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THE SCHLUMBERGER ARRAY IN GEOPHYSICAL PROSPECTION FOR ARCHAEOLOGY

A critical evaluation of earth resistance surveys using the Schlumberger array through laboratory simulation and field studies, coordinated with geophysical and archaeological surveys of specific sites in England and Greece

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Abstract

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The Schlumberger array, or Schlumberger, was one of the first resistance arrays to be used to detect buried archaeological features. The early work used fixed probes and widely spaced traverses. Recent simulation work, however, suggested that the array should give improved resolution and depth penetration over the Twin-Probe array. This thesis is an attempt to operationalise the Schlumberger for use in archaeological prospection. This has been achieved via a co-ordinated use of laboratory simulation and field studies.

Initial fieldwork in England suggested that the use of point electrodes created response patterns that were dependent upon the relative direction of linear targets. This was verified using a simulation tank modified to represent field procedure. The recognition of this response, therefore, required each survey area to be surveyed twice. The re-survey requires the two current probes to be positioned at right angles to the original survey points.

The Schlumberger was then used in a battery of methods to investigate the problem of the archaeological interpretation of small, discrete scatters of ceramic sherds that cover the landscape in Greece. The research has indicated a variation of intra-site patterning that may be significant to the function of these sites. Overall, the results suggest that the relationship between the 'site' and its environment is a complex one, one that can be oversimplified when the ceramic evidence is viewed in isolation. The Schlumberger indicated possible structural elements within some of these sites.

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CHAPTER 1

Approaches to geophysical survey in archaeological science and a contextual problem

1.1. Introduction

The involvement of geophysics in archaeology has had a long history (Wynn 1986). As a general prospecting tool geophysical techniques have had startling success on almost all forms of substantial archaeological structure and on many levels of the site hierarchy (c.f. Pocock 1983; Carr 1982, Table 1). From Atkinson's earliest work in defining elements of prehistoric habitation at Dorchester-on-Thames in England (Atkinson 1952, 1963), research into prospection spread quickly and seemingly unabated throughout the 1960s. In Europe major centres for specialist work in geophysics for archaeology were founded in France, Italy, Germany and Britain.

If the bibliographic content of a discipline can be used as a measure of the state of a subject, then the 1960s was a florescent period, not only for the intrusion of science into archaeology as a whole, but also an acceptance, no matter how tacit, of the implications of geophysical prospecting. Not only had an international journal been dedicated to the subject of geophysical prospection in archaeology, but reports of the new techniques were passed on to the archaeological fraternity via specialist periodicals and the publication of popular books on the nature of the new subject area. Within archaeology this modern method, coupled with the armoury of techniques that were in use, were collectively to be named 'Archaeological Science' (c.f. Pyddoke 1963, Brothwell and Higgs 1963). The academic subdivision for geophysics has recently been termed 'archaeogeophysics' (c.f. Heron and Gaffney 1987).

Perhaps one of the characteristics of the use of geophysical prospection in archaeology is the implementation of certain techniques and, indeed, certain methods for these techniques in routine archaeological work. Somewhat extraordinarily, the extended use of these techniques did not spawn an expansion into novel applications or new techniques, indeed, the reverse may be said to have been true. By the late 70s, in Britain the lack of research proposals for prospection was highlighted during an investigation into the strength of science in the funding of Archaeological Science as a whole (Hart 1985). The amount of new technical work published in the 1970s was sparse, especially in the European sphere. The accent of much of the new research in Europe has been in the field of data processing (c.f. Spicer 1985, Scollar et al 1986), perhaps to the detriment of novel techniques and applications. However, this is a valid area of research as the computerised capture of data has radically increased the amount of area covered by field exponents (c.f. Kelly et al 1984). This, therefore, has given greater validity to statistical processing of large data sets and increased the explanatory powers of most practitioners of prospecting techniques.

A greater interest in the more technical matters has come from the United States, where a recent influx into the subject by interested geophysicists has found many applications for novel techniques and equipment (c.f. von Frese 1984). However, on the whole, the majority of routine archaeogeophysical prospecting work in Britain has been carried out using proven detection devices, viz earth resistance meters and magnetic fluxgate gradiometers (c.f. Catheral 1985, Clark 1975).

1.2. Geophysics and Field Archaeology.

As has been outlined above the implementation of geophysical prospection has involved, in real terms, the use of only two techniques on a regular basis. However, in Britain we have seen geophysical prospection techniques used in a number of important archaeological survey projects, for example the Stonehenge Environs Project (Richards 1985, Entwhistle and Richards 1987), Maddle Farm Project (Gaffney and Gaffney 1986, Gaffney, Gater and Start 1989), Solway Plain Project (Bewley 1985), and at Wharram Le Street (Rahtz et al 1986). The majority of these projects have used magnetic survey methods primarily because of the nature of the expected archaeology i.e. pits and ditches. Other projects have used geophysics to 'test' unusual results of field survey, (c.f. Healy 1983). It is from the experience of such projects that research priorities have been drawn up for archaeological prospection, which include the investigation of novel electrical resistance array characteristics (Clark

1987). It is only from this fruitful dialogue that relevant research areas can be targeted.

Turning toward the Mediterranean, whilst we can see pioneering work in the form of the Lerici Foundation in Italy (c.f. Lerici 1959, Linnington 1963), we see a relatively late use of geophysics in Greece. However, it is an area that has proved highly susceptible to the introduction of novel techniques (c.f. Fisher 1977). One positive aspect of this late arrival of geophysical techniques is that they have been incorporated within more mature archaeological strategies. Within survey projects in both Spain (Jones et al 1982) and Italy (Lloyd and Barker 1981) geophysical results have been used within a problem oriented framework. Another striking example of geophysical prospecting in the Mediterranean is the survey at Stymphalos, Greece. The resistance survey at Stymphalos was slightly different in nature to the previous two projects as there was never any intention to excavate any part of the classical city. The resistance survey went hand-in-hand with a standing monument architecture search, and together, they have produced some of the most important information on ancient town planning during this decade, as well as producing some of the most spectacular geophysical results to date (Williams 1985).

Perhaps more typical of the use of geophysical results comes from the site at Palaikastro, Crete (MacGillivray and Sackett 1984), where there was an attempt to circumvent the limitations of the surface survey at the Bronze Age town with the use of a magnetometer survey. The very thorough survey, although using advanced statistical treatment of the data, gave no archaeologically useful results. This survey, along with the study at Wharram le Street cited above illustrate the perils of 'scientific' archaeological strategies which are not based on human behavioural models. At Palaikastro the geophysical survey did not succeed because there was no model of human activity on the site to suggest that magnetometry would be informative; in fact, given a knowledge of the archaeology, a resistance survey would probably have given more informative archaeological results.

At the Wharram query-villas, in contrast, magnetometry eminently suited the abundant ditches and enclosures, kilns and industrial areas. Although loosely part of an overlapping approach to the question of function of these sites, the excellent results provided by the magnetic survey could not aid the interpretation of site function. Moreover, the attempt at a rigorous scientific sampling strategy for the test excavations added little to our understanding of these sites and nothing to the functional interpretation of the site. The basic reason for this is that the strategy contained no core of behavioural or social questions. Perhaps the problem of location and plan of building ranges, and hence function, might have been resolved using a more flexible approach. Areas of possible structural significance suggested by the magnetic data, could have been identified to direct smaller scale resistance work. This is a critically important point, as it could have helped reassure the archaeologist in the interpretation of building evidence and hence, modify the trench sampling strategy.

In the last few years the amount of geophysics carried out in Greece has increased dramatically. The result of this new wave of specialists has come at a very welcome point in time. The enthusiasm has been matched by an up-grade in the quality of commercially available equipment. Small scale surveys such as the ones at Lesbos (Papamarinopoulos et al 1985), Dion (Tsokas et al 1986), Thasos (Jones 1986), Mandalo, Aiges and at Karista (Tsokas et al 1987) are regularly reported in both archaeological and geophysical journals. A complementary new trend is the possibility of using geophysical and geochemical techniques as integrated components in archaeological investigation of archaeological regions (c.f. Chapter 8 below), The proposed scale of activity to be investigated would radically alter the choice of techniques and the methodologies employed.

1.3. The 'New Archaeology' and the Classical Tradition in Greece.

Traditional archaeological research in the Mediterranean lands may be personified by the work of Classical archaeology. It has been a subject that is dominated by major towns, upstanding architecture, beautiful objects and powerful history. Of course, all of these components of the past are valid and profitable avenues of research. However, the so-called 'New Archaeology' of the sixties and the seventies has derided not only the study of objects for their own sake, but also the 'rules' that govern the pattern of research. It is therefore not the study of the history of art and 'event oriented' archaeology that is wrong, but the lack of interplay between the other elements in the observed society. The traditional view that is based only on generalised statements from historical sources, will be only as detailed about a particular subject as the source allows. It is perhaps because of this subconscious fear that the sources may be 'wrong' that Classical archaeologists have not been ready to form hypotheses and methodologies that would test them using strictly archaeological evidence.

It was a rush of novel research designs that made archaeology in general such an exciting subject in the 1970s. Classical archaeology, however, was not so readily assimilated into the mainstream of the new archaeological trends (c.f. Renfrew 1980, Snodgrass 1985). Even by 1981 Dyson had concluded that the proper time and space frame for gathering together all of the classical archaeologists that were really interested in the New Archaeology would be a telephone booth. The content number in the booth, he surmised, would not trouble the Guinness Book of Records (Dyson 1981). This is of course is an exaggeration and is based on the often muted response to the New Archaeology by the more traditional practitioners in the United States. In Britain, although the change in direction has also been slow, it is possible to see some clear trends. However, the very fact that some parts of archaeology have embraced the new concepts, and rejected some of the most unpromising, has allowed the Classical archaeologist to choose the aspects that would be most suited to his area of research. Thus for the first time, the advances in theory and methodology may go hand-in-hand with technological advances from other disciplines. Therefore the huge data-base gathered from text and excavation may be accessed in a more suitable framework. This is an exciting challenge at a time when the fundamentals of all humanistic studies are being questioned. It is via the use of hypotheses and rigorous methodologies that the concept of quantification can help determine the nature of archaeological inference. It is from an appreciation of the meaning of the archaeological record that the new Classical Archaeology can turn away from an event dominated, history directed past, to one involving processes and participants (c.f. Snodgrass 1987). It is a new past that may still interrogate the sources but does not need to 'speak' about unwritten aspects of a culture.

1.4 Regional survey, science and interpretation

One of the major tenets of the New Archaeology was the need to mirror the strict scientific research models of the 'hard' sciences. This was a widespread movement among many of archaeology's related subjects (see for example Harvey 1969, and for a wider perspective Bintliff 1986). This involved not only the imitation of scientific rigour, but as a prerequisite all data bases had to be quantified. The collection of quantifiable data-bases via rigorous methodologies and hence analytical procedures was a product of the desire to produce statistically meaningful patterning from all kinds of archaeological artefacts.

Whilst the initial methodological work on surface survey inevitably came from the United States (Binford 1964), the ability to say Big Things about theory from archaeological data meant that the surface survey technique was incorporated in many research designs all over the world. The uses for field survey have proved as varied as the methodologies themselves (see Macready and Thompson 1985, Haselgrove et al 1985). The earlier work tended to be dependent simply upon the need to locate 'sites' - defining then as obvious foci of human settlement - and analysing their spatial and chronological patterning across the landscape. Although, as we shall see, the inferences from the seminal surveys were inevitably simplistic, the new surveys in the Mediterranean quite simply changed the quality and quantity of information on previously largely unknown rural communities. (e.g. McDonald and Rapp 1972; Potter 1975, 1987).

The majority of sites located by even semi-intensive methodologies in the Mediterranean area have been small in size (e.g. projects in Boeotia, Nemea, Keos; see Cherry 1983). A major interpretational problem has been caused by the phenomenal recovery rate of these small, localised scatters of ancient ceramic artefacts located on modern field surfaces. The archaeological data base from the field surface has accumulated in such a way in Greece as to question modern conceptions of past societies. The division has arisen from the traditional Classical Archaeological approach of depending on written sources, which centre on the Ancient towns, and the impact of the recognition of a full rural past. In short it is the theoretical impasse of 'townscape' and 'landscape'. It has been the methodological leap to quantitative regional survey that has produced this theoretical dichotomy. There is little practical and certainly no academic reason why the information gathered by either approach should be totally disregarded. Whereas initially the archaeological evidence often played a minor role in the interpretation of historical landscapes, simply because the evidence was at odds with the contemporary literary sources, the wealth of information from intensive archaeological surveys has now reversed that situation (see Chapter 6). However, the quality of the literary and epigraphic evidence, although open to manipulation to answer inappropriate questions, should not be dismissed without due care (Lloyd 1986). Just as clear, however, is the fact that the absence of references to a particular subject in Classical literature does not mean that it did not exist, nor an event occur. In the form of analysis that will be described later, it is taken a priori that all evidence collected in a rigorous manner is good evidence, unless it can be proven to have been disturbed beyond comprehension and should be treated accordingly. All evidence should be treated with equal weight until signature responses, which can be recognised as forming a specific part of the archaeological evidence, are obtained. This may result in polythetic archaeological definitions that may increase the interpretative ability over otherwise compromised data-bases.(c.f. Clarke 1968 chapters 1 and 6; Sokal and Sneath 1963).

Although the advent of regional surveys in the Mediterranean meant that the information potential was increased substantially, it is apparent that the interpretation of the basic evidence from surface scatters is still open to debate. The discussion between Cherry (1983, 1984) and Hope-Simpson (1984) on fundamental sampling inference in field survey is a case in point. It is, however, an argument worth pursuing because it is the ability to assess the quality of samples statistically that has segregated the New Classical archaeology from the Old (c.f Snodgrass 1985, p.34). Therefore the very methodology of regional survey has increased this conflict of views.

The extensive sampling strategies used by modern intensive surveys in the Mediterranean have proved exceptionally efficient at locating 'sites' and explaining them in terms of their surrounding environment. However, the weak point in such strategies is that the information that is collected can tell us nothing about functional or structural intra-site definition. This is due to the extensive nature of the data capture. That is, the fieldwalkers are always a set distance apart and cannot examine the whole of the ground surface. They therefore cannot map the discrete, localised patterning of the cultural material that is known to exist. Such information can only be collected by sampling or total collection strategies operated at the site level.

The realisation that the precise mapping of intra-site surface debris can convey complex yet useful information has been accepted slowly in the Mediterranean area. Most surveys were until recently quite satisfied to acquire dating information for their sites via spatially uninformative 'grab' samples. However, recent survey projects have shown that each site may have many different use-areas and, therefore, the overlapping spatial information must be broken down to make sense of the data. Many of the projects in the 70s produced highly inventive sampling schemes, but now it is increasingly common to attempt to grid out and cover the whole of a site's area (c.f. Bintliff and Snodgrass 1985, 1988b). In fact, the subtle variability of ceramic information can only be measured by intensive sampling of areas of interest. When intra-site information is collected, not only can it aid basic interpretational problems, such as the origin of the surface material, but it expands considerably the information context for the geophysicist.

At a minimum level, irrespective of climatic or topographic context, geophysical techniques ought to be able to predict the presence or absence of subsurface remains and the degree of disturbance or preservation of those remains (Heron and Gaffney 1987). In practice this must mean the location or otherwise of any major cultural anomaly, if the post-depositional processes have allowed a significant measurable contrast to be maintained. For each use of a particular investigative technique, the reasons for that choice must be determined by both the expected cultural remains and the state of preservation. This at the outset has serious implications for the use of geophysical techniques in field survey research. By definition the 'sites' located by surface survey are already plough damaged i.e. much of the surface cultural remains would not have been located if modern farming were not so destructive to previously buried archaeological layers.

From prior knowledge of the expected building materials used in the past in Greece, it was decided that the resistivity technique of prospecting would be the best way to detect the highly resistant walled features thought to be structural elements associated with the Greek ceramic surface scatters. The most popular method of resistance measurement which has had the most proven success in archaeological work in the past two decades is the so called 'Twin-Probe' array (Aspinall and Lynam 1970).

The Twin-Probe has been popular for three major reasons. Firstly, it is very easy to use, especially over a gridded area. Secondly, the signal strength of response is very good over most archaeological features. Thirdly, and possibly most importantly, the form of response is highly predictable and easy to interpret. However, over the years two major criticisms have been levelled at the Twin-Probe. In practice low resistance anomalies can be difficult to detect. This is not so much a criticism of the Twin-Probe alone, but of all resistivity arrays used in archaeological work (c.f Clark 1975). More importantly, small near surface anomalies can give complex and virtually contradictory signals. This is a troublesome phenomenon that the author has experienced when using the array on the Great Bedwyn villa site in England and has been discussed at great length by Houlder (1983). As sites located by field survey are often either close to the surface, or at least have rubble near the surface then the 'Twin-Probe' array may not be very suitable for such sites. As the definition for these sites states that the remains are in fact partially destroyed, then the relatively poor anomaly resolution of the 'Twin-Probe' array must also argue against its deployment in surface survey strategies.

However, simulation studies have suggested that the so called 'Schlumberger' array may have the characteristics of simple response and good anomaly resolution that would be beneficial to the problems of field survey (Houlder 1983; see Chapter 2). Yet, as will be noted in the following chapter, there are many logistical problems to be dealt with if the Schlumberger array is to be used efficiently within archaeological prospection.

The research within this thesis naturally breaks down into two areas. Firstly, there is a need to investigate the Schlumberger and decide how to optimise its field procedure whilst maintaining the useful properties of the array. This was a critical consideration in the research design involving the cross reference between simulation studies and field work. Secondly, there is the further investigation into the problem of the small rural sites located using field survey techniques. In this case the application of the Schlumberger array does not necessarily answer all of the research questions by itself, but forms part of a battery of techniques.

CHAPTER 2

The Schlumberger Array

2.1 Introduction

The Schlumberger array has been used infrequently for archaeological prospecting work during the last 30 years: the majority of the Schlumberger survey work was done in the first half of that period. The array itself is a standard four probe resistivity configuration, comprising of a pair of current electrodes and a pair of potential electrodes. The major defining criteria for the Schlumberger array is that the current electrodes are to be spaced far apart by comparison with the distance between the potential electrodes. The potential probes are situated between the current probes. In geological prospecting terms it has been suggested that the ratio of the current probe separation to the potential probe separation (CC:PP) should be greater than 4.6:1, in order that the measured voltage to separation ratio approximately equals the voltage gradient at the midpoint of the current spread. (Keller and Frischknect 1966, pp.95-96).

Some of the more specialised aspects of the array performance, which may well influence the characterisation of the array, will be treated later (Chapters 3-5). This chapter will deal with some aspects of resistance theory that are particularly important to this application of the Schlumberger array. This chapter will also be both a reflection on past Schlumberger prospecting in archaeology, whilst indicating the new avenues that will be explored in succeeding chapters. A detailed description of resistance theory itself will not be covered as there is nothing novel about the fundamental properties used in this application of the Schlumberger array.

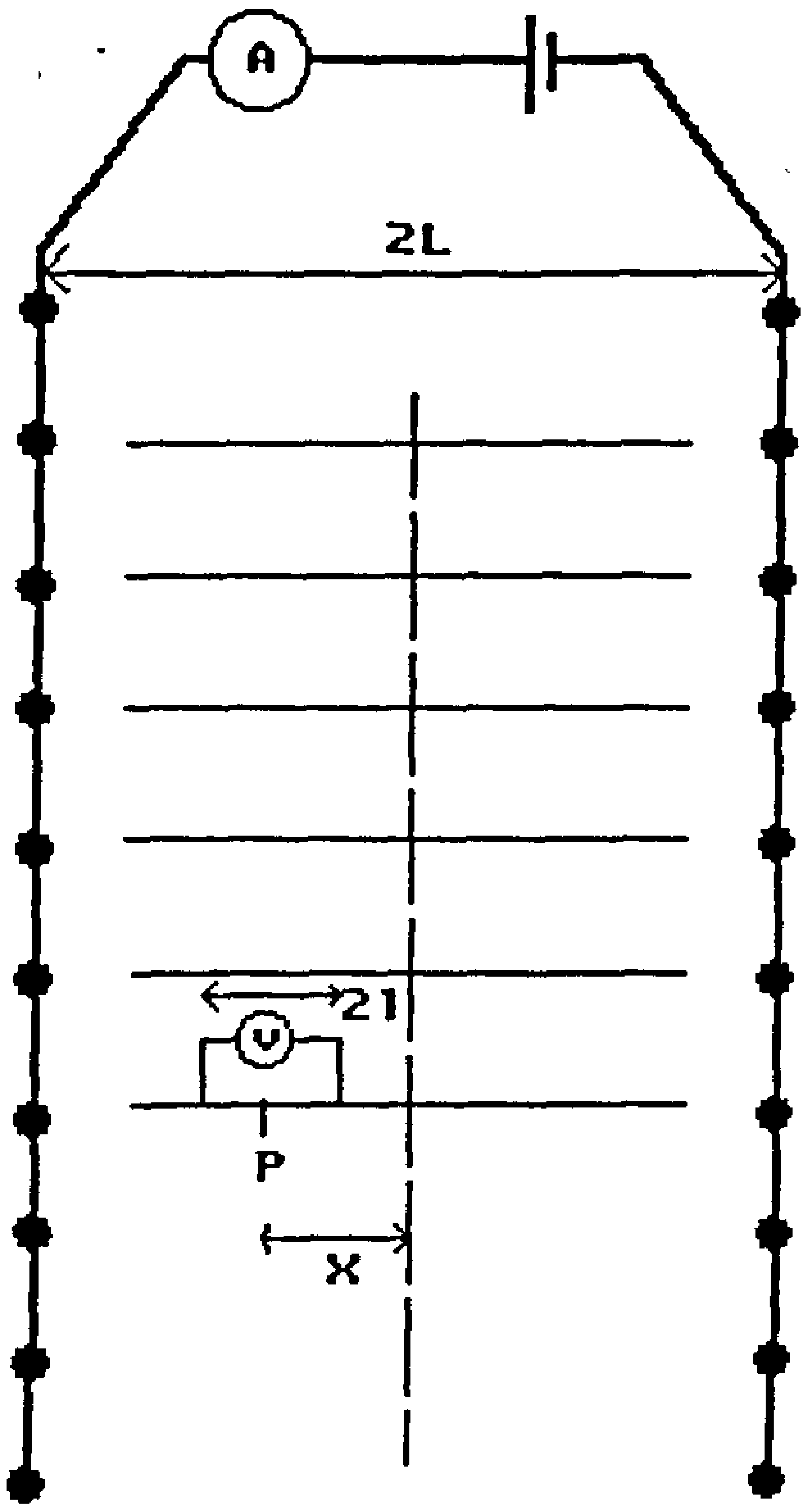
2.2 The Schlumberger Array and Archaeological Prospecting

After the initial trials using the Wenner resistance array (Atkinson 1952), the Schlumberger array was one of the first electrode configurations experimented with in archaeological prospecting. The first published archaeological work involving the Schlumberger array was on a Romano-British villa site at Barnsley Park, England (Dunk 1962). Resistivity survey was chosen at Barnsley Park due to the underlying clay which would give good contrast for the stone walls that were known to be close the the surface. The Schlumberger array was used because theoretical considerations suggested that this array would give the most easily interpretable results when the buried features were close together and near the surface. Dunk experimented with different probe distances in the field and finally chose a distance between the two current probes (C-C) = 8'6", a distance between the two potential probes (P-P) = 6", resulting in a CC:PP ratio of 17:1. The sample measurement interval for this work was very coarse, measurements were made along the sides of 50ft squares. It was suggested that the intention was merely to assess whether archaeological features could be located using the technique. After filtering, the results were contoured and an acceptable agreement with the known archaeology was apparently obtained (see Webster's comments in Dunk 1962).

The Schlumberger method was again used on the Barnsley Park site by Rees and Wright (1969), this time using a C-C distance of 8', a P-P distance of 6", resulting in a CC:PP ratio of 16:1. The measured apparent resistances were then changed to resistivities via a constant multiplier. The measurements were taken every 3ft, along traverses that were 20ft apart. Obviously, the sample interval is again very coarse, but a stated aim was for the traverses to cross buildings 'several times'. The results indicated the presence of walls close to the surface, as well as rubble and paving situated at a depth of a 'few feet'. There are many problems with the field method chosen at this site, especially the traverse spacing. It was argued that a site such as a villa should exhibit a regular plan and, therefore, one could justifiably interpolate between the very wide traverses. However, this is not a valid assumption and would certainly not be adequate for a site where a degree of secondary use is suggested. No ditches or robbed out walls were interpreted from the Schlumberger survey results.

A major methodological feature used at the Barnsley Park site involved the Schlumberger probes being mounted on a hinged board (particularly discused by Hesse 1966a). The survey strategy therefore involved the movement of all four probes. A significant problem in such an arrangement are large scale resistance changes, possibly due to geological conditions, and complex response patterns due to near surface remains (see Clark, below). This is particularly pertinent when the CC:PP ratio is very small.

In 1971 part of a major study of new techniques involved the use of an experimental form of the Schlumberger array. In an effort to accelerate the collection of data, as well as make its retrieval more systematic, Iliceto (1971) used a methodology involving the laying out of two lines of current electrodes, thus allowing an area of 'uniform electric gradient' to be achieved between the two lines (see Fig. 2.1). In such a method a constant current is applied betwen the parallel set of probes, which results in a homogeneous field between the two sets of current electrodes. The only correction that is then required is for the positional distance from the centre of the array to be calculated. Despite the obvious problems of using a direct current source, Iliceto utilises a methodology that has been of particular use in geological geophysics when following the extent of linear anomalies (e.g. Parasnis 1972 (Fig.36)). Two points that Iliceto made about the moving potential system



Resistivity

$$= \frac{\pi}{2l} \, \frac{L^2 - x^2}{2L} \, \frac{\Delta V}{I}$$

Figure 2.1. Schlumberger measurement using line electrodes. After Iliceto 1971.

was that:

> "(1) The geological structures must be the same over great distances and their direction practically rectilinear.
> (2) The current must be uniform. In archaeology it is sometimes possible to satisfy these two conditions by taking into account the lack of depth of the soil that contains archaeological remains."
>
> Iliceto 1971, p.78.

These two conditions prove to be of great interest in any study that purports to further the idea of an 'off-set' methodology. Neither of the conditions are likely in the majority of archaeological cases, especially on plough damaged sites. The major problem, which may be highlighted by point (1), in the results from the Merovingian cemetery at Garchy is a distortion due to the position of an anomaly. In this particular case a low resistivity object showed signs of a high resistance 'kick' on the side away from the nearest current line. This deviant behaviour was supported with reference to a theoretical curve produced by Parasnis (1965).

Despite the increase in the rate of data capture due to the methodology used by Iliceto, the major research areas in this study included further methodological efficiency and a theoretical investigation based on a point source methodology. The latter area of interest would help interpretation in some of the more difficult situations that may be found e.g.

changes in geology.

2.3 The Schlumberger Array and Archaeological Simulation Work.

The theoretical modelling or simulation studies of near surface anomalies in the late 60s and 70s were somewhat negative about the archaeological use of the Schlumberger array. Lynam (1970) used an array with a separation ratio (CC:PP) of 11:1, whilst Clark (1980) used separation values of 6:1 and 7.5:1. In both cases the research workers simulated archaeological features with 'ideal' characteristics; keeping the potential probes in the centre of the array and moving all four of the probes. The work of Lynam, whilst emphasising the low background resistance that has to be measured with the Schlumberger array, also noted that there was no central peak reversal on the experiments that he carried out, and that depth penetration was characteristically good.

Clark, however, managed to obtain a number of very curious response forms from simulations with the array. In a series of simulations to investigate the possibilities of many different arrays, the Schlumberger did not appear to do very well. The major reason for this pessimism is due to the small separation ratio chosen by Clark. The resolution for the array will deteriorate as the equipotentials broaden out as the current probes are brought together. The small distances between the probes in relation to the object size really made Clark's Schlumberger array respond in a manner similar to the Wenner array. Clark was correct in saying that used with those parameters the Schlumberger offered no real advantages over the Wenner. When using such small CC:PP ratio, the array tends towards Wenner-like responses. In such circumstances the field is not uniform at the centre of the array and, hence, the Schlumberger array is often referred to in the geological literature as the 'gradient' array (c.f. Keller and Fischknecht 1966; Bertin 1976).

An alternative method of investigation, using computer simulations, attempted to review a similar suite of resistivity anomalies. The computer simulations offered by Houlder (1983), highlighted a number of intriguing possibilities. Firstly, he indicated useful attributes belonging to a number of less fashionable arrays, whilst noting some serious deficiences of the traditional archaeological arrays. Although Houlder only used the most simple of geometrical shapes in his simulations, the sphere, the fact that a spherical anomaly can be approximated by a bipolar charge makes it possible to calculate the effect due to the buried sphere. Given certain conditions i.e. an homogeneous environment ideally represented under computer simulation, the resistivity variations within the soil are considerably smaller than the difference in resistivity between archaeological anomalies and the surrounding soil.

The important problem of complex archaeological targets was not assessed. However, even with simple shapes Houlder detailed complex responses from a number of arrays, including the Twin-Probe. Near surface targets were particularly difficult to interpret. However, Houlder noted no deviant behaviour for the Schlumberger array. Indeed, whilst the basic shape of response was not greatly affected by either sphere size or depth, the resolution of the Schlumberger was 2.5 times greater than the Twin-Probe array (ibid p.44).

Houlder's conclusions about the Schlumberger array were that whilst its basic response shape was complex i.e. a central non-reversible peak always surrounded by two inverted negative peaks, it is easy to interpret due to the relative magnitude of the central peak (circa 4.5 times the absolute magnitude of the negative side peaks). Tank simulation work would therefore suggest that the Schlumberger array could offer a quality of data that has not been achieved with the traditional archaeological arrays.

2.4 The Schlumberger Array and Elementary Resistivity Theory.

Many factors can influence the electrical properties of rocks and soils. On the whole, however, the most important factor determining the electrical resistivity (or conductivity, as the reciprocal property is called), is the presence of interstitial water. The Schlumberger array, as in all resistivity prospecting, relies upon the water to allow the current to flow through the overburden of the archaeological site. The dissolved salts within the solutions create a path through which the electrical current can move. The resultant variation in resistivity due to climatic changes in surveys of archaeological sites is well noted (c.f. Hesse 1966b; Al Chalabi and Rees 1962; Clark 1980). However, even small localised changes within the substratum can determine a large variation in the 'background' upon which the archaeological features have to be identified.

Characteristically, resistivity measurements are obtained using a four probe arrangement - two current and two potential probes. This is a critical experimental design and allows the problem of unknown and varying contact resistance between two contact probes to be negated. It is now common practice to sample the ground with two potential probes in order to circumvent this problem. Whilst there is an infinite number of arrangements of these four probes, specific characteristic responses are obtained depending on each arrangement.

The measurements are usually taken using an alternating current power source. This avoids the problems of polarisation, which is the build up of ions around the polarised current probes, due to the use of a direct current power source.

