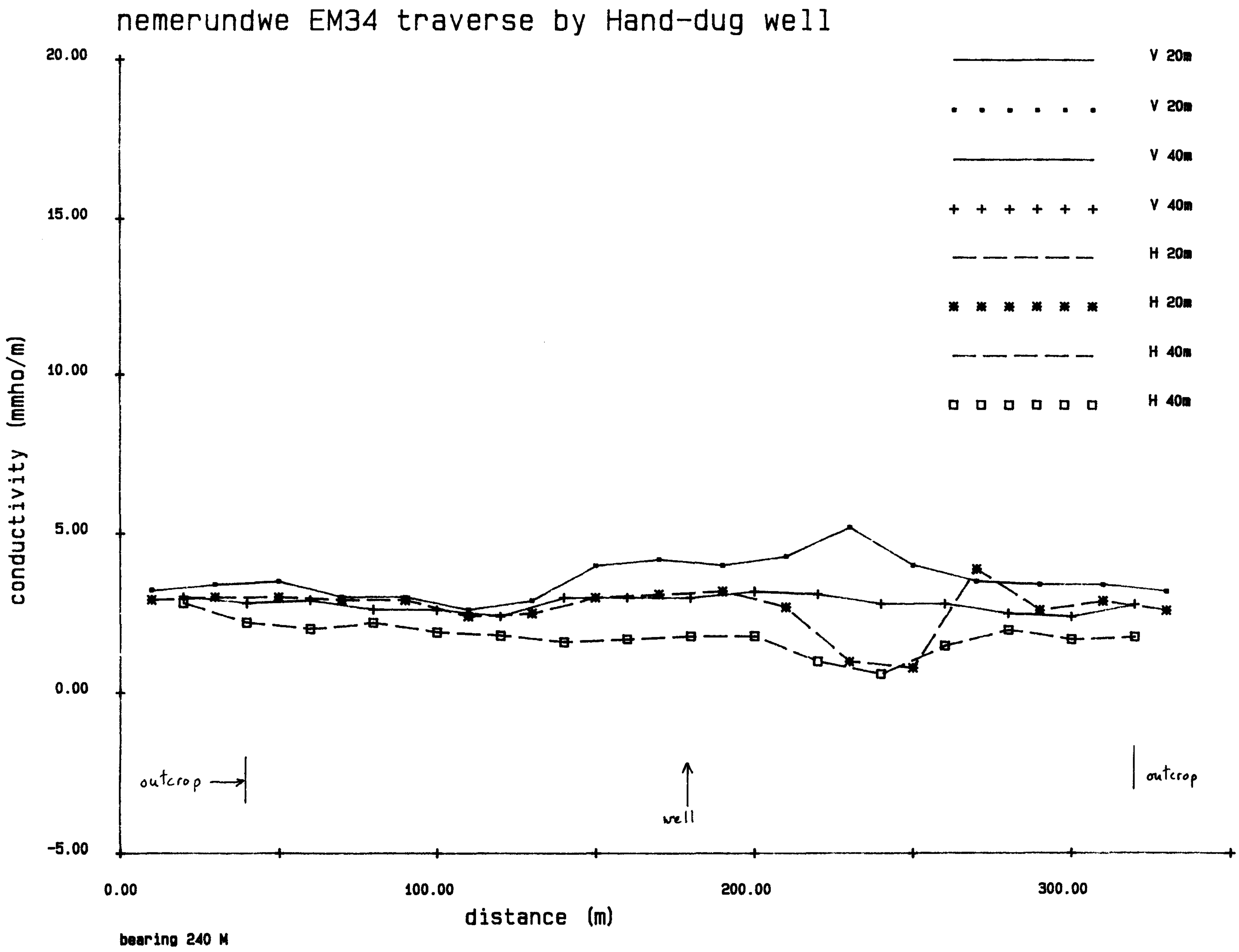
nemerundwe traverse 3 (past banana garden)
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
banana garden
VES
vlei bottom
0.00
100.00
200.00
300.00
distance (m)
bearing c.60 M


nemerundwe EM34 traverse 4
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
300
200
100
0
distance (m)
bearing c. 240 M

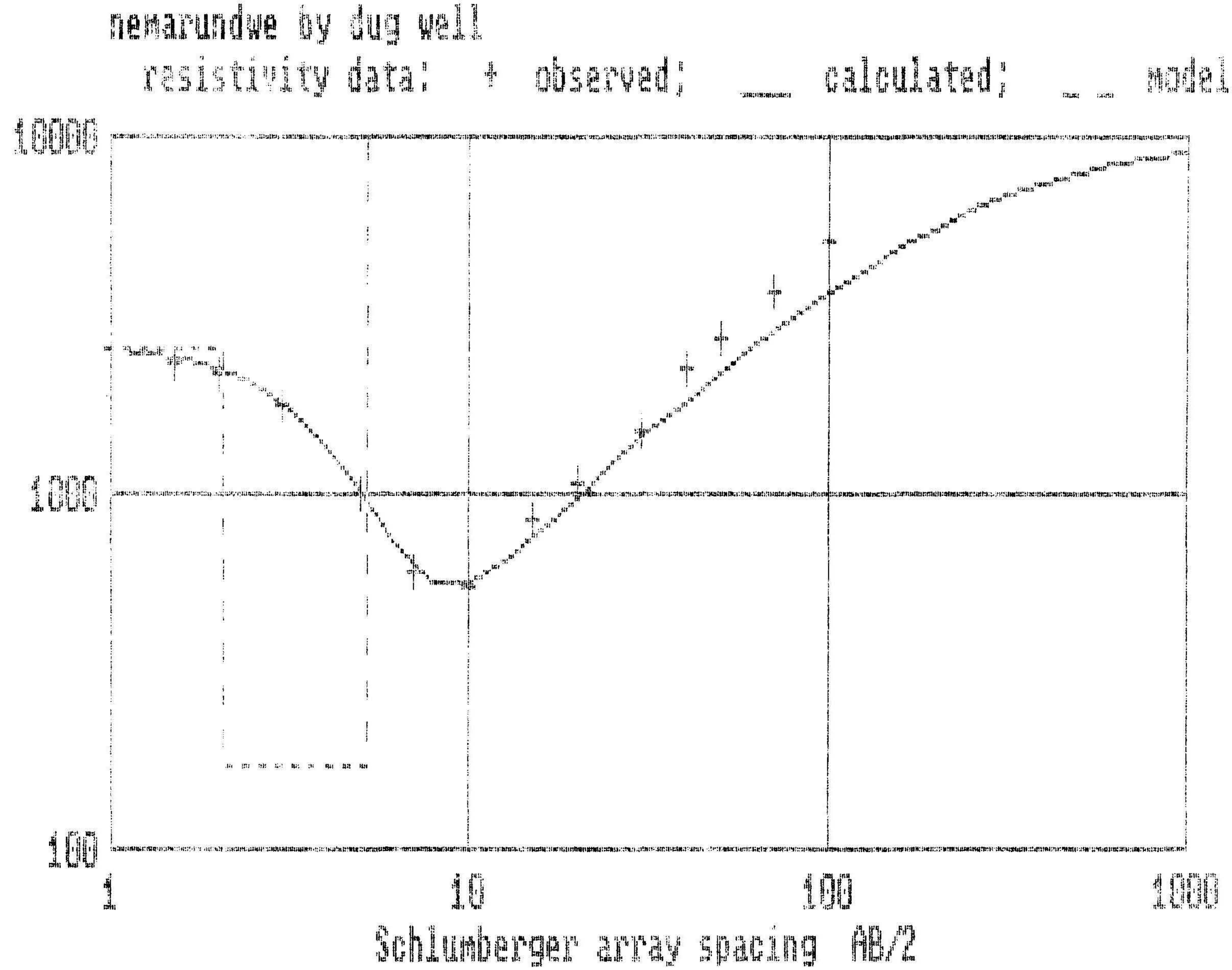


Model parameters for site:
nemarundwe

Layer	Thickns.	Restvty.	Depth
1	1.00	1500.00	1.00
2	0.90	29.00	1.90
3	6.60	600.00	8.50
Substrait		10000.00	*****



nemerundwe EM34 traverse by Hand-dug well
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
well
outcrop
0.00
100.00
200.00
300.00
distance (m)
bearing 240 M



Model parameters for site:
nemarundwe

Layer	Thickns.	Restvty.	Depth
1	2.05	2550.00	2.05
2	3.15	175.00	5.20
Substrait		10000.00	*****

2.12 Zimuto: School for the Blind and Sidings

Area G

Map 1930 D4, grid reference 273 7792

2.12.1. Introduction

Lineaments along the courses of vleis had been identified by Greenbaum and Wright (personal communication) as potentially suitable sites for boreholes to provide water to the School for the Blind and to the railway sidings in the east of the area. There are two boreholes serving the Mission and other school, which are sited on the high ground above the vleis, are fitted with motor pumps and are reputed to be very reliable.

There is extensive granite-gneiss outcrop in the area, in addition to local but widespread exposures of what might be loosely termed a talc-schist. A metadolerite dyke with a SW trend can be followed across the area.

2.12.2. Geophysical studies

The two vleis have been considered separately as Site 1 for the vlei which runs SE from the School for the Blind, and Site 2 for the intersecting vleis to the south of the Mission. In both cases 3 EM ground conductivity traverses were run: one along the length and 2 across the vlei; in each case 2 VES were measured at the intersection of the profiles.

A VES was measured at the site of an existing borehole as calibration, which was interpreted as indicating 10m of saprolite with a resistivity varying from 60 to 115 ohm m, overlying bedrock with a resistivity of 1100ohm m.

Site 1
EM no.1 shows a significant thickening of high conductivity material in the vlei, as the vertical coil responses indicate. The horizontal coil responses are irregular, although there is some suggestion of steep-sided conductive bodies. Similarly EM no.2 shows that the conductive surface layer thickens across the vlei, although outcrops near the bottom of the vlei reduce the vertical coil response. EM no.3 corroborates these findings, and again irregular results in the horizontal coils are shown.

The VES results indicate that at both positions there is around 3m of low resistivity saprolite overlying moderate resistivity saprolite (or saprock) to a depth of about 20m.

Site 2
All the EM traverse results are very irregular, indicating rapidly varying thickness of saprolite, as well as steep-sided contacts. However it appears that the E-W trending vlei has a systematic thickening of saprolite across its width, whereas the NE-SW trending vlei has not.

The VES results indicate an averaged depth of saprolite of about 20m at VES3 and about 10m at VES4. The resistivities range from about 30 to about 80 ohm m.

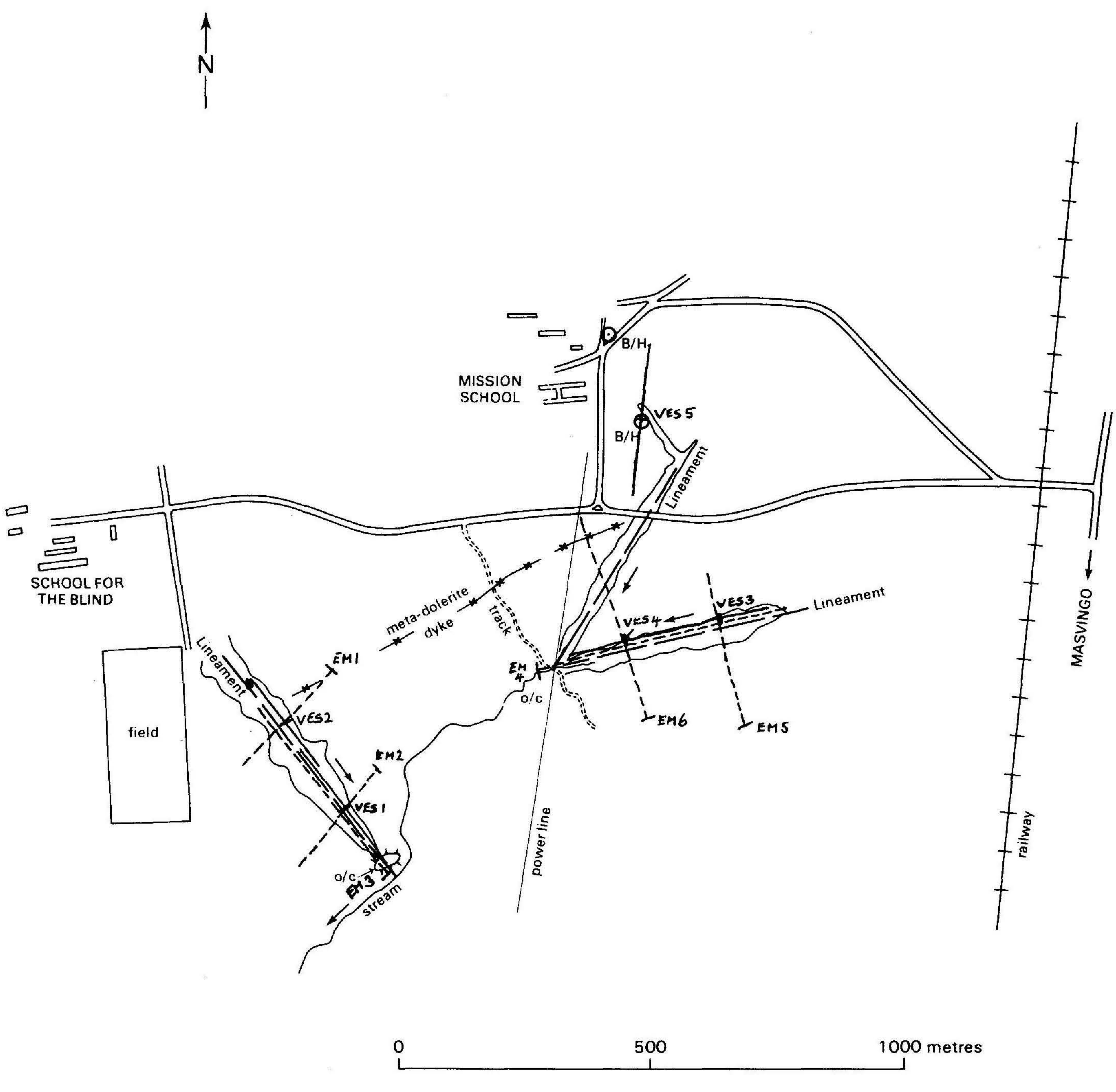
2.12.3. Discussion

The main deduction must be of a irregular bedrock topography in both areas. Any specific values of depth determined from VES data will be averaged along the line of the array. Over most of the area the saprolite appears to be thick, perhaps over 20m, although the widespread patches of outcrop indicate the limitations of this statement. The value of the geophysical results is in indicating areas where the possibility of shallow bedrock is lower, and this has been followed in guiding sites for potential drilling. A peg was inserted at site 1 upstream of the metadolerite dyke, to benefit from the possibility of sub-surface damming effects.