The sampling of the ground is achieved in the manner that can be thought in terms of Ohm's Law.

i.e. $$R = \frac{V}{I} \qquad (2.1)$$

where R is the resistance of the material, measured in terms of the current (I) and the voltage (V). The resistance is proportional to p, which is the resistivity of a material. The resistivity is defined as the resistance of a cube with a side of unit length. In the simplest case, the resistivity is calculated as follows.

$$p = R.A/L \qquad (2.2)$$

In considering a point source, which is making contact with a semi-infinite medium of a uniform resistivity p, then given the dimensions in Fig.2.2, then the resistance of the hemispherical shell of radius r is, given 2.2

$$R = \frac{pdr}{2\pi r^2} \qquad (2.3)$$

The current density (j), which is the current passing normally through a unit area of the hemisphere, is

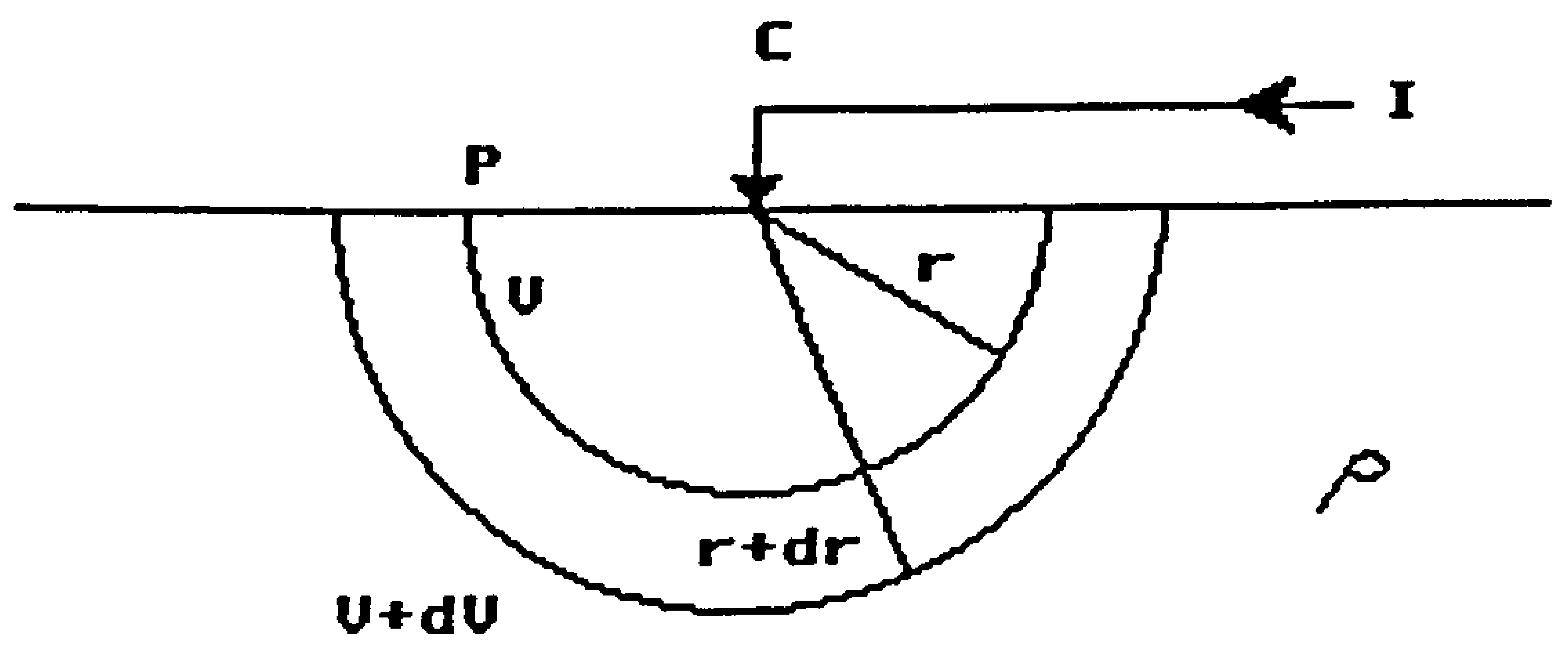


Figure 2.2 The section of an hemispherical equipotential surface due to a point source. The medium is regarded as semi-infinite and homogeneous.

$$j = \frac{I}{2\pi r^2} \qquad (2.4)$$

Using Ampere's rule and Ohm's law, the current flowing across the shell is

$$I = \frac{V - (V + dV)}{pdr/2\pi r^2} = \frac{2\pi r^2}{p} \frac{dV}{dr} \qquad (2.5)$$

or

$$dV = - \frac{pIdr}{2\pi r^2} \qquad (2.6)$$

To estimate the potential at any given point, it is neccesary to integrate, that is

$$V_P = \text{int } dV = - \frac{pI}{2\pi} \text{ int } \frac{dr}{r^2} = \frac{pI}{2\pi} (1/r) \qquad (2.7)$$

or

$$V_P = \frac{pI}{2\pi r} \qquad (2.8)$$

From this expression it is therefore possible to calculate the potential at any given point, P, due to a single current source at C_1. The current sink being at infinity.

As described above, for practical considerations there are two current probes - a current source and a current sink. The diagram in Fig.2.3. shows a generalised view of a four probe array. The probes are in the same linear relationship as would be expected for a Schlumberger survey i.e. CPPC. The current probes C_1 and C_2 have a current strengths of I.

The potential at P_1 due to the source C_1 is

$$V_{P1} = \frac{pI}{2\pi C_1P_1} \qquad (2.9)$$

and due to C_2,

$$V_{P2} =- \frac{pI}{2\pi C_2P_1} \qquad (2.10)$$

The total potential at this first point is therefore

$$V_1 = \frac{p}{2\pi} \left\{ \frac{I}{C_1P_1} - \frac{I}{C_2P_1} \right\} \qquad (2.11)$$

Using similar logic, the potential P_2 is

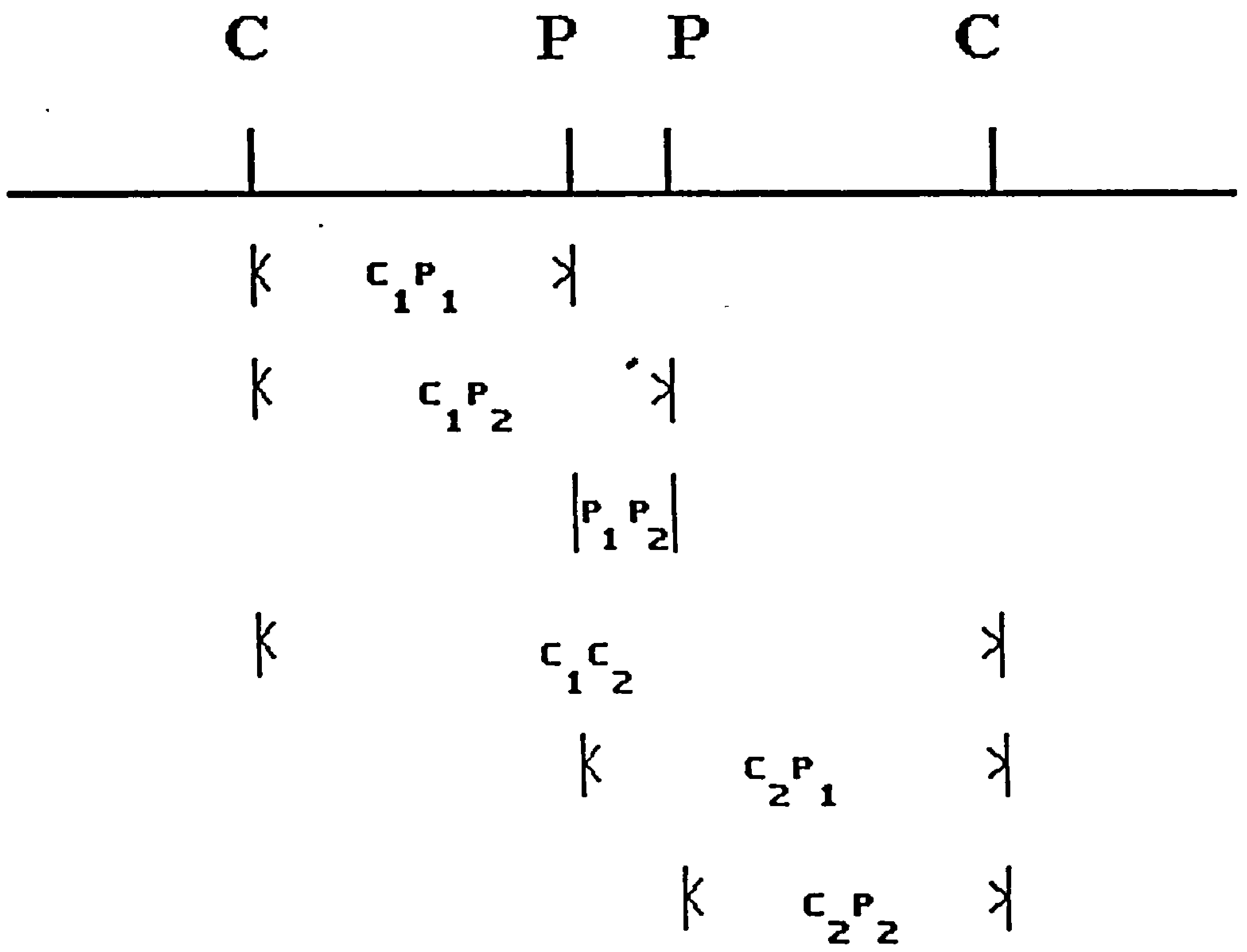


Figure 2.3 Section of a generalised "Schlumberger" array.

$$V_2 = \frac{p}{2\pi}\left\{\frac{I}{C_1P_2} - \frac{I}{C_2P_2}\right\} \qquad (2.12)$$

The potential difference (V) between the points P_1 and P_2 is then given by

$$V_1 - V_2 = V = \frac{p\,I}{2\pi}\left\{\left\{\frac{1}{C_1P_1} - \frac{1}{C_2P_1}\right\} - \left\{\frac{1}{C_1P_2} - \frac{1}{C_2P_2}\right\}\right\} \qquad (2.13)$$

The four probe formula would then simplify to

$$V = \frac{pI}{2\pi}\left\{\frac{1}{C_1P_1} - \frac{1}{C_2P_1} - \frac{1}{C_1P_2} + \frac{1}{C_2P_2}\right\} \qquad (2.14)$$

The term in the large brackets controls the effect due to the position of the probes. This is normally called the "Geometry Factor". In the previous Schlumberger simulation work described above (section 2.2), the Geometry Factor was maintained as a constant.

Clearly, the resistivity for any given position could then be calculated using

$$p = \frac{V2\pi}{I(G)} \qquad (2.15)$$

where (G) is the geometry factor.

It should also be evident that the geometry factor can vary, both between the current probes and also perpendicular to the C-C line. In the latter case, then the values C_1P_1, C_1P_2, etc, can be accurately calculated using the Pythogoras Theorem (see Fig.2.4.). This allows for the change in gradient, thereby calculating the apparent resistivity of the medium from the recorded resistance. The standard practice in both laboratory and the field was to measure the resistance at a set point, and use the expression in 2.15 to calculate the resistivity.

2.5 The Schlumberger Array and the variation in Current Density.

Separating the current probes by a large distance creates the theoretical conditions for a Schlumberger i.e. that the potential gradient at the centre of the array should be small. The further apart the current probes are, the larger the area that is available for 'ideal' Schlumberger measurements. It is patently true that when in a homogeneous medium, the same manipulation to resistivity can be made when deviating from this non-uniform gradient (see eqn 2.14). However, it is clear in the latter case that the unknown paths of the current lines and the change in current density

$$V = \frac{\rho_1 I}{2\pi}\left[\frac{1}{C_1P_1} - \frac{1}{C_2P_1} - \frac{1}{C_1P_2} + \frac{1}{C_2P_2}\right]$$

where $C1P1 = (A^2 + B^2)^{0.5}$; $C_2P_1 = (A^2 + C^2)^{0.5}$;
$C1P2 = (A^2 + (B+dB)^2)^{0.5}$ etc

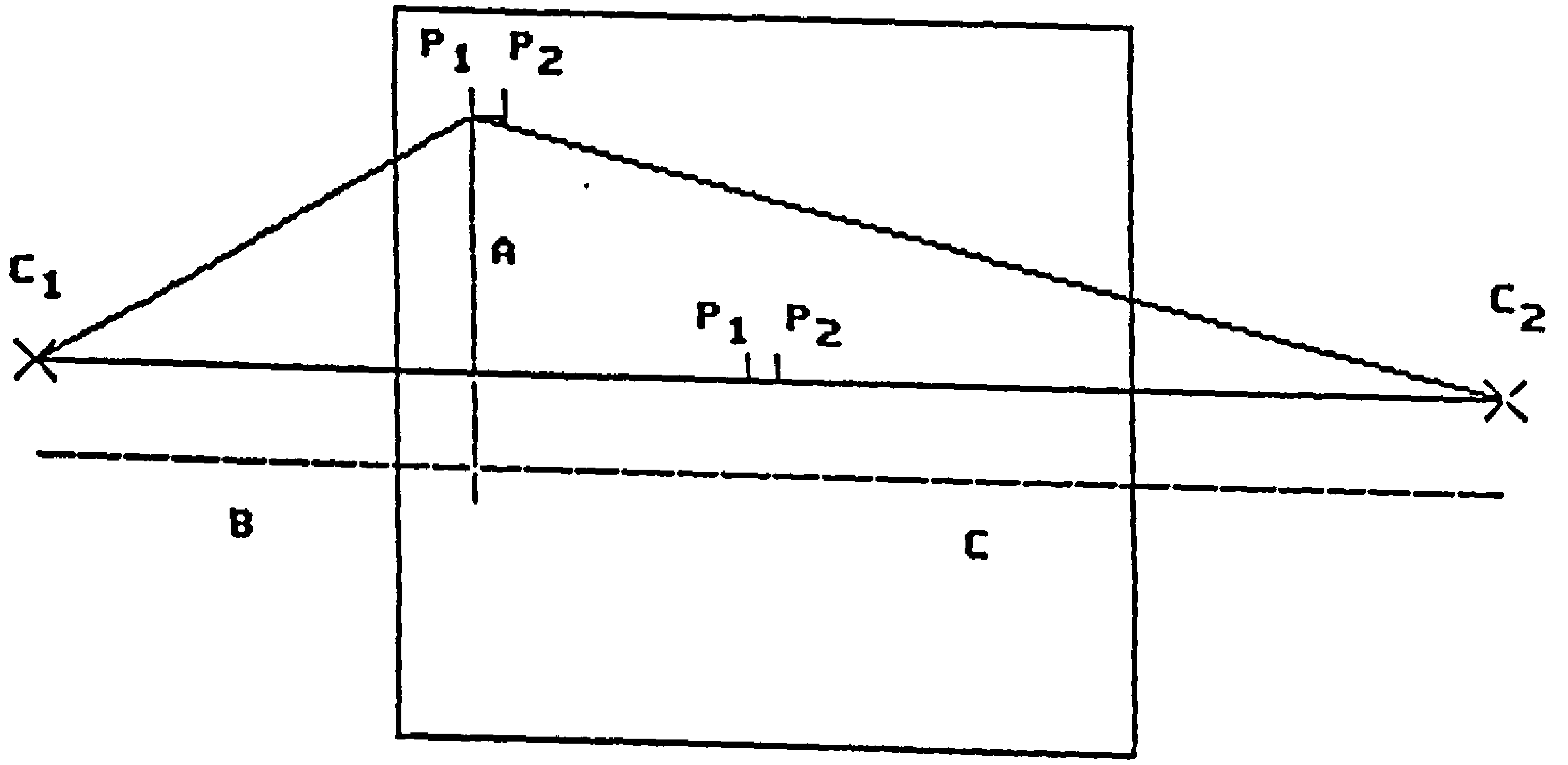


Figure 2.4. Generalised view of the Schlumberger, incorporating two point sources and a square collection grid.

with depth, are both problematical in interpretation.

The diagram in Fig.2.5. shows the general way the current paths flow between the two point electrodes introducing the current into the ground. With a knowledge of the equipotential lines it is clear that a wide spacing will increase the depth penetration of the array. However, with the Schlumberger it is particularly important to know the change of current density within the area assumed to be a "uniform" field. In the application described in this thesis then the area under inspection is the central part of the line between the current probes, and lines parallel with the central line (see Chapters 3-5). Given the dimensions identified in Fig.2.6., then the horizontal component of current density can be quantitatively assessed for any depth and for any position relative to the two probes (c.f. Telford et al 1976).

$$j_x = \frac{I}{2\pi} \; \frac{x}{r_1^3} - \frac{x-L}{r_2^3} \qquad (2.16)$$

For any point mid-way between C_1-C_2, then $r_1=r_2=r$, and $x = L/2$, then

$$j_x = \frac{I}{2\pi} \; \frac{((L/2) - ((L/2)-L))}{(r^3)} \qquad (2.17)$$

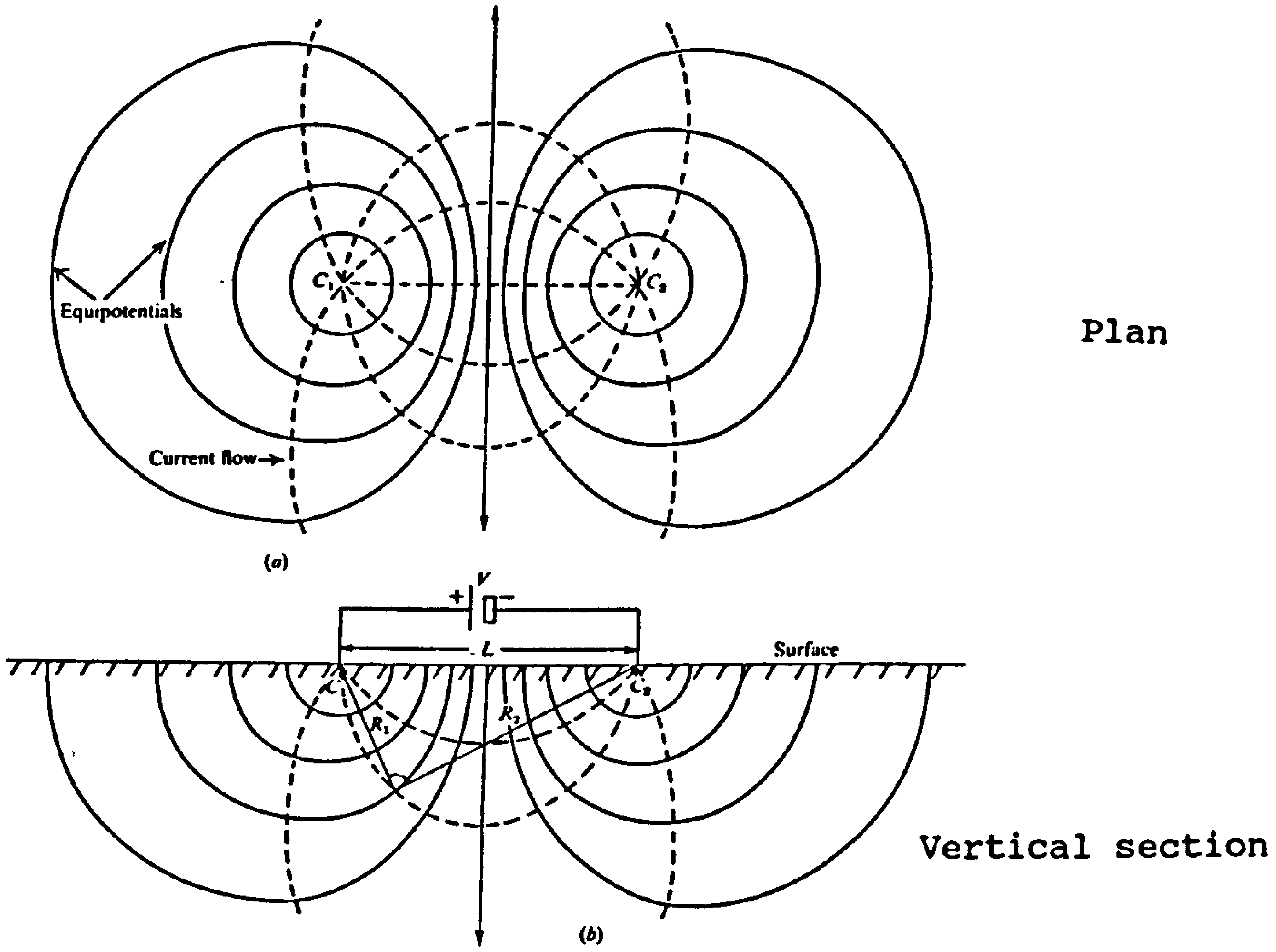


Figure 2.5 General view of the distribution of equipotentials and current flow lines for two point sources of current. (From Telford et al 1976).

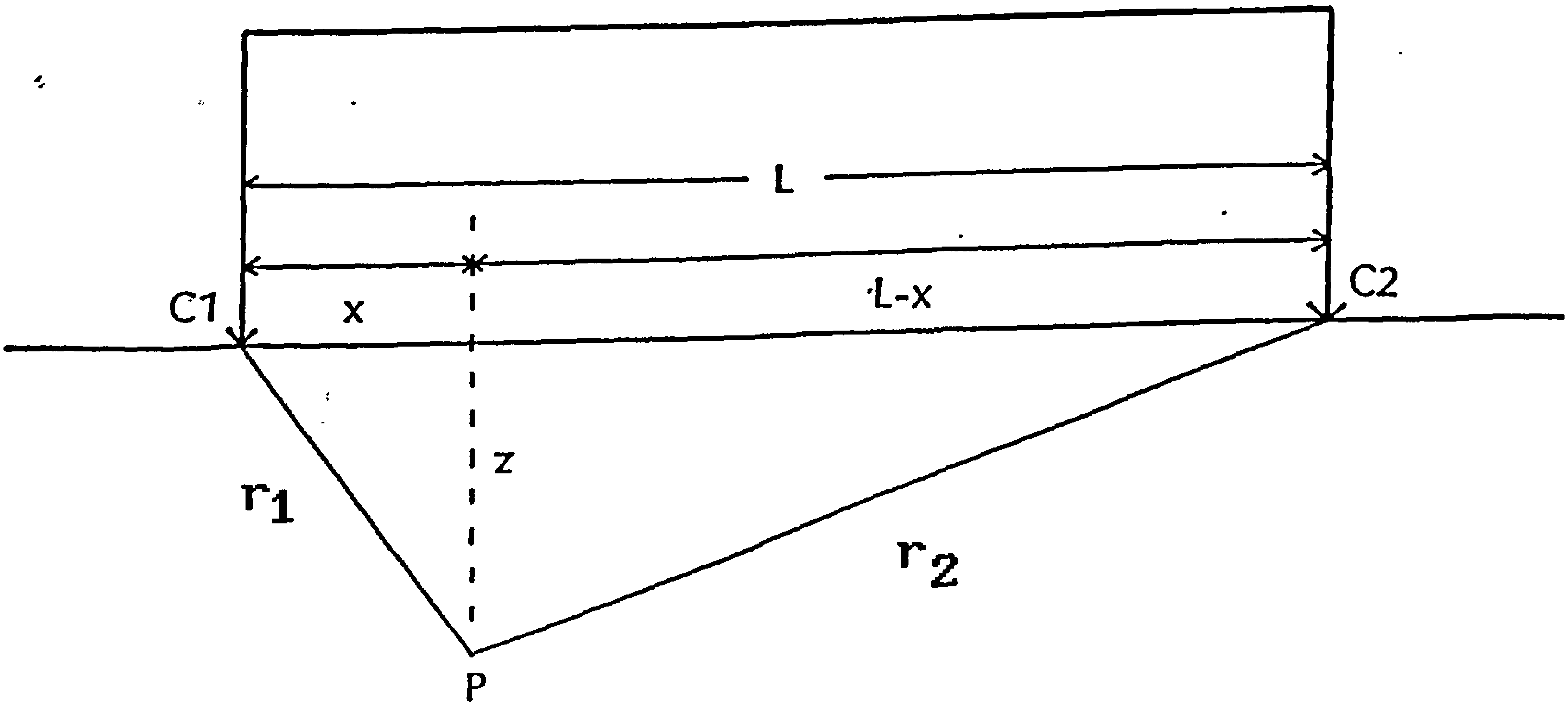


Figure 2.6. Parameters used in the text for investigating the change in Horizontal Current Density with depth.

$$= \frac{I}{2\pi} \frac{((L/2) - ((L/2)-L))}{(r^3)} \qquad (2.18)$$

From Pythagoras theorem

$$r^2 = z^2 + (L/2)^2 \qquad (2.19)$$

therefore,

$$r = (z^2 + (L/2)^2)^{0.5} \qquad (2.20)$$

The current density, therefore

$$j_x = \frac{I}{2\pi} \frac{(L/2 - (L/2-L))}{(z^2 + (L/2)^2)^{3/2}} \qquad (2.21)$$

$$= \frac{I}{2\pi} \frac{L}{(z^2+L^2/4)^{3/2}} \qquad (2.22)$$

$$= \frac{I}{2\pi} \frac{L}{(z^2+L^2/4)^{3/2}} \qquad (2.23)$$

Using eqn 2.17 it is possible to investigate the change in current density with depth for a selection of C-C separations. Naturally, this is particularly important if we are to look at true Schlumberger responses rather than some form of gradient array. In Fig.2.7. the horizontal current density at a particular depth has been expressed as a fraction of the horizontal current density at the surface (i.e. z=0). It is assumed that the current source is the same for all of the C-C separations. The depths chosen for this diagram (z = 0.25m; 0.5; 1.0; 2.0) are representative of 'archaeological' depths. It can be quickly seen that the assumption of a near uniform field is not true until the C-C separation is large i.e. >20m. In none of the early archaeological simulation work described above does the C-C separation achieve this size.

However, set against these criteria is the fact that the absolute values measured are also severely depressed when the C-C separation is made larger. The current density values in Fig.2.8. are expressed as a fraction of the smallest C-C separation (3.0m). Clearly, a sensitive instrument is required to measure the absolute values of resistance when the C-C value is greater than 10.

In the following chapters a great deal of information will be collected on the response of the Schlumberger array when readings are taken over a square grid. In the following examination of the spatial variation of the current density, it is assumed that C-C =40m, the current is 1 mA, and the depth information is collected at the three points indicated on Fig.2.9. The three points are positioned on a notional 20x20m square grid positioned centrally between C_1 and C_2. Despite the variation in absolute current density between

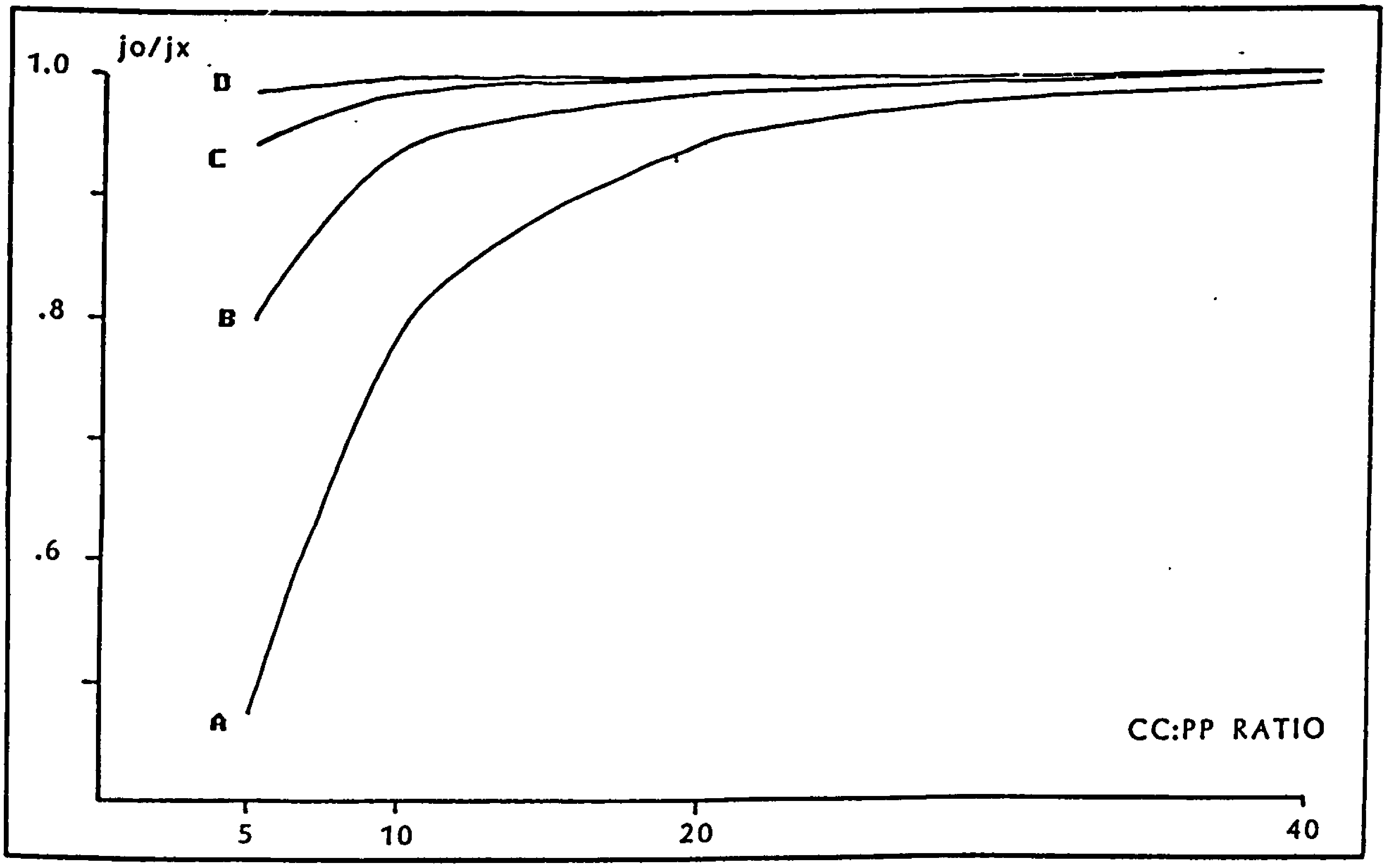


Figure 2.7. The variation of Horizontal Current Density (expressed as a fraction of the Horizontal Current Density (HCD) at the surface) at a particular depth due to the change in the CC:PP separation ratio. A = 2.0m; B = 1.0m; C = 0.5m; D = 0.25m; j_0 is the HCD at the surface; j_x is the HCD at the depth.

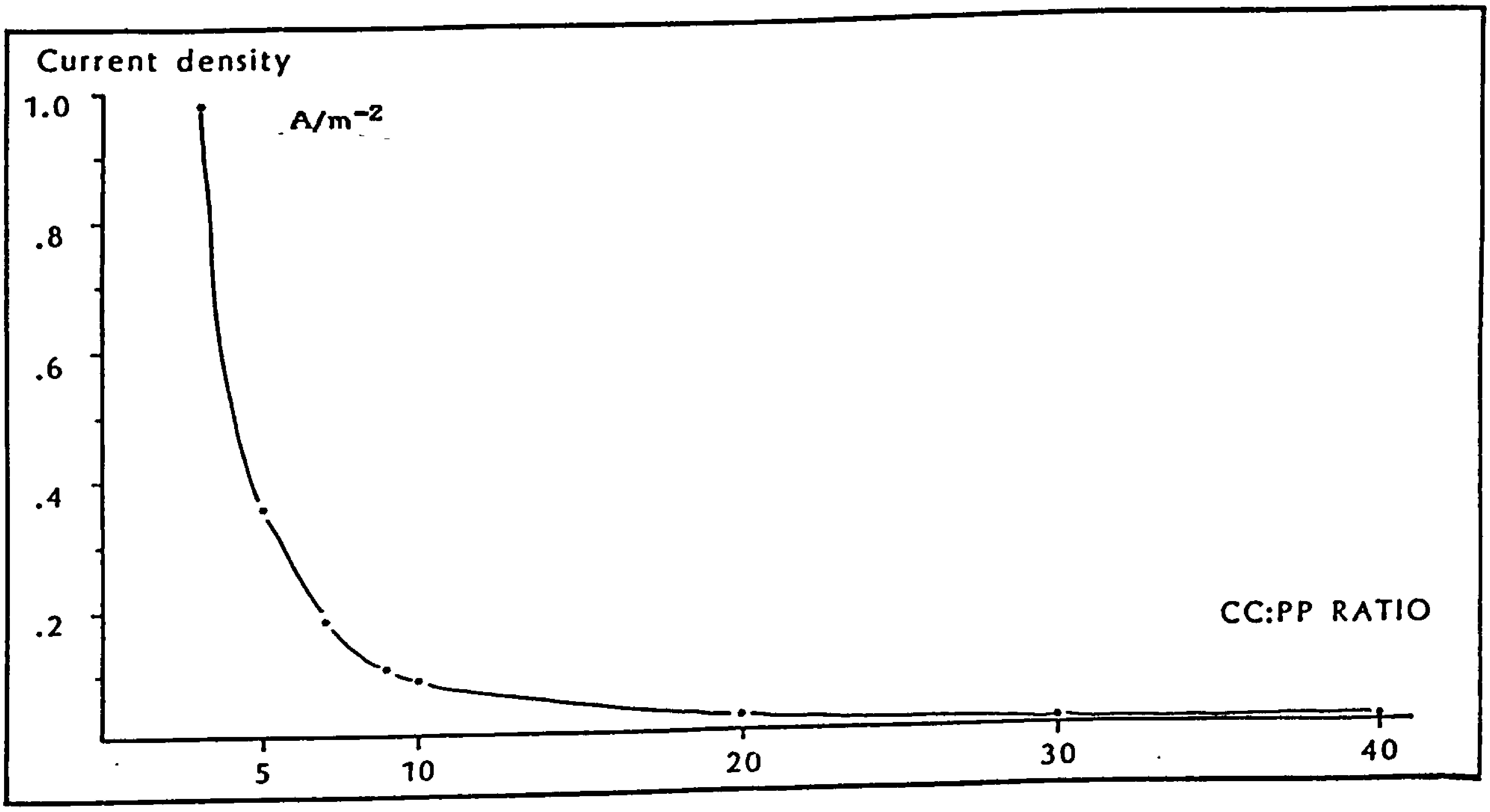


Figure 2.8. The change in horizontal current density due to the CC:PP ratio. The value of the current density is expressed as a decimal fraction of the highest value (at CC:PP = 3).

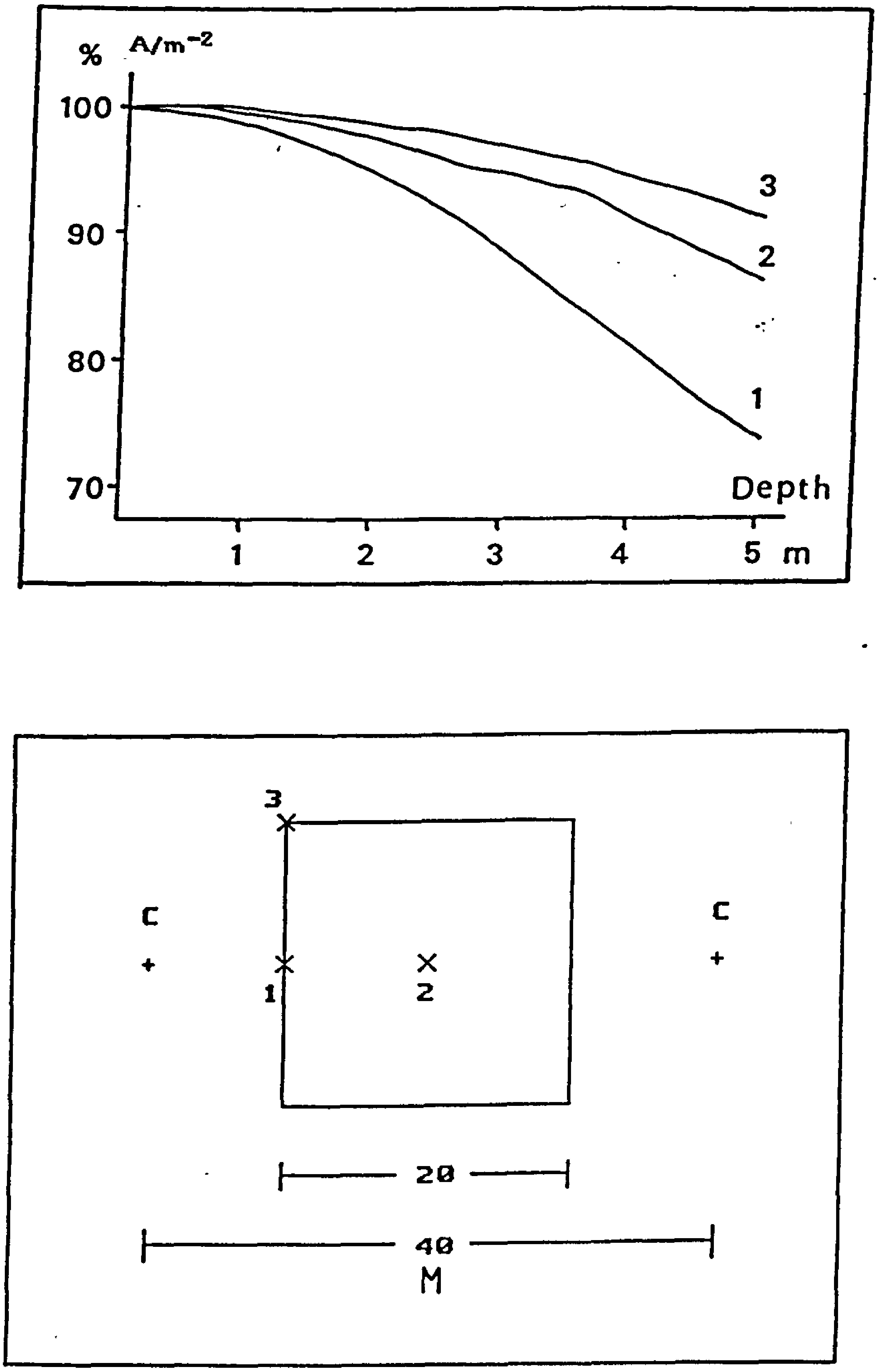


Figure 2.9. The variation in horizontal current density at three points on the Schlumberger grid due to change of depth.

points 1-3 (see Table 2.1), the current penetration is very similar in the archaeological depths i.e. <2m.

<u>Table 2.1.</u> The variation in horizontal current density (Am^2) at points 1-3 (see Fig.2.9.). The value in parentheses is the value at that depth as a fraction of the value at the surface

	Position		
Depth (m)	1	2	3
0	0.0123	0.0050	0.0055
1	0.0121 (98.4)	0.0049 (98)	0.0055
2	0.0116 (94.3)	0.0048 (96)	0.0054 (98.2)
3	0.0109 (88.6)	0.0047 (94)	0.0053 (96.4)
4	0.0100 (81.3)	0.0045 (90)	0.0052 (94.6)
5	0.0091 (74.0)	0.0043 (86)	0.0050 (90.9)

The similarity of the current density suggests that the response with depth should be similar across the grid. It is hoped that the small changes in current density will mean that there will be little variation in response no matter where in the 20x20m grid the object is positioned. The only inhibiting factor is the drop in current density across the grid i.e. it is the ability to measure very small changes in voltage that is critical to the success of the Schlumberger array.

In summary, it is theoretically possible to use point sources for an off-set Schlumberger array. If the measurements are taken within a centrally placed 20x20m grid then the only restricting problem concerns the ability to measure very small changes in voltage.

2.6. Research orientation for the Schlumberger array

This chapter has been both reflective upon past work involving the Schlumberger array and sketched some of the interesting theoretical aspects of using stationary point sources and a square collection grid. It has been suggested that the reason why the Schlumberger has not produced acceptable results in the past is due to the parameters used in the modelling.

It is hoped that by using the Schlumberger at the limits of the technology available, then we will see a reproducible response that is 'typical' i.e. sharp anomalies, good depth penetration and a simple measurement procedure.

CHAPTER 3

THE SIMULATION TANK AND METERING SYSTEM

3.1 Introduction.

Following experience of interpreting field responses from resistivity survey, it was felt that the major route for enquiry of the Schlumberger array would be via simulation studies. Although initial 2-D computer investigations carried out by Houlder (1983) on the various probe arrays suggested that the Schlumberger performed very well (see section 2.3), it was felt that further information could be gained from the 3-D representation of relatively complex and certainly more realistic archaeological features and conditions.

3.2 Why simulate ?

One of the major reasons for using geophysical techniques in archaeological situations is that they are relatively cheap by comparison to traditional archaeological ways of gathering information. Therefore, it is inconceivable that, when ambiguous field responses are obtained, they should be excavated rather than simulated in the laboratory. However, it is noticeable how few theoretical or tank simulation studies have been published concerning the response to buried anomalies in resistivity surveying in an archaeological context. At best, minor illustrative experiments have been published, ad hoc, to 'prove' that unusual responses are possible for specific configurations. For example, Young and Droege (1986) have published a single 'Half-Schlumberger' 2-D conducting paper simulation to validate field results. Similarly, Iliceto (1971) has used a previously published theoretical response (Parasnis 1965) to confirm Schlumberger results using a DC line electrode system (see section 2.3). Although it is a truism that there are no 'signature' responses in resistivity surveying, nor do we have the regular, yet constraining problem of systematic local changes due to ,say, the earth's magnetic field, we are potentially confused by small scale changes in topographical, geological, environmental and pedological factors. It is clear that the publication of relevant theoretical and simulation studies showing the response from various electrode configurations with respect to the above factors would allow a greater certainty in the choice of resistivity array. The failure to publish such studies has probably increased the use of popular arrays in unsuitable conditions.

One point is clear; an exhaustive investigation of 'active' simulation studies is required for the interpretation of field data. Simulation studies in archaeogeophysical prospection may be conveniently divided into two types.

(A) Computer simulation, and

(B) 'Host-medium' simulation.

3.3 Computer Simulation

Reference has already been made to unpublished computer simulation work by Houlder (1983) in Chapter 2. In summary this work suggested that very good anomaly resolution and depth detection were possible for the Schlumberger array. Whilst such studies can point to certain attributes belonging to specific arrays, they are dependent on many in-built limitations. In particular the many inherent non-systematic errors known to occur in electrical surveying, such as probe contact resistance, cannot be accounted for. For this reason, and due to the difficulty in simulating complex 3-D situations by computer, it was decided not to explore this avenue of research.

3.4 'Host-Medium' Simulation

One way of achieving a better approximation of the field situation is by using a simulation study involving the movement of probes or object (see for example Manhart 1972, Habberjam 1969). Again, a number of unpublished tank simulation studies are relevant here. Undoubtedly, the archaeological work of Clark (1980) is the most comprehensive. The response from Clark's tank simulations were not entirely expected, although some of the most interesting Schlumberger responses were not pursued. The major reason for this is the wide ranging nature of the thesis. Also, as the data collection was based on only a single traverse system, this work inevitably lost some of the explanatory power of the otherwise well-designed simulation tank. An alternative 'host-medium' approach involves the investigation of anomalies in the 2-D surface of conducting paper. A recent published example is cited above, whilst it has been used in this thesis to investigate the effect of the shape of anomaly cross-section on the shape of resistance response.

3.5 Design of the Saline Tank

For this part of the research a plastic tank was filled with a conducting liquid (KCl solution) to simulate an homogeneous medium. Such tanks have been used in the geological sciences to simulate in particular, multi-layered earth for vertical electrical soundings (VES), whilst archaeological investigations have concentrated on horizontal variation (e.g. Clark 1980, Lynam 1970, Heron 1984).

Although a large simulation tank was already in use at Bradford for electrical resistivity work, the inflexibility of the existing operation warranted a new rig to be designed. In practice, a two-tier research strategy was envisaged for the simulation experiments where :-

(1) Firstly, in an effort to find out the limitations of of the Schlumberger array e.g. how reliably the resistances could be converted to resistivity or the investigation of positional aspects of the array, a very simple, but flexible, system would be built. The proto-rig allowed each probe to be moved individually.

(2) Secondly, resulting from the experience from part (1) a rigid system was designed to speed up the collection of

data. No attempt was made to computerise the system due to the limited time available. However, the system was designed to allow computerisation at a later date if required.

Due to the plan outlined above, the following criteria were prominent in the design stage of the new tank.

(A) To study the Schlumberger in a meaningful way, with respect to the expected field practice, a large surface area is required. For practical reasons the potential-potential (P-P) distance may be reduced to a minimum of only 12mm, and as the current-potential (CC:PP) ratio must be large, i.e at least up to 40:1 for the initial experimental side of the work, then a tank with a large surface area must be used if errors due to wall effects are to be kept to a minimum. The close proximity of the tank edges would have produced anomalous responses when the resistance was measured either side of the current-current (C-C) line. This is not a particular problem when the simulation study involves the movement of the anomaly rather than any of the probes (the normal practice in archaeological tank simulation). In an effort to simulate archaeological survey more accurately, it was decided that the two current probes and the anomaly would be fixed in position, with the potential pair free to move around the tank surface. As outlined elsewhere (Chapter 2), theoretically, a large CC:PP ratio is critical due to equipotential and hence array considerations. It is only through the investigation of many CC:PP ratios that the full implications for the Schlumberger array may be assessed (see Chapter 5).

(B) The major practical innovation to be investigated in the tank was the movement of the potential probes along and off-set from the C-C line. Two alternative probe designs were possible. Firstly, a rigid grid system of probes, or secondly, a totally flexible set with individual rows of probes. In the event it was decided to utilise both, with the initial research being undertaken on the latter system.

(C) The system had to be able to respond to 'complex' archaeological environments, however difficult this situation may be to achieve.

In accordance with the arguments outlined above, a plastic tank of 1.0x0.7x0.7m in dimensions was modified to accommodate a Schlumberger array with a CC:PP ratio of up to 40:1. Flexibility was ensured by a system of rigid plastic supports with machined slots, regularly spaced every 45mm. Individual probes were made to fit onto 16mm stainless steel tubing (Fig 3.1), between the supports. After initial trials with this system it was decided to lock together the two potential probes to increase accuracy of positioning. This ensured definite P-P interprobe spacing, a necessity if a moving P-P system was to be maintained.

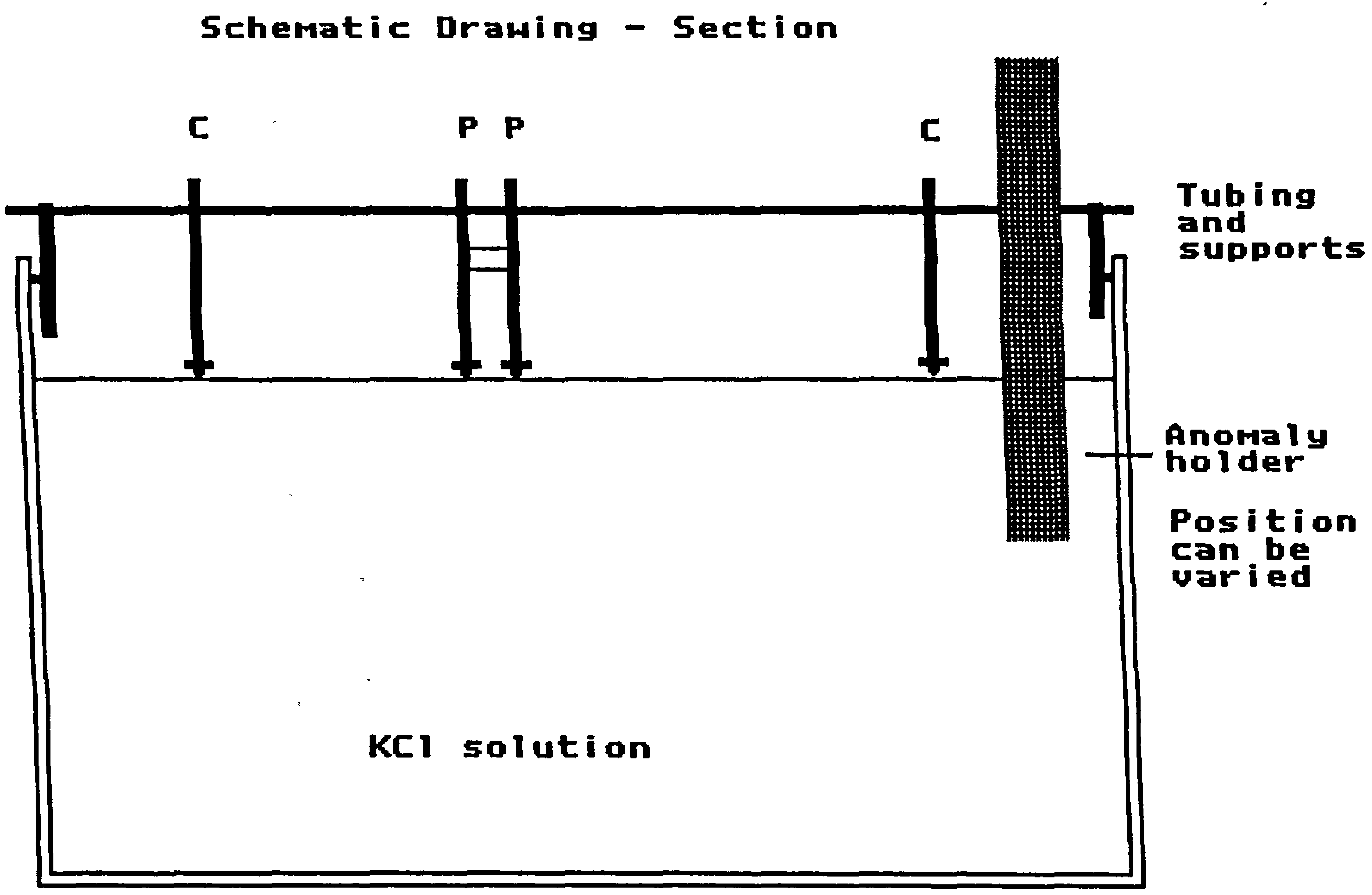


Figure 3.1 The modified tank. The probes could slide along the steel tubing. The potential probes were locked together to increase accuracy.

3.6 Summary of the Initial Tank Experiments

(A) Initial measurements revealed that allowing some margin for error, the least distance that could be achieved between the potential probes was 12mm. Therefore, to achieve a 40:1 CC:PP ratio required a C-C distance of 480mm. In fact, after expanding the current probes around the potential pair, the measured value for the resistance of circa. 0.2 ohms, proved to be at the practical limit for the modified Bradphys resistance meter. (A Bradphys MK3 (No.4) (Aspinall and Pickard 1971) had been modified to measure low resistance readings via a change in the gain on the amplifier.) Initial experimental results, however, proved puzzling until the meter had been re-calibrated.

(B) Experiments to confirm the theoretical corrections required to adjust for position around the centre of the array.

Initial measurements confirmed that the the potential gradient between the current probes (see Fig. 3.2) is similar to that theoretically predicted e.g. Kunetz (1966, Fig.1 Fig. 3.3).

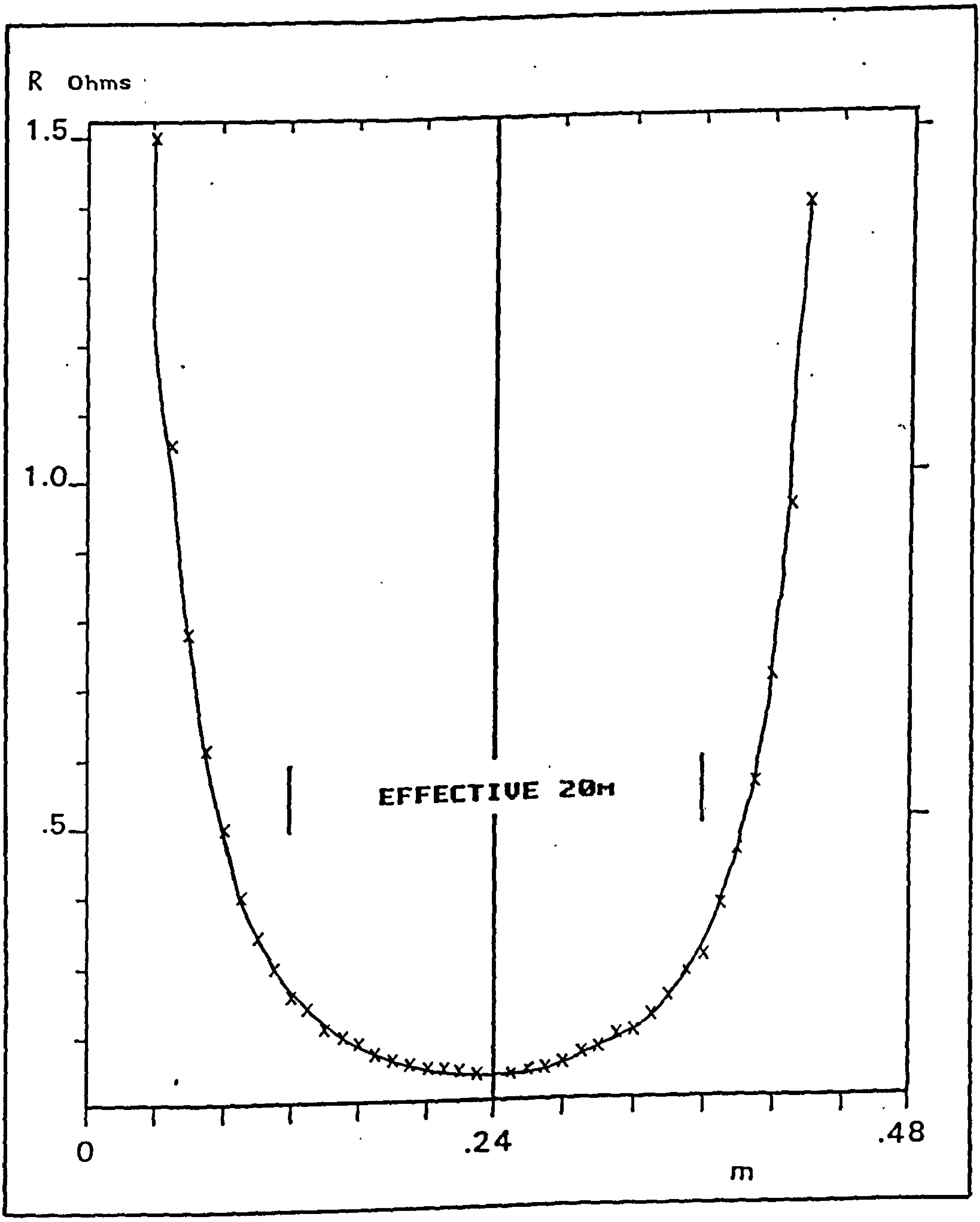


Figure 3.2. The variation in resistance on a straight line between two point sources. The current probes are positioned at 0mm and 480mm. The P-P spacing is 12mm.

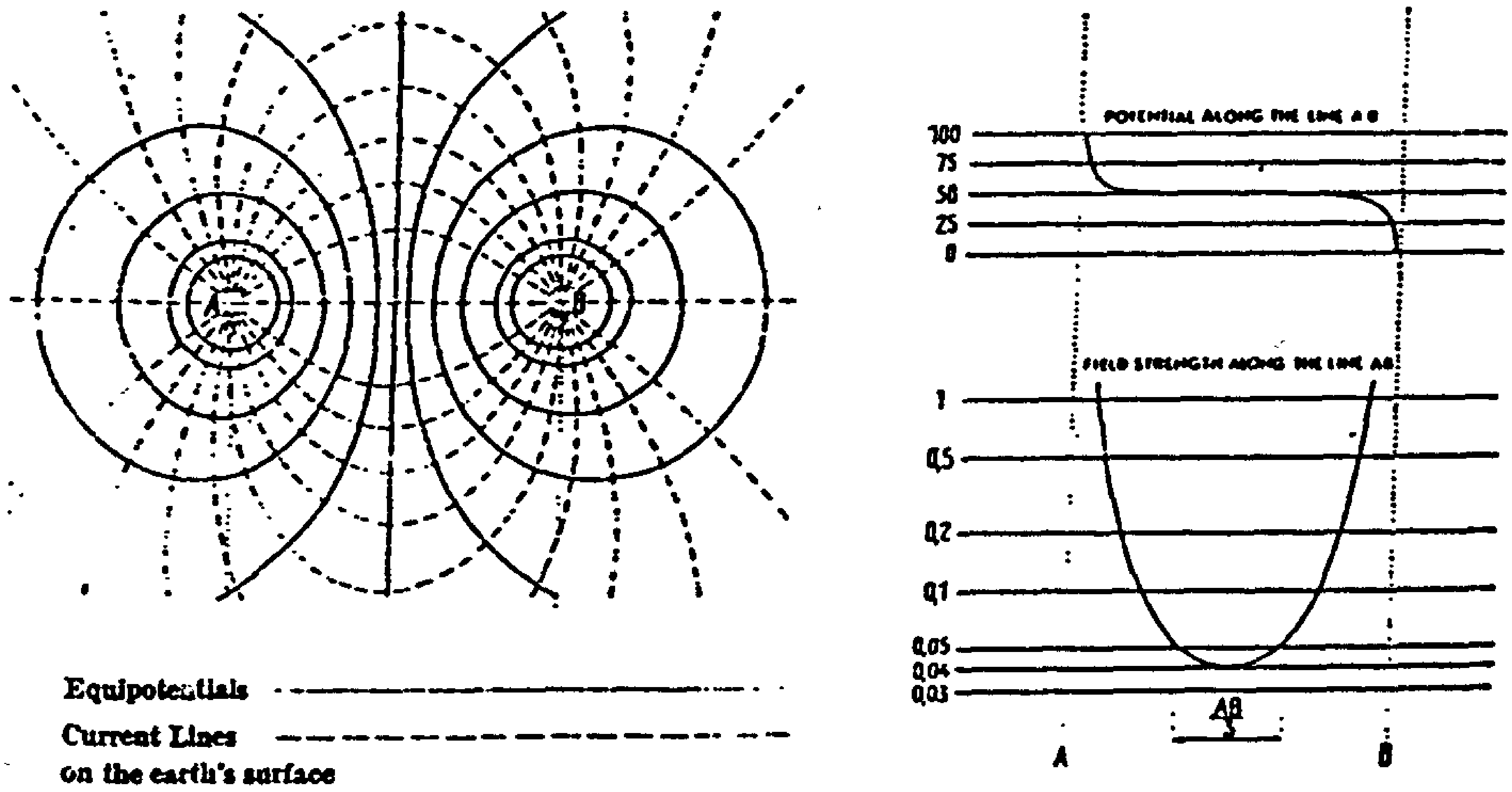


Figure 3.3. The theoretically predicted gradient, after Kunetz 1966.

Field strength equates with resistance shown in Fig.3.2.

Table 3.1.

The change in the resistivity via resistance, due to the re-calibration of the meter is as follows (Fig. 3.4). The values are for the C_1-C_2 line.

RESISTIVITY

Using...	A. Uncorrected resistance	B. Corrected
Total average	1.95+/- .145 ohm-m (+/- 7.4%)	1.82+/- .066 ohm-m (+/- 3.6%)
'20m' average	2.04+/- .089 ohms (+/- 4.4%)	1.86+/- .046 ohms (+/- 2.5%)

9.7% change in average

Not only has the value of the mean been changed by a significant amount over the effective 20m line, but the standard deviation on the set of readings has also decreased. Although, technically, it is possible to correct for any position, even close to the current probes, the problem arising near the probes is that positioning is critical because the correction factors change rapidly in this area. Conveniently then, it appeared to be possible to correct over a 20x20m grid. The initial results were achieved with the

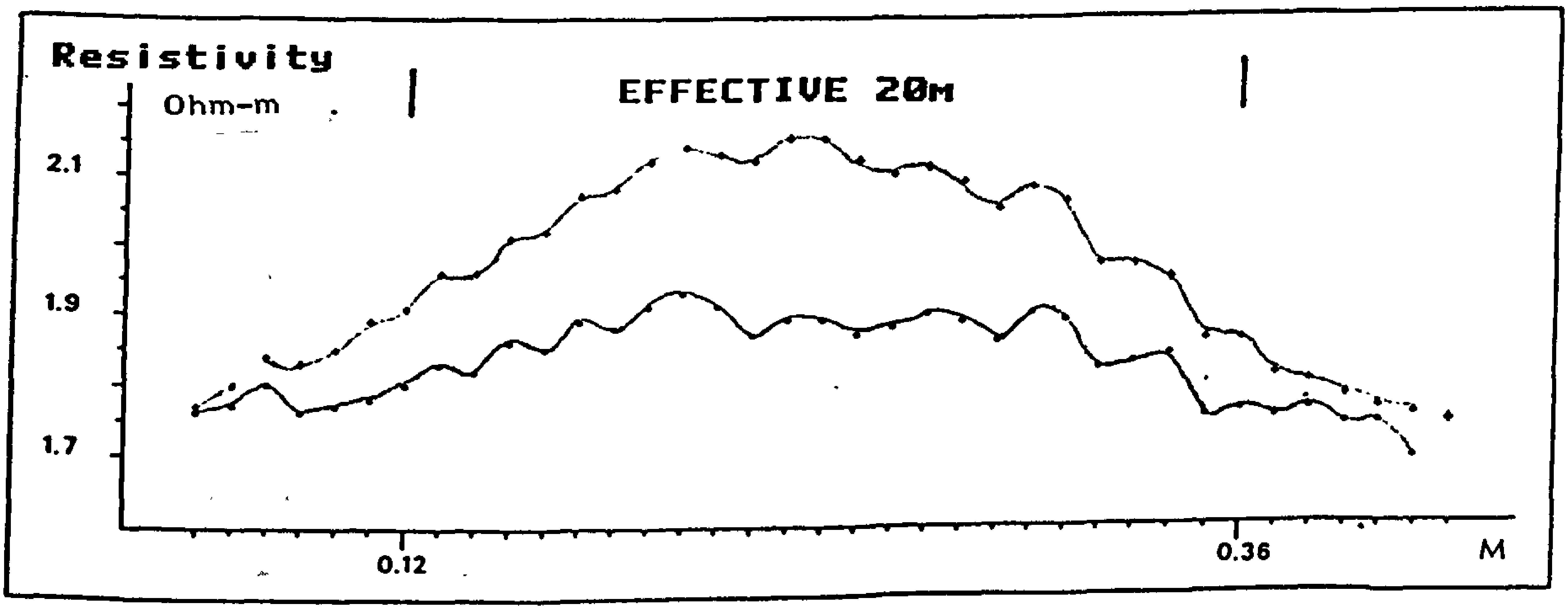


Figure 3.4. The variation in resistivity between two point sources positioned at 0mm and 480mm. The upper curve, indicated by the crosses, are from uncorrected resistance values. The lower curve, indicated by the dots, are values calculated from corrected resistance values.

modified Bradphys. The trend observed in Fig. 3.5 for the over-correction of the resistances near the current probes on the central traverse may be seen again in Fig. 3.6. There are a number of possible reasons why this trend has been observed. Firstly, the correction applied to the resistance values, due to the Geometry Factor may have been incorrect. This was checked and proved not to be the case. Secondly, it is possible that the correction of linearity for the resistance machine may be incorrect. The linearity was again checked, and found to give the same result. However, this could still be the cause, as the resistance meter was being used at its practical limits. The third possible factor could be the size of the probes used in the tank simulations. In theory, these should be pin-heads, just making contact with the surface of the water. However, in practice, the screw heads are large for a good surface contact to be maintained. This could lead to a divergence from the theoretical conditions. If either of the latter are the cause of the minor trend, there was no practical alternative available during the experimental period.

As derived above (section 2.5), it is possible to correct for the lateral change in potential. Assuming that the P-P distance of 12mm is equivalent to 1m in the field, then during this stage of the research, three off-sets were available in the tank at 3.75m (45mm), 7.5m (90mm) and at 11.25m (135mm). The results obtained from the first two off-sets are shown in Fig. 3.7. No results are offered from the third off-set as the resistances were too

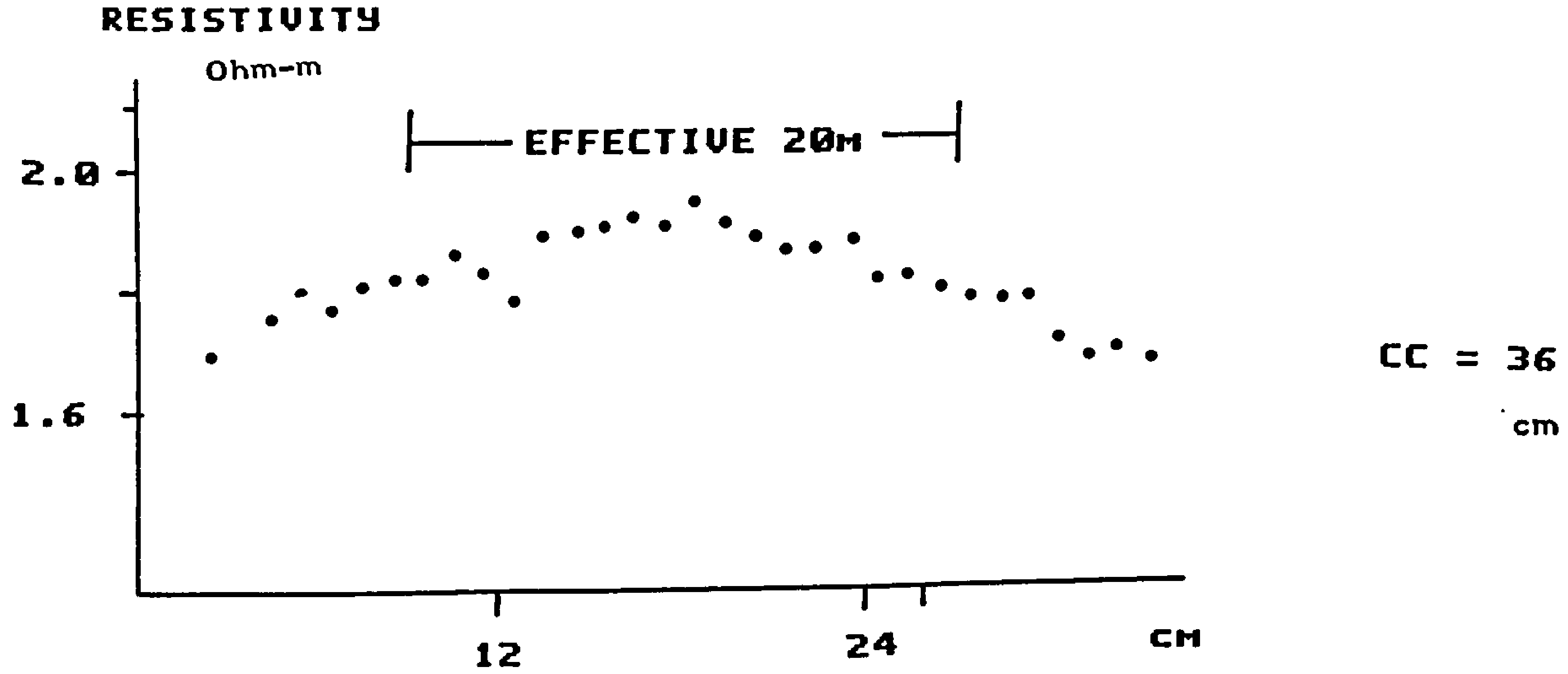


Figure 3.5 The variation in resistivity between two point sources.