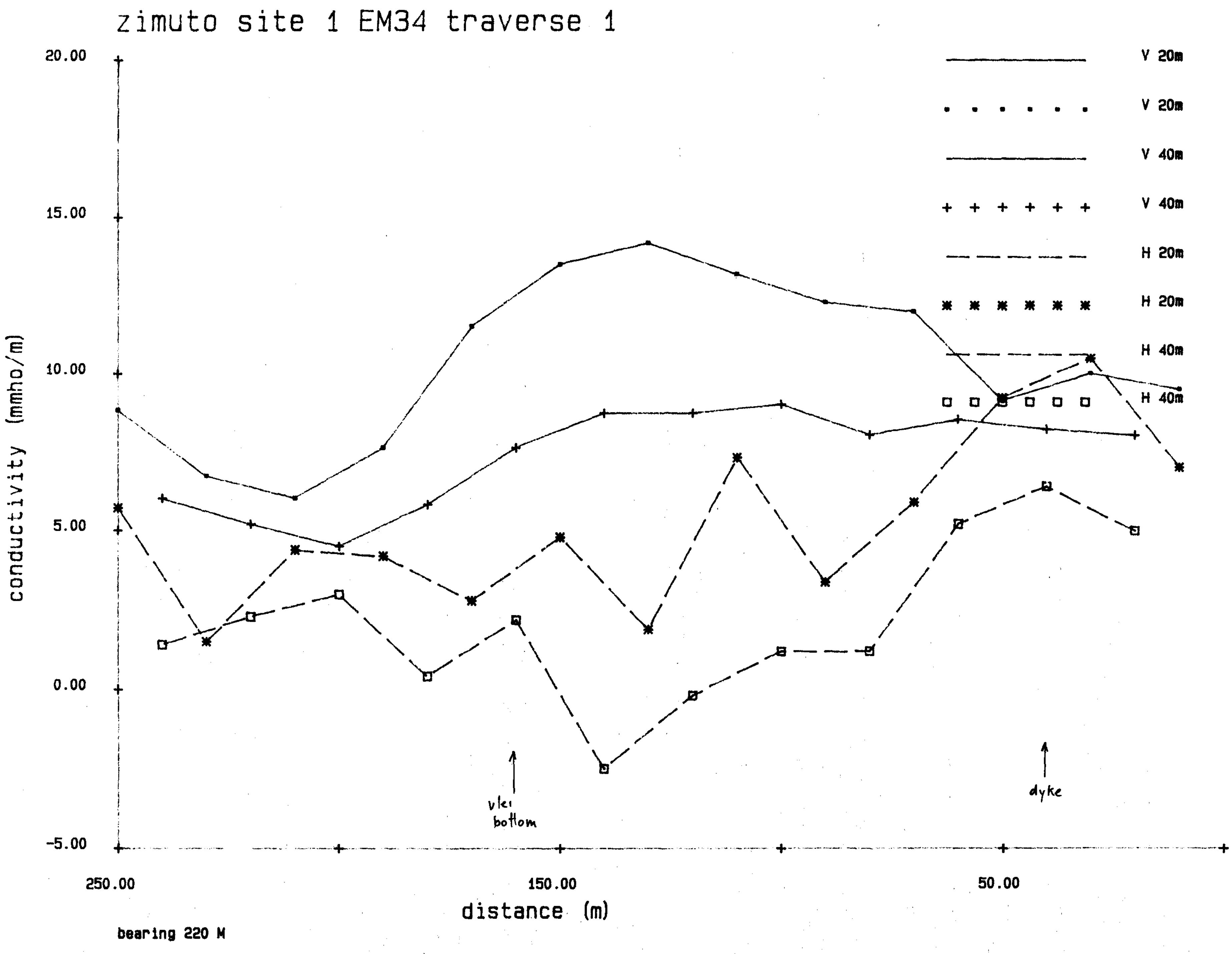
2.12.4. Conclusions

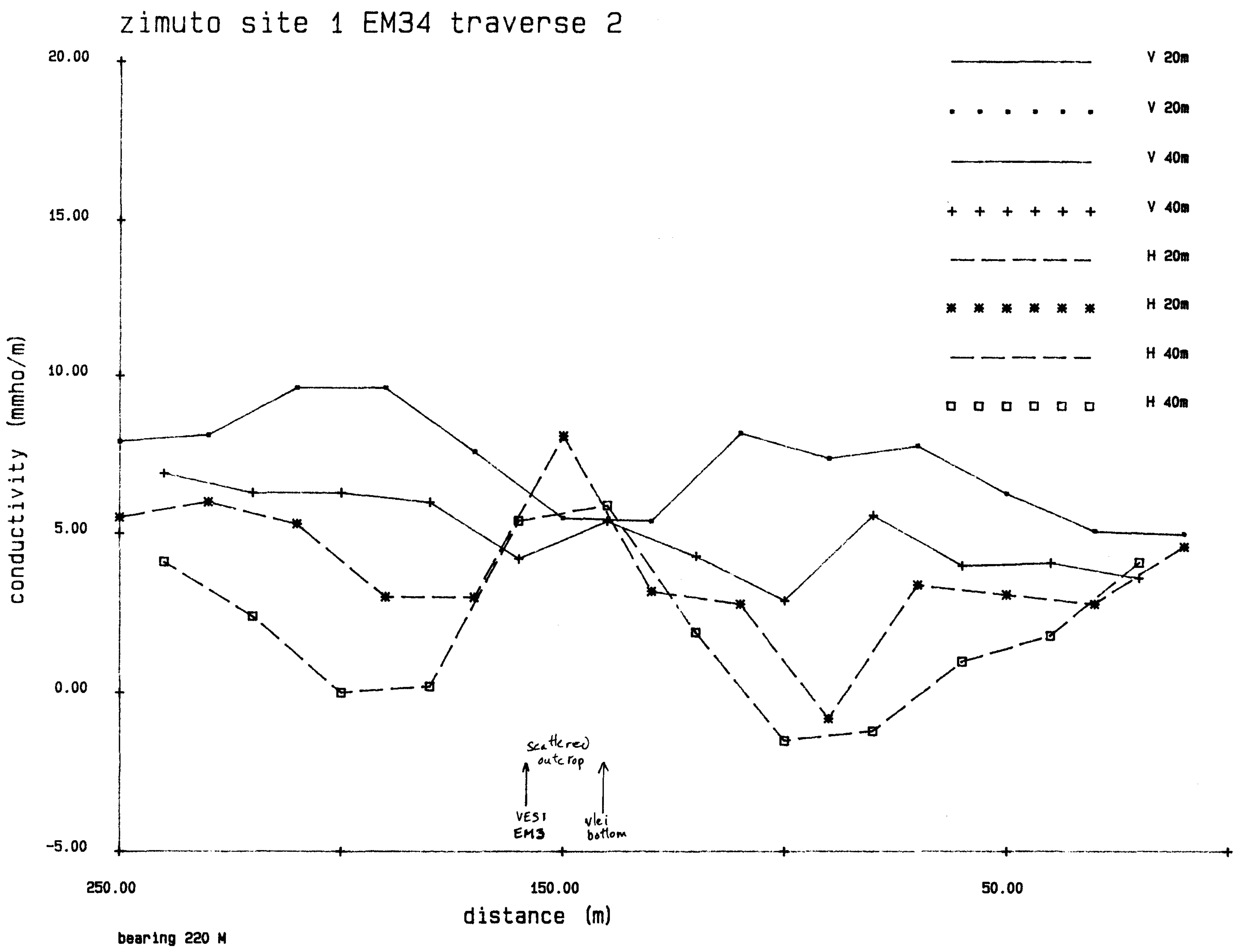
At both sites the bedrock topography is irregular, varying from around 20m depth to outcrop within a few metres. Two sites have been suggested for possible boreholes: the first has been pegged at site 1 in the vlei bottom, where the saprolite is thick and upstream of the intersection of a dyke which might raise the local water-table ; the second is for site 2 and indicates a general area where the saprolite is consistently thick.

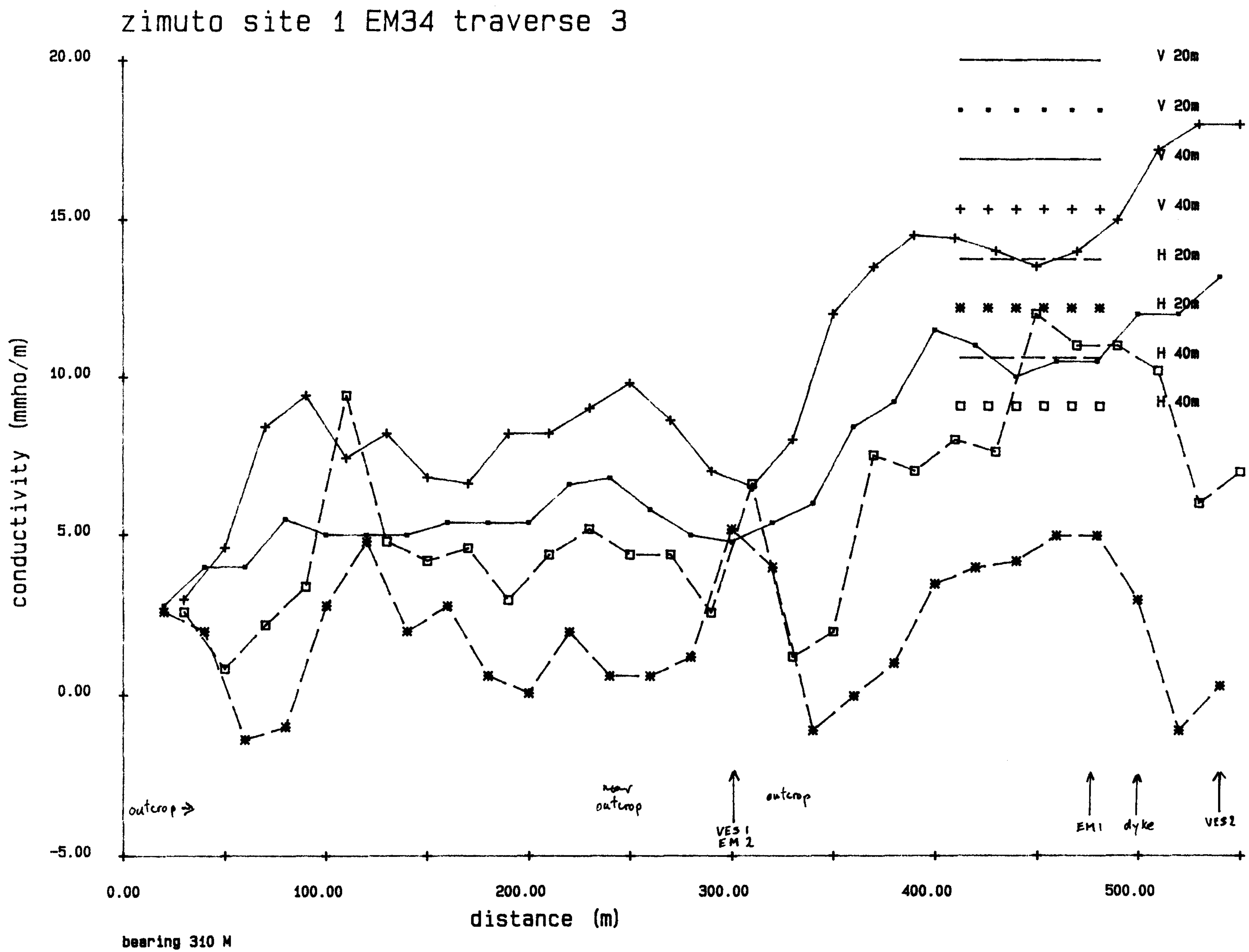
ZIMUTO MISSION: AREA G: MAP 1930 D4

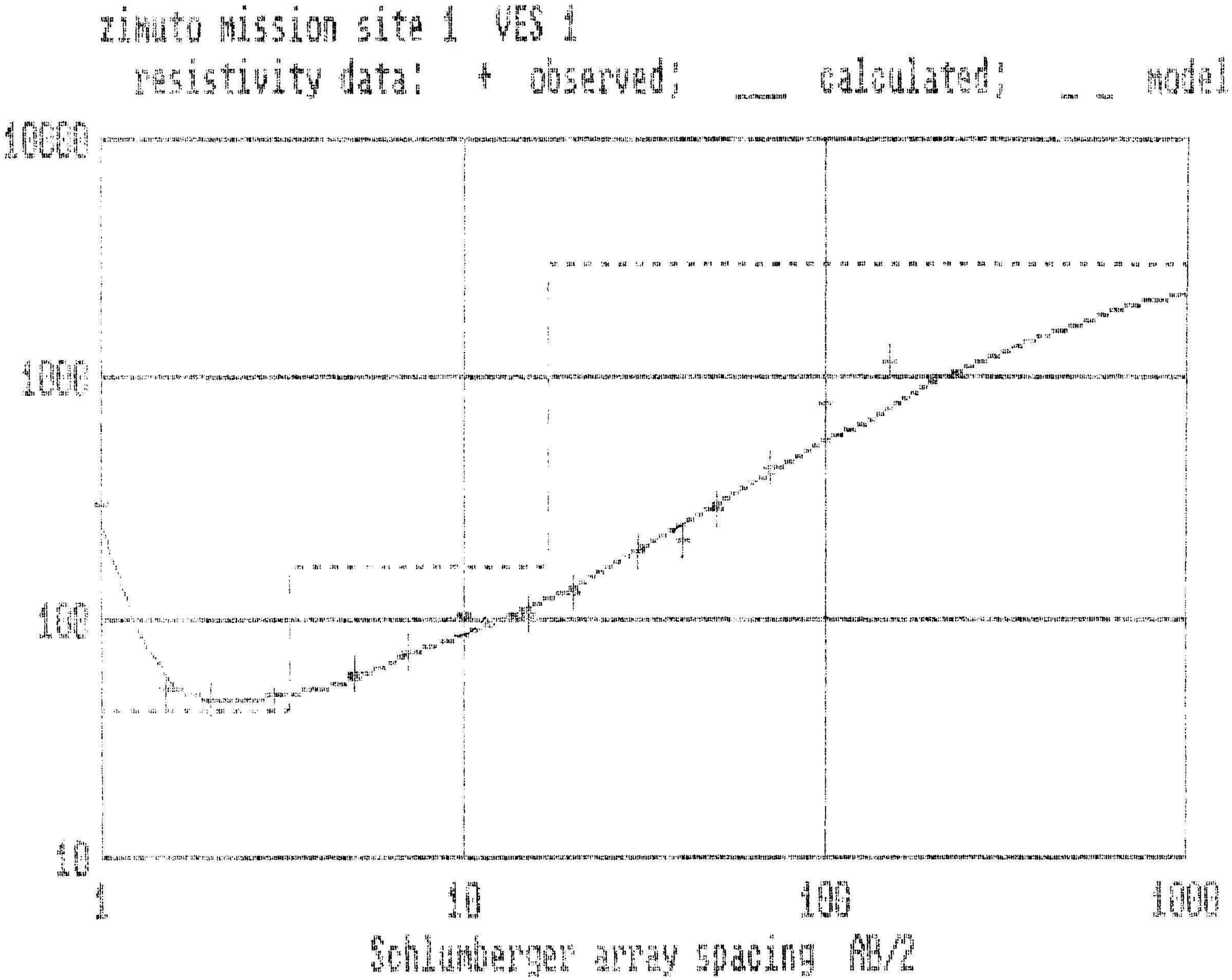


(AIR PHOTO 1972)


zimuto site 1 EM34 traverse 1
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
250.00
150.00
50.00
distance (m)
vlei bottom
dyke
bearing 220 M