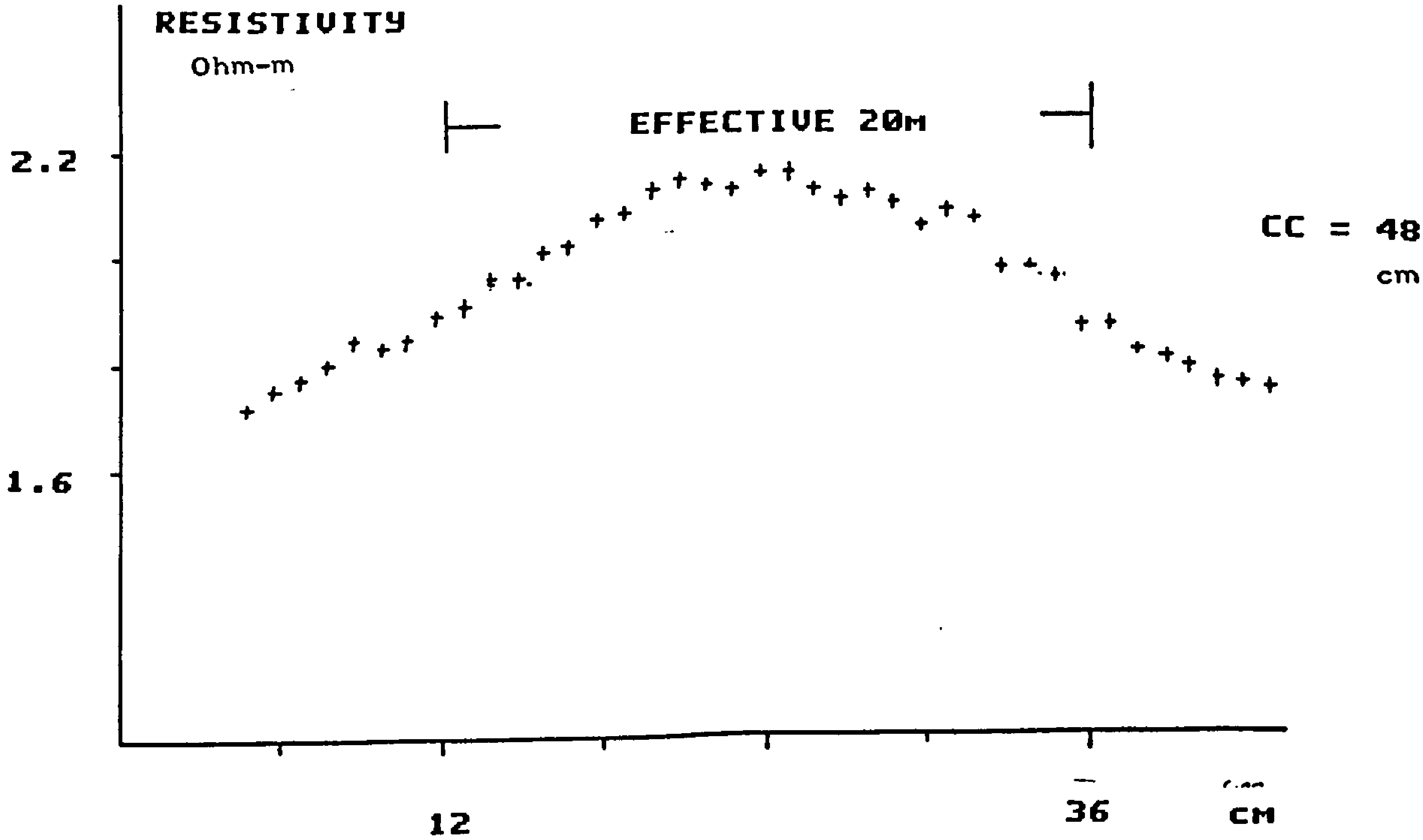


Figure 3.6 The variation in resistivity between two point sources.

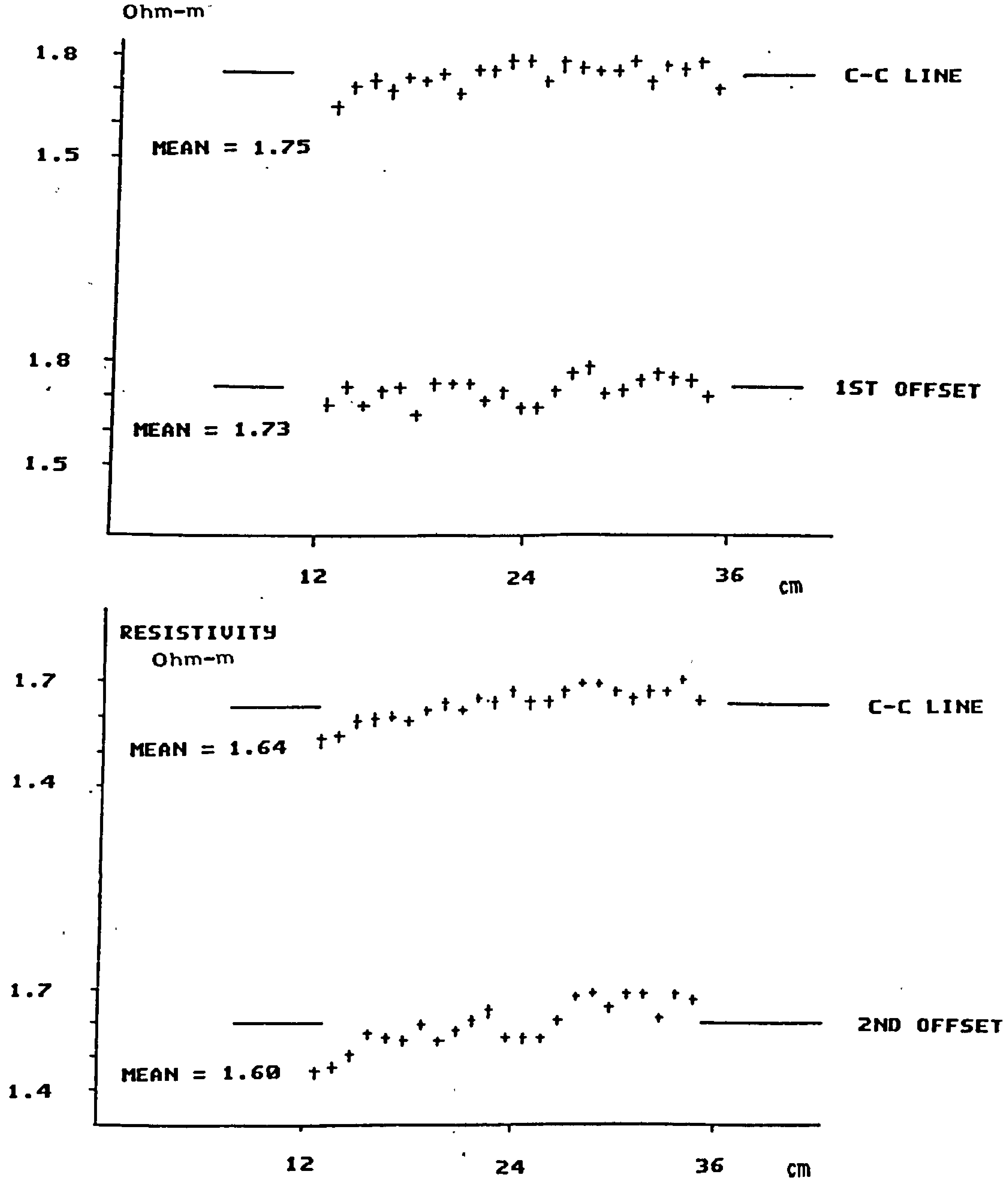


Figure 3.7. A comparison of the measured resistivities between the central line and the off-set positions in the tank.

small to be measured reliably. The difference in means between the two experiments is due to the experiments being run on different days. The changes in the average resistivity between the two off-sets and the C-C line is well within statistical scatter. This proves that given an homogeneous medium it is possible to correct for the changes in potential gradient at any position off-set from the straight through C_1-C_2 line.

3.7 The Constant Current Device

To work in association with the new rigid grid system, a device was built to boost the current output from a Geoscan RM4 resistance meter from 1mA to a nominal 50mA. This was done for a number of reasons. In particular, it was felt that the very small changes measured with the Bradphys MK4 (constant current = 5mA), although intrinsically accurate, were too low to be measured with great confidence. This would be particularly true when investigating the small reverse peak changes due to high resistance anomalies, or when simulating low resistance objects. Secondly, the RM4 was chosen for the source current and measurement instrument because the electronics were more stable and logging software was available. The 50mA Constant Current Source was designed by Dr. R. Walker and Mr. P. Dale to the author's specifications. As this is not the author's original work the device will not be dealt with in detail here. A block diagram for the device may be seen in Fig. 3.8. Initially, a switch was incorporated into the system to save the drain on

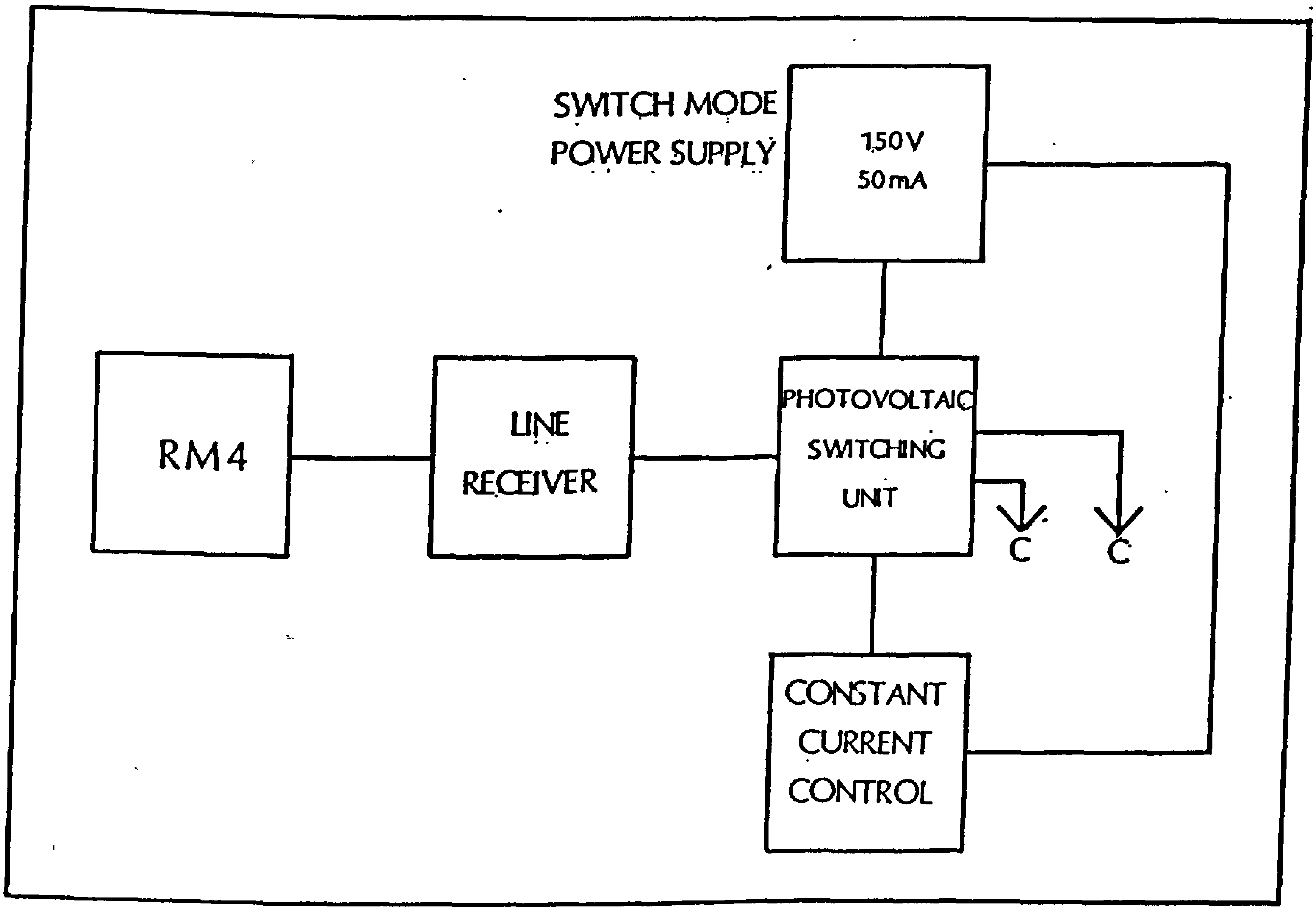


Figure 3.8. Block diagram for the Constant Current Source.

the battery, as well as to lessen the risk of serious electrical shock. However, power consumption on the batteries proved somewhat less than anticipated, whilst adequate safety procedures made the system safe.

Again, the RM4 meter was recalibrated in conjunction with the constant current device. The response from the meter was studied over all the possible ranges of the meter, on both the 'urban' and 'rural' settings. A relationship between the measured and real resistance was obtained and all data treated accordingly.

3.8 THE FIRST SET OF TANK SIMULATION RESULTS

(A) Schlumberger response to buried objects

As it proved possible to adjust the resistance values for the position of the potential probes with respect to the current probes, the logical progression for the tank study was to investigate the influence of anomaly size and position on array response. The minor tank investigation of the Schlumberger array by Clark produced a number of very peculiar responses for the Schlumberger, especially when the object was positioned close to the earth's surface (e.g. Clark 1980 Fig.5.21). Of particular concern to the present author was the possible distortion of the equipotential lines due to large features, probably of geological origin, positioned in the vicinity of the current probes. Two interpretational problems would occur if anomalies near the current probes produced huge edge effects; firstly, it would be expected that small anomalies would be swamped by the large anomaly and, secondly, there may be some problem in joining together grids if the response to an anomaly is disproportionate in the two cases. Of course, one of the attractive features of such an off-set system is that the effect on the current probes is constant throughout the grid.

Initial tank studies were intended to substantiate the possibilty that the anomaly response was:-

(1) of a large percentage change by comparison with a background resistivity.

(2) of a form that was simple with a single positive (or negative) peak and small side reverse peaks, which would not hinder the interpretation of complex archaeological situations.

(3) reproducible, with the position of the anomaly on the grid having no affect on the (corrected) percentage change of response.

(4) the same relative response between positive and negative peaks, no matter what position or depth of the object.

Table 3.2.

Anomaly simulation. In all of the tank experiments in this series of experiments the following size of cylindrical perspex anomaly was used:-

H1 - 3mm dia. x 70mm Equivalent to 0.25m. (assuming
H2 - 6mm dia. x 70mm Equivalent to 0.50m. P-P
H3 - 12mm dia. x 70mm Equivalent to 1.00m. equals
H4 - 18mm dia. x 70mm Equivalent to 1.50m. 12 mm)

One large sandstone block 54mm dia. x 200mm was also used to simulate a large, high resistance anomaly. In this first series of experiments no conducting anomalies were used as good sample preparation for low resistance anomalies proved to be somewhat elusive (see Appendix 3).

(B) The Peak:Reverse Peak Ratio.

Theoretical considerations suggested that the Peak:Reverse Peak Ratio for a sphere should be in the region of 4.5:1 (see Houlder 1983 p.44). An experiment was devised to investigate this phenomenon across the central line of the grid. It was hoped that the presence of this ratio could be used to validate experimental results i.e. if the ratio was within certain limits then the experimental results would be taken as valid. The insulator H4 was placed approximately 3mm (i.e. equivalent to 0.25m) beneath the surface of the conducting medium. The potential probes were positioned along the axis of the array at every 50mm, between the distances of 50mm and 300mm from current probe C1. In this particular experiment the potential probes were kept in the same place whilst a continuous trace was taken of the array response. The variation in the ratio of the Peak:Reverse Peak resistance shows an interesting trend. Whilst the ratio in the centre of the array is very close to the expected 4.5:1, the ratio increases dramatically when the potential probes get closer to the current probes (see Fig. 3.9). Interestingly, in terms of the resistance it is clear from Fig. 3.10 that the increase in the positive peak has clearly made the largest contribution to this change, rather than a change in the reverse peak. More importantly, when the results are changed to resistivity i.e. the results corrected for resistance, as well as the change in potential gradient due to position, a more or less constant relationship is produced. When changed to resistivity, the Peak:Reverse Peak was found to be 2.2 +/- 0.14 (+/- 6.3%). The large variation in the ratio is probably due to the imprecision of the very low reverse peak readings. However, the average value for the ratio is lower than anticipated. It should not be due to the movement of the anomaly rather than the probes, and must in part be due to the use of a cylinder, rather than a sphere. However, the value of this ratio will be noted in many of the following experiments, to see if it varies at all. We have conclusive proof that for any position on the central line not only can we promptly demarcate the position of an

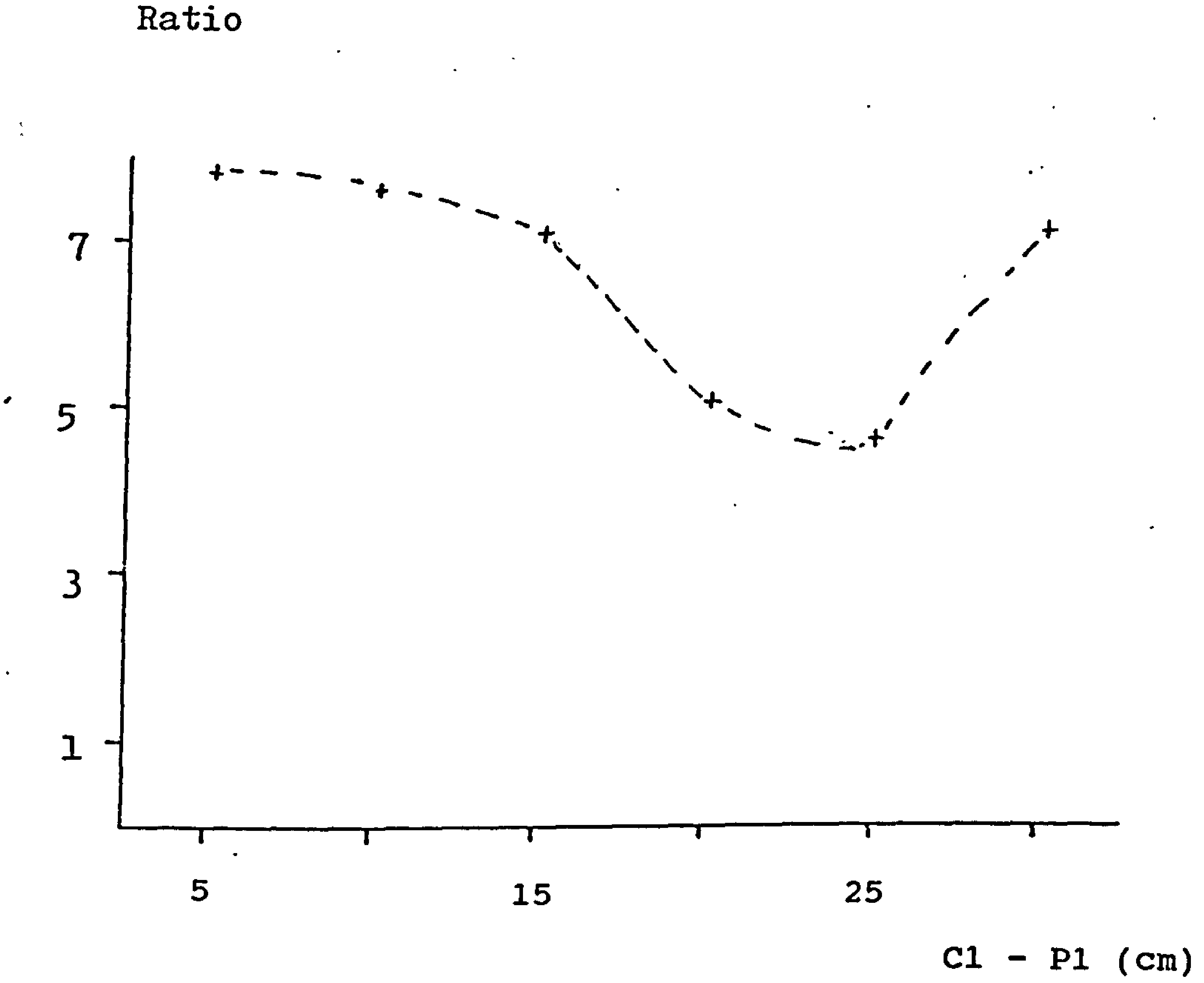


Figure 3.9 The Peak:Reverse Peak Ratio with respect to C_1-P_1 separation.

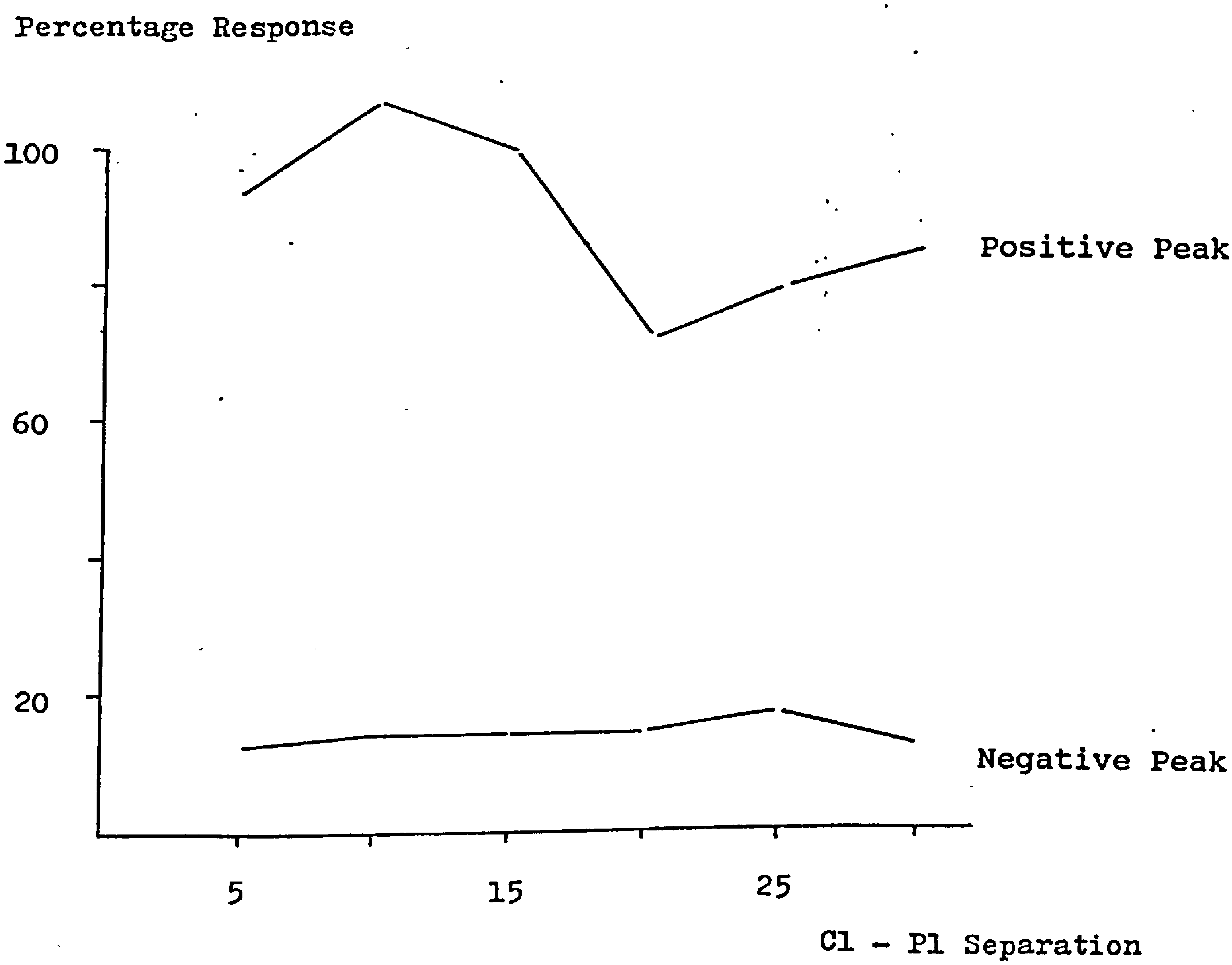


Figure 3.10. The positive and negative peak response with respect to C_1-P_1 separation.

anomaly, but the Peak:Reverse Peak Ratio remains virtually constant. Thus at least for simple anomaly shapes the ratio may be used to assess results, irrespective of actual value. There are, however, practical limits to the use of this ratio when fixed measurement positions are used, as the maximum values of the peaks may not be measured, due to the exact anomaly position with respect to the fixed position of the probes.

(C) The effect of large anomalies on the interpretation of smaller scale archaeological features.

Undoubtedly, one of the major problems to be answered by the tank simulations was whether the Schlumberger array would 'see' large features within the grid, either archaeological or geological, that were situated outside of the "effective" 20m survey area. In particular it was thought that large features situated under a current probe may distort the equipotentials so significantly that the interpretation of small subtle features may be hindered. In an effort to investigate this problem, large cylindrical and also large flat objects were placed under current probe, C1, and the resistance measured. In these experiments the resistance measurements were taken every 10mm over the complete '20m' line, as well as for some distance outside the "effective" 20m area as necessary.

(D) The Effect of Linear High Resistance Objects under Current Probe, C1.

In this set of experiments a series of tests were performed with high resistance objects remaining stationary under current probe C1. With reference to the expected trend observed in the 'straight-through' C-C line (Fig. 3.11), usually with a standard deviation in the range 2.5-4% of the mean),the presence of the linear objects appeared to disrupt the trend in a regular way. In the following experiments the cylinders were placed perpendicular to the C-C line.

In the first experiment the insulator H4 was placed directly under the probe C1. In order to create the largest possible distortion of the current, the object was placed as close to the surface as was practicable without the object touching the probe. A graphical representation of the data may be seen in Fig. 3.12, whilst a summary of the results is detailed below. The first half readings is the average of the readings in the half of the 20m nearest to the probe C_1; the second half is the half of the 20m nearest to probe C_2. As a standard format, C_1 is positioned at '0', and drawn as the left hand probe. Where appropriate the standard deviation of the mean is given. Occassionally, the statistical error has been ommited if the standard deviation was not an adequate way of defining the scatter of results.

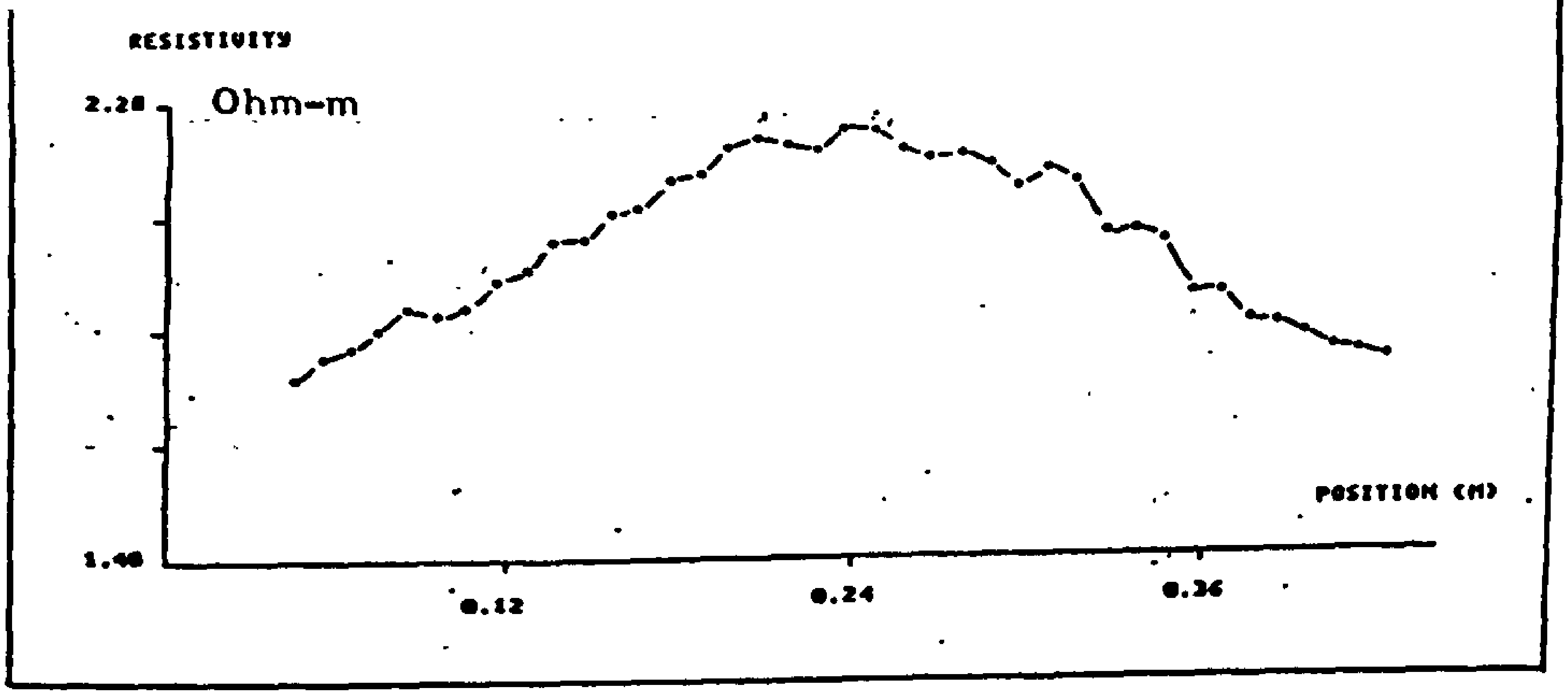


Figure 3.11. The variation in resistivity along the C-C line with no object present.

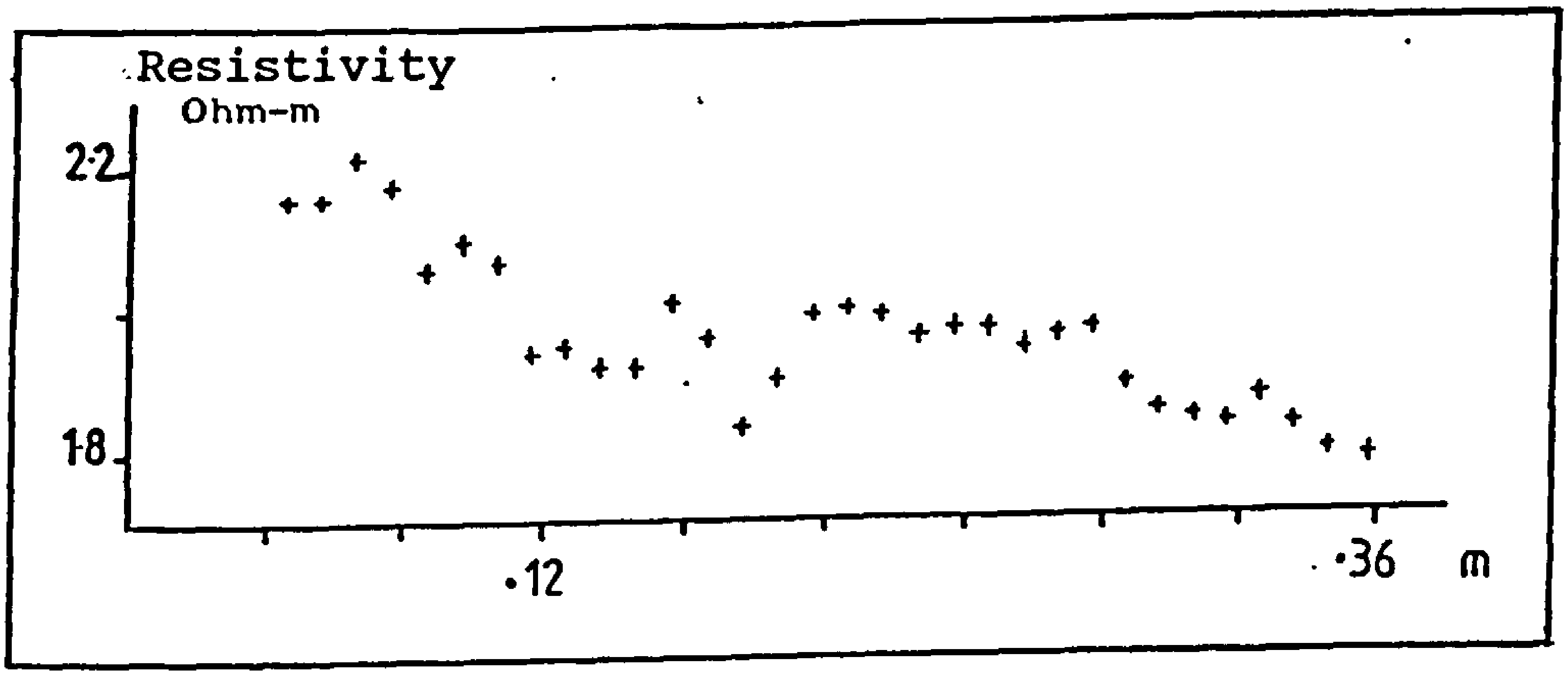


Figure 3.12. The variation in resistivity along the C-C line due to object H4.

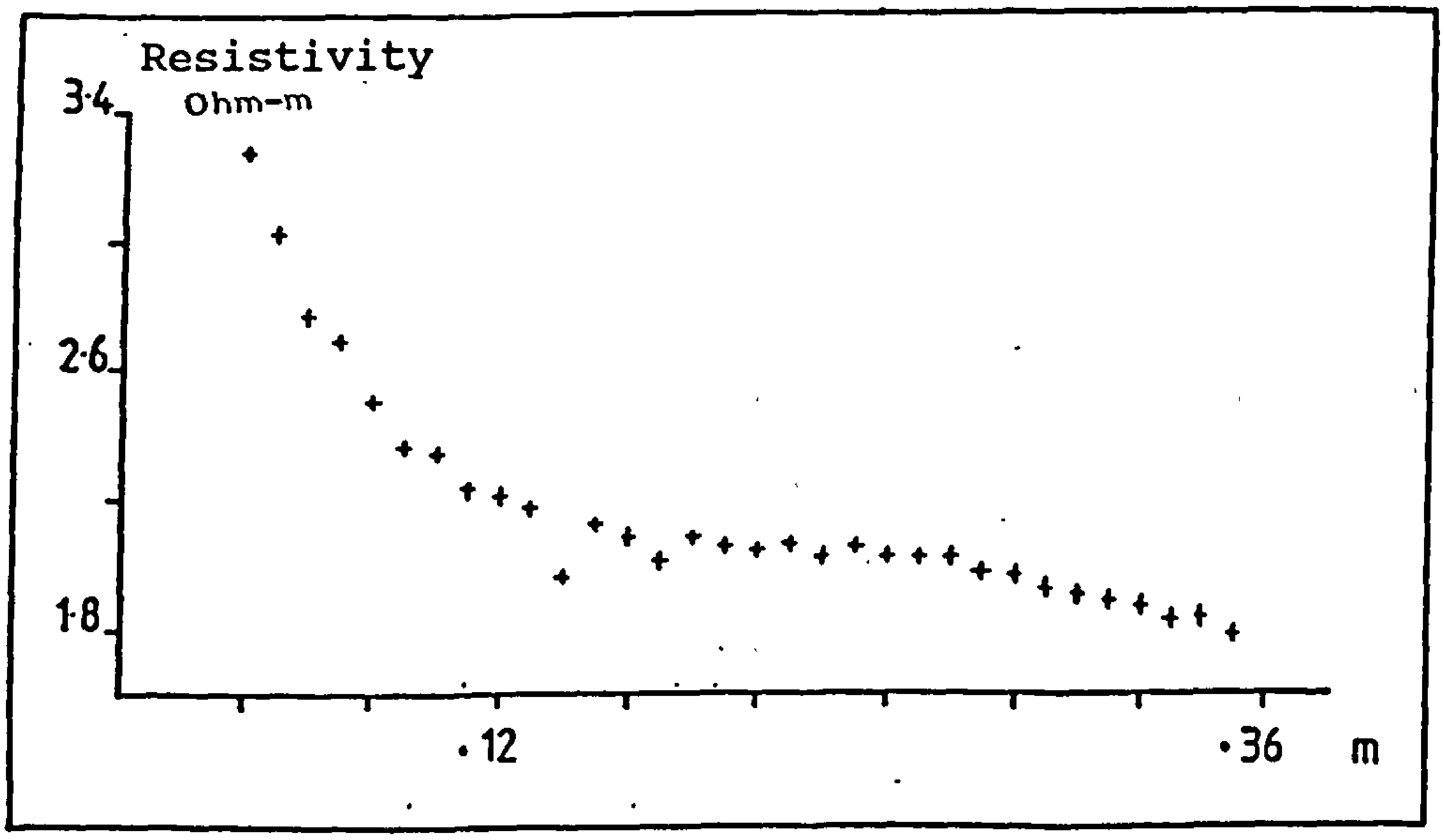


Figure 3.13. The variation in resistivity along the C-C line due to the sandstone block.

TABLE 3.3 . Summary for the experiment with H4 directly under C1.

'Half' statistics i.e the two halves of the 'effective' 20m

	Mean	S.D	(S.D/mean)x100
A. The half nearest C1	1.95		
B. " " furthest	1.88	+/- .07	3.7%
Effective 20m stats.	1.91	+/- .07	3.7%

Increase at edge of grid (1) over "homogeneous" Bkgd= 3.7%
(2) over "20m" Bkgd = 2.1%

A number of interesting facts emerge from this first experiment. In this case it is likely that the second half statistics may be regarded as being the homogeneous background. Although there is a slight increase in resistance in the first half statistics, which is not statistically significant, the actual standard deviation is decreased due to the change in shape of the 20m curve i.e. the slow downward trend of the homogeneous medium has been arrested. Also, the actual change above background, using either of the two background determinations, is minimal and would not affect archaeological interpretation.

In the second experiment the large sandstone block was placed directly under the current probe C1. A graphical representation can be seen in Fig. 3.13, whilst the summary statistics are detailed below.

<u>TABLE 3.4. Summary for the experiment with the large sandstone cylinder directly under C1.</u>

'Half' statistics

	Mean	S.D	(S.D/mean)x100
(A)First half	2.07	+/- .07	+/- 3.3%
(B)Second half	1.92	+/- .08	+/- 4.2%
Effective 20m stats	2.00	+/- .11	+/- 5.3%

Increase at edge of grid (1) over "homogeneous" Bkgd = 15%
(2) over "20m" Bkgd = 10.5%

The diagram representing the change in resistivity in the vicinity of the effective 20m line clearly shows the problem as it had been envisaged. Although the potential probe P1, is only 13mm displaced from the edge of the object i.e. just over 1m in field terms, there is no trace of a negative side peak. The lack of this 'classic' Schlumberger trait will be remarked upon later. However, although the increase in the first half mean resistance is just significant, the trend over the 20m is a slow moving trend which would not be recognisable as an archaeological, or any other type of feature. In the simulations that follow, all the features that are of an archaeological scale have very clear edges.

Perhaps the most disconcerting of the statistics in the

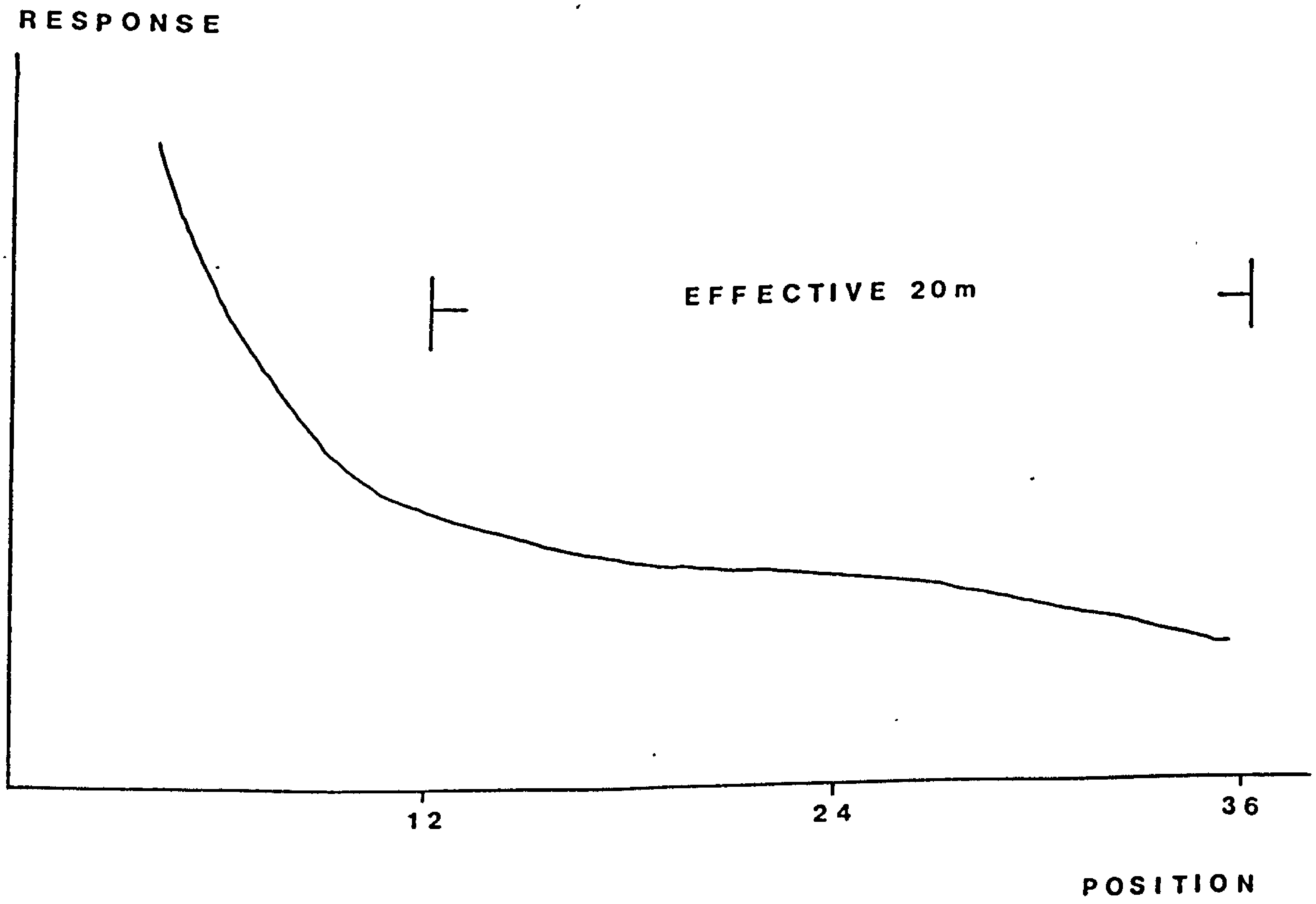


Figure 3.13a. A generalised view of the distortion in resistivity along the C-C line due to an object positioned under probe C_1.

above table (Table 3.4), is that of the increase at the edge of the grid. It was thought that this large increase was due to the extreme nature of this simulation. This experiment was repeated, examining the response on the second off-set (see Table 3.5). As expected, the change in the response at the edge of the grid is less than on the straight through line.

TABLE 3.5. The effect of the large sandstone block directly under probe C_1, on the readings of the second off-set.

	(A) No Object	(B) With Object
1st half	2.16 +/- .09 (+/-4.0%)	2.25 +/- .12 (+/-5.2%)
2nd half	2.22 +/- .06 (+/-2.6%)	2.39 +/- .05 (+/-2.2%)
Total	2.19 +/- .08 (+/-3.6%)	2.32 +/- .11 (+/-4.9%)

Increase at edge (1) over 'homogeneous' Bkgd = 5.9%

To try to simulate a slightly more realistic situation, the sandstone block was dropped to approximately 3mm below the surface i.e approximately 0.25m in real terms. In this experiment the effect on the second off-set was also monitored, as well as the resistivity without the anomaly present (see Fig. 3.14).

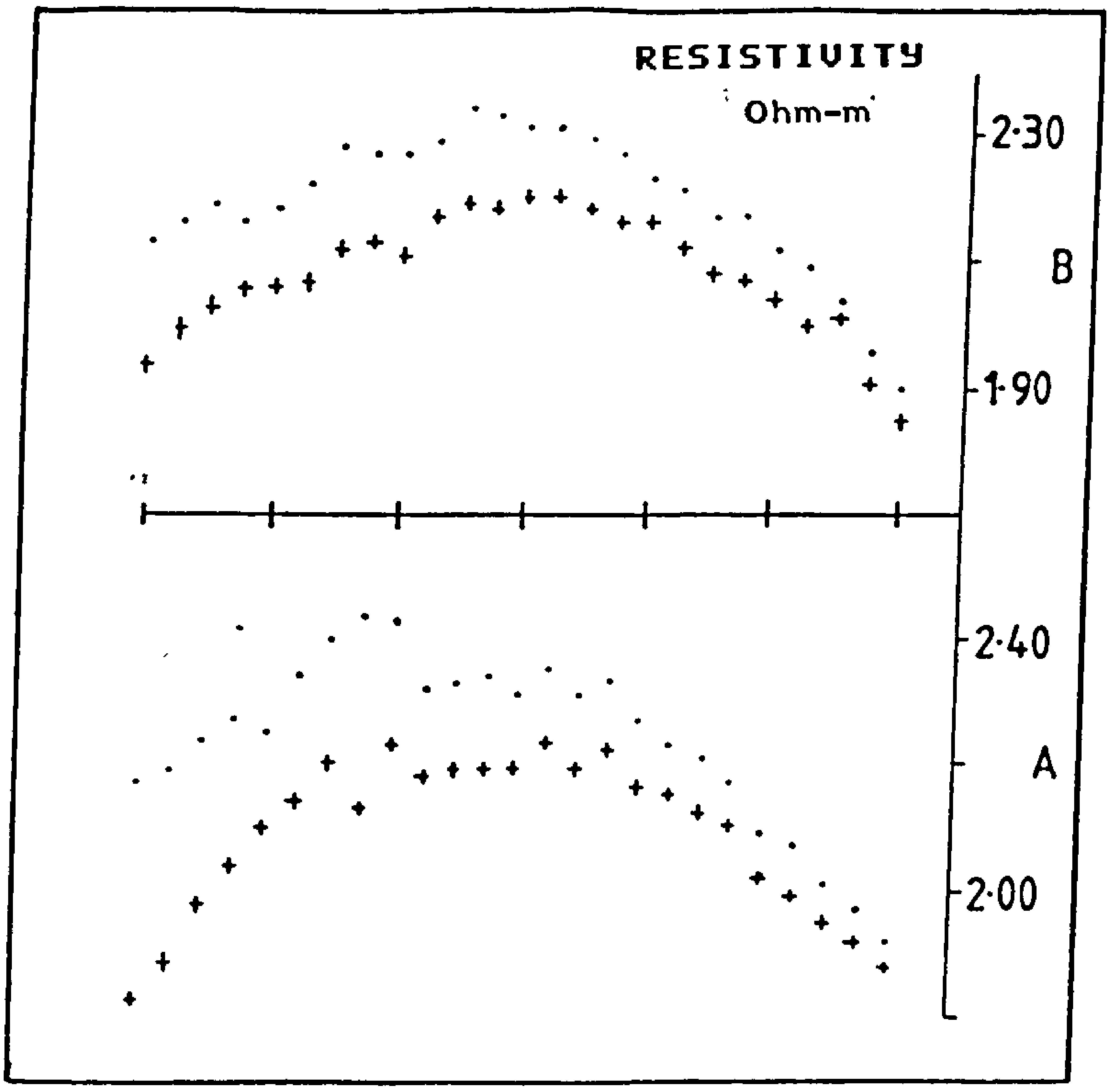


Figure 3.14 The crosses indicate the variation in resistivity (A) on the C-C line (B) on the second offset. The dots indicate the distortion in the resistivity due to a sandstone block 0.25m below C_1.

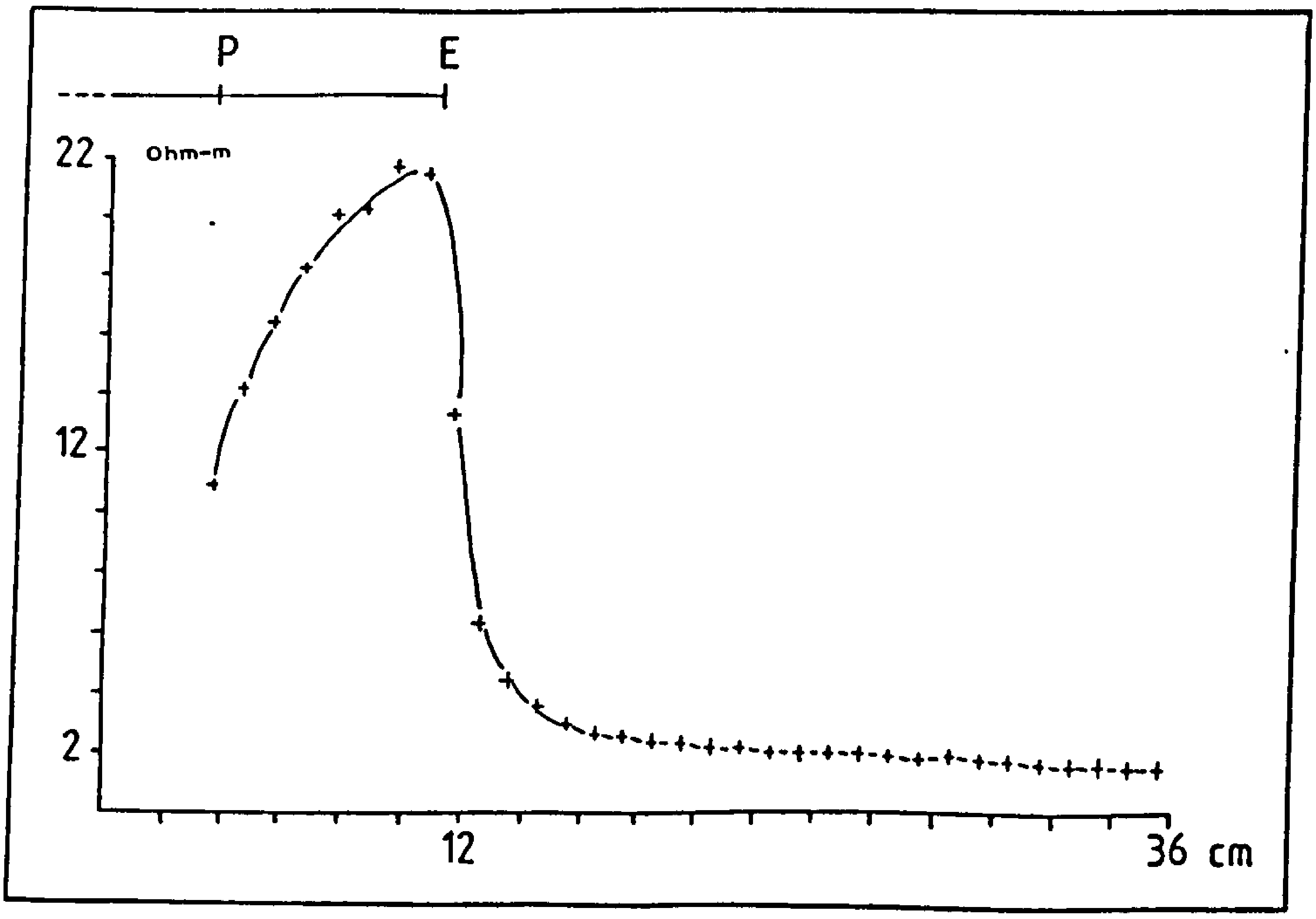


Figure 3.15. The variation in resistivity along the C-C line due to a laminated object at C_1.
For explanatiom of 'P' and 'E' see Fig.3.16.

TABLE 3.6 . Summary of results for the sandstone block at a depth of 3mm (=0.25m) on the Zero and Second off-set, without the anomaly. (c.f. Table 3.7).

	(A) Zero off-set	(B) Second off-set
1st half	2.08 +/- .12 (+/-5.8%)	2.09 +/- .11 (+/-5.3%)
2nd half	2.12 +/- .10 (+/-4.9%)	2.11 +/- .07 (+/-3.2%)
Total	2.09 +/- .12 (+/-5.7%)	2.08 +/- .09 (+/-4.5%)
Combined	2.09 +/- .11 (+/- 5.2%)	

TABLE 3.7 . Summary of results for the Zero and Second off-set, with the sandstone block 3mm (equivalent to 0.25m) beneath C_1.

	(A) Zero off-set	(B) Second off-set
1st half	2.16 +/- .15 (+/-6.8%)	2.15 +/- .13 (+/-6.1%)
2nd half	2.32 +/- .08 (+/-3.3%)	2.25 +/- .07 (+/-2.9%)
Total	2.24 +/- .01 (+/-6.3%)	2.20 +/- .11 (+/-5.0%)
Combined	2.22 +/-.13 (+/-5.8%)	

Increase at edge (A) over 'homogeneous' medium Bkgd= 3.8%

" " " (B) " " " " = 1.9%

What can be clearly seen here is:-

(1) The increase due to the object is not as pronounced as that for the previous experiment. Therefore, such an anomaly would have to be buried at a very shallow depth and immediately beneath a current probe to have an effect on the effective 20m.

(2) The form of the curve has changed dramatically. In the latter experiments the curve has been less severely changed, with the original 'characteristic' shape being disrupted.

(3) The change in curve shape is characteristic of a slow trend that would be, in most cases, unnoticeable.

(E) LAMINATED OBJECTS

The use of the cylinders were thought to be a very extreme case, with few possible archaeological examples. Clark (1980), has suggested that resistivity anomalies caused by many archaeological features may in fact approximate to horizontal high resistance lamina. Therefore,a continuation of the simulation work was to use a thin-layer, high resistance sheet. A perspex sheet (150x150x3mm),or multiples of it, when placed under the C1 probe, produced massive changes in the vicinity of the current probe. The results from a single sheet under the probe C1 are shown below (see Fig. 3.15).

TABLE 3.8. Summary of resistivity measurements for a single sheet of perspex. The object was positioned 40mm past the

current probe and 110mm into the rig. The object was at a depth of 6mm (equivalent to 0.5m).

1st half 2.93 ohm-m
2nd half 1.89 +/- 0.09 ohm-m (+/- 4.38%)
Value over object 18.8 +/- 4.0 ohm-m
20m statistics 2.41 +/- 1.03 (+/- 42.7%)

Assuming that the second half statistics are meaningful, then using two standard deviations about the mean would give a normal range of 2.07-1.71 ohm-m. The resistivity only descends to within that range after 110mm i.e. 9.2m. However, in many ways it is again the shape of the response that is most important. Firstly, there is no negative peak on coming off the anomaly. Secondly, the largest response in resistivity comes not at the centre of the object, but very close to the edge; it was unclear at this stage if this was a result of the position of the object, or its shape. Despite the distance required for the response to drop to within the nominal range, the actual rate of change is very sharp if the huge response to the object is acknowledged. Whilst the eight resistivity values over the object record a massive increase of 895% over the nominal background resistivity, the peak value was 23.6 ohm-m i.e. 1150% increase. The major interpretative point arising from this experiment is that when the object is very close to a current probe, but not within the 'effective' 20m zone, it may well be seen using this method. However, it is likely that only very specific anomaly shapes and sizes will produce such an abnormal response. Even in this case a huge change at a grid edge next to a current probe would suggest anomaly interference and would result in further attention if found in the field.

Preliminary results had shown that when the object was placed at the centre of the array a broad central peak and two small side peaks were obtained. In the next table the results for the same thin sheet, at the same depth, but lying from 150mm to 300mm from probe C1.

TABLE 3.9. Summary of resistivity measurements for a single thin sheet (Fig. 3.16).

	Mean Resistivity
1st half	1.92 ohm-m
2nd half	1.77 +/-.17 ohm-m (+/-9.6%)
Total object	2.00 +/-.14 ohm-m.

The average reading for the anomaly is 22% above the background, whilst the peak is 31% above background.

To investigate this change more fully, a similar object was positioned at intervals along the C-C line to see how the

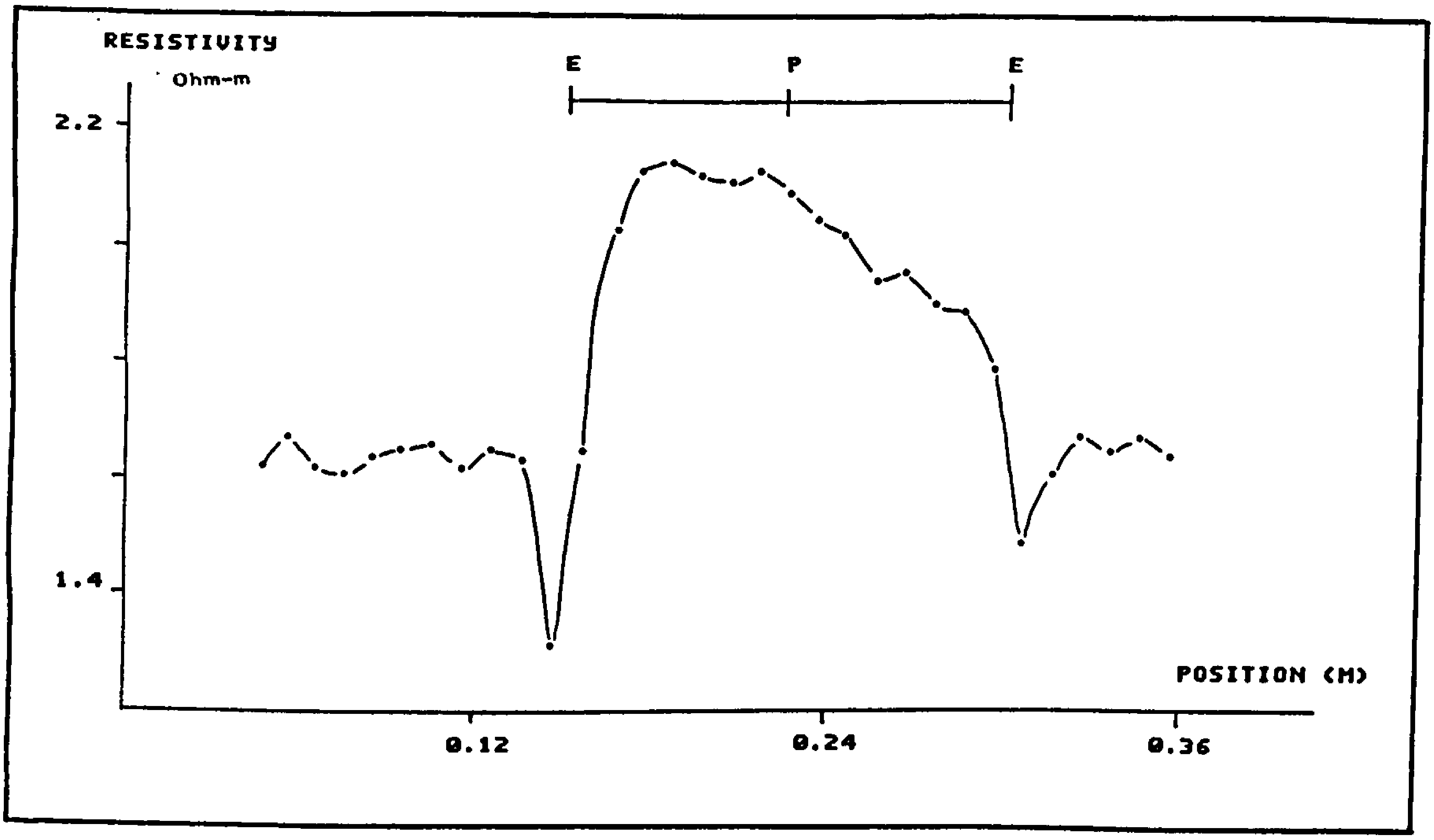


Figure 3.16. A single sheet of perspex at a depth of 6MM.
'E' represents the ends of the object.
'P' represents the object's centre.

form of the response changed (see Fig. 3.17). The relevant information for this series of experiments is summarised in the following tables.

TABLE 3.10. Summary of resistivity measurements for position B. The object comprised of 3 identical perspex sheets fixed together, to give an object size of 150x150x9mm. The object was positioned at a depth of 12mm i.e. 1m, with one edge directly under the C1 probe and with the other 150mm into the C-C line.

	Mean Resistivity
1st half	4.65
2nd half	1.77 +/-.06 (+/-3.5%)
20m statistics	3.27 +/-3.30 (+/-101%)

TABLE 3.11. Summary of resistivity measurements for position C. The object comprised of 3 identical perspex sheets, as in Table 3.10. The object was positioned with one edge 70mm from C1, with the other edge 150mm further along the C-C line. The object was positioned at a depth of 12mm i.e. 1m.

	Mean Resistivity
Total object	2.13 +/-.29 (+/-13.6%)

Background at @ 1.68, therefore peak is 44% above Bkgd

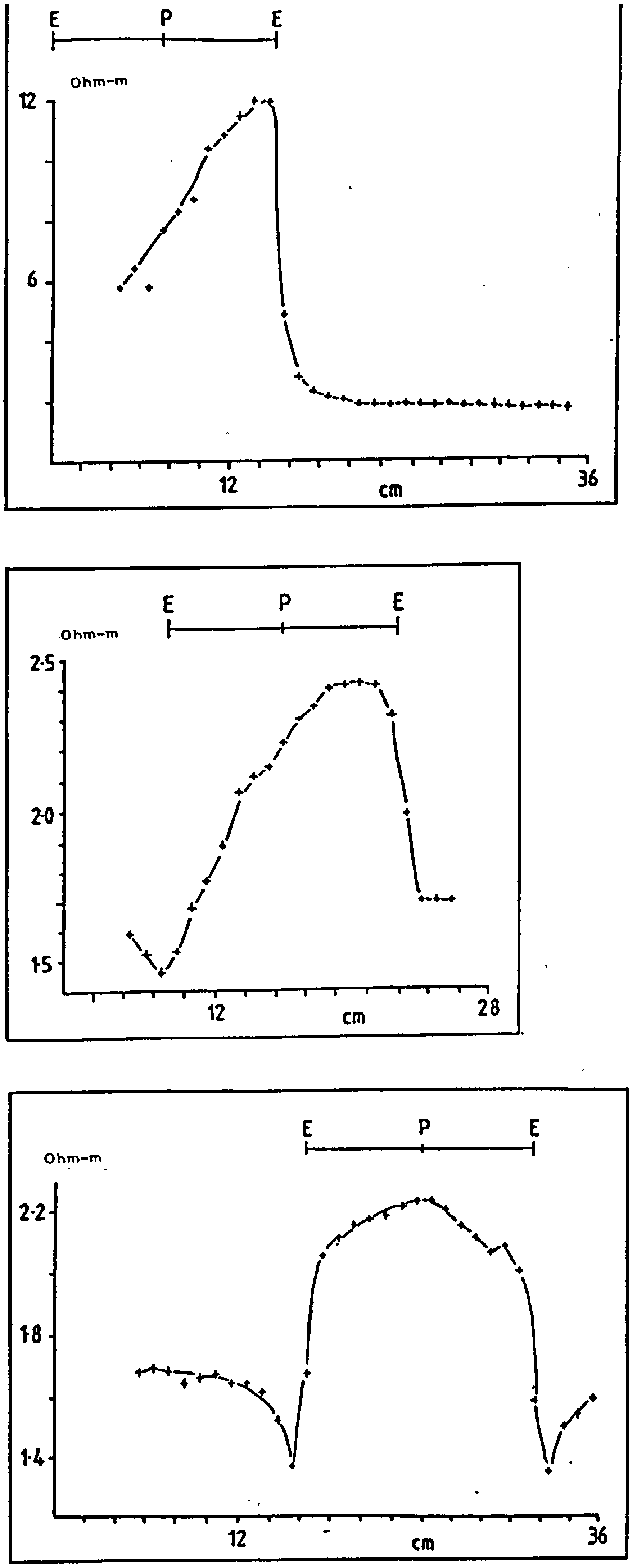


Figure 3.17. The change in the variation in resistivity due to the position of a laminate object.

TABLE 3.12. Summary of resistivity measurements for position D. The object comprised of 3 identical perspex sheets, as in Table 3.10, at a depth of 12mm i.e. 1m. The object was positioned exactly in the centre of the array.

	Mean Resistivity
1st half	1.91 +/-.32 (+/-16.7%)
2nd half	1.87 +/-.32 (+/-17.3%)
Total object	2.15 +/-.07 (+/-3.2%)

Background at 1.68, therefore peak is 33% above Bkgd

A graphical summary of the data may be seen in Fig. 3.18. The information in this figure is not drawn to the same scale, as the slight depth differences render such comparisons worthless. However, it is the form of the response that is important in this investigation. The diagram clearly shows that as the object becomes more central, so the peak in response and the centre of the object converge. This has to be due to the change in deformation of the equipotential lines. In the centre of the array the current lines are almost parallel to the surface of the medium and get disrupted in a predictable, symmetrical way. However, when the object is moved from the central position, the equipotentials are not distorted symmetrically with respect

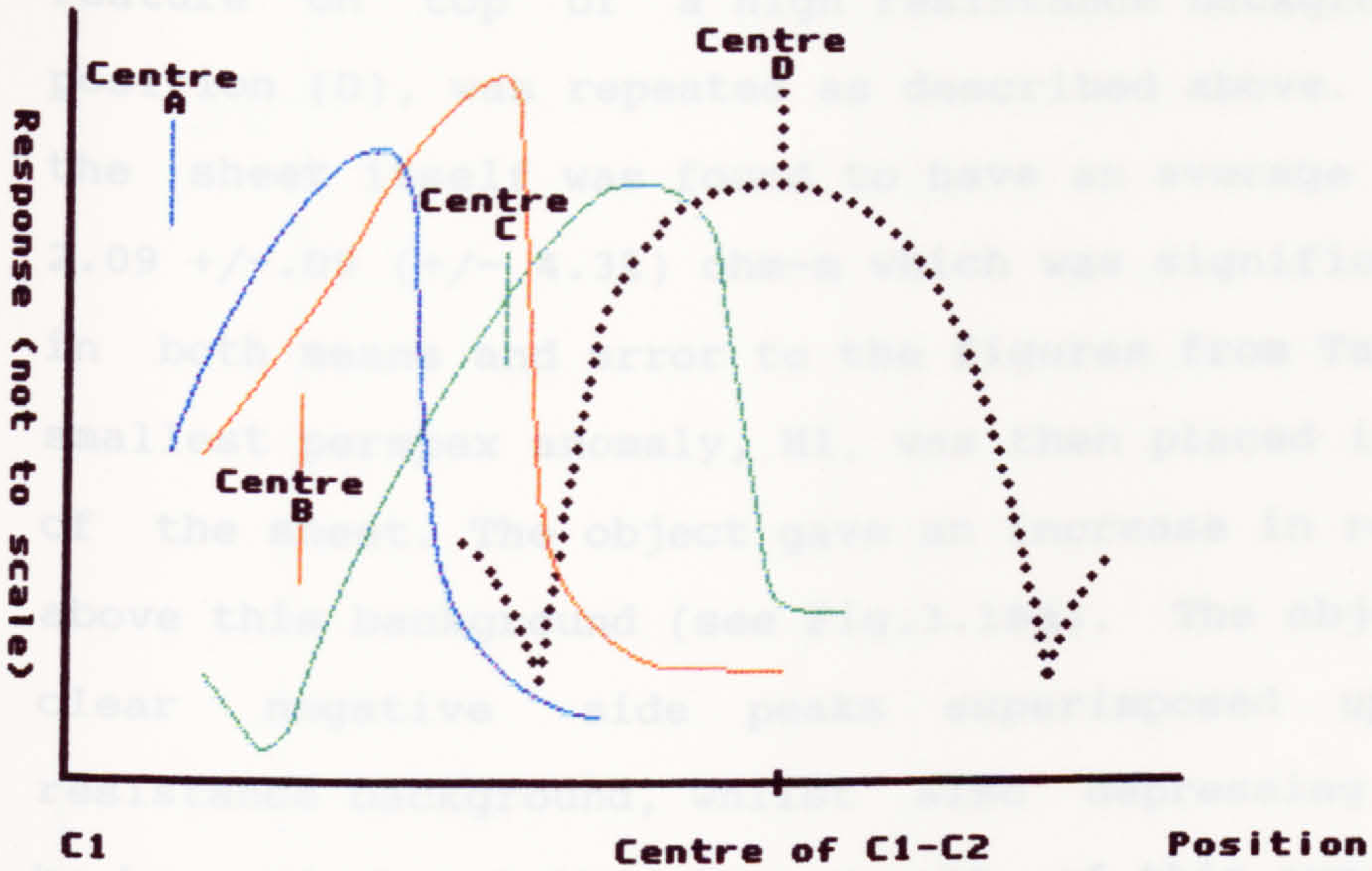


Fig.3.18. Response due to position of the perspex sheets.

to the object, as the potential gradient is steeper near to the current probes (see Chapter 2). The response off-centre is similar to that reported by Parasnis, and is re-investigated later using a small, archaeological sized, spherical anomaly.