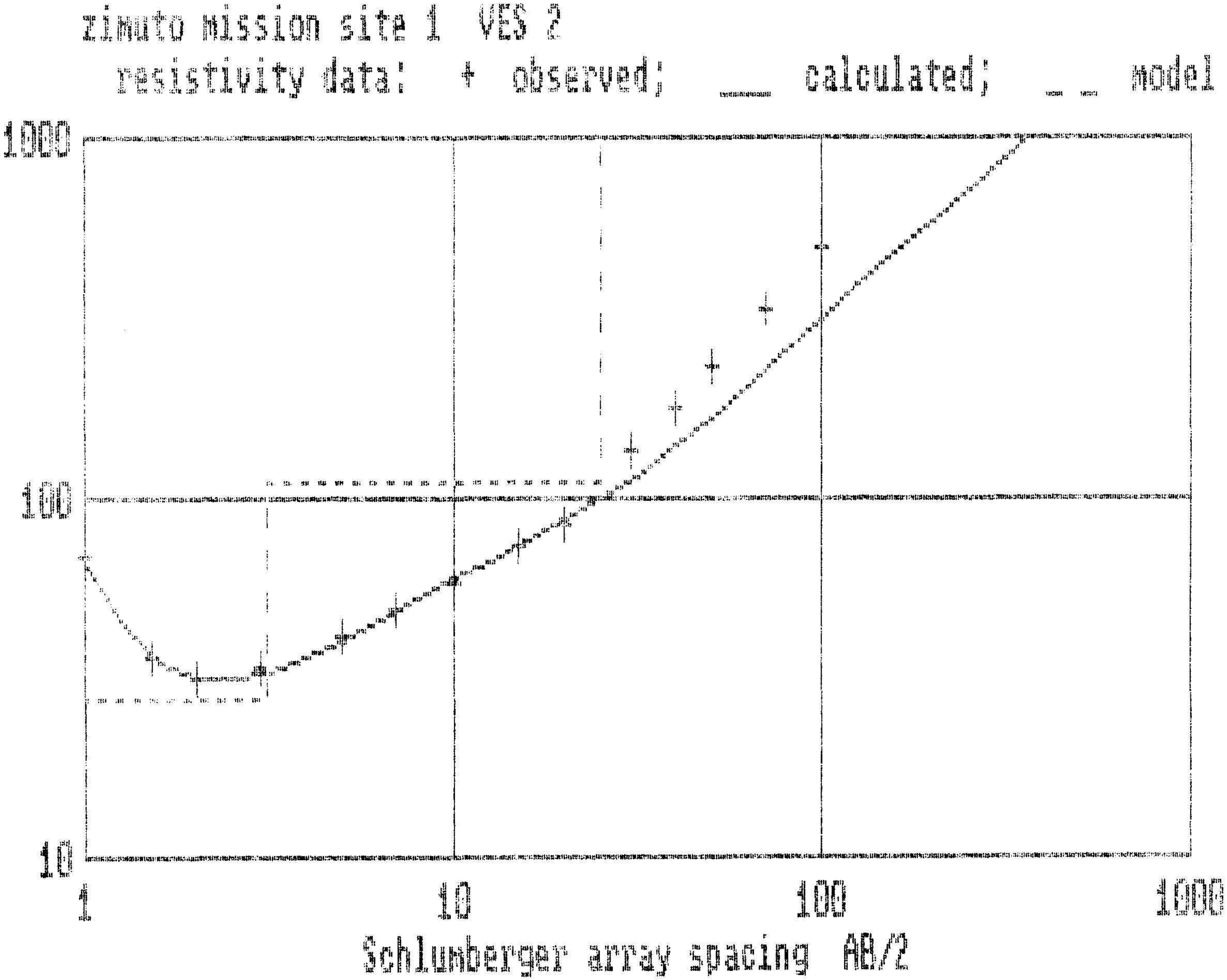

zimuto site 1 EM34 traverse 2
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
scattered outcrop
VES1
EM3
vlei bottom
250.00
150.00
50.00
distance (m)
bearing 220 M


zimuto site 1 EM34 traverse 3
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
0.00
100.00
200.00
300.00
400.00
500.00
distance (m)
outcrop
near outcrop
VES 1
EM 2
outcrop
EM1
dyke
VES2
bearing 310 M



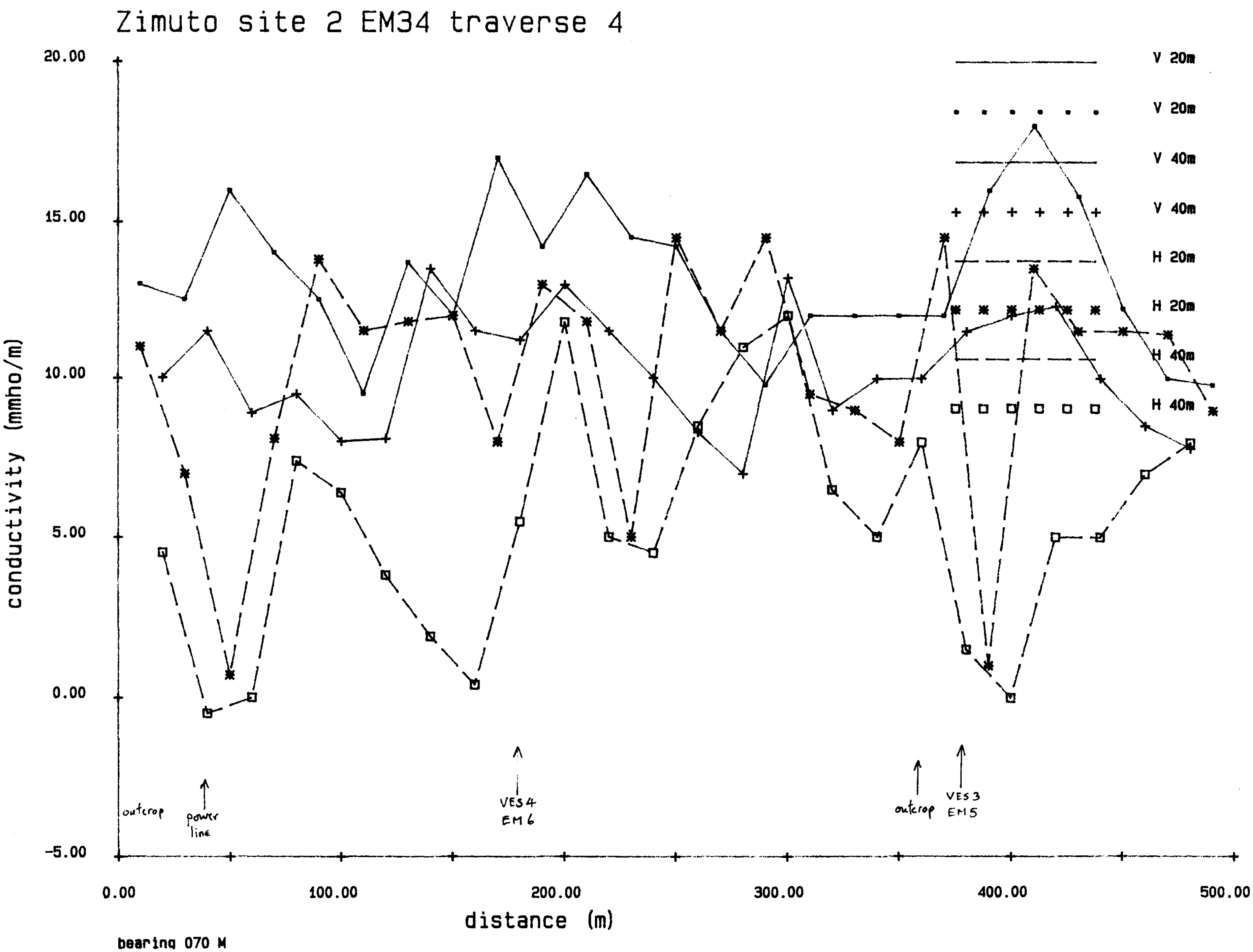
Model parameters for site:
zimuto

Layer	Thickns.	Restvty.	Depth
1	0.22	500.00	0.22
2	3.08	42.00	3.30
3	13.70	160.00	17.00
Substrait		3000.00	*****

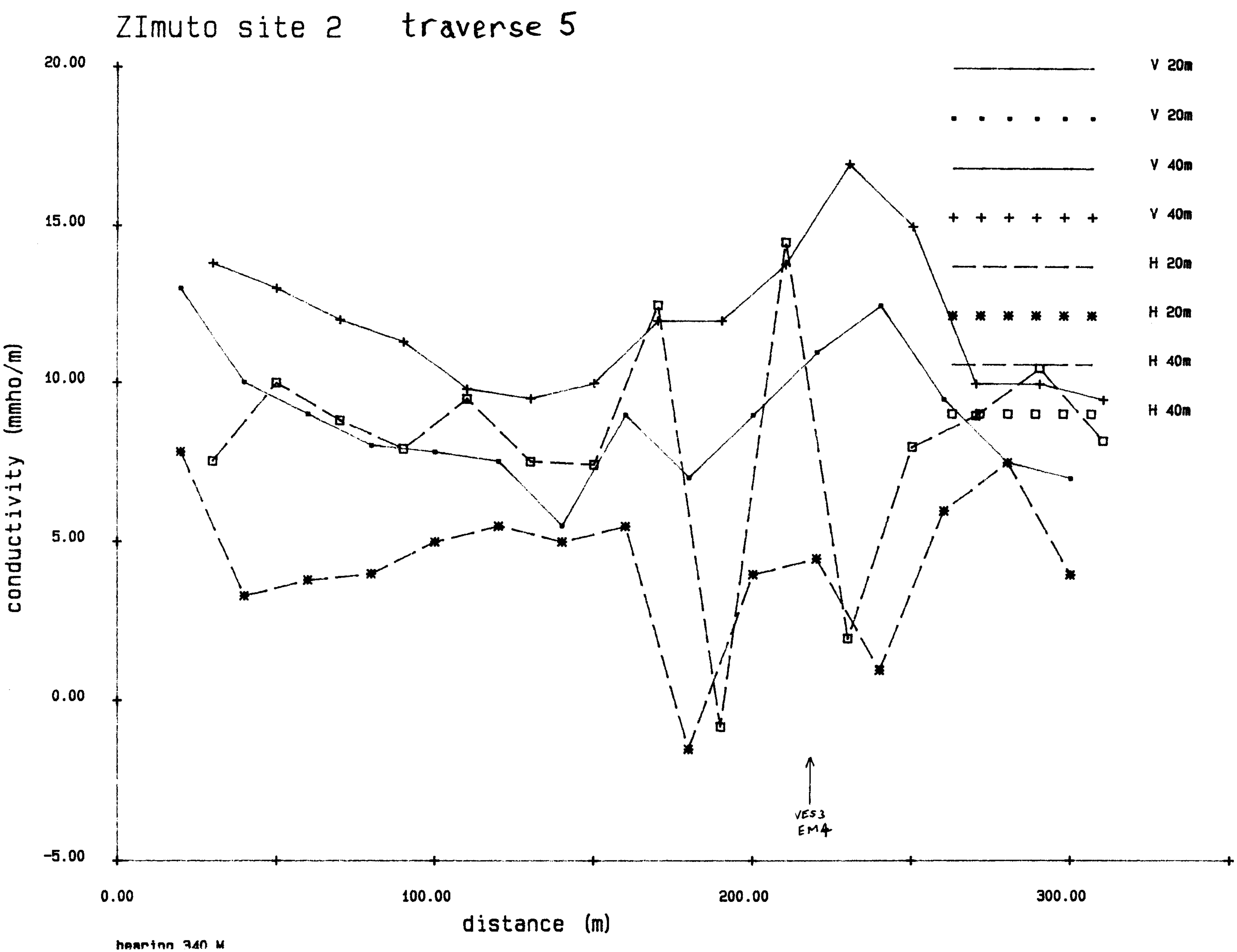


Model parameters for site:
zimuto

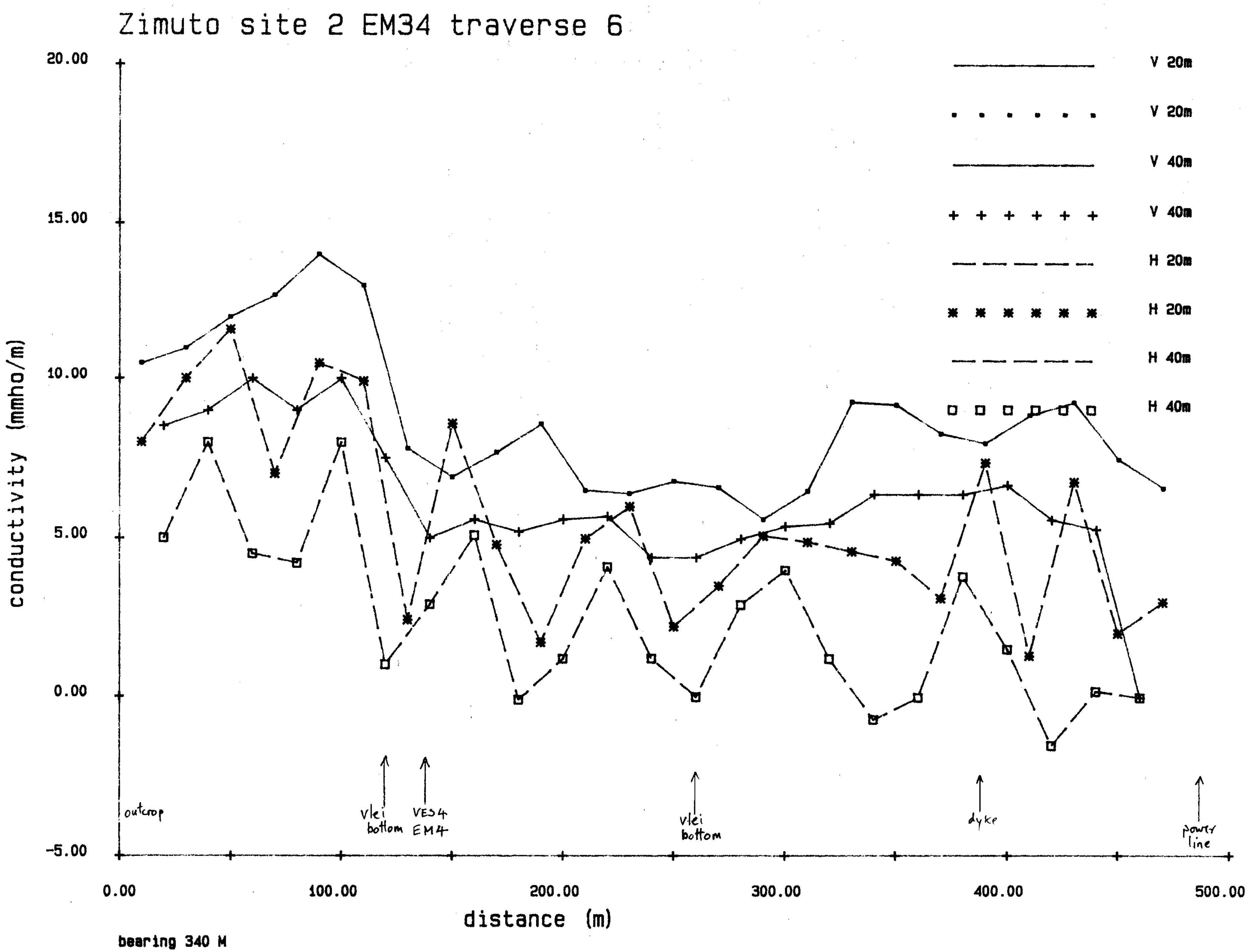
Layer	Thickns.	Restvty.	Depth
1	0.28	385.00	0.28
2	2.82	29.00	3.10
3	21.90	110.00	25.00
Substrait		5000.00	*****



Zimuto site 2 EM34 traverse 4
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
power line
VES 4
EM 6
outcrop
VES 3
EM 5
0.00
100.00
200.00
300.00
400.00
500.00
distance (m)
bearing 070 M



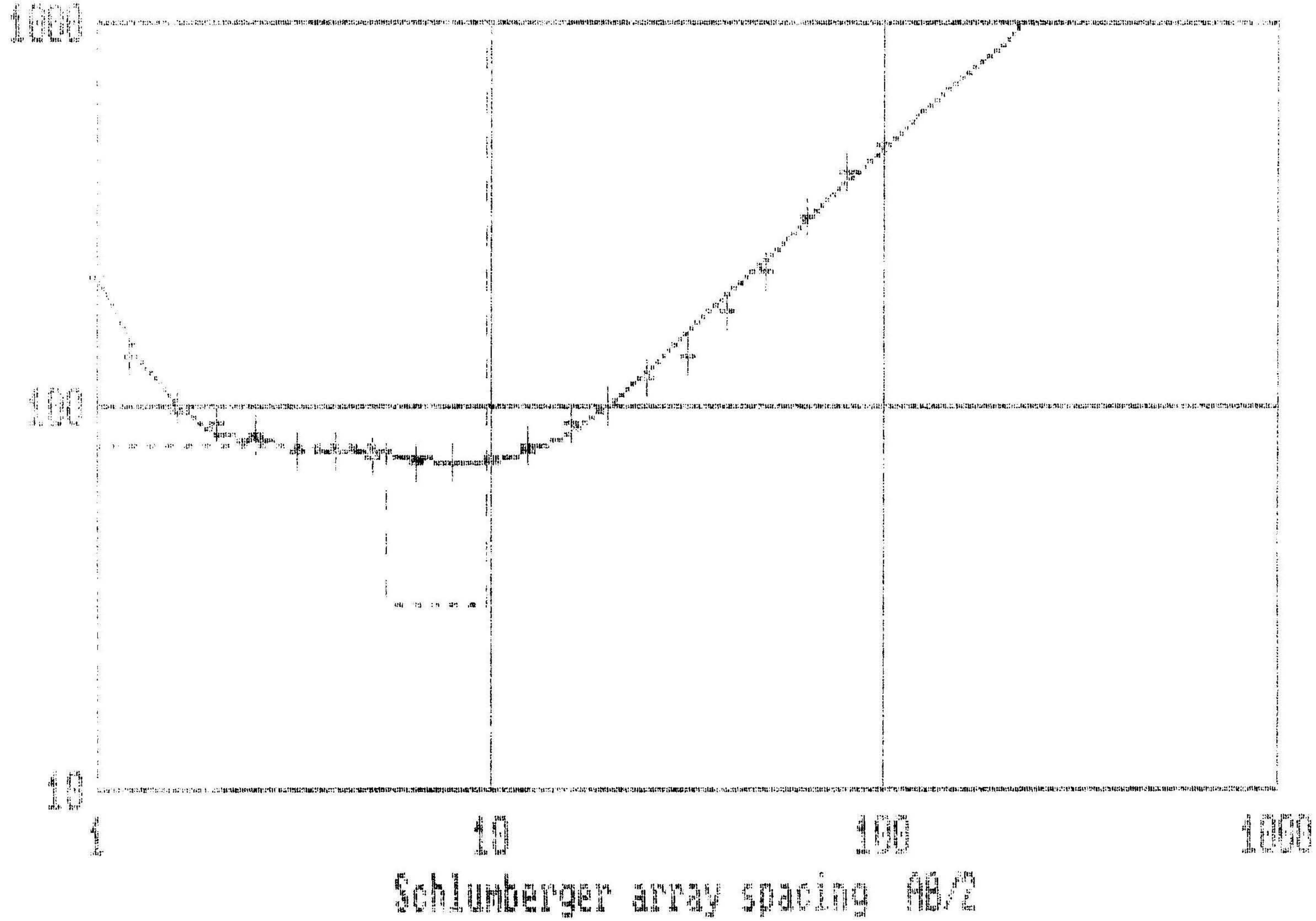
ZImuto site 2 traverse 5
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
VES3
EM4
0.00
100.00
200.00
300.00
distance (m)
bearing 340 M