Another problem that clearly one would wish to answer is whether it is possible to discriminate a small archaeological feature on top of a high resistance background. The final position (D), was repeated as described above. The area of the sheet itself was found to have an average resistivity of 2.09 +/-.09 (+/- 4.3%) ohm-m which was significantly similar in both means and error to the figures from Table 3.12. The smallest perspex anomaly, H1, was then placed in the centre of the sheet. The object gave an increase in response of 57% above this background (see Fig.3.18a). The object also gave clear negative side peaks superimposed upon the high resistance background, whilst also depressing the general background by 2-3%. The result of this experiment was to demonstrate that even with an extreme background it was possible to clearly define a small anomaly. Under such circumstances the underlying high resistance anomaly probably helps to define the smaller feature by concentrating the current into lines virtually parallel with the sheet. The large change and the small error associated with the response support this view.

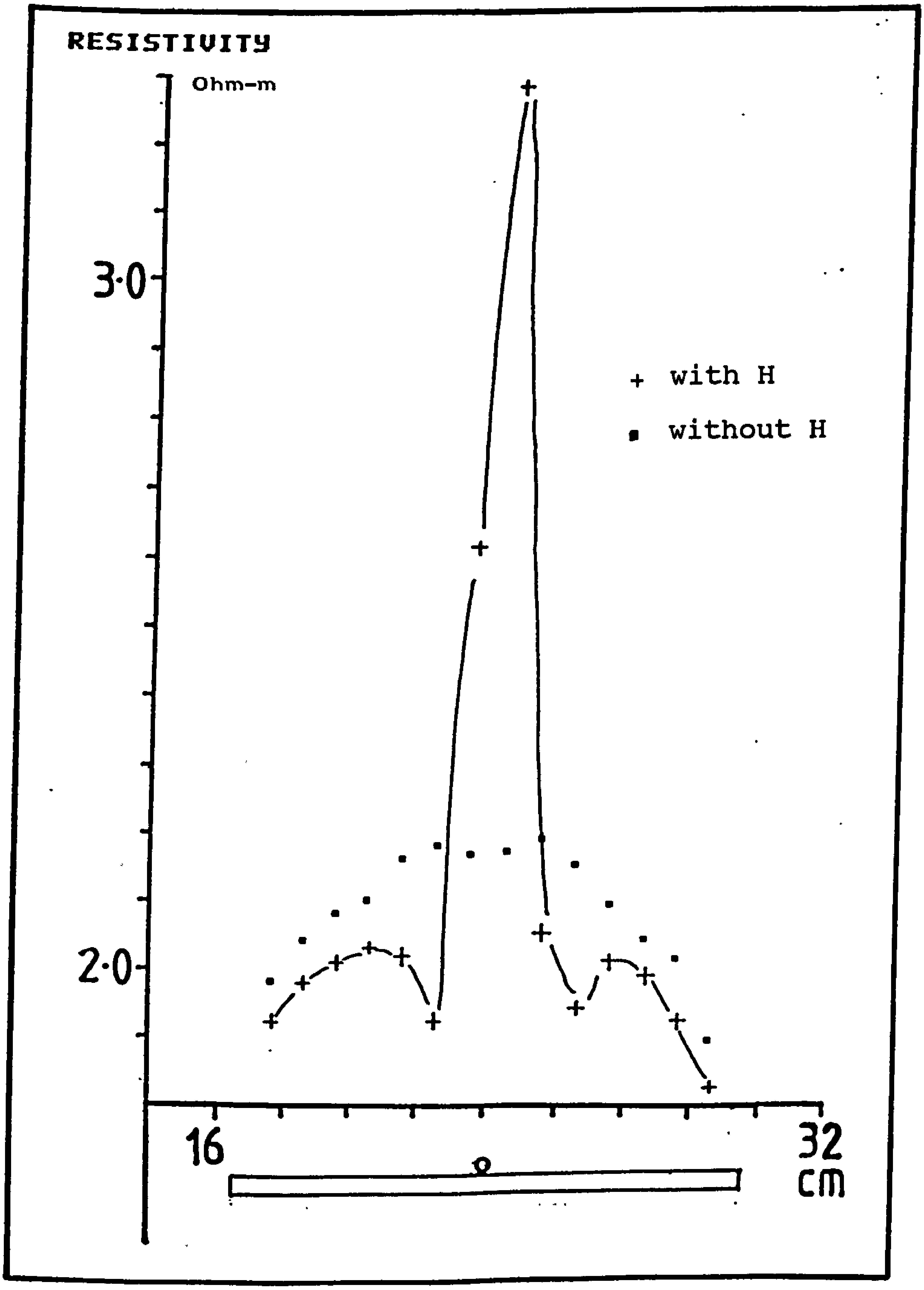


Figure 3.18a. The high resistance object H_1 situated on a central, high resistance laminate object.

3.9 SIMULATION EXPERIMENTS USING CONDUCTING PAPER

At the beginning of chapter 3 (sections 3.2 and 3.4)reference was made to a second 'host' medium simulation technique using conducting paper. In this study conducting paper simulations were used to ascertain precise information on a) different shaped features, and b) exactly similar features of both low and high resistance. From the initial experiments in Chapter 3 it was clear that a number of different types of response appeared to be possible using an off-set Schlumberger.

One particular worry was that objects of similar overall size, but with different cross-sections may give fundamentally different responses. To investigate this phenomenon two features, one circular and one square, were positioned first centrally and then to one side of the centre of the array. In all of the following cases the contacts for the current probes were painted with conducting silver paint 300mm apart, whilst the potential was measured every 10mm using two pencil point contacts. The procedure for the experiments was to measure the voltage drop every 10mm, starting 10mm from the current probes. The feature was then painted in position to represent a low resistance anomaly and the measurements retaken. The feature was then cut out to form an identical high resistance feature, and the measurements were then retaken. The percentage change from the original set of measurements were then worked out and plotted.

A) Cylindrical cross-sectioned feature.

Fig.s 3.19 and 3.20 show the responses for both a centrally and off-set spherical cross-sectioned object. The object is at a depth of 5mm to the top of the object. In the second case the centre of the object is at a horizontal distance of 50mm from the contact C1.

Table 3.13 The change in potential gradient due to a cylindrical, cross-sectioned feature placed in a conducting paper medium.

1. Central object.	Peak	Reverse Peak	Ratio
LOW	-18.7%	6.5%	2.9:1
HIGH	25.8%	-3.3%	8.1:1

2. Off-set object	Peak	Reverse Peak	Ratio
LOW	-22.4%	6.5%	3.5:1
HIGH	27.8%	7.3%	3.8:1

For both of the centrally placed objects the reverse peaks were difficult to ascertain, as the background was quite varied. In fact for this series of experiments the objects were not ideally placed to assess the Peak:Reverse Peak Ratio, as the centre of the object was always placed under a probe rather than between probes. Thus the maximum response of both peaks were not attained. However, in all

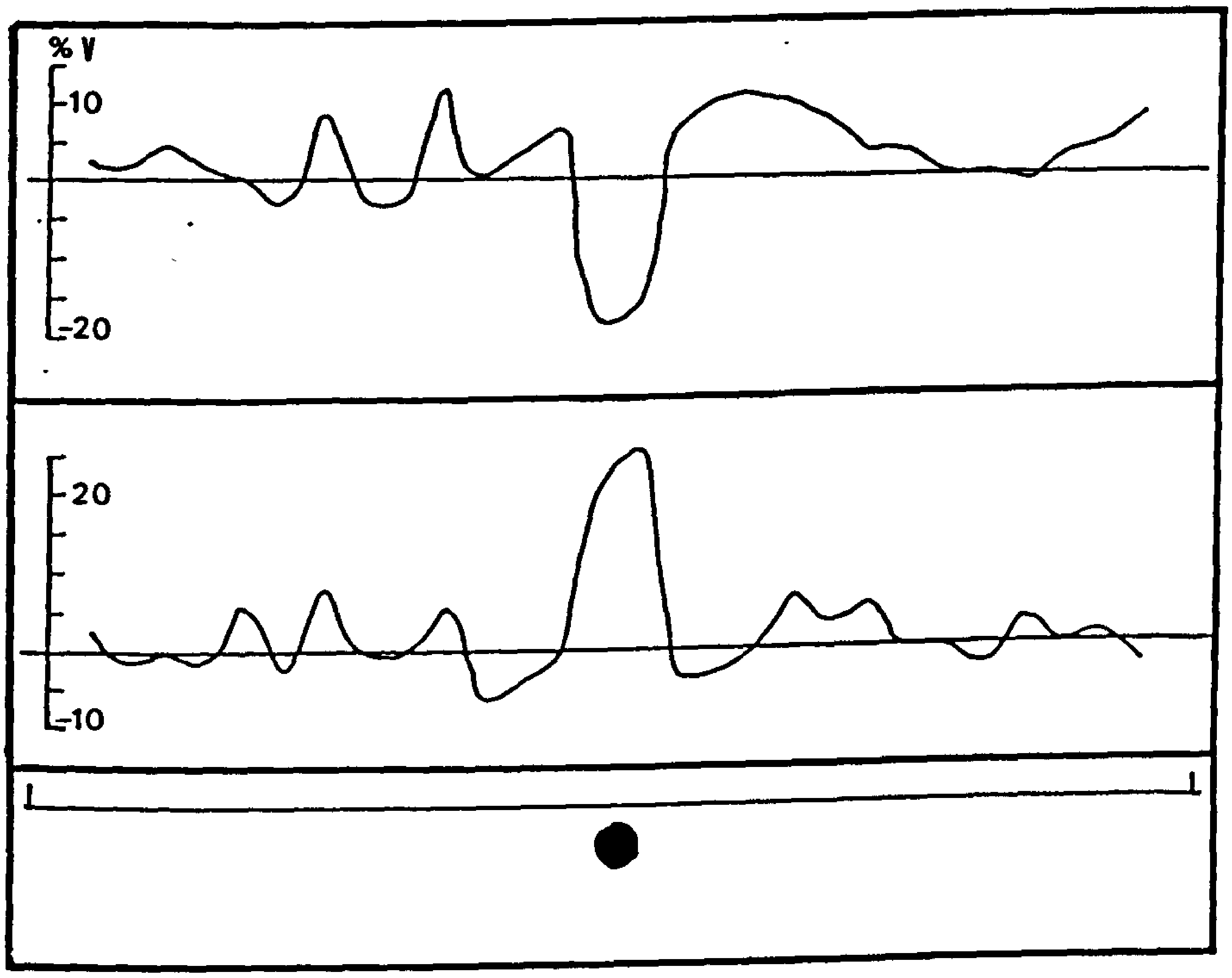


Figure 3.19. The percentage change in voltage due to a centrally positioned cylindrical cross-sectioned feature. The upper portion of the diagram represents a low resistance feature, whilst the lower portion shows the results for a high resistance object.

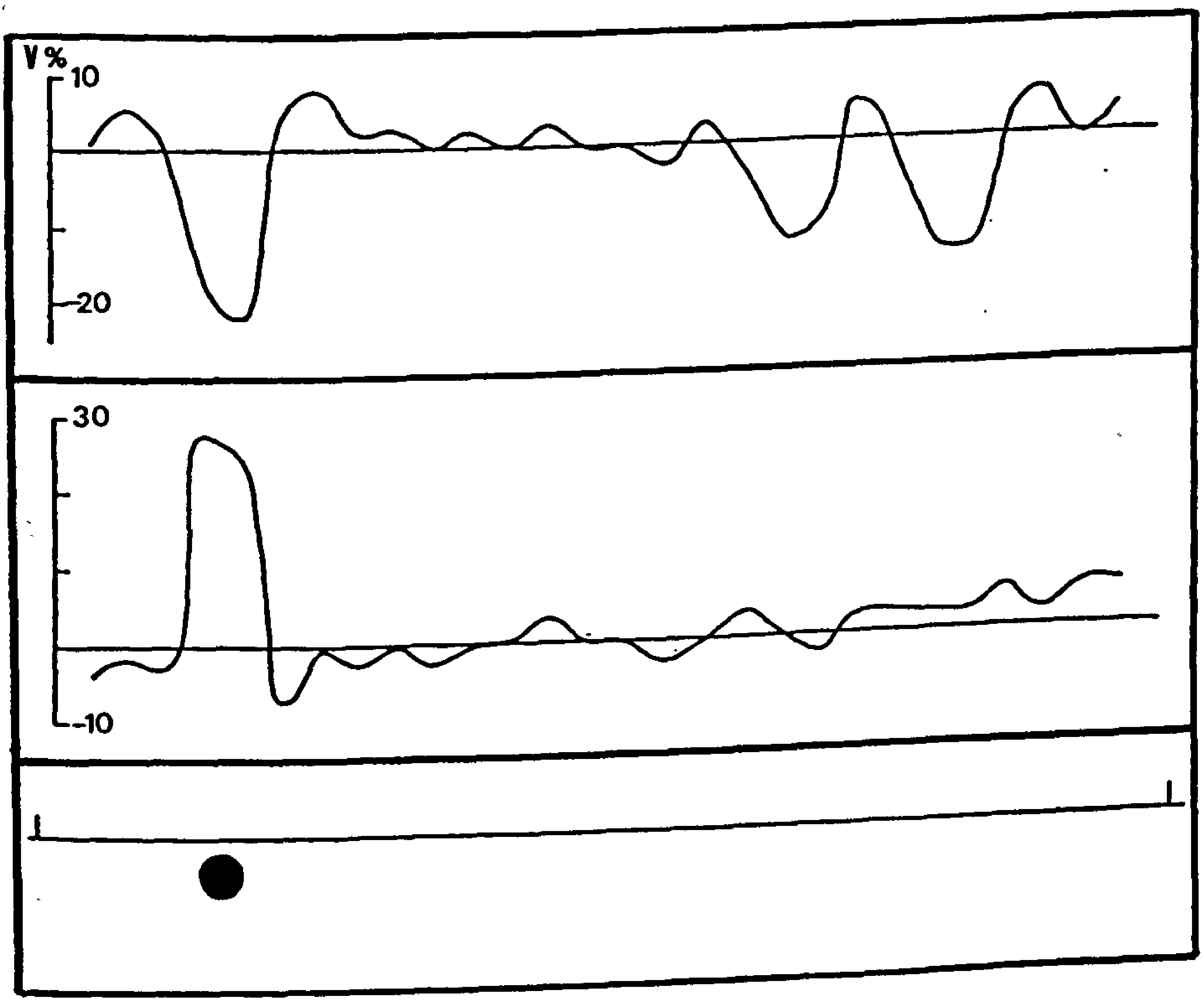


Figure 3.20. The percentage change in voltage due to an off-centre, cylindrical cross-sectioned feature. The upper portion of the diagram represents a low resistance feature, whilst the lower portion shows the results for a high resistance object.

four cases the features were very easily discriminated. Not surprisingly the high resistance features tended to give greater percentage response than the low resistance features. Although it may be argued that this was predictable from the tank experiments, it is probably due to the contrast between the host medium and the objects.

B. Square cross-sectioned feature.

In Fig.s 3.21 and 3.22 can be seen the repeat experiment of (A) above using a square sectioned feature. The experimental conditions were identical in every other respect.

Table 3.14 The change in potential gradient due to a square, cross-sectioned feature placed in a conducting paper medium.

1. Central object	Peak	Reverse Peak	Ratio
LOW	-19.0%	6.5%	2.9:1
HIGH	41.9%	-6.9%	6.1:1

2. Off-set object	Peak	Reverse Peak	Ratio
LOW	-25.4%	4.5%	5.7:1
HIGH	40.8%	-9.5%	4.3:1

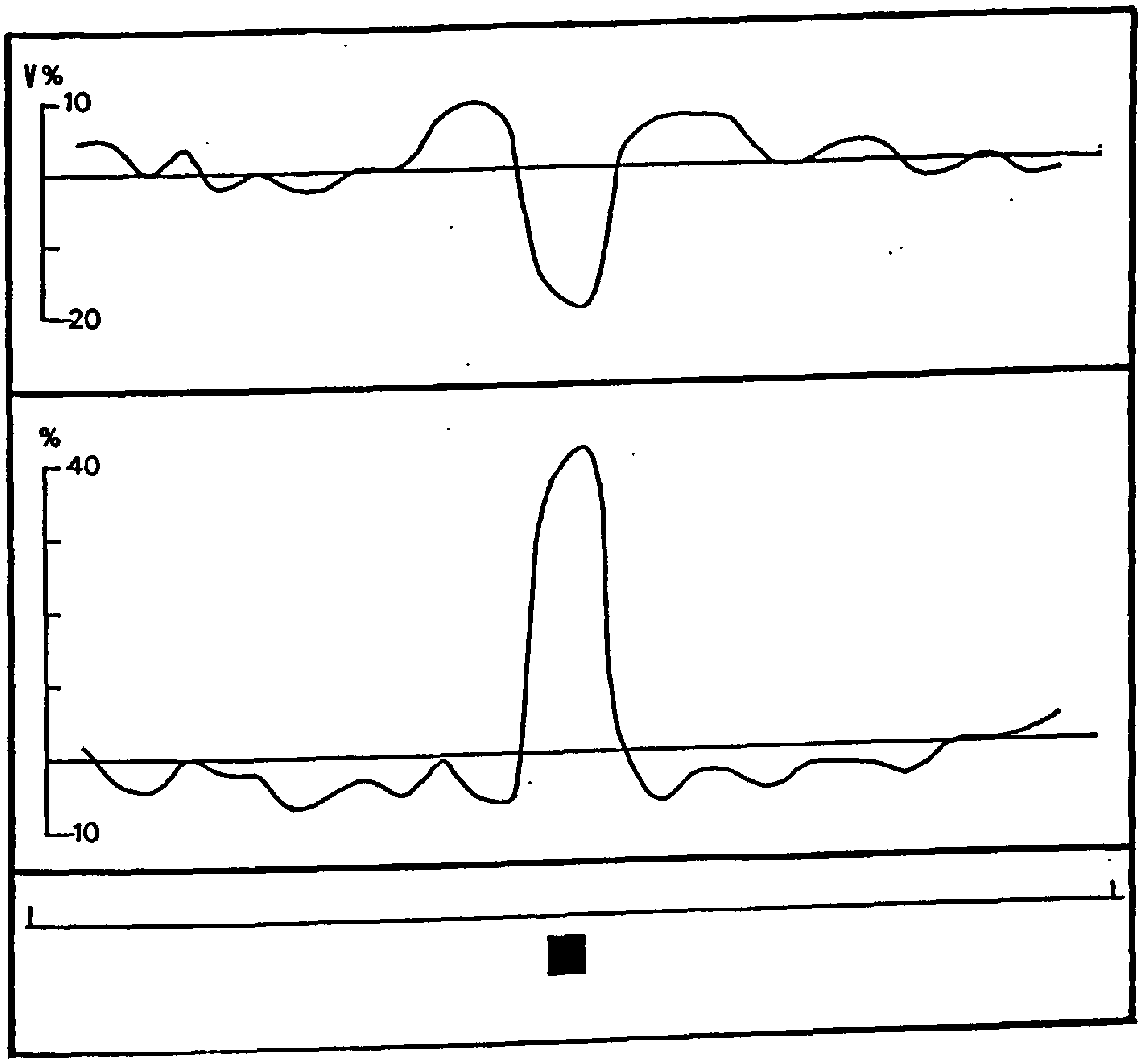


Figure 3.21. The percentage change in voltage due to a centrally positioned, square cross-sectioned feature. The upper portion of the diagram represents a low resistance feature, whilst the lower portion shows the results for a high resistance object.

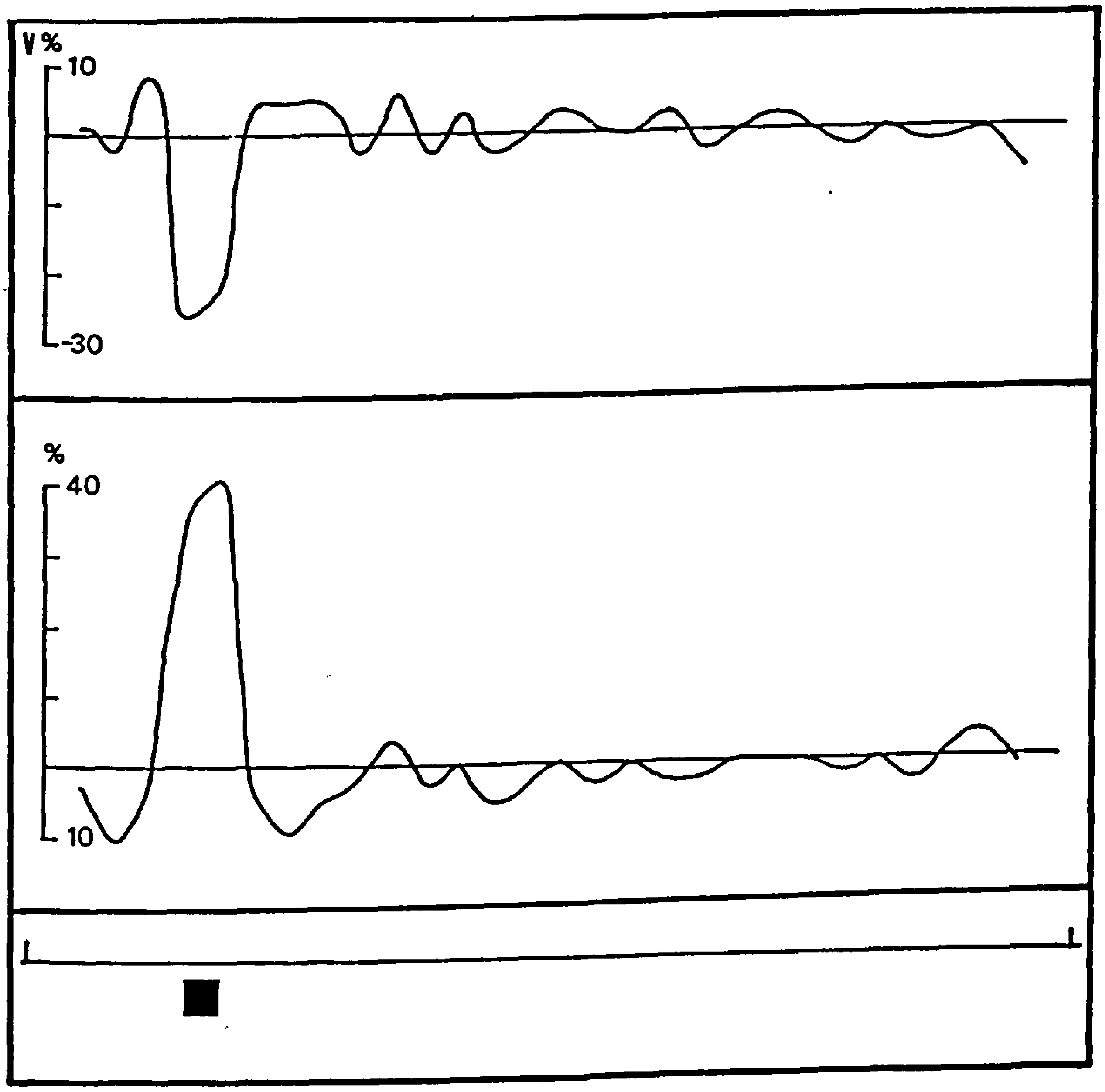


Figure 3.22. The percentage change in voltage due to an off-centre, square cross-sectioned feature. The upper portion of the diagram represents a low resistance feature, whilst the lower portion shows the results for a high resistance object.

Again, all of the features are clearly discriminated with characteristic Schlumberger responses. What is of most concern here is that the form of response does not differ from the response for the circular cross-section object, no matter which position the object is placed in. The major difference appears to be of magnitude of response rather than form. Whilst the low resistance square object gave a slightly greater response, the high resistance square object gave a much greater response than the circular cross-section object. This differential response is due to the distortion of the current at each point. At the centre of the array the current will be virtually perpendicular to the face of the feature. In the off-set position this will not be the case. Therefore, in the former position the current will be deviated to a much greater extent. Not only is the change slightly greater for the central position, but that change as a percentage of the similar low resistance feature is also greater than the off-set position i.e. 62.4% against 46.8%.

The orientation of this set of experiments was to indicate whether the shape of object was important for small archaeological type features. Clearly the form is not, but the magnitude of response may differ depending on position of object. It is noted that the conducting paper experiments replicates a system of line current electrodes, rather than the point sources used in the tank experiments and the field work.

3.10 Complex Archaeological Shaped Objects

After earlier success using conducting paper it was decided to do some experiments with slightly more complex features, that would mimic the laminated tank simulations. The object size in both experiments was 70mmx10mm and was placed at a depth of 5mm. The same procedure was adopted as for the previous experiments.

A. Central positioned object.(Fig.3.23, a+b)

The low resistance object produced huge changes, with the voltmeter measuring 0 on the two central positions.The reverse peaks were large, with changes up to 47.1%. A result of this huge change was that the effective 20m edges the changes were still 2.9% and 5.8% above the background.

The high resistance object differed from the low resistance object in that the peak was only 39.4%, with a reverse peak of 17.6%. At the edges of the 20m area the values obtained were -1.9% and -2.9%. Both of these responses are very similar to responses from the tank simulations. Perhaps one very important interpretational aspect is that in the high resistance case the peak is not a good description of the response. It would appear that the response has 'peaked' virtually on the edge of the object. This is due to the severe distortion at the face of the object, with the current then running virtually parallel along the main axis of the object c.f the percentage change for the square object at the centre (41.9%).

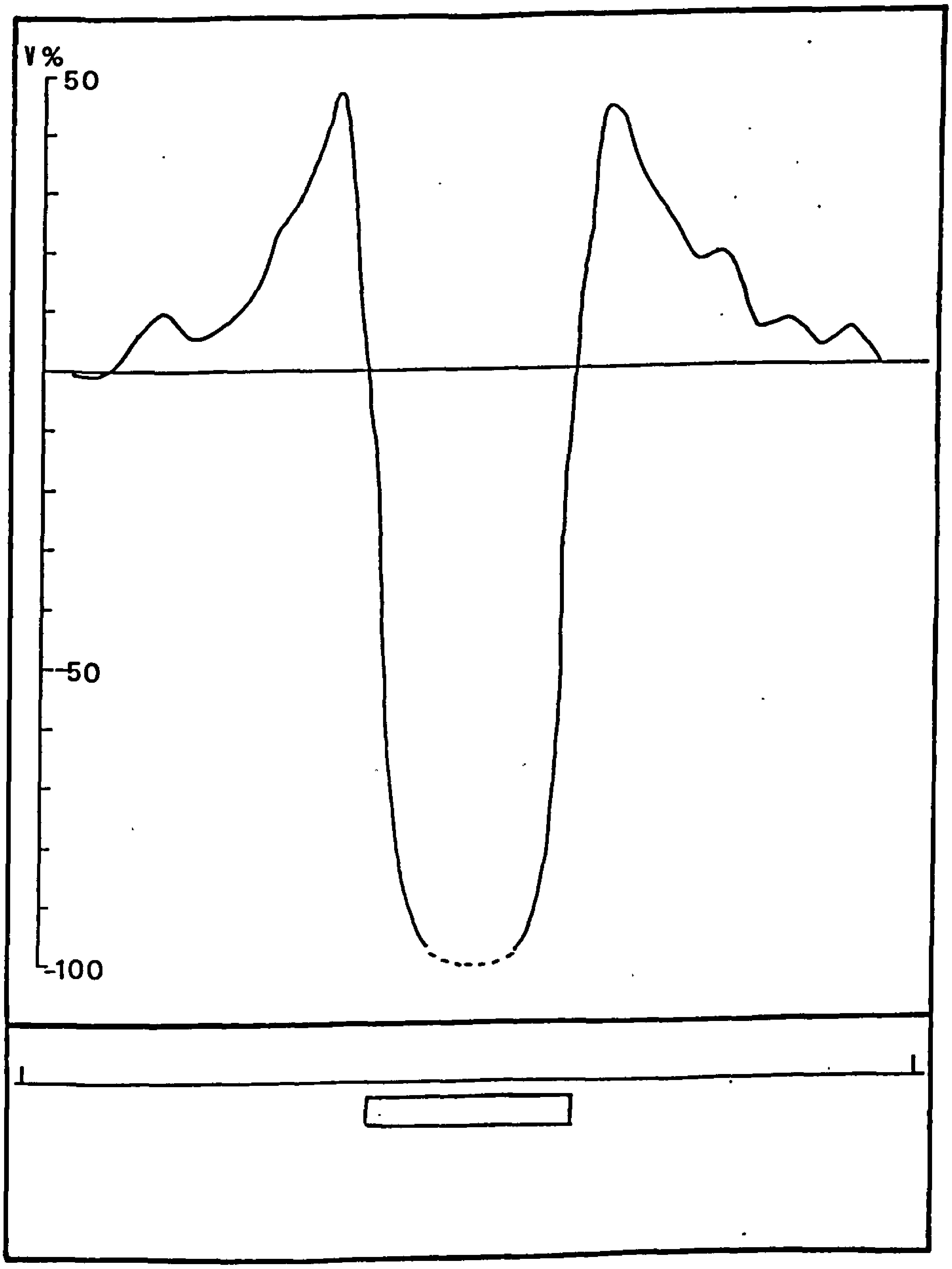


Figure 3.23a. The percentage change in voltage due to a central, laminate object.

The results indicate a low resistance object.

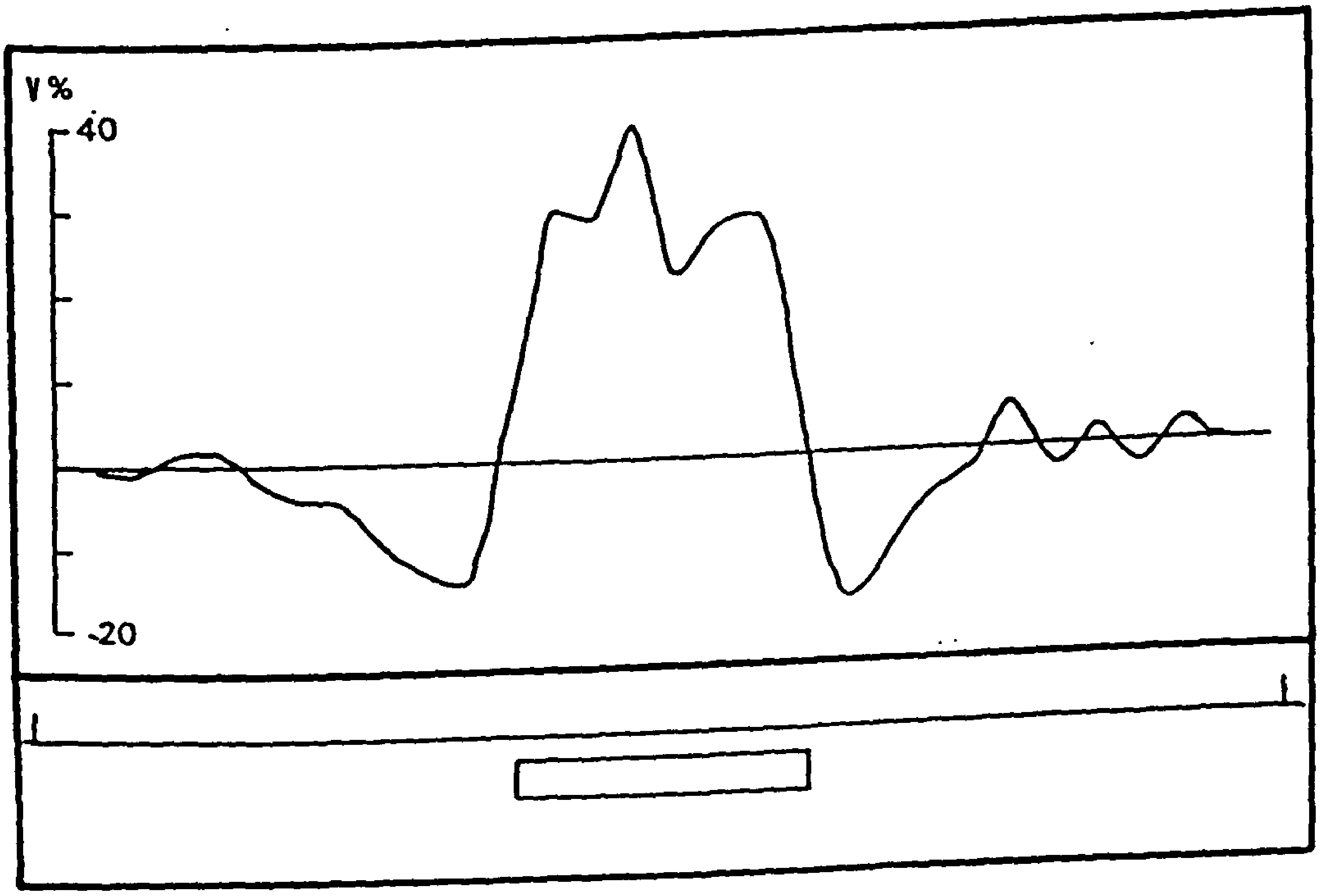


Figure 3.23b. The percentage change in voltage due to a central, laminate object.

The results indicate a high resistance object.

2. Off-set object. (Fig 3.24)

The object was placed 15mm horizontally from the C1 probe and at a depth of 5mm. The low resistance object again produced huge negative changes on the object itself, whilst having a reverse peak of 68.4%. At the far 20 metre edge the measured change is still 8.0%.

The high resistance response is very interesting for this position, as on the C2 side of the anomaly there is virtually no reverse peak (-5.6%). This is despite the major peak of 78.6%. The response is very similar to many of the tank slab features c.f Fig. 3.15. Not only is the loss of reverse peak familiar, but also the more gentle slope on the edge nearest to C1.

In both sets of paper experiments the results have helped clarify response forms for low and high resistance bodies.

3.11 CONCLUSIONS

The experiments described above have answered some important questions. In general terms the experiments have shown the feasibility of using an off-set Schlumberger within the homogeneous medium of a simulation tank. The errors associated with the calculated resistivity

(a) across the central line between the C-C electrodes, where the correction is greatest, and

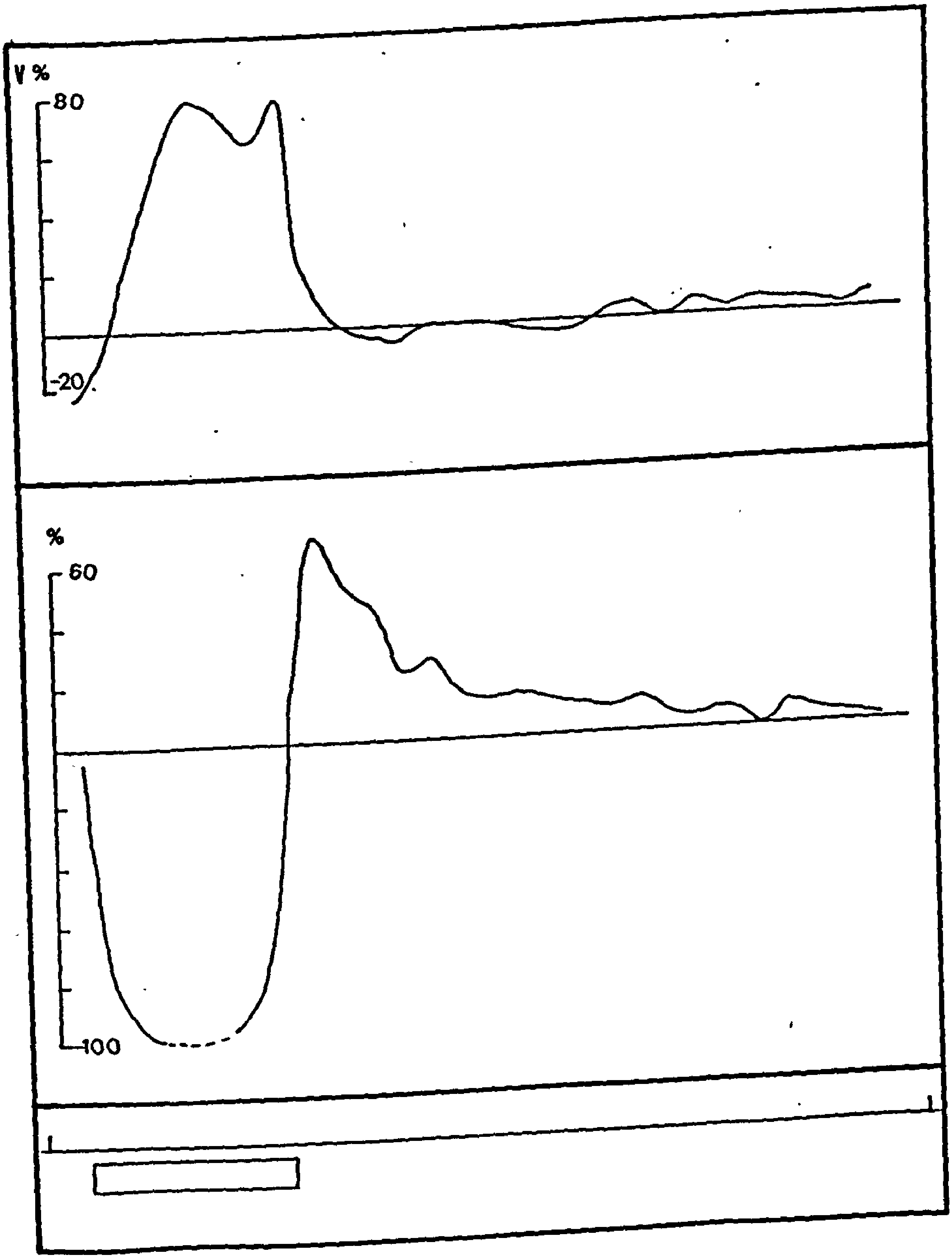


Figure 3.24. The percentage change in voltage due to an off-centre, laminate object. The upper portion of the diagram represents a high resistance feature, whilst the lower portion shows the results for a low resistance object.

(b) across an 'effective' 20m grid, were very small.

In relation to the four questions raised above (section 3.8(a)) we can say:-

(1) the anomaly response was, without exception, always of a large percentage change by comparison with the background resistivity.

(2) Within certain parameters we can say that all the response forms showed simple single peaks. The use of laminated anomalies certainly hindered the interpretation of small features situated alongside the laminar, but did not cause problems when a feature was placed on the laminar object.

(3) The general responses were reproducible, with similar Peak:Reverse Peak ratio. Again, the laminar objects caused some deviation from the expected response.

(4) Some information has been gathered on the position and response, but this will be more fully investigated in Chapter 5.

CHAPTER 4

Field trials using the Schlumberger Array

4.1 Introduction.

Whilst none of the following seven field tests of the Schlumberger array described in this chapter are very extensive, all of them were performed to assess one or other of the problems of the array identified through previous experimental work. Trials were initially carried out to observe the effect of current probe position when using the non-moving current probe system. Encouraged by the initial success of tank simulations using the off-set method, it was hoped to ascertain whether the value of the background resistivity may be radically changed by the presence of bodies of differing resistive nature, and whether such changes can interfere with the interpretation of anomalies produced by small archaeological features.

4.2 Survey at the University of Bradford.

A lawned area at the University of Bradford acted as a test area for the off-set method in the field. The site which contains no known archaeological remains, but probably overlies demolished terrace buildings, is an ideal extreme situation for the method to be tested in. An area of 20x4m was surveyed with the current probes at positions A and B and then repeated with the probes at positions C and D (Fig.4.1). The C-C distance was 30m whilst the P-P distance was 0.5m, giving a CC:PP ratio of 60:1. This gave values on the straight-through line and three off-set lines. A Twin Probe survey was also performed to look at the comparative form of signal response. As chance would have it the Twin-Probe survey showed a clear, but broad, high resistance anomaly at the S-W end of the survey (Fig.4.2). The survey revealed no other discrete anomalies, but showed a slight increase in resistance toward the N-E edge.

The two Schlumberger surveys whilst showing a more complex response, reveal a number of important features (see Fig.s 4.3, 4.4).

(1) The agreement in response between the two Schlumberger surveys is excellent. The ageement is good not only between the form but also the strength of response.

(2) The broad, high resistance feature of the Twin-Probe

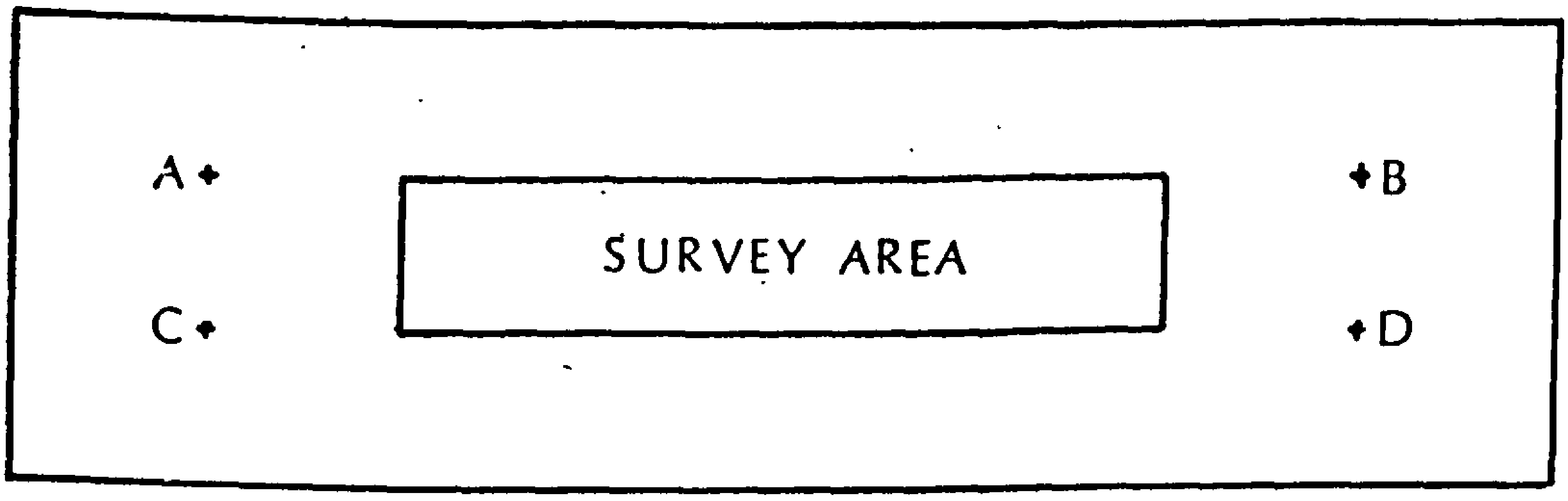


Figure 4.1. Survey at the University of Bradford. The distance A-B and C-D is 30m. The survey area is 20x4m.

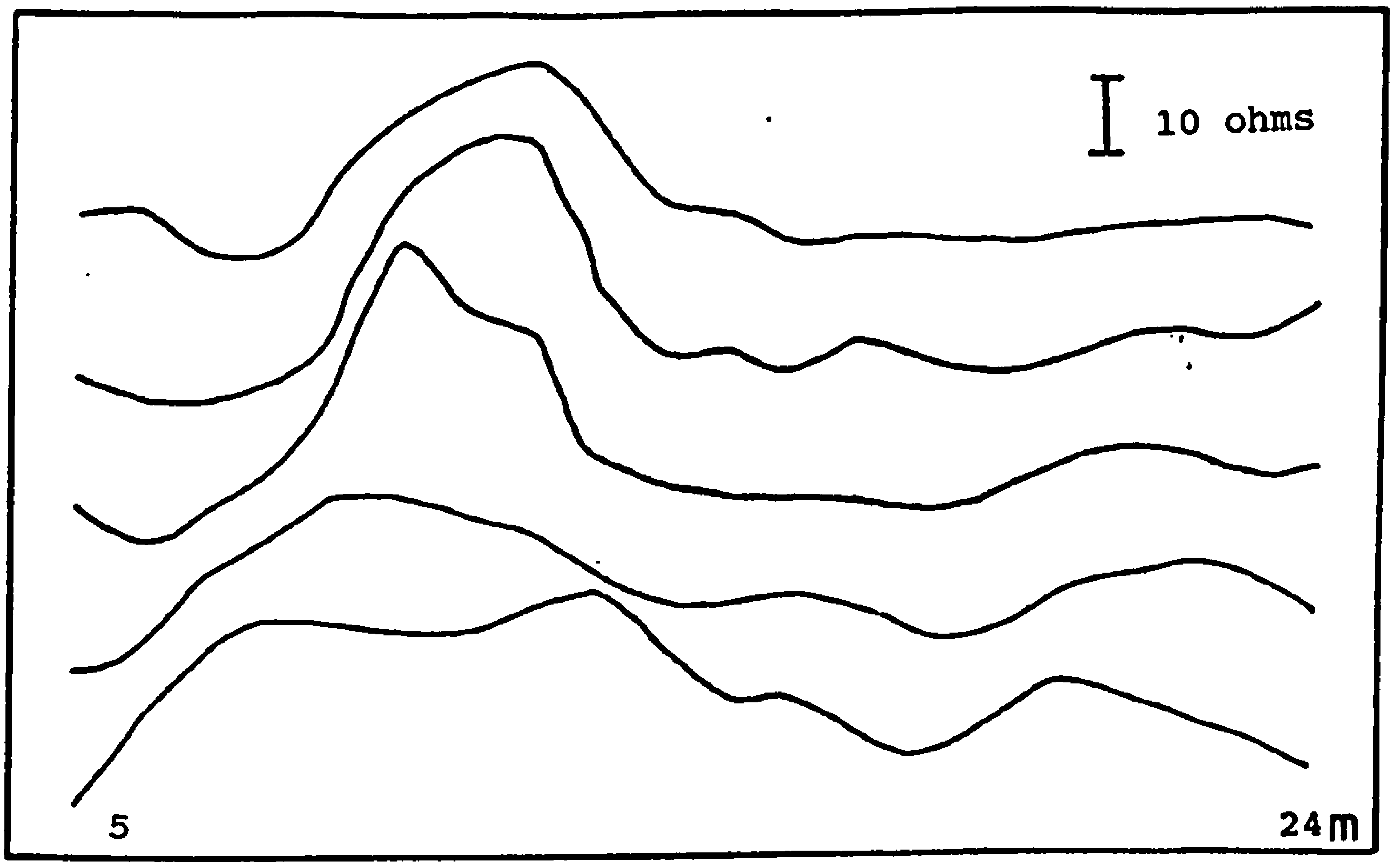


Figure 4.2. Survey at the University of Bradford. The Twin-Probe resistance results.

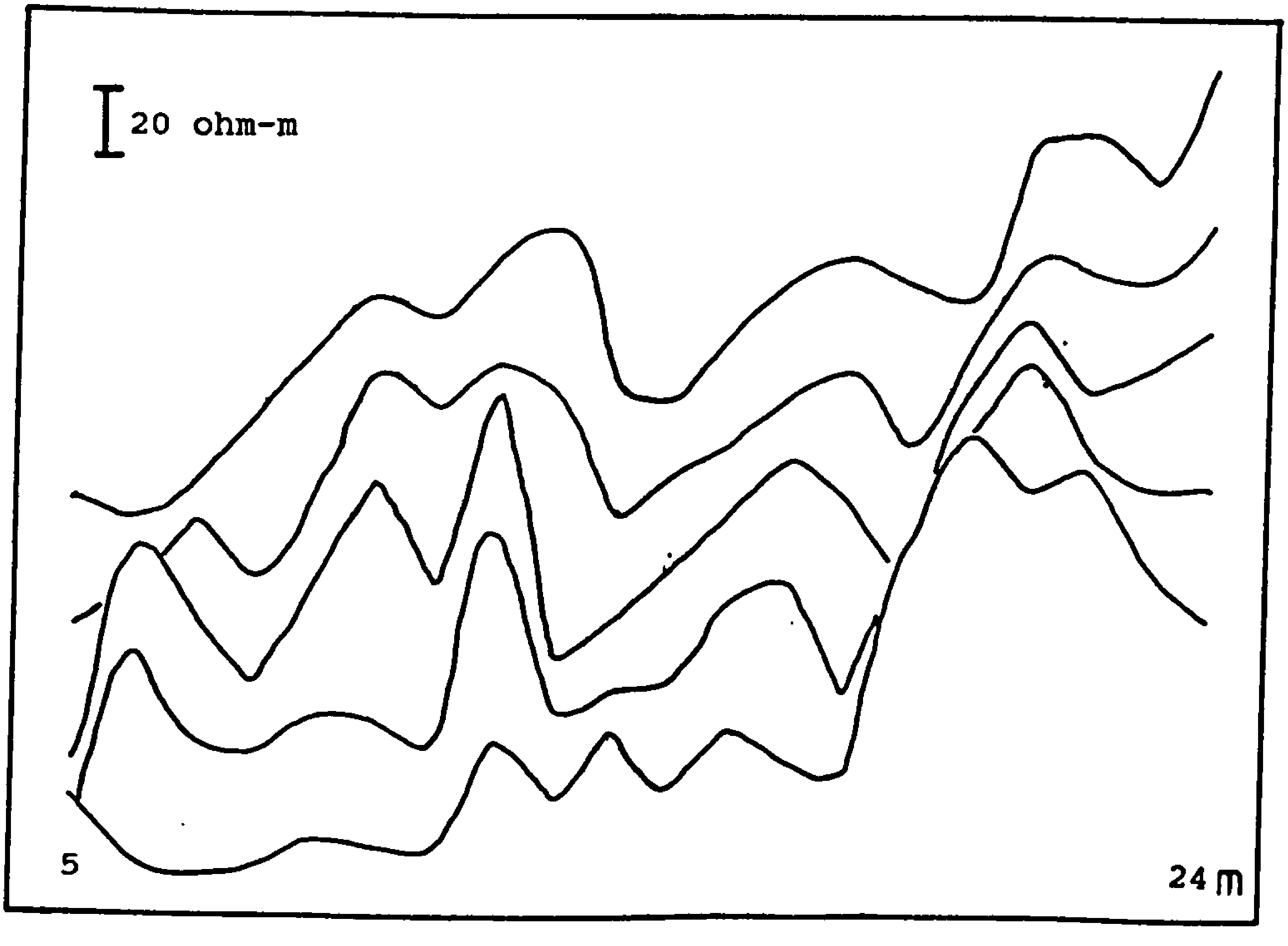


Figure 4.3. Survey at the University of Bradford. The Schlumberger results with the Current probes at A-B.

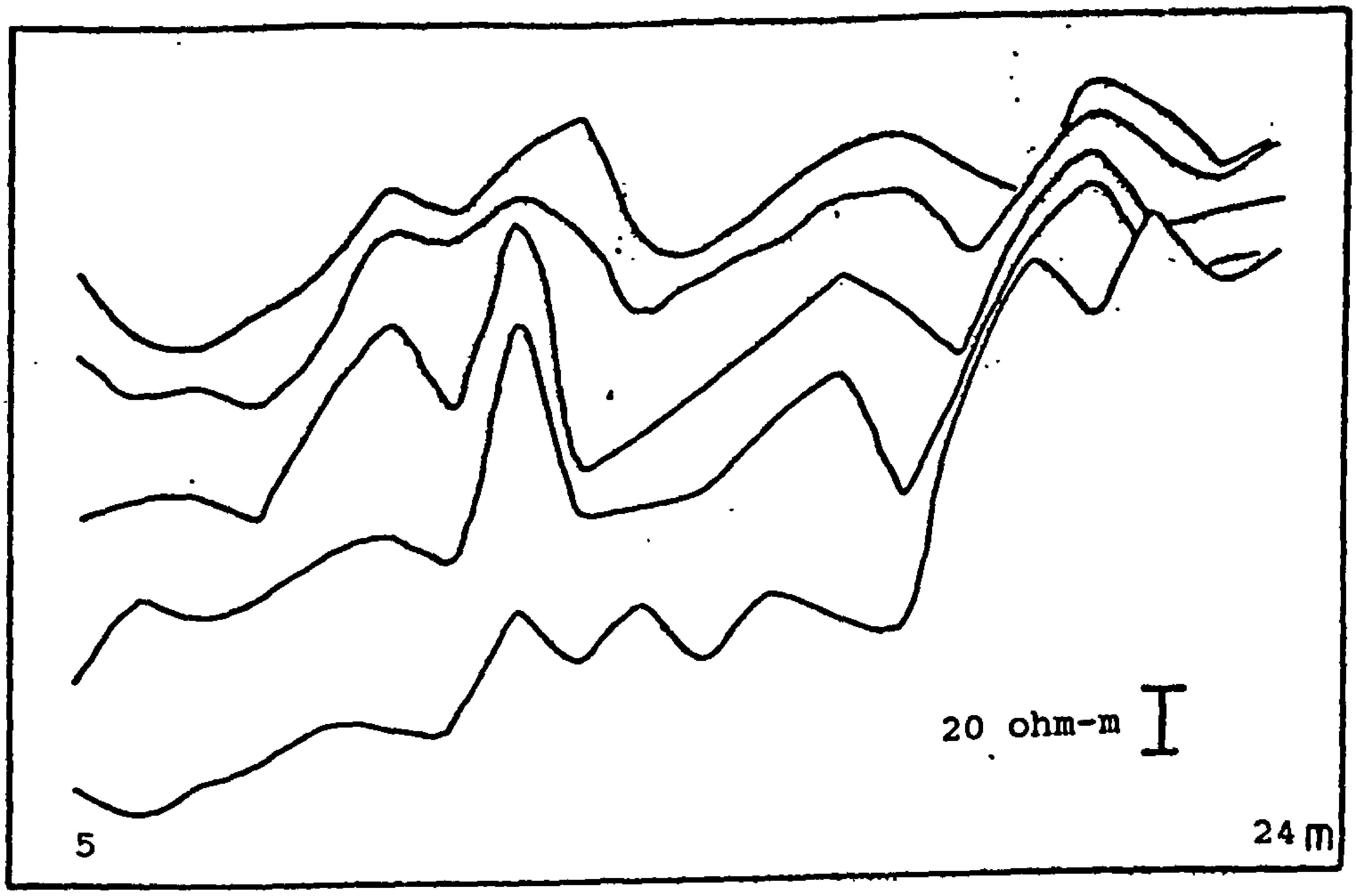


Figure 4.4. Survey at the University of Bradford. The Schlumberger results with the Current probes at C-D.

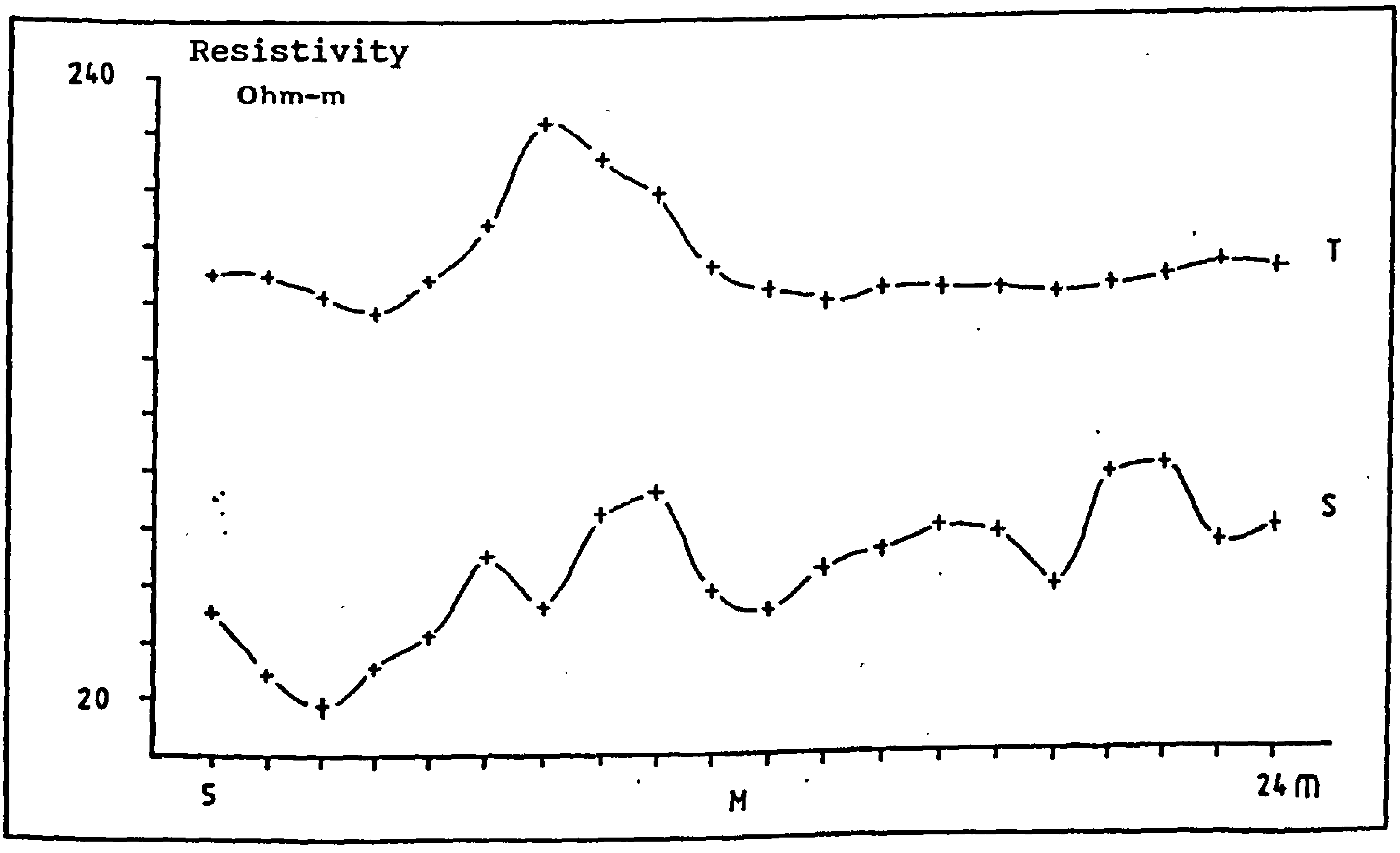


Figure 4.5 Survey at the University of Bradford. A comparison between a Twin-Probe and a Schlumberger run.

survey appears to resolve itself into two high resistance features. One of two conclusions may be drawn here. Either the response is proving the supposed feature resolution of the array, or there are some more complicated edge effects that did not show up in the original simple tank simulations. In terms of the major feature, although the background is difficult to estimate for the Schlumberger, the Schlumberger feature shows an approximate increase of 80%, whilst the Twin-Probe increases by approximately 40% over the nominal background.

(3) There is a gradual increase in resistivity toward the N-W edge of the survey area, superimposed upon which there appears to be a high resistance feature. In the Schlumberger data this feature is delimited by a sharp drop in resistance. In Fig. 4.5 can be seen a direct comparison between a Twin-Probe and a Schlumberger run. In fact, in this particular traverse there is a minor drop in the Twin-probe response at the same station. However, the Twin-Probe response could not have been interpreted as a feature edge.

In this case-study it may be argued that the movement of the current probes to a second position parallel to the original C-C line produces little difference to the original off-set Schlumberger pattern of response. However, distinct differences between the Schlumberger and the Twin-Probe surveys were noted. The larger increase in the Schlumberger for the anomaly in position 21-22 (Fig.4.5), suggests that lateral current probe positioning may be important.

4.3 All Hallows Hill, Tickhill, South Yorkshire.

This site had proved particularly responsive to electrical resistivity survey techniques, using the Twin-Probe arrangement. Part of the results from the large Twin-Probe survey are shown in Fig. 4.6. It is evident from this diagram that a very coherent series of anomalies were located that probably represent an early (11th century) two cell chapel. The dot-density display, although broad in range, shows the possibility of anomalies to the N-E of the structure. It was suggested that, due to the higher internal resistance of the eastern cell of the church, that this cell may have been paved. The Schlumberger survey concentrated on the two Eastern grids, thus covering the whole of the two-celled structure.

The object of this particular exercise was again to test the influence of varying the C-C probe position. However, the major limitation of the work at the University was that, due to space limitations, the C-C line could only be moved parallel to the original C-C line. In this case it was possible to survey two complete 20x20m grids. Therefore, the strategy for each grid was to mark two centrally positioned C-C lines i.e. at right angles to one another. To extend our knowledge on the change of resistivity due to current probe position, the grids were surveyed using both current probe positions.

In Fig. 4.7 the two grids were surveyed with the C-C line

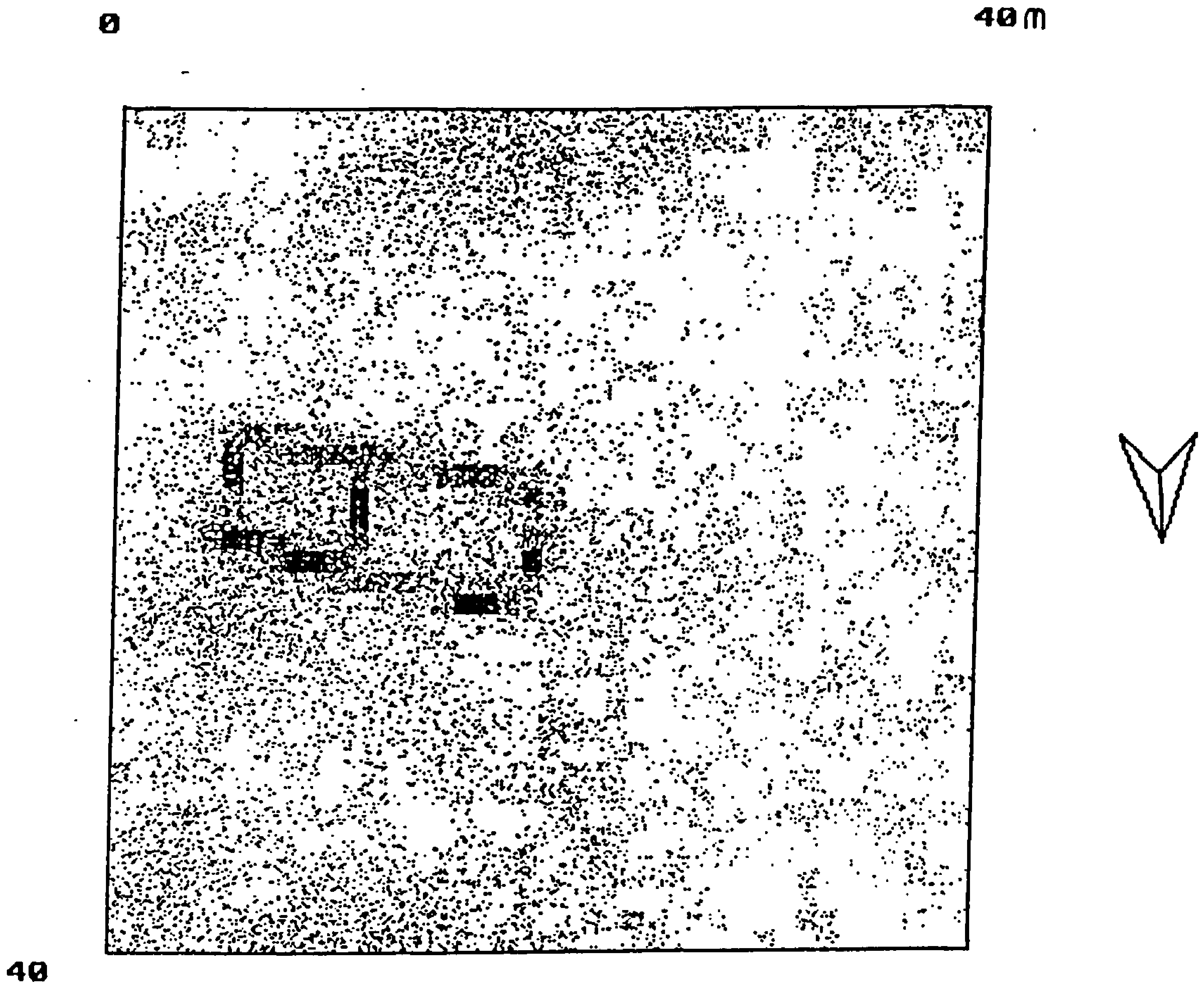


Figure 4.6 Twin-Probe results from Tickhill.
Min = 20 ohms. Max = 45 ohms.