Zimuto site 2 EM34 traverse 6
20.00
15.00
10.00
5.00
0.00
-5.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
vlei bottom
VES4 EM4
vlei bottom
dyke
power line
0.00
100.00
200.00
300.00
400.00
500.00
distance (m)
bearing 340 M

zimuto site 2 VES 2 150m downstream from big tree

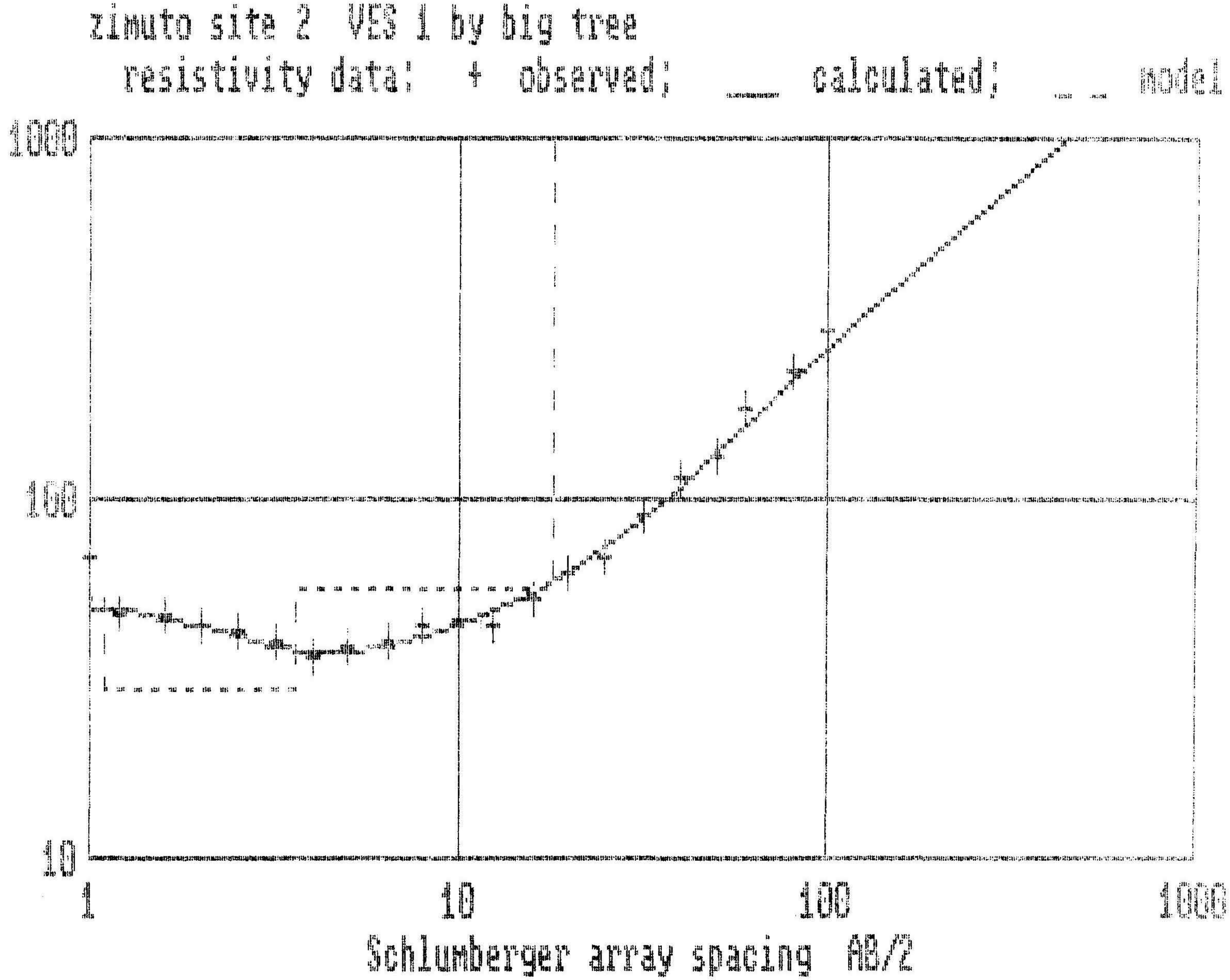
resistivity data: + observed; __ calculated; _ _ model



Model parameters for site:

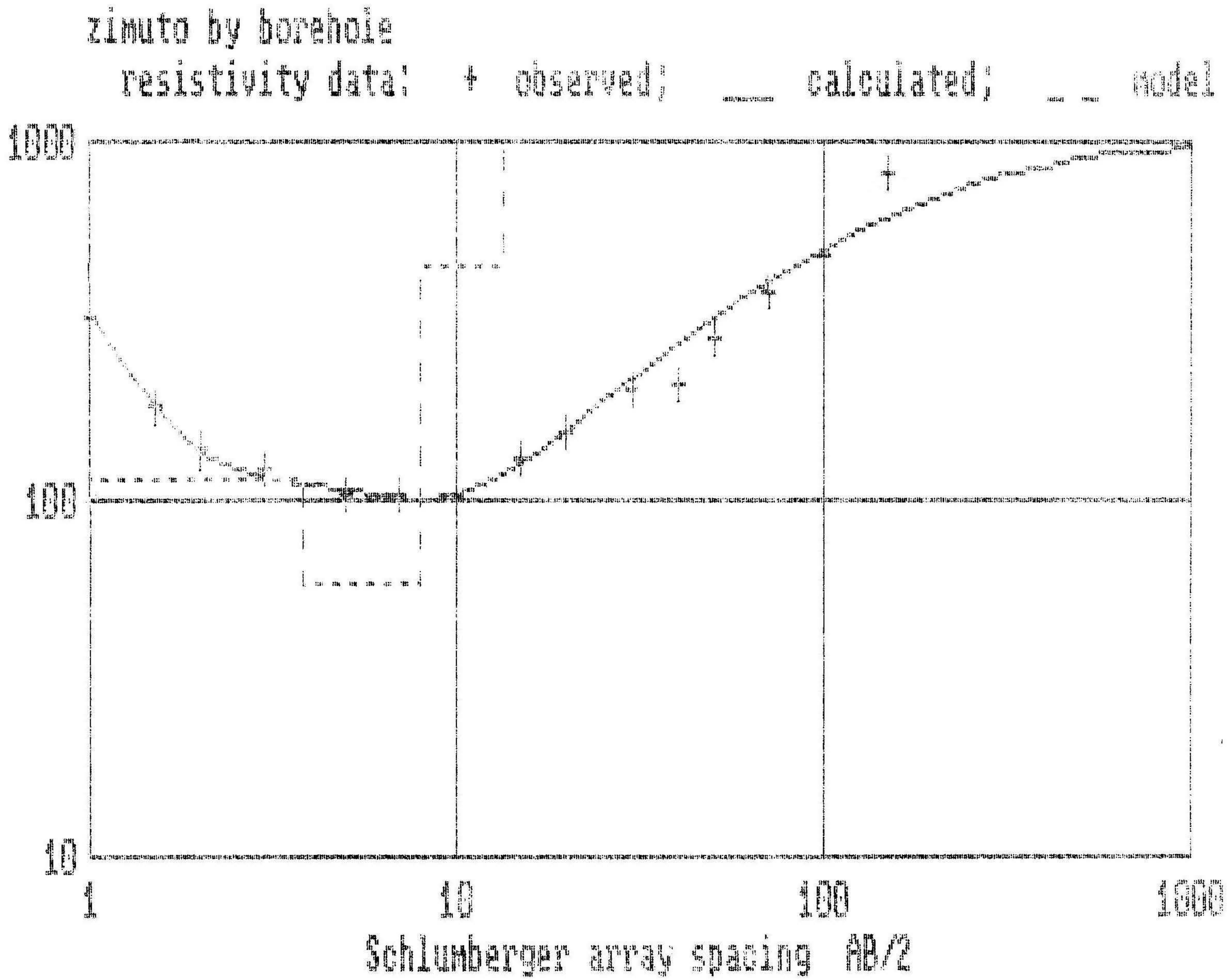
zimuto

Layer	Thickns.	Restvty.	Depth
1	0.29	1250.00	0.29
2	5.13	77.00	5.42
3	4.28	31.00	9.70
Substrait		10000.00	*****



Model parameters for site:
zimuto

Layer	Thickns.	Restvty.	Depth
1	1.10	31.50	1.10
2	2.50	29.00	3.60
3	14.40	55.00	18.00
Substrait		5000.00	*****



Model parameters for site:

zimuto

Layer	Thickns.	Restvty.	Depth
1	0.35	1100.00	0.35
2	3.45	115.00	3.80
3	5.55	60.00	9.35
Substrait		1100.00	*****

2.13. Sarahuru Junction

Area J

Map 2030 D3, grid reference 246 7677

2.13.1. Introduction

In the 1986 project (Smith and Raines, 1987) a seismic refraction and EM profile had been measured across a major lineament reported by Greenbaum (1986). A number of boreholes had been drilled in the vicinity, although the information relating to them had become confused. A hand-pump was operation on one bore and a derelict pump was discovered by an abandoned bore, which was reported (local sources) as being high yielding. The 1986 survey ran between these points. The results from the initial geophysical work had been encouraging that the saprolite could be both thick and sandy. Further inspection by Greenbaum and Wright (personal communication) suggested that the area warranted some further geophysical work in order to site a borehole, with a motorised pump.

2.13.2. Geophysical studies

An EM34 ground conductivity profile was measured from beneath an isolated kjope across the lineament which followed a narrow valley. A VES was measured close by. The purpose of these investigations was to ascertain the thickness of saprolite near to the kjope, which might serve as a site for a water storage tank from a nearby well. An MRT array was measured along the line of the 1986 survey (Griffiths, 1987).

The EM results show that the thickness of regolith increases away from the kjope, but the response of the vertical coils suggests that the conductivity also increases, and the two effects cannot unambiguously be separated. However the VES interpretation indicates 7m of saprolite (resistivity 13 ohm m) overlying a layer with a resistivity of 125 ohm m, the base of which is not seen, so is likely to be at least 40m thick, a result which gives support to the analysis of the EM data. The maximum thickness from the EM data occurs over the lineament, and then decreases to the east.

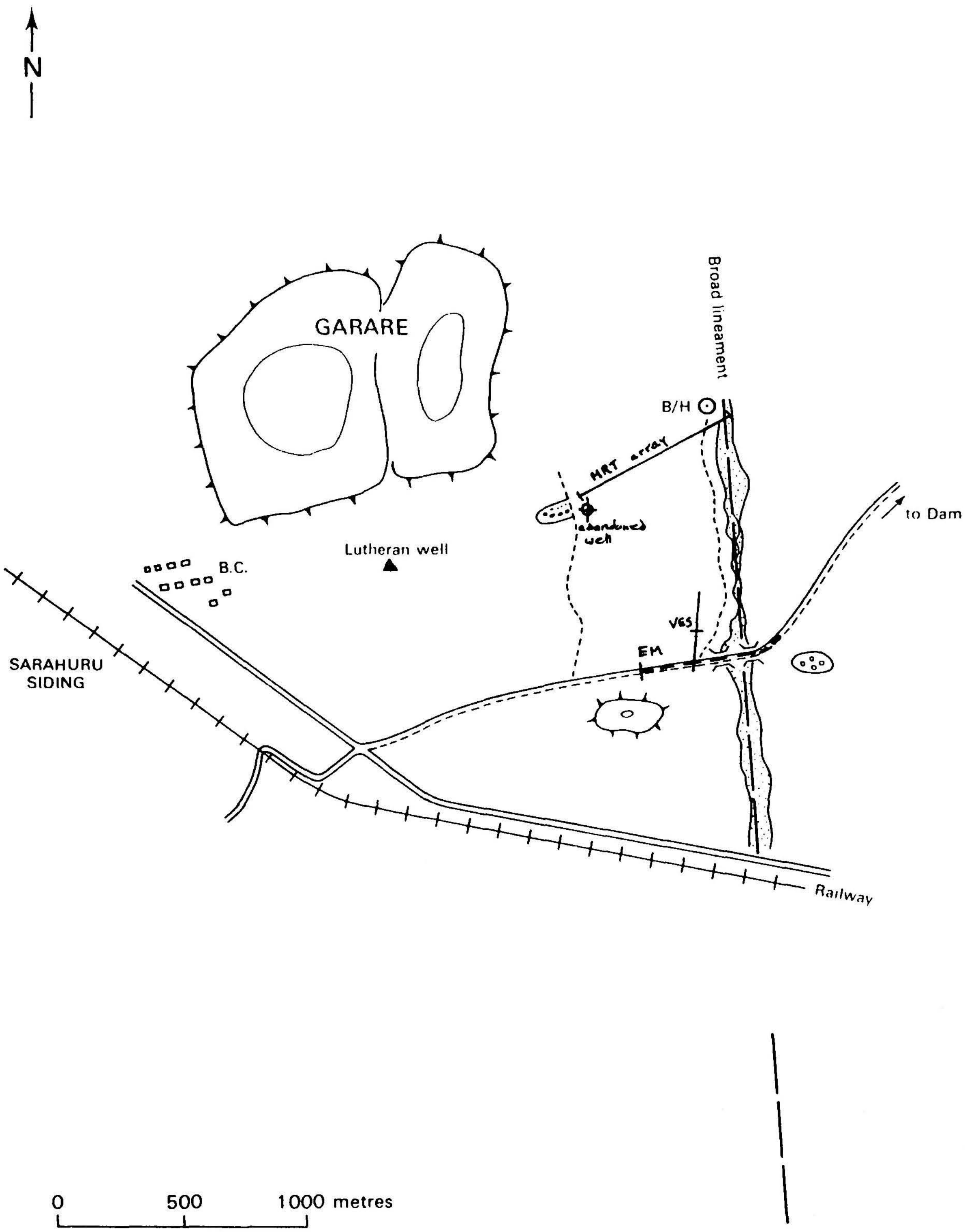
2.13.3. Discussion

Griffiths' (1987) results confirm the general picture provided by the other geophysical methods, although the suggestion of a step in Smith and Raines (1987) is not supported, a gradual depth increase being preferred. This is more in accord with the findings presented here. All the information we have collected supports the indications of the saprolite being 40m or more thick away from obvious outcrop features and to the west of the lineament. Beneath a surface layer, which may be 7m thick and rather clay-rich, the saprolite has a higher resistivity and may reasonable transmissive.

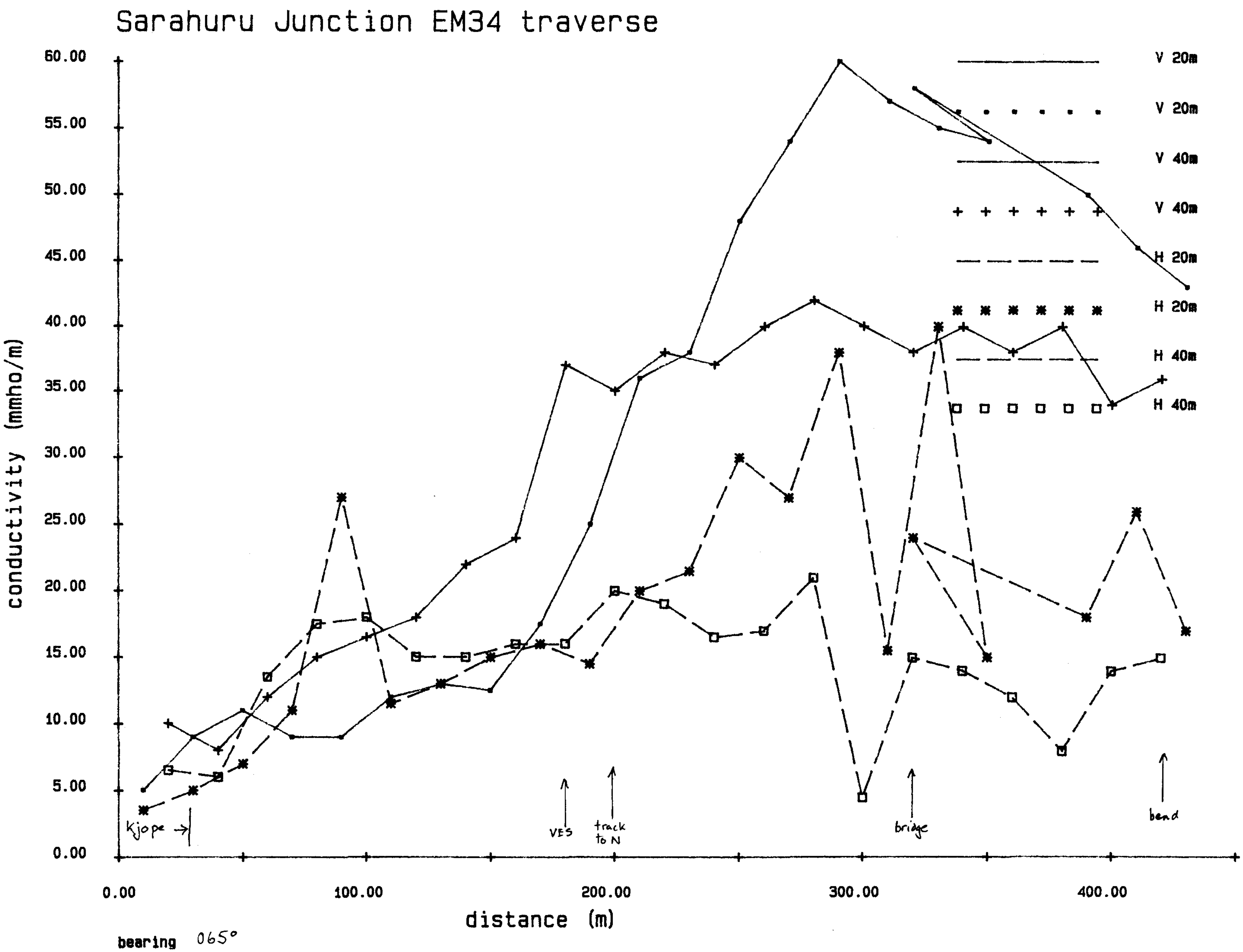
2.13.4. Conclusions

A borehole site along or to the west of the lineament should encounter 40m or more of saprolite which would be moderately sandy, and which would provide a adequate yield. No specific site has been recommended for drilling.

SARAHURU B.C.: AREA J: MAP 2030 D3



(AIR PHOTO 2025)



Sarahuru Junction EM34 traverse
60.00
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
conductivity (mmho/m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
Kjope
VES
track to N
bridge
bend
0.00
100.00
200.00
300.00
400.00
distance (m)
bearing 065°

2.14. Chinyika Clinic

Gutu

Map 1931 C2, grid reference 340-1 7842

2.14.1. Introduction

Under an agreement with GTZ (the German aid agency), BGS carried out a site investigation for collector wells in the area of Chinyika Clinic. Two vleis running north-south on either side of the clinic were investigated by E.P.Wright (personal communication) with a view to identifying both suitable depth of overburden and material which could readily be excavated. It was planned that a geophysics survey team from MEWRD, Harare would systematicaaly survey the area with detailed Schlumberger VES, but this exercise required some preliminary guidance from BGS geophysicists.

2.14.2. Geophysical studies

Eastern vlei A seismic refraction profile was measured along the bottom of the vlei. The profile was 230m long, with shot points at 0, 35, 75, 115, 155, 195 and 230m. Shot point 0m was on outcrop. A 'Plus-Minus' analysis (Hagedoorn, 1955) was carried out, and showed that a strong refractor with a velocity of 5.0km/s beneath a top layer with a velocity of about 1km/s, with a thickness which varied from 8m (some 20m N of outcrop) to 12m at the northern end.

Two VES were measured along the course of the vlei. VES no.2 confirms the result at the northern end of the seismic profile, indicating 15.5m of saprolite with a resistivity of 83 ohm m, overlying the basement (resistivity 1000 ohm m). VES no.1, some 120m N indicates 30m of saprolite, with a resistivity of nearly 200 ohm m. The solution has very little sensitivity to variation in the thickness of the 200 ohm m layer.

An EM34 traverse was measured across the vlei at the seismic shot point at 0m. The profile shows relatively little variation, although there is a slight anomaly to the west of the outcrop. From these data, there is no conclusive evidence for a fracture system in the vlei, and the minimum may indicate the subcrop of the basement dipping beneath the saprolite. On the west bank of the vlei it appears that the thickness of saprolite increases.

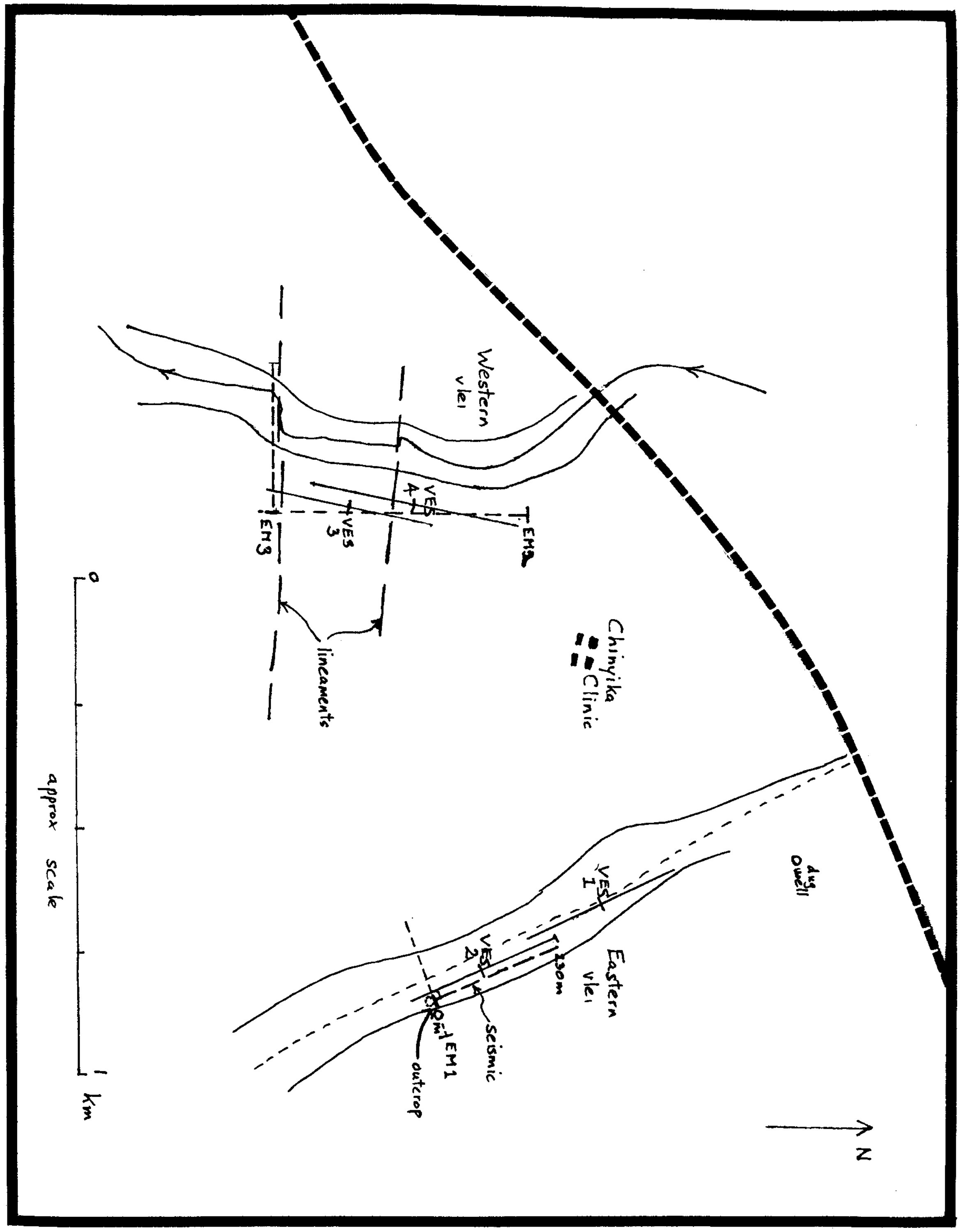
Western vlei: A well-defined stream-bed follows the vlei, and a number of lineaments intersect the stream at points where it shows notable deviations. Two EM traverses were measured in the main vlei, EM no.2 being parallel and EM no.3 crossing the stream-bed. Two VES were measured along EM traverse no.2. The EM traverses do not indicate any fracture system associated with the vlei. The thickness of saprolite decreases down-vlei and is more-or-less constant across the vlei. The VES results indicate between 2 and 10 m of saprolite, with a resistivity between 10 to 50 ohm m.

2.14.3. Discussion

The various methods applied in the eastern vlei are consistent in the information they produce, showing a relatively thin regolith overlying basement. However in the western vlei, the resistivity are not consistent with the EM data. It is possible that the saprolite is highly conductive and thin in this area, and with the existing data it is not possible to eliminate that model from one in which the saprolite is about 10m thick and with a resistivity of 50 ohm m. As an initial appraisal, it is suggested that the eastern vleiis a more likely target to be investigated in further detail.

2.14.4. Conclusion

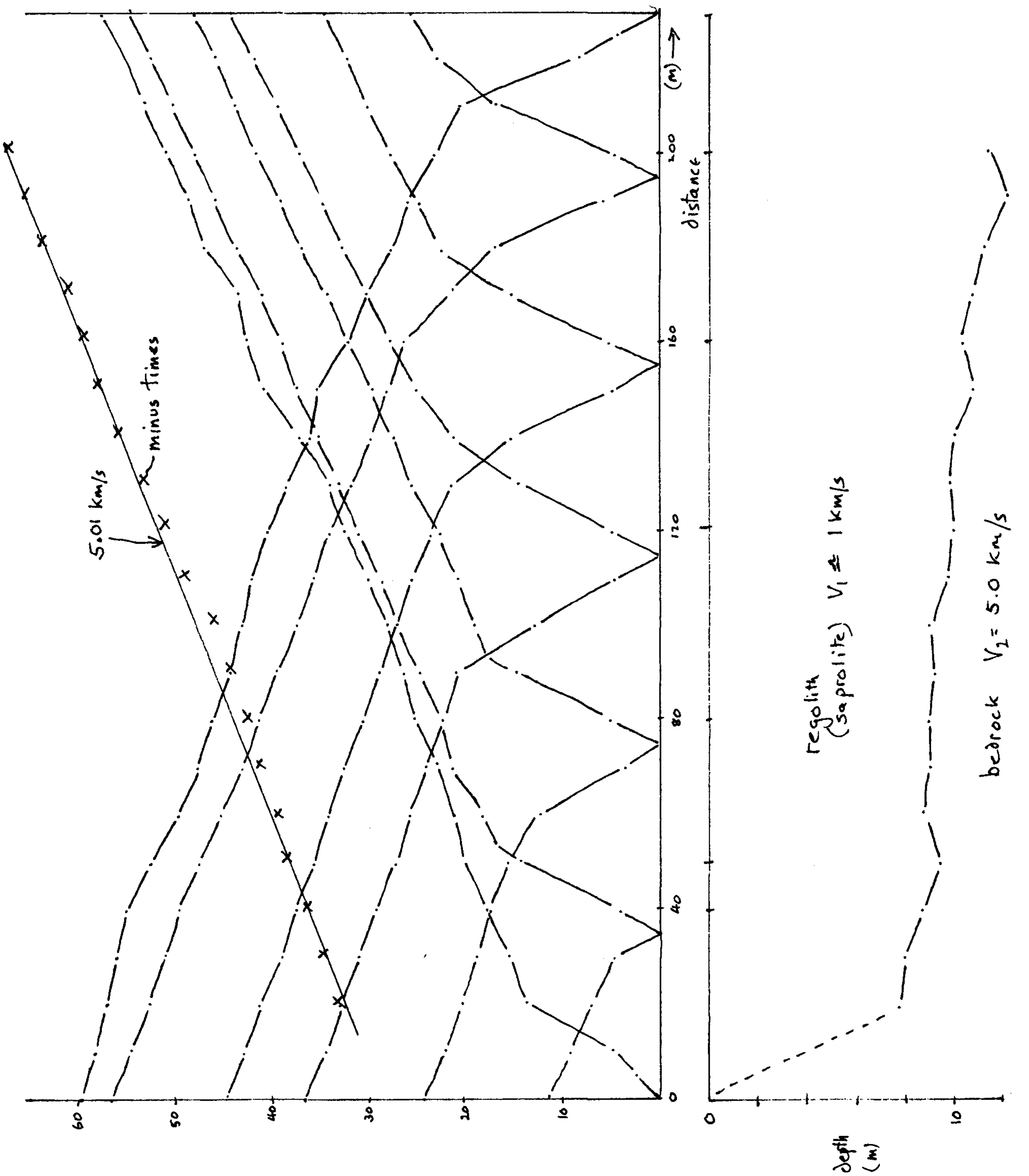
The eastern vlei offers prospects of finding areas of saprolite with a thickness of 15m and over, having a fair transmissivity and reasonable 'diggability'. The water table is likely to be near surface. In the western vlei the prospects of finding saprolite deeper than 10m cannot be assessed, but it is possibly shallow and clay-rich.



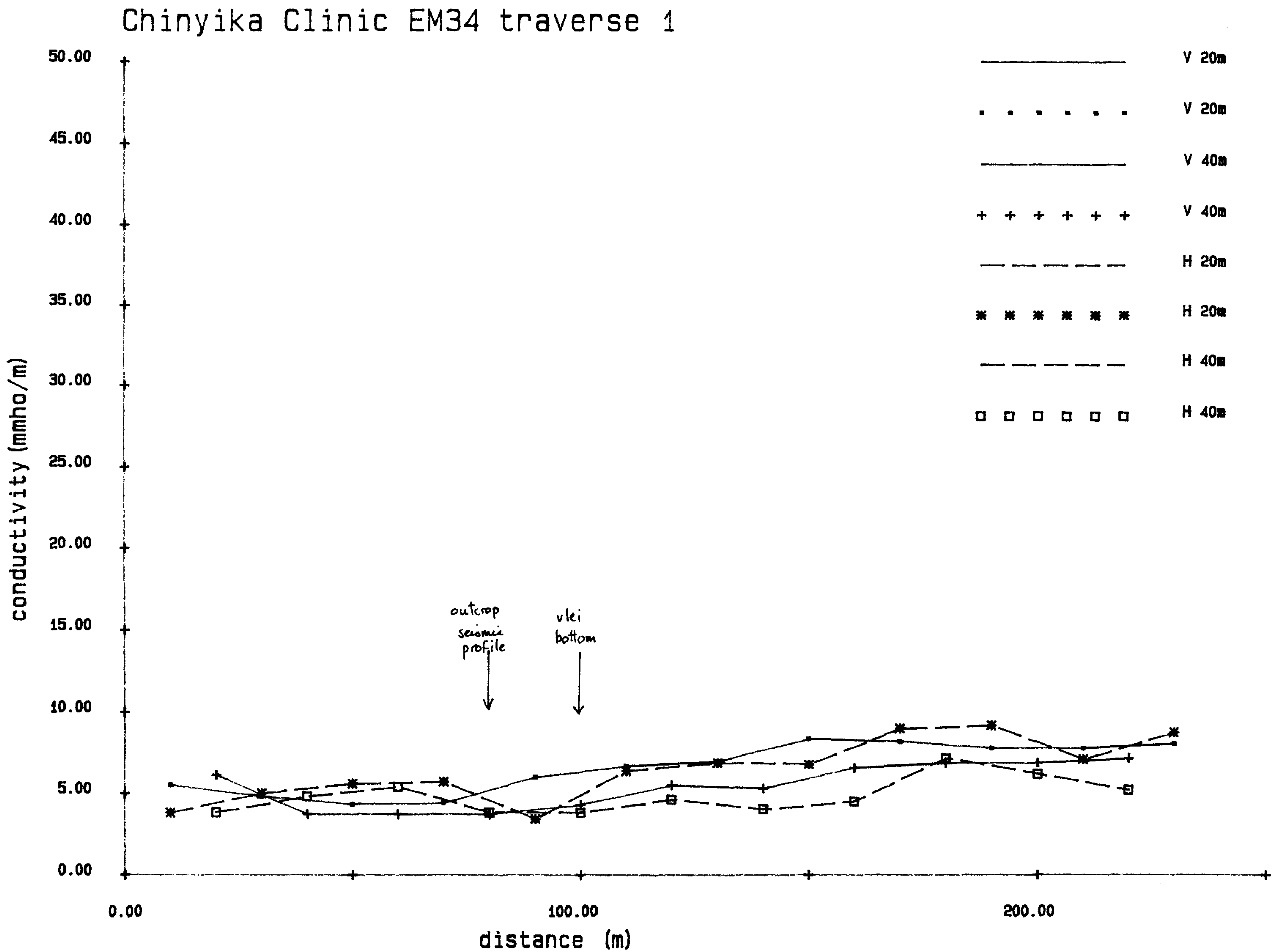
CHINYIKA CLINIC: GUTU AREA

MAP 1931 C2

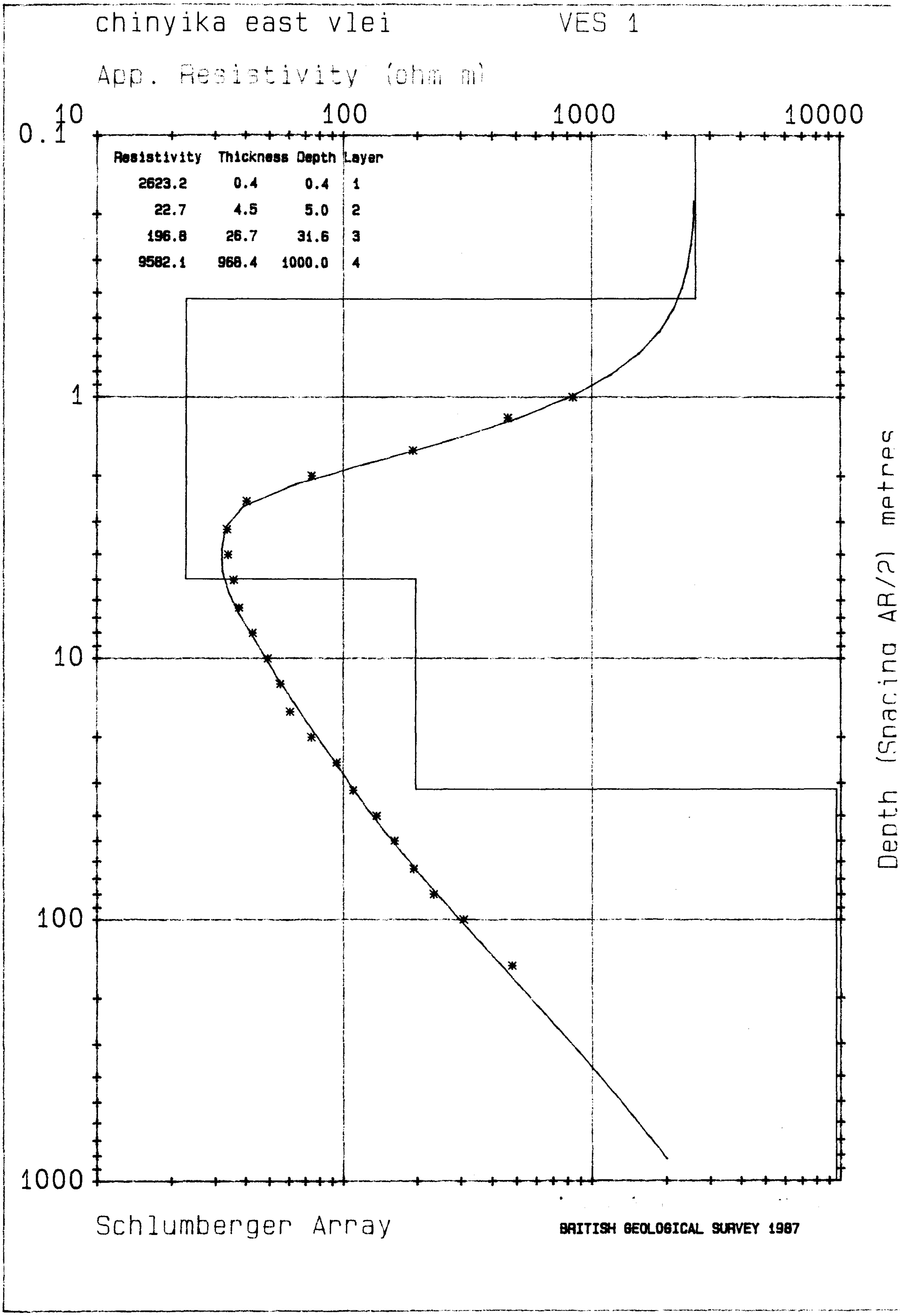
Position of geophysical surveys



Chinyika Clinic: results of seismic refraction survey

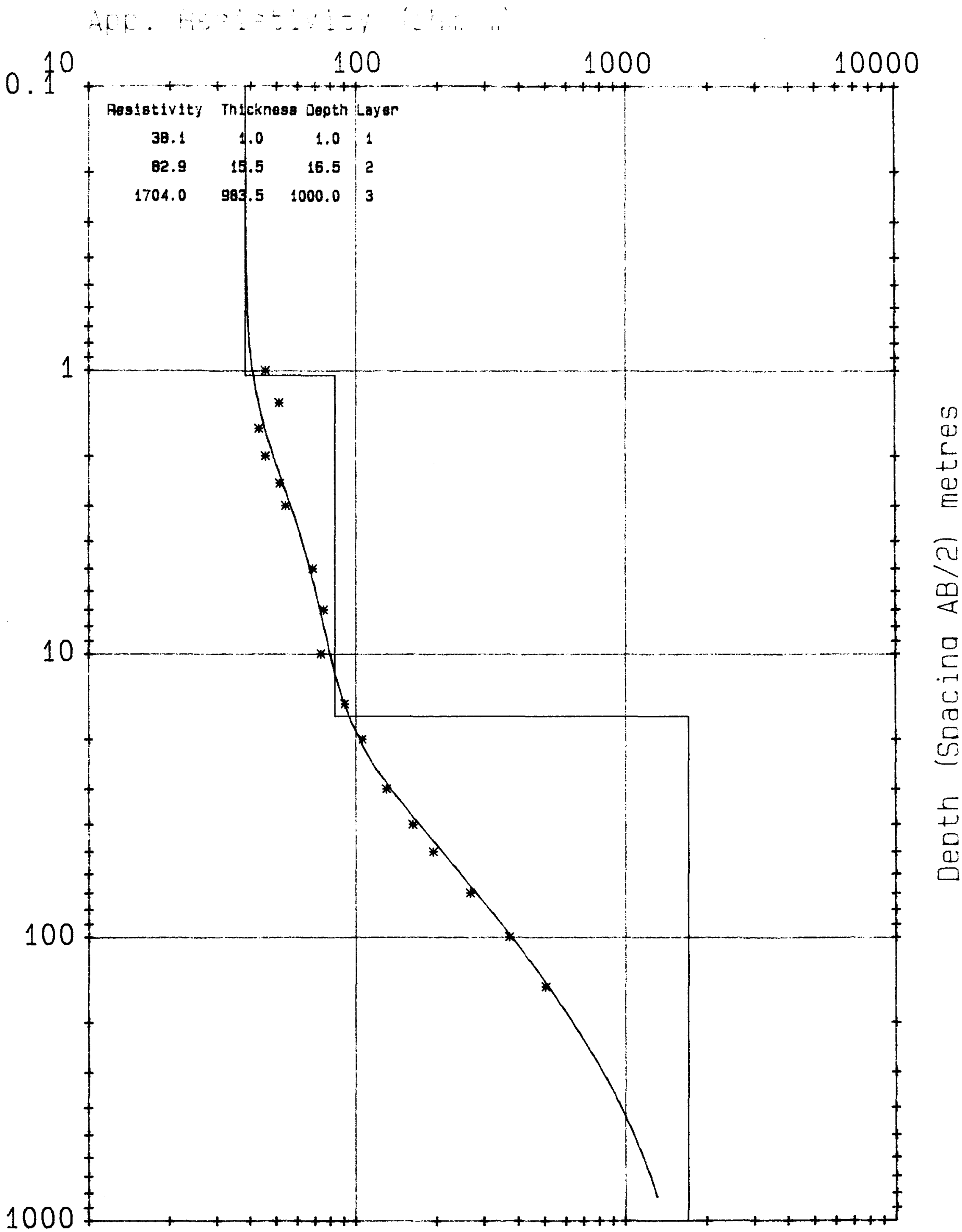


Chinyika Clinic EM34 traverse 1
conductivity (mmho/m)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
distance (m)
0.00
100.00
200.00
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
outcrop
seismic profile
vlei bottom



chinyika east vlei
VES 1
App. Resistivity (ohm m)
10
100
1000
10000
0.1
1
10
100
1000
Resistivity Thickness Depth Layer
2623.2 0.4 0.4 1
22.7 4.5 5.0 2
196.8 26.7 31.6 3
9582.1 968.4 1000.0 4
Depth (Spacing AR/2) metres
Schlumberger Array
BRITISH GEOLOGICAL SURVEY 1987

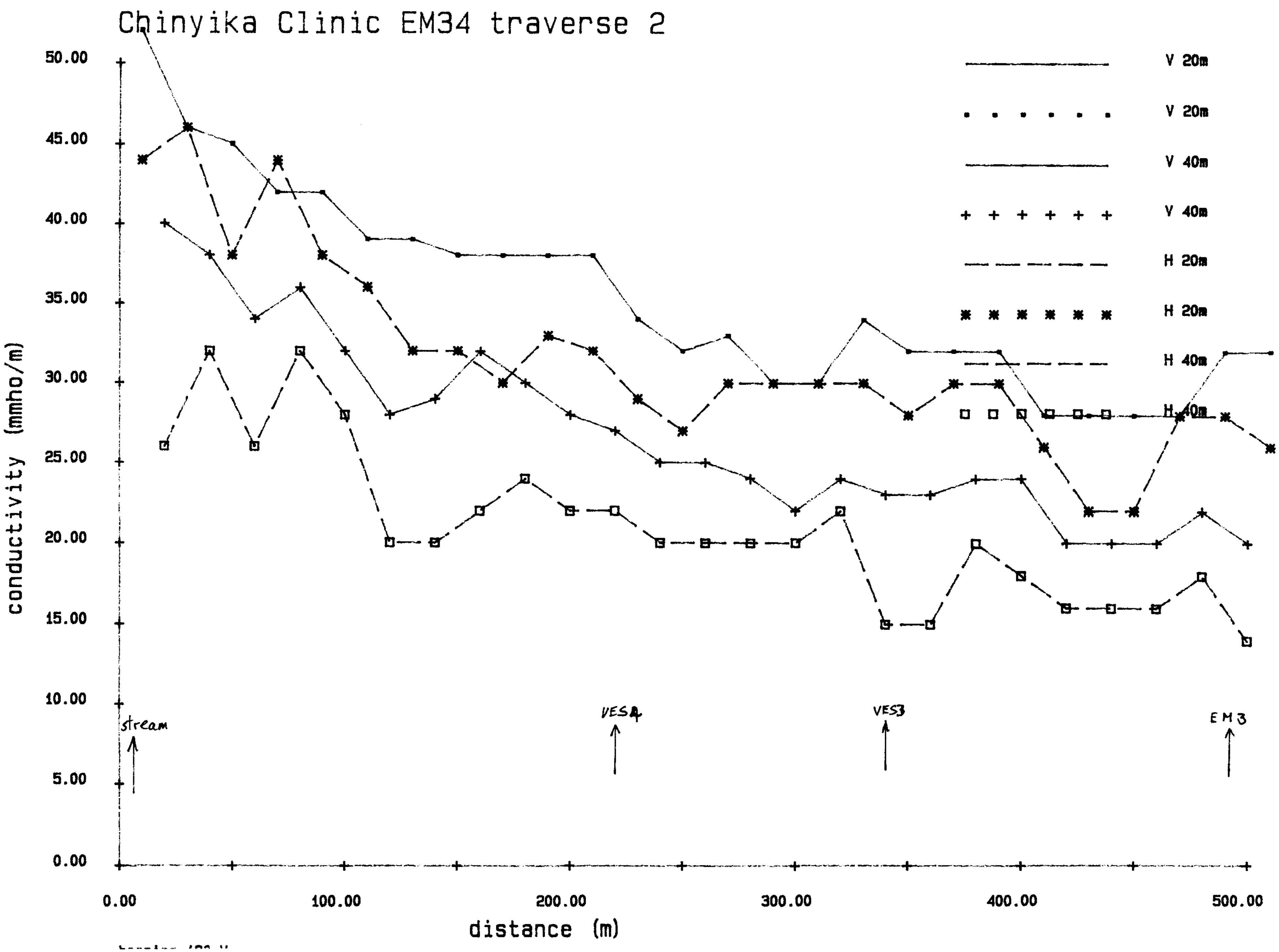
chinyika clinic east vlei VES no. 2



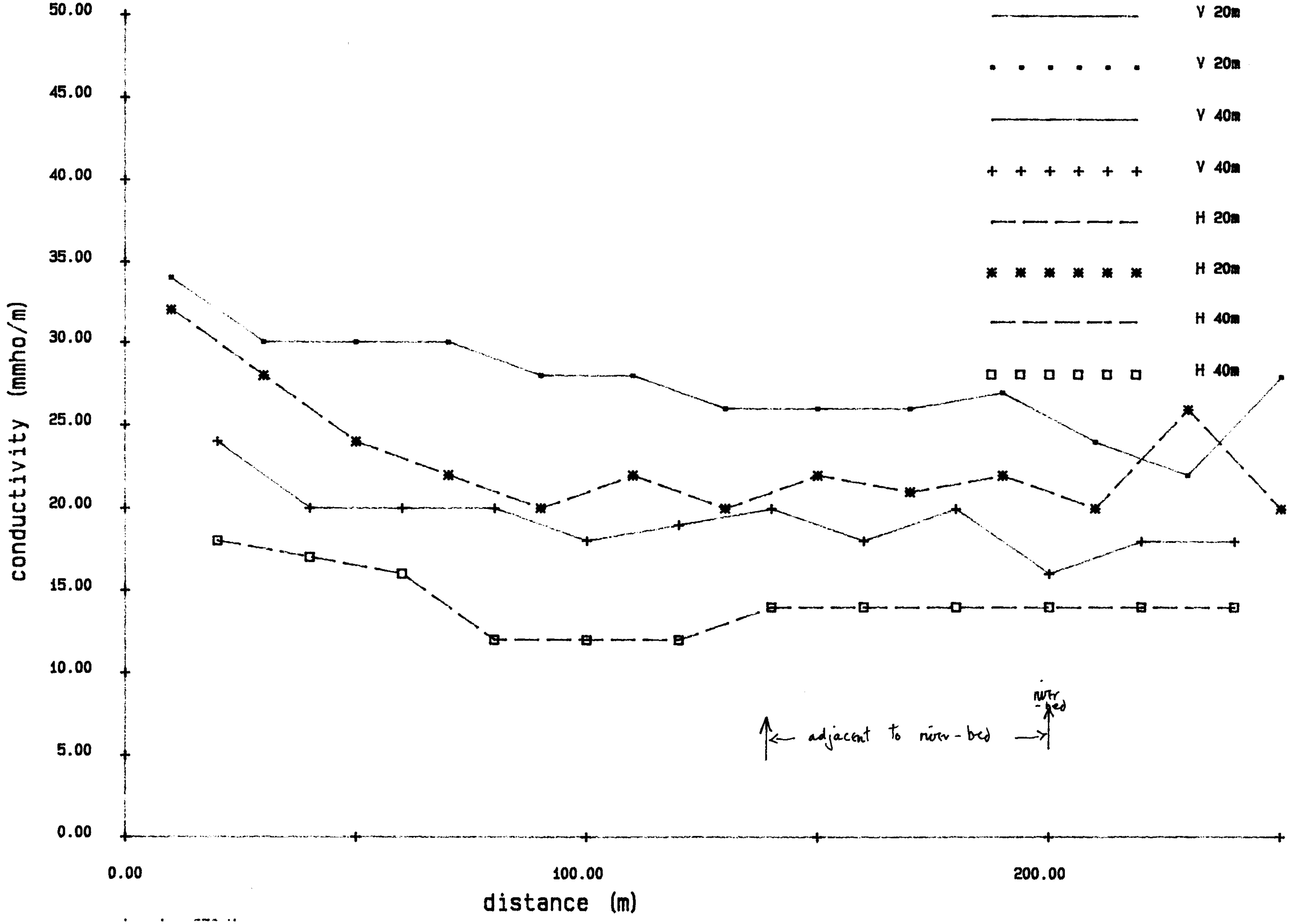
Resistivity	Thickness	Depth	Layer
38.1	1.0	1.0	1
82.9	15.5	16.5	2
1704.0	983.5	1000.0	3

Schlumberger Array

BRITISH GEOLOGICAL SURVEY 1987

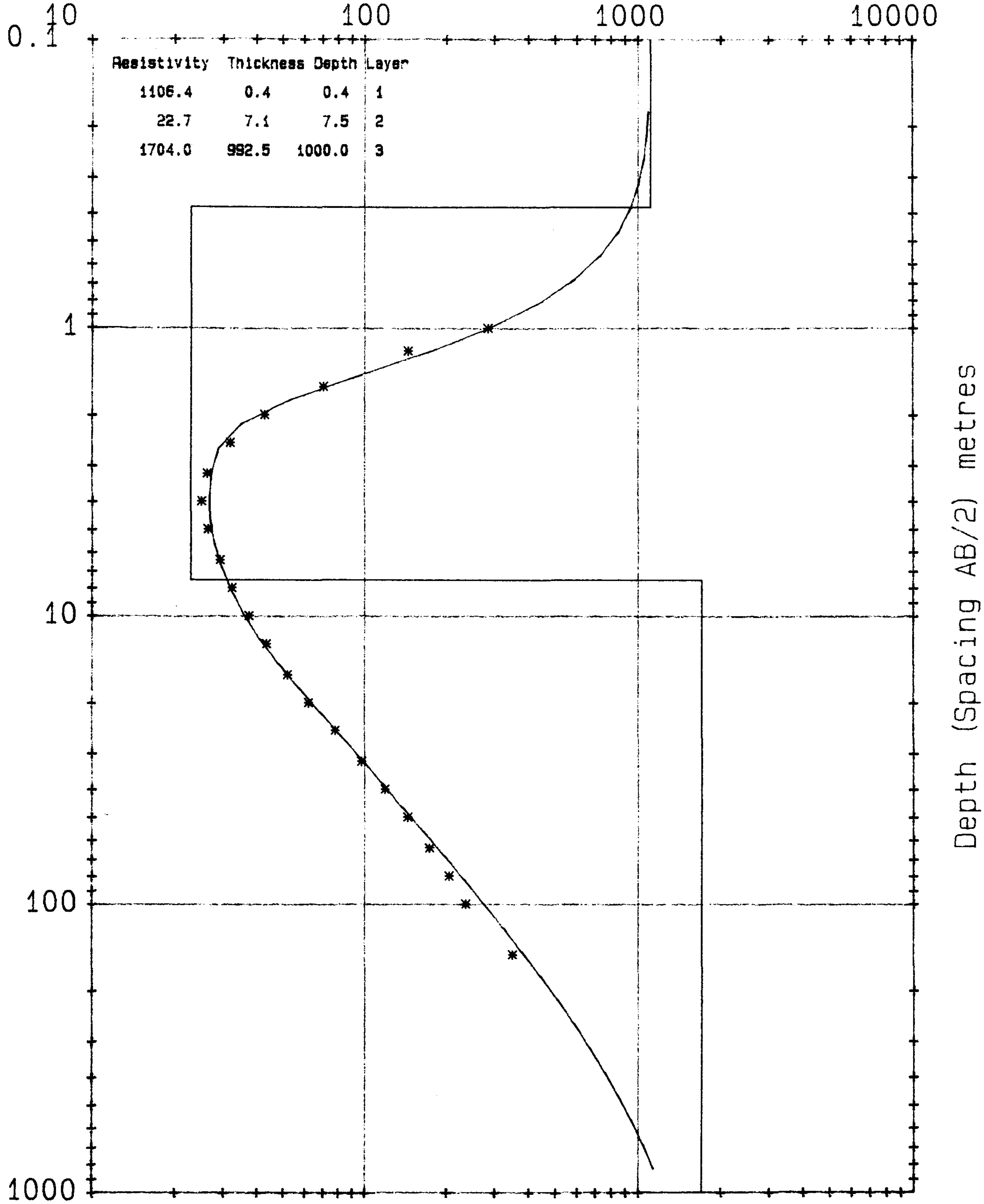

Chinyika Clinic EM34 traverse 2
conductivity (mmho/m)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
100.00
200.00
300.00
400.00
500.00
distance (m)
V 20m
V 20m
V 40m
V 40m
H 20m
H 20m
H 40m
H 40m
stream
VES4
VES3
EM3

Chinyika clinic EM34 traverse 3



chinyika west dambo VES no.3

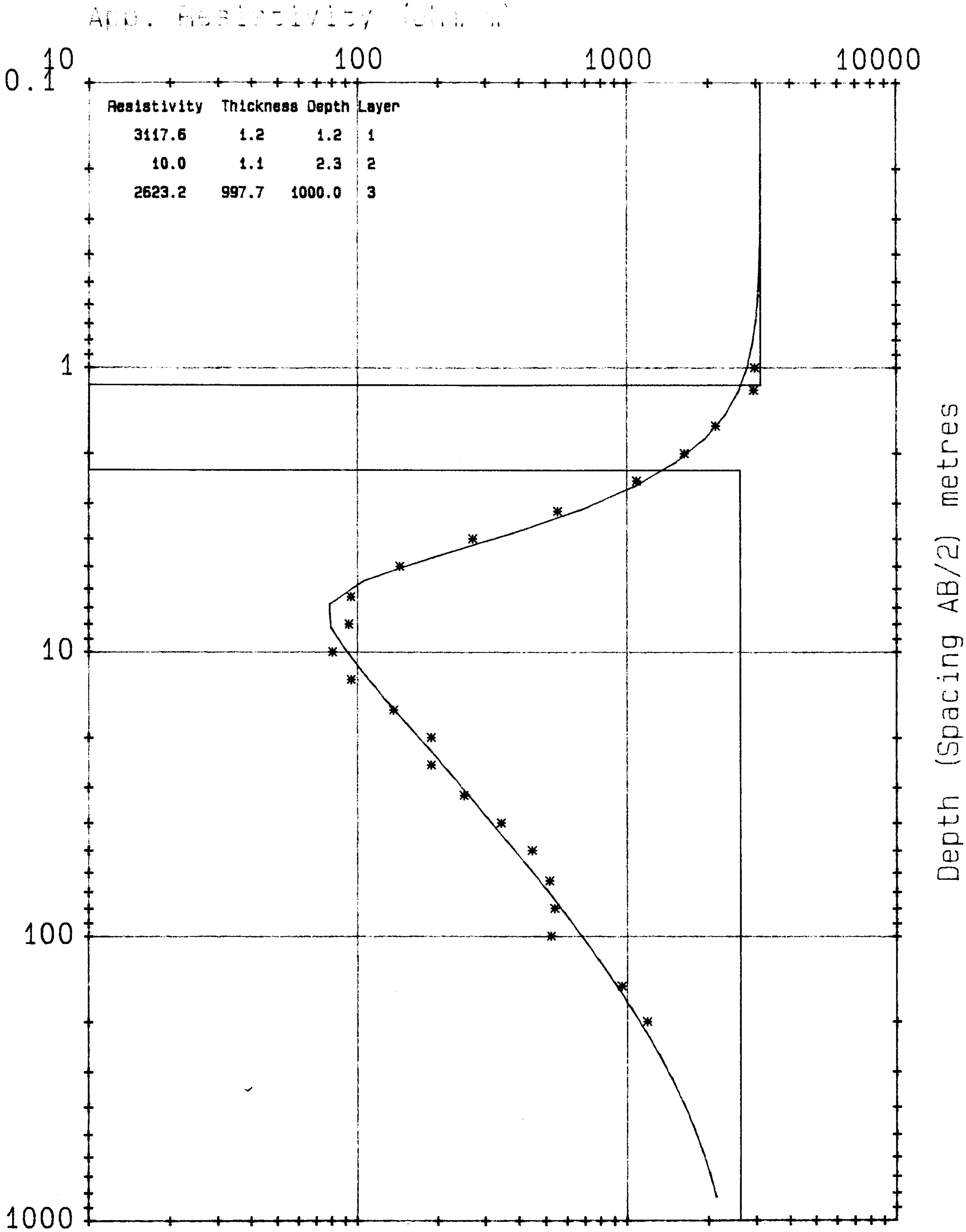
App. Resistivity (ohm m)



Schlumberger Array

BRITISH GEOLOGICAL SURVEY 1987

chinyika west vlei VES no. 4



Resistivity	Thickness	Depth	Layer
3117.6	1.2	1.2	1
10.0	1.1	2.3	2
2623.2	997.7	1000.0	3

Schlumberger Array

by M. P. Rainsbury, P. D. Jackson

BRITISH GEOLOGICAL SURVEY 1987

2.15. **Soti Source**

Gutu

Map 1931 A3, map reference 313-4 7846

2.15.1. Introduction

The broad valley occupied by the source of the Sote River was identified by Wright (personal communication) as worthy of further investigation as a site for a collector well. The village of Soti Source is on the edge of a low kjope, and the objective was to identify an area nearby, over which the Hydrogeology Departmental geophysics team could conduct systematic Schlumberger soundings.

2.15.2. Geophysical studies

Two VES and 2 EM traverses were measured in the area to the north of Soti Source village, where the land falls gently away from scattered outcrops close to the kjope towards smooth relief of the vlei. The VES were measured relatively close to the kjope in broad valleys, to establish whether there was much thickness of saprolite developed. EM traverse no.2 was measured along the line of the MRT array.

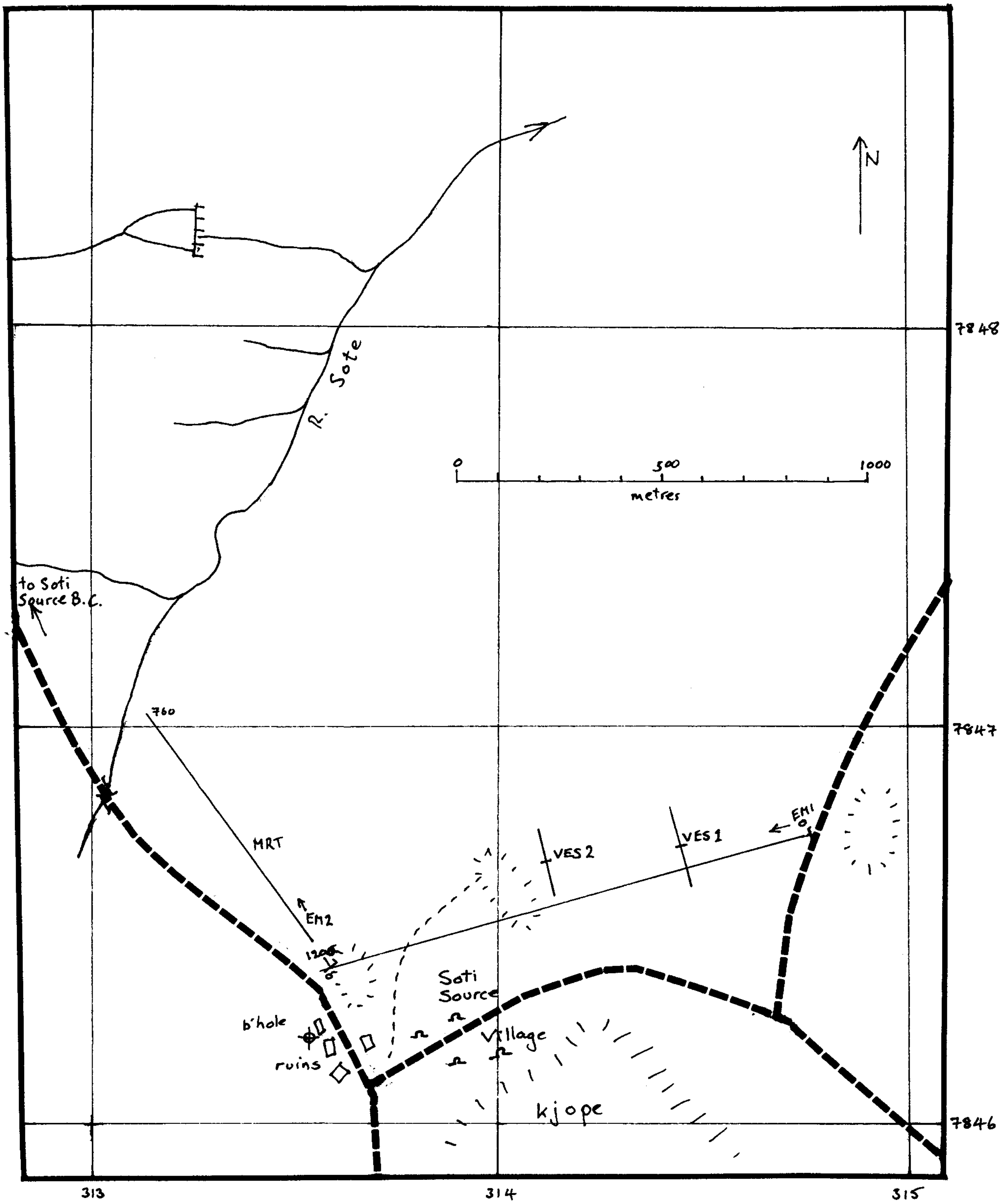
The indications from both VES is of considerable lateral variations, with up to 12m of saprolite with a resistivity of 50ohm m, which might indicate suitable conditions for a collector well. The EM results also indicate considerable variation in both small and moderate scale structures. A moderate thickness of saprolite is indicated, although on traverse no.2 thinner developments are noted between 150 and 350m, and between 500 and 600m. There is also evidence of steep sided contact with the underlying basement at around 170m, 430m and 650m.

2.15.3. Discussion

None of the geophysical results give clear-cut responses in indicating thickness or extent of saprolite. However, the indications are that the bedrock topography is rough, but that between outcrops, in the broad valleys, saprolite is well developed, extending probably from the bottom of the vlei to close to the kjope. A network of VES measurements should be measured in sites suitable for the application of collector wells, stetching as far as necessary towards the outcrop.

2.15.4. Conclusion

There is evidence of saprolite being up to 12m thick and it is reasonable to expect greater thicknesses elsewhere, because the bedrock has an uneven relief. The outcrops dip steeply into the overburden. A detailed grid of VES measurements could be obtained wherever other considerations, such as recharge or useage of the collector well, might determine.

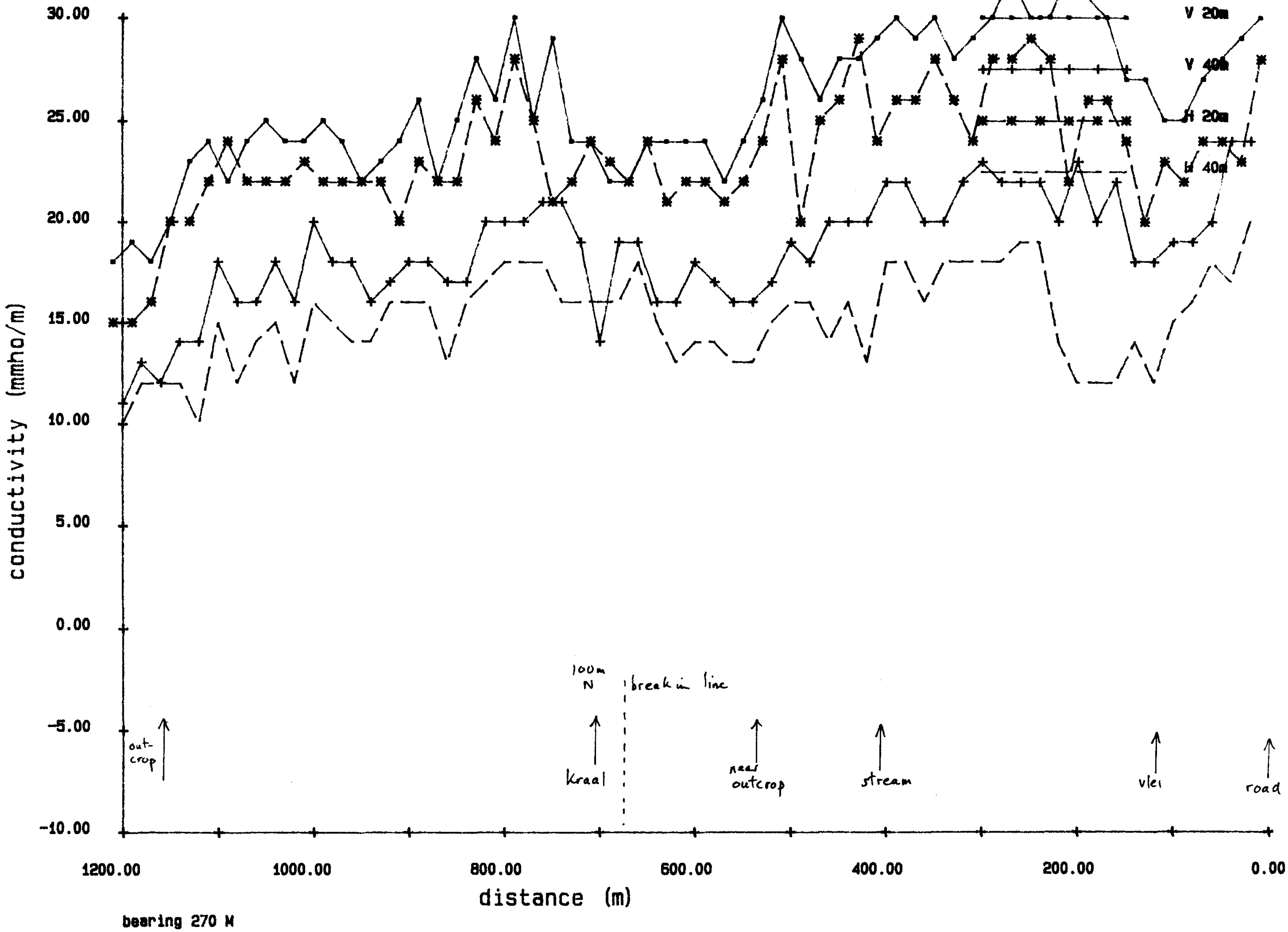


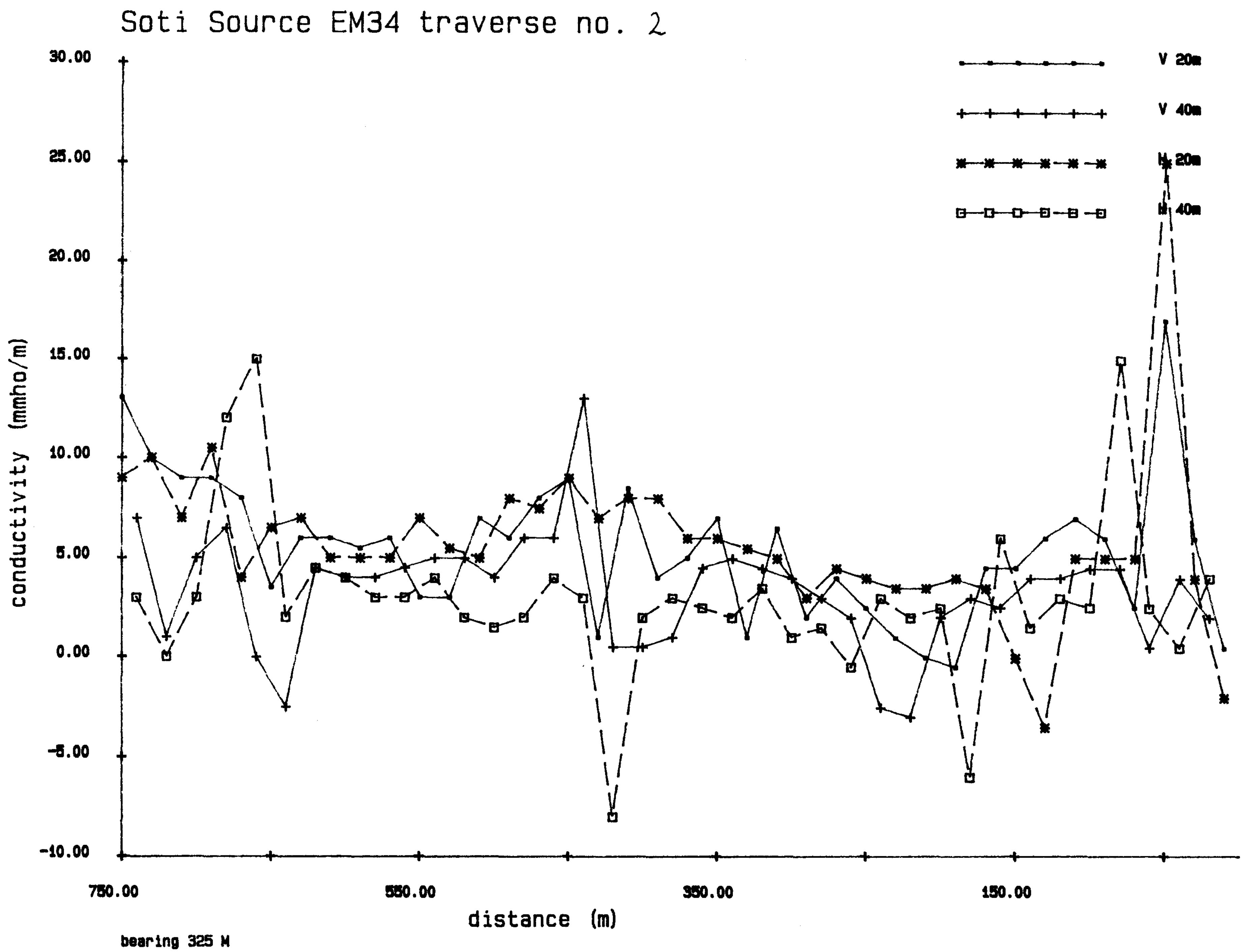
SOTI SOURCE: GUTU AREA

Map 1931 A3

Position of Geophysical Observations

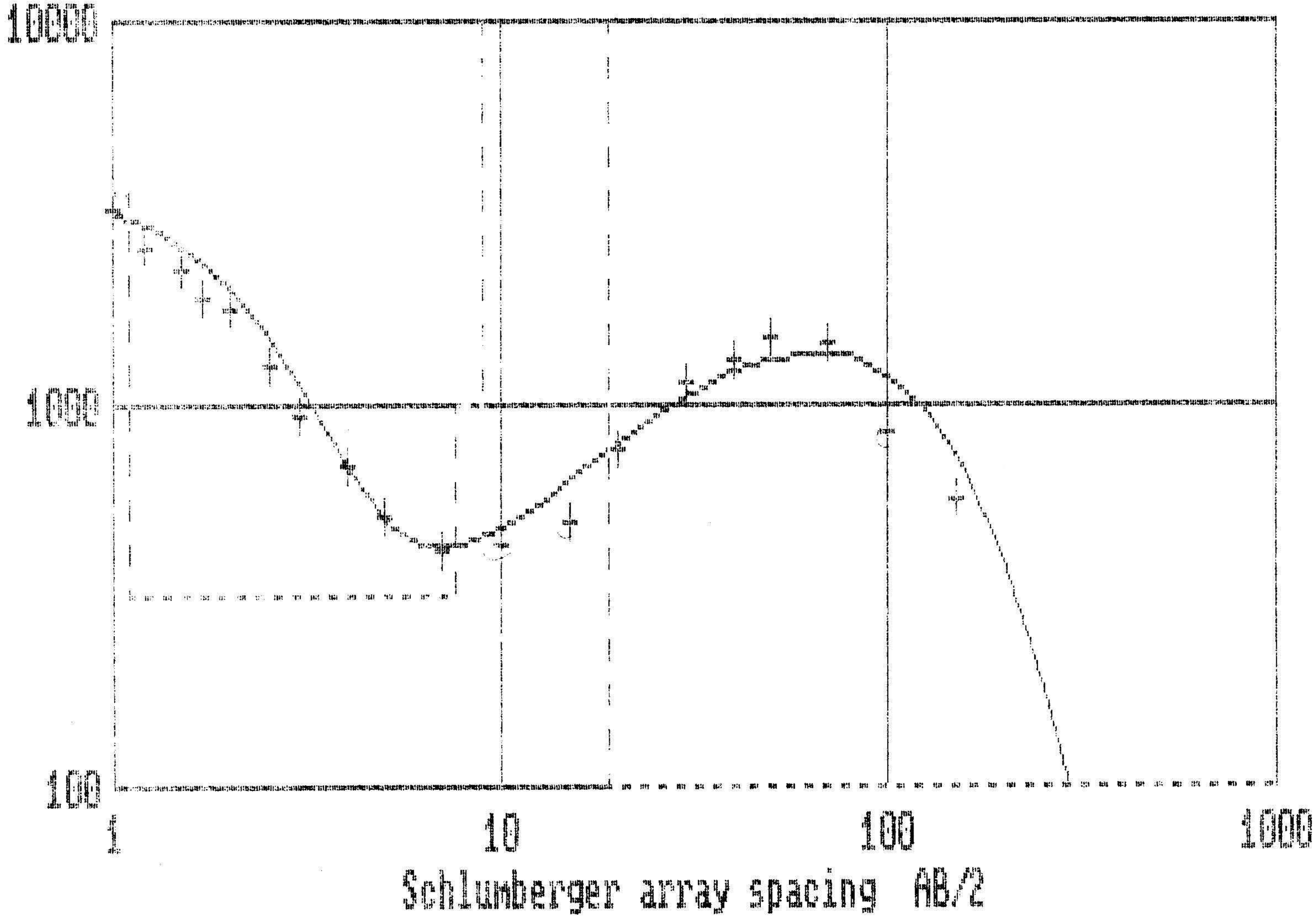
Soti Source EM34 traverse no. 1





Soti Source EM34 traverse no. 2
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
conductivity (mmho/m)
V 20m
V 40m
H 20m
H 40m
750.00
550.00
350.00
150.00
distance (m)
bearing 325 M

soti source VES 1 by valley centre
resistivity data: + observed; __ calculated; _ _ model

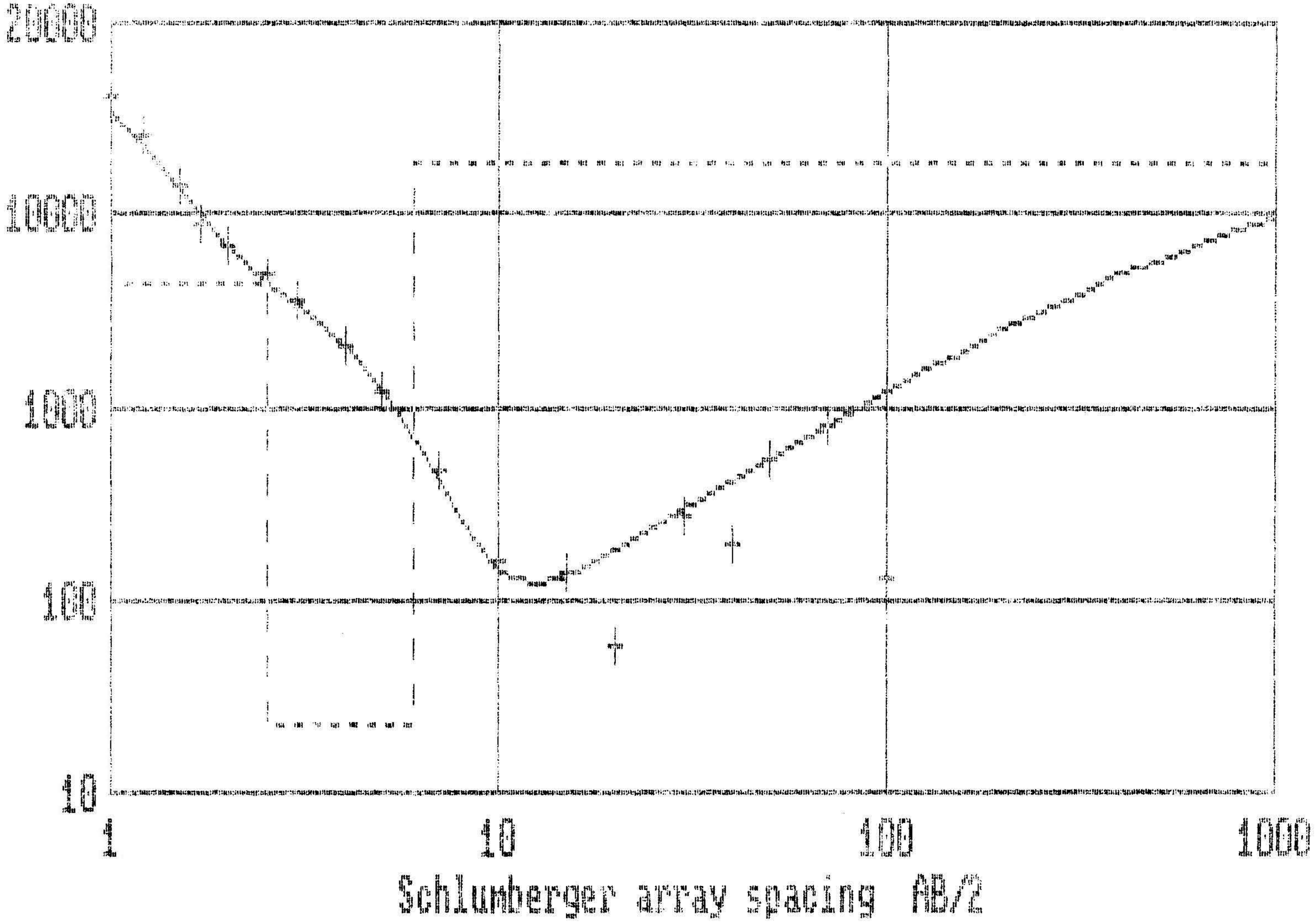


Model parameters for site:
zimuto

Layer	Thickns.	Restvty.	Depth
1	1.10	3500.00	1.10
2	6.50	320.00	7.60
3	1.40	1000.00	9.00
4	10.00	10000.00	19.00
Substrait		10.00	*****

soti source VES 2 (close to outcrop)

resistivity data: + observed; ___ calculated; _ _ model



Model parameters for site:

soti source

Layer	Thickns.	Restvty.	Depth
1	0.45	2000.00	0.45
2	2.05	1300.00	2.50
3	3.50	1000.00	6.00
Substrait		5000.00	*****

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