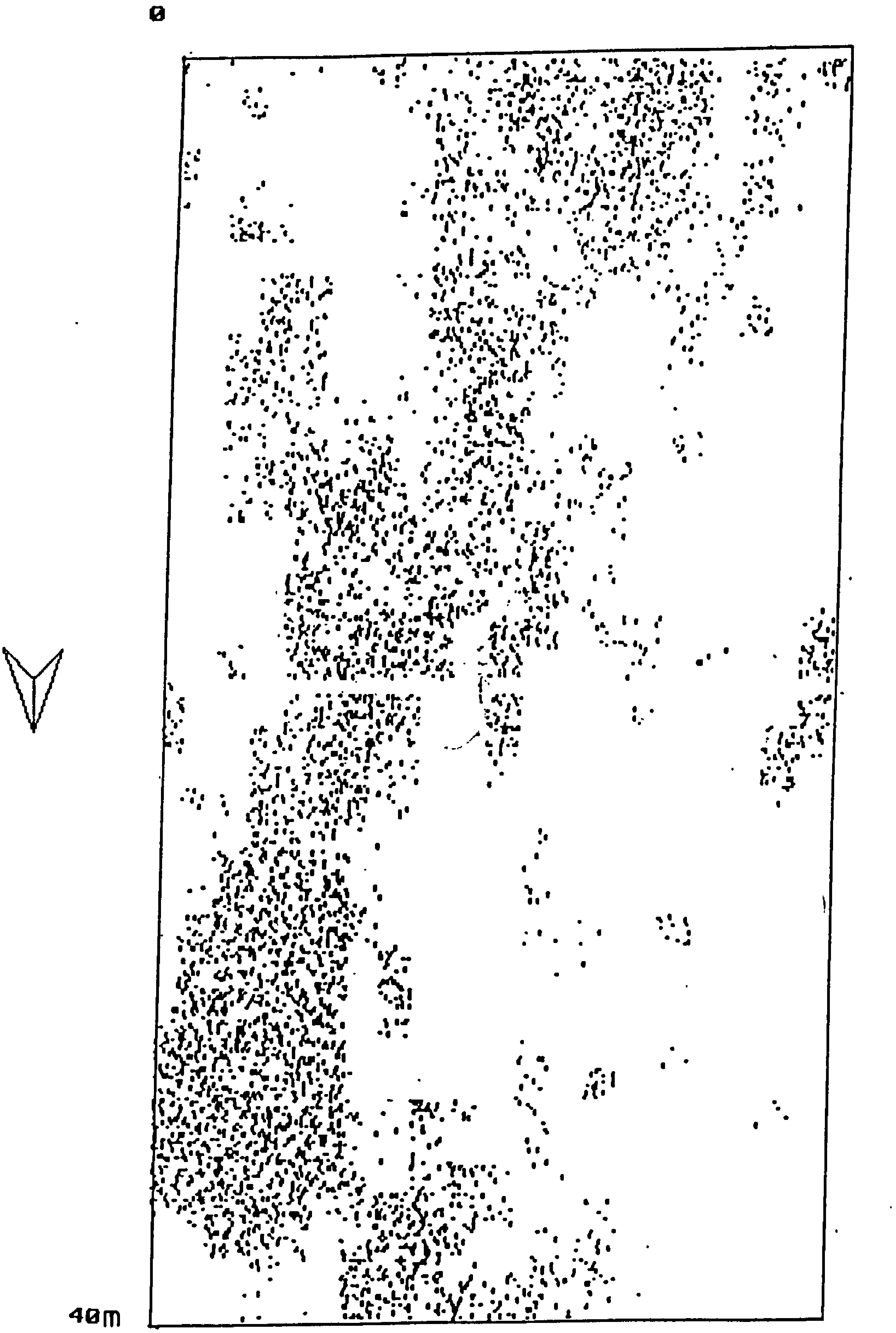


Figure 4.7. The Schlumberger survey from Tickhill. The Current probes are positioned E-W.

E-W (CC distance =30m). Quite evident from this diagram was the fact that the 'expected' response was not obtained i.e. a plan similar to the Twin-Probe results had not been detected. Although the N-S walls of the feature are present, evidence for the longer E-W walls are absent. An additional large, high resistance feature which was angled approximately SW-NE is readily visible. This is probably of geological origin and almost certainly accounts for the high internal resistance of the eastern cell seen in the Twin-Probe survey. These results should be compared with the plot in Fig. 4.8, which shows the results of the survey with the C-C line N-S. Again, surprising results were obtained; in this case it is the N-S component of the archaeological feature that is missing. The supposed geological anomaly that was so clear in Fig. 4.7 is also effectively lost with the re-orientation of the current probes.

Given the fact that for two reasons it is appropriate to work in a grid size of 20x20m, that is:-

(a) they are a convenient size to use in the field and are standard within the School's work, and

(b) the distance required between the C-C probes to ensure a similar current density throughout the grid requires a large CC:PP ratio.

It would then appear that two practical problems must be raised.

(1) Does each grid have to be surveyed twice with the C-C lines positioned at right angles i.e 800 readings per 20x20m

Figure 4.8. The Schlumberger survey from Tickhill. The Current probes are positioned N-S.

grid ?, or

(2) Can one orientate the grid so that the strike angle is 45 degrees to any hypothesised structure? If this was so, then only one set of readings would be required for each grid i.e. 400 readings per 20x20m grid.

With these two questions in mind a third grid was positioned over the two-celled structure with a strike angle of approximately 45 degrees. It is clear from Fig. 4.9 that it is not sufficient to orientate a grid in such a manner to get good or even adequate results with only one set of measurements. In most cases it would appear at least prudent, if not totally necessary to survey each grid twice with the C-C lines at 90 degrees to one another. This will be investigated more fully later in a series of tank experiments described in section 5.6. In terms of data presentation the two data sets measured at right angles were aligned and added together. In Fig. 4.10 a simple dot-density plot highlights the most important features of this combined data set. Inevitably, the clarity of the data is not as good as the individual plots. It is therefore suggested that a Schlumberger survey, such as the one described above, may be interpreted at three levels. The first two levels involve the interpretation of the two right angled components, where detailed directional trends may be observed and followed, and thirdly a combined illustrative format where anomalies are merged, enhanced and ultimately given a second dimension.

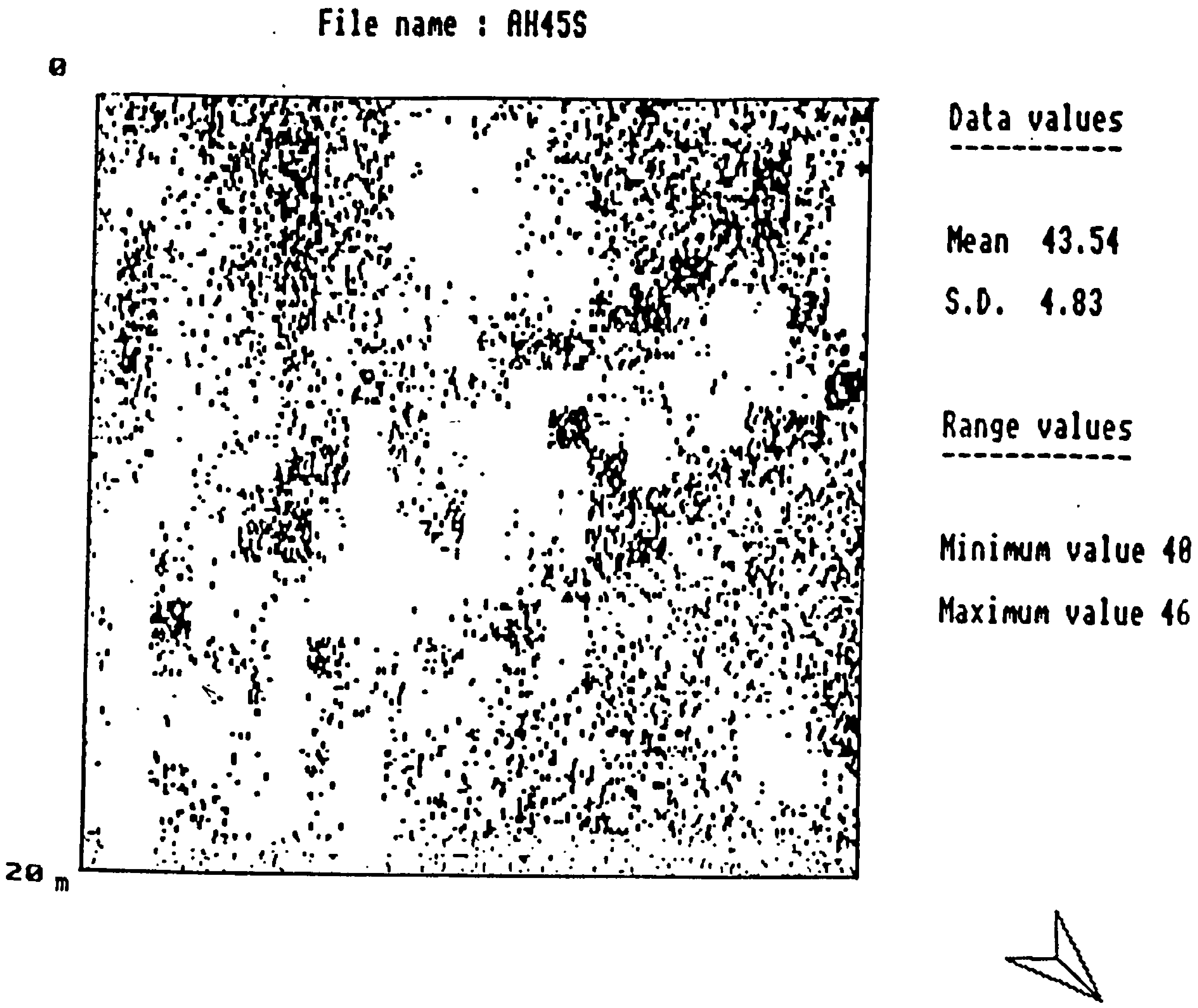


Figure 4.9. The Schlumberger survey from Tickhill. The Current probes are positioned NE-SW.

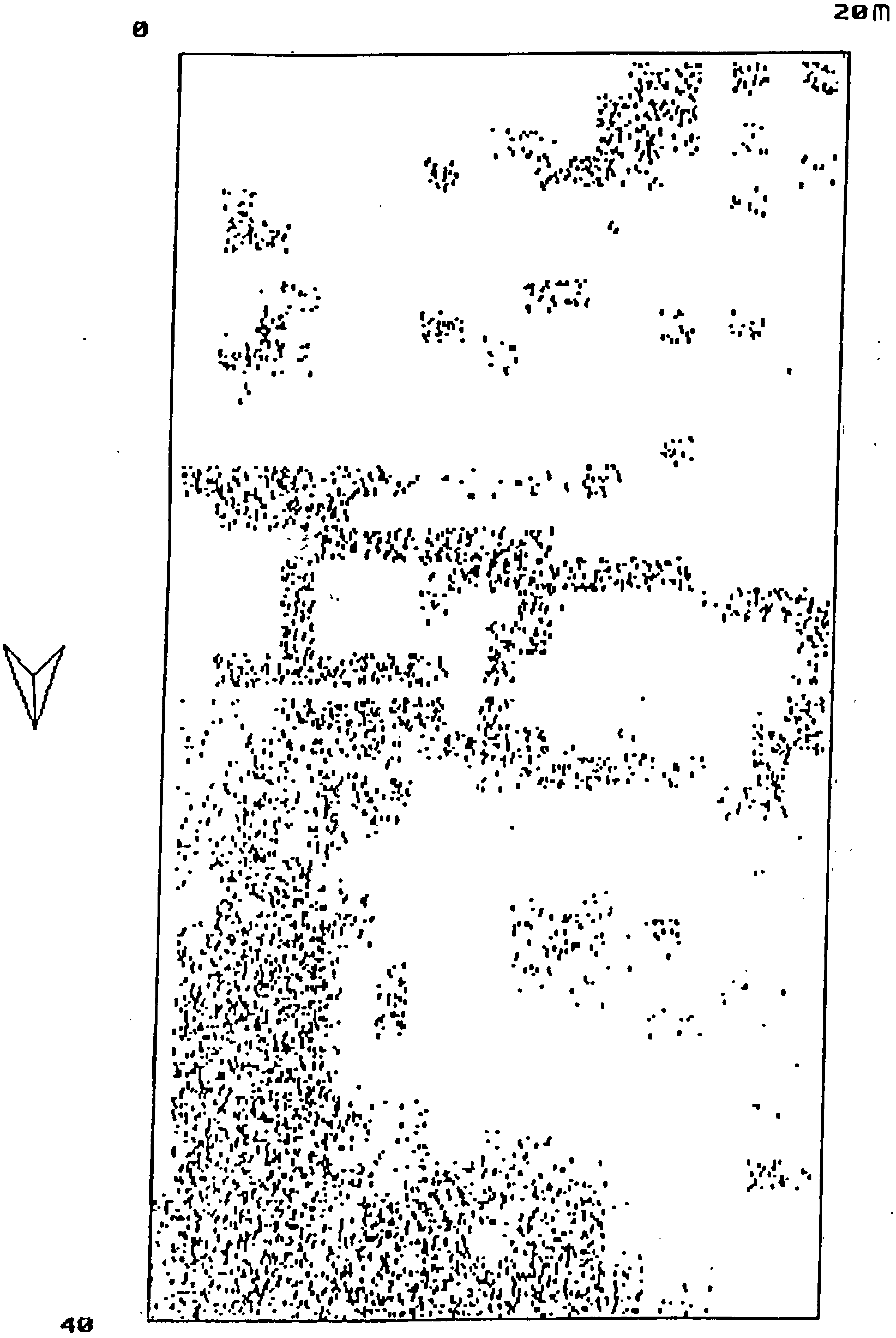


Figure 4.10. The Combined Schlumberger survey from Tickhill.

4.4 Chesters Villa, Woolaston Grange, Gloucestershire.

The site at Woolaston Grange is now a ploughed crop mark site siuated on the Welsh side of the river Severn. Although the site has had some keen antiquarian interest in the past (Scott Garrett 1938) it has also received recent interest due to its important economic position (Allen and Fulford 1987). The author conducted a 40 grid Twin-Probe survey over a number of the crop marks, as part of a larger research programme into functional aspects of the site. Whilst on the site a small Schlumberger survey, again of 20x40m in size, was placed over a particularly interesting area. The area chosen produced quite ephemeral Twin-Probe anomalies due to the nature and post-depositional aspects of the archaeology. The survey (Fig. 4.11) indicated a wall turning at the eastern edge of the two grids, slight indications of walls appeared in the centre of the grids and an area of high resistance is seen on the western edge of the area.

The Schlumberger survey was performed in the same manner outlined at All Hallows. During the first set of measurements the C-C probes were positioned E-W (Fig. 4.12). The turning wall at the eastern edge of the grid is very clearly seen, as is a very sharp low resistivity edge to the feature. Two possibilities emerge for this low resistivity edge.

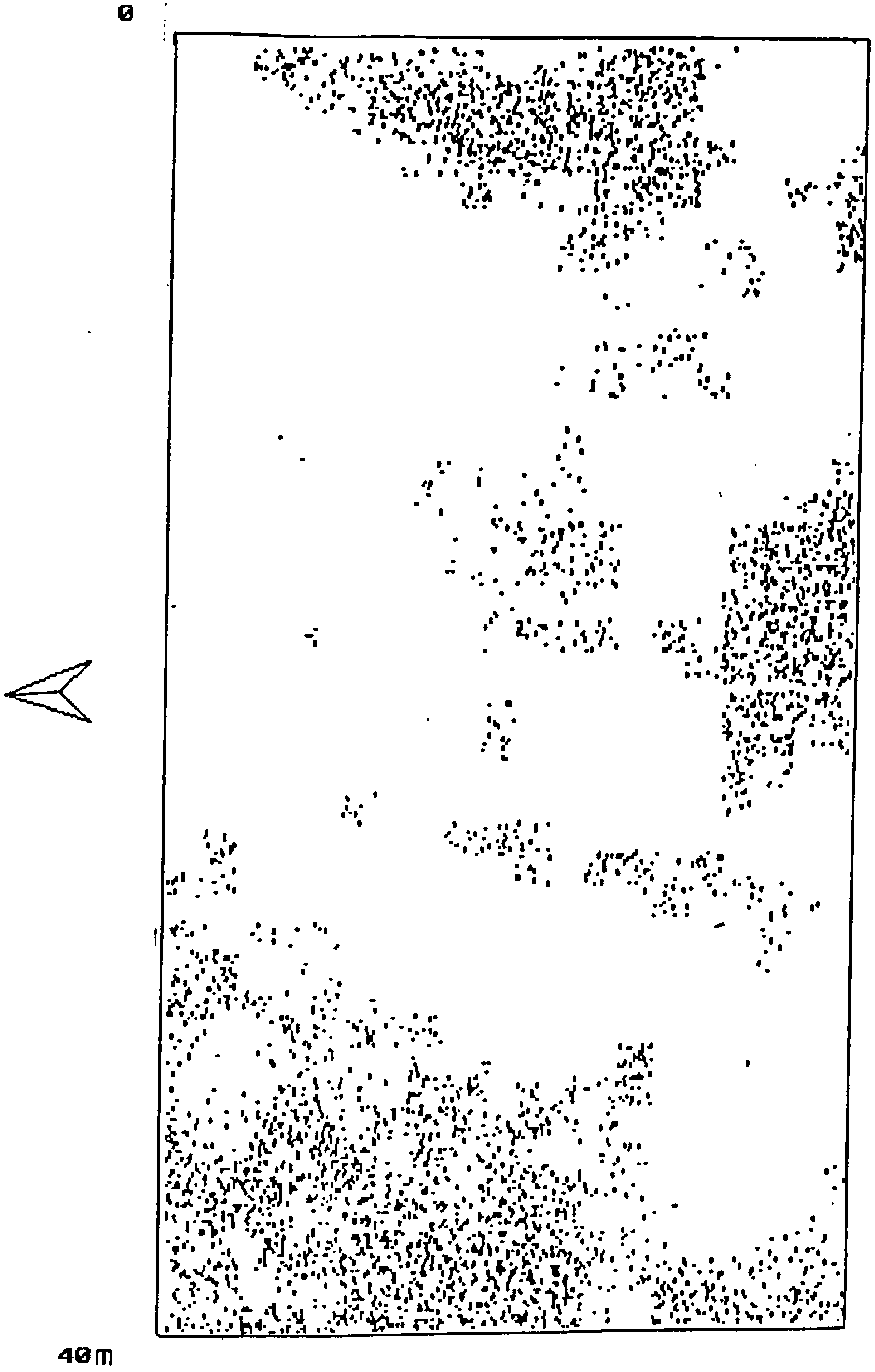


Figure 4.11. The Twin-Probe survey from Woolaston Grange.

Figure 4.12. The Schlumberger survey from Woolaston Grange. The current probes are positioned E-W.

(1) It may be a reverse peak resulting from the position of the object with respect to the current probes, or

(2) It may be a genuine low resistance feature running parallel with the wall.

The likely answer to this problem will be more evident after the second series of tank simulations described in Chapter 5.

Traces of high resistance anomalies may be seen running approximately N-S, along with a high resistance platform at the western edge of the survey area.

The complementary grid with the C-C line N-S (Fig. 4.13), again shows the broad high resistance at the eastern edge of the area and a parallel low resistance feature. The rest of the survey area appears to lack the detail of the previous plot, showing only a confusing picture of elongated E-W anomalies. The combined plot of both C-C contributions shows quite clearly all of the major features (Fig. 4.14). However, as the dot -density plot does not show the large changes in the centre of the array, the changes are detailed using two X-Y plots. The first is from the line of measurements going N-S (Fig. 4.15). In this diagram we can see that although the form of response is similar for both the Twin and the Schlumberger, the percentage change is much greater for the archaeological features (approximately 40% for the Schlumberger and 12% for the Twin). In the second X-Y plot (W-E, Fig. 4.16), it is again apparent that whilst the

Figure 4.13. The Schlumberger survey from Woolaston Grange.
The current probes are positioned N-S.

Figure 4.14. The Combined Schlumberger survey from Woolaston Grange.

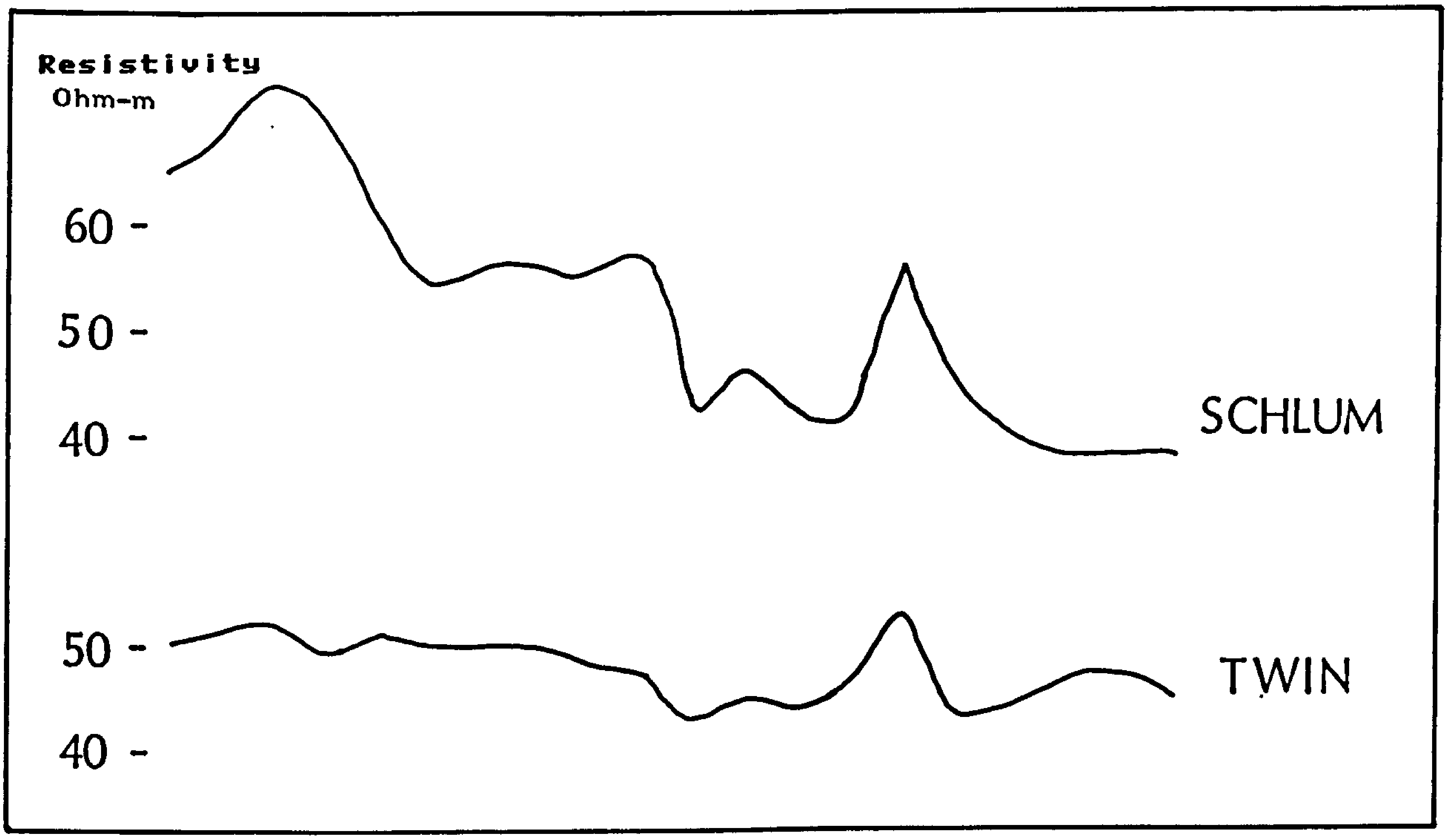


Figure 4.15. A comparison between the Schlumberger and the Twin-Probe surveys at Woolaston Grange.

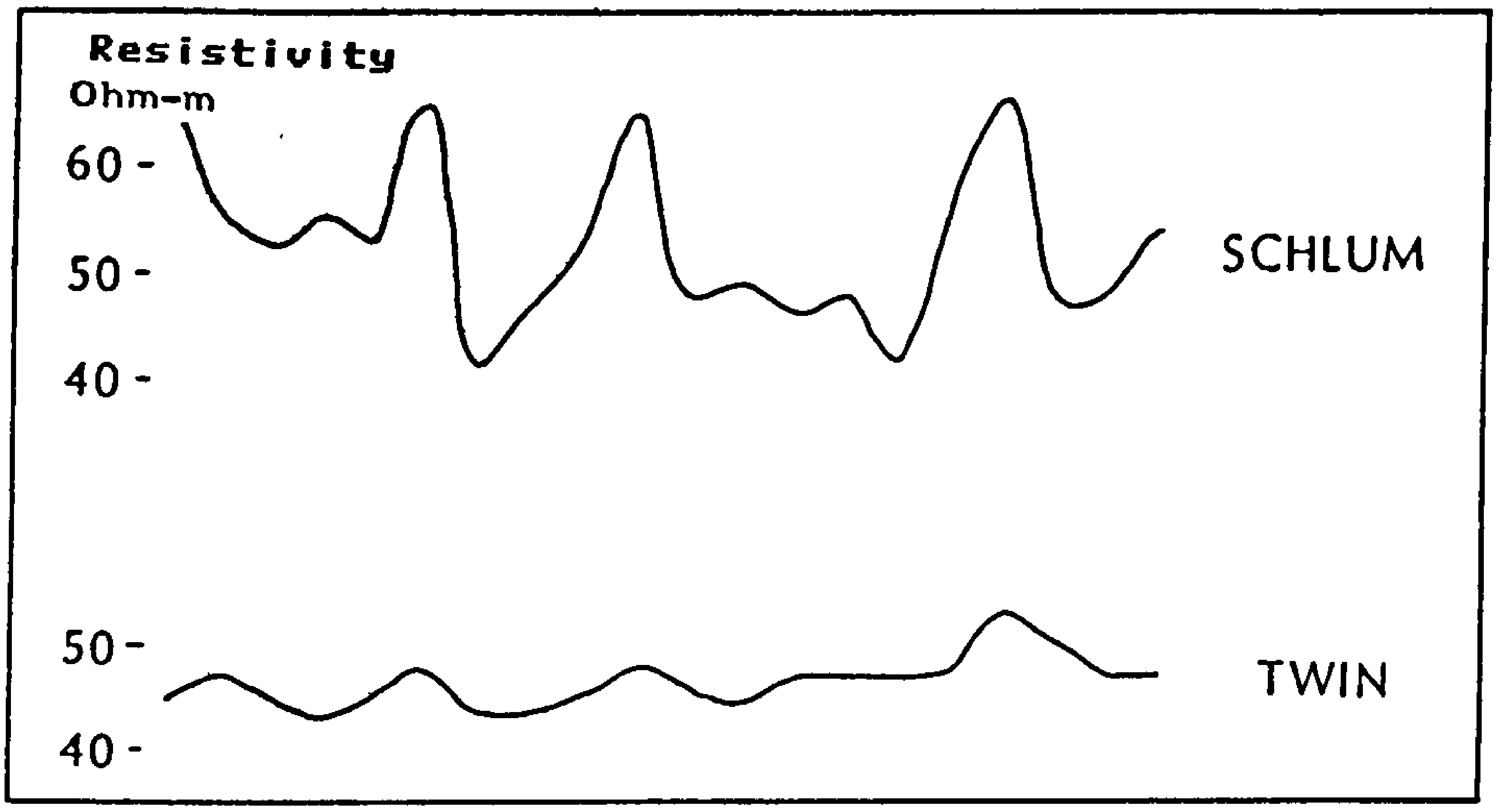


Figure 4.16. A comparison between the Schlumberger and the Twin-Probe surveys at Woolaston Grange.

form is similar, the changes in the Schlumberger response are much greater. In the latter case the presence of reverse peaks appear quite clearly. However, the form is still very similar to the Twin-Probe and , importantly, can be interpreted in a similar manner.

4.5 Brighouse, West Yorkshire.

The Schlumberger results from the surveys at All Hallows and Woolaston Grange had proved somewhat unexpected. The apparent polarisation of the array when traversing high resistance features required a large amount of experimental work to corroborate the initial surveys findings. Although a lot of this work could be done using the simulation tank, it was thought that the surveying of a single, long high resistance field anomaly would be advantageous. The author was notified of such a feature by Dr R. Walker who was using an old field boundary in Brighouse to conduct array tests. Initially the twin probe was set up and a central line was marked, with the centre point showing the greatest resistance over the boundary wall. The central line was at a right angle to the buried wall. The modern field showed two different resistance levels either side of the old boundary. As the difference was large, the position of the remote probes were then moved to the other field and the measurements repeated. A comparison of these two remote station positions are shown in Fig. 4.17.Clearly the agreement is very good, with both positions showing a difference in the resistance between fields of approximately 30 ohms. The major central feature is shown with a huge change of 88% over the background in the lower resistance field. The feature would appear to be at least 4m wide.

The central line was then resurveyed using the

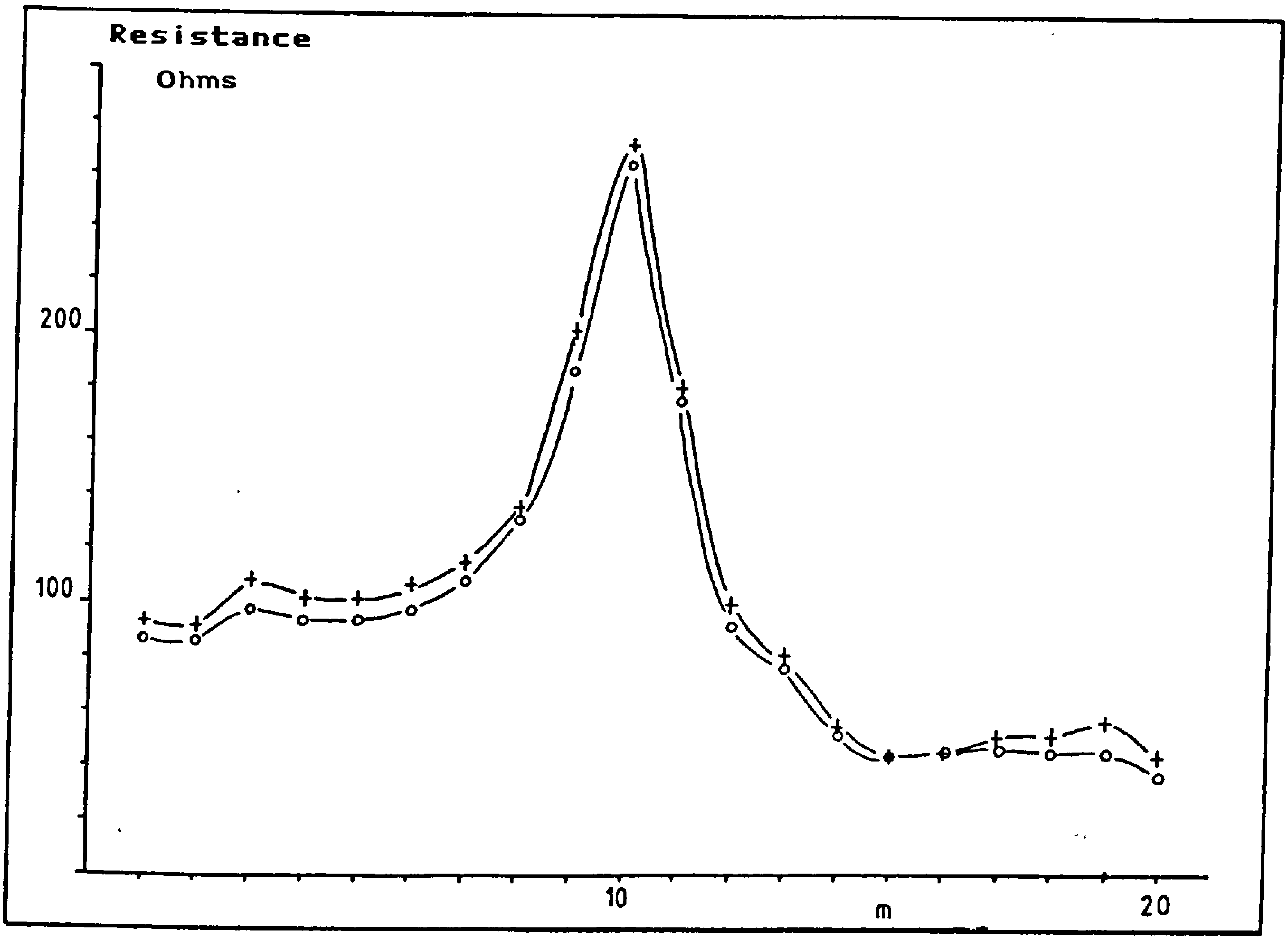


Figure 4.17. A comparison between two remote stations for the Twin-Probe at Brighouse.

Schlumberger array. The C-C distance was 30m and the P-P distance 0.5m. The strike angle to the wall was then varied as shown in Fig. 4.18. In the first, central position the main anomaly is very clearly seen, with a 90% change over the grass field with the lower resistivity (see Fig. 4.19). In that field the average resistivity measured using the Schlumberger array was 265.5 +/-14.5 ohm-m (+/-5.6%), as opposed to 125 +/-6.0 ohms (+/-4.8%) for the Twin-Probe. Therefore, in this case the level of the background noise is compatible. However, in the higher resistivity field another single peak was measured. Although this does not appear in the Twin-Probe record there is no reason to suspect that it could not represent an object buried at some considerable depth.

The results for the subsequent profiles gave us results that supported previous field work. Position 2 gave a massive 124% increase at the central point, position 3 110% and position 4 40% above the background of the same field. Statistics are somewhat less important here, than the form of response. Positions 2 and 3 show a peak movement away from the centre of the array. Also, once the angle has approached 45 degrees the percentage change is much reduced. Once the angle has reached 70 degrees the shape of response has changed totally. The single peak has split into two side peaks, both about 40% above the notional background. It was not possible to run the C-C line along the line of the boundary as there were trees regularly placed along it. In fact, the resistivity values for the two fields appear to have equalised. The evidence from the Brighouse experiment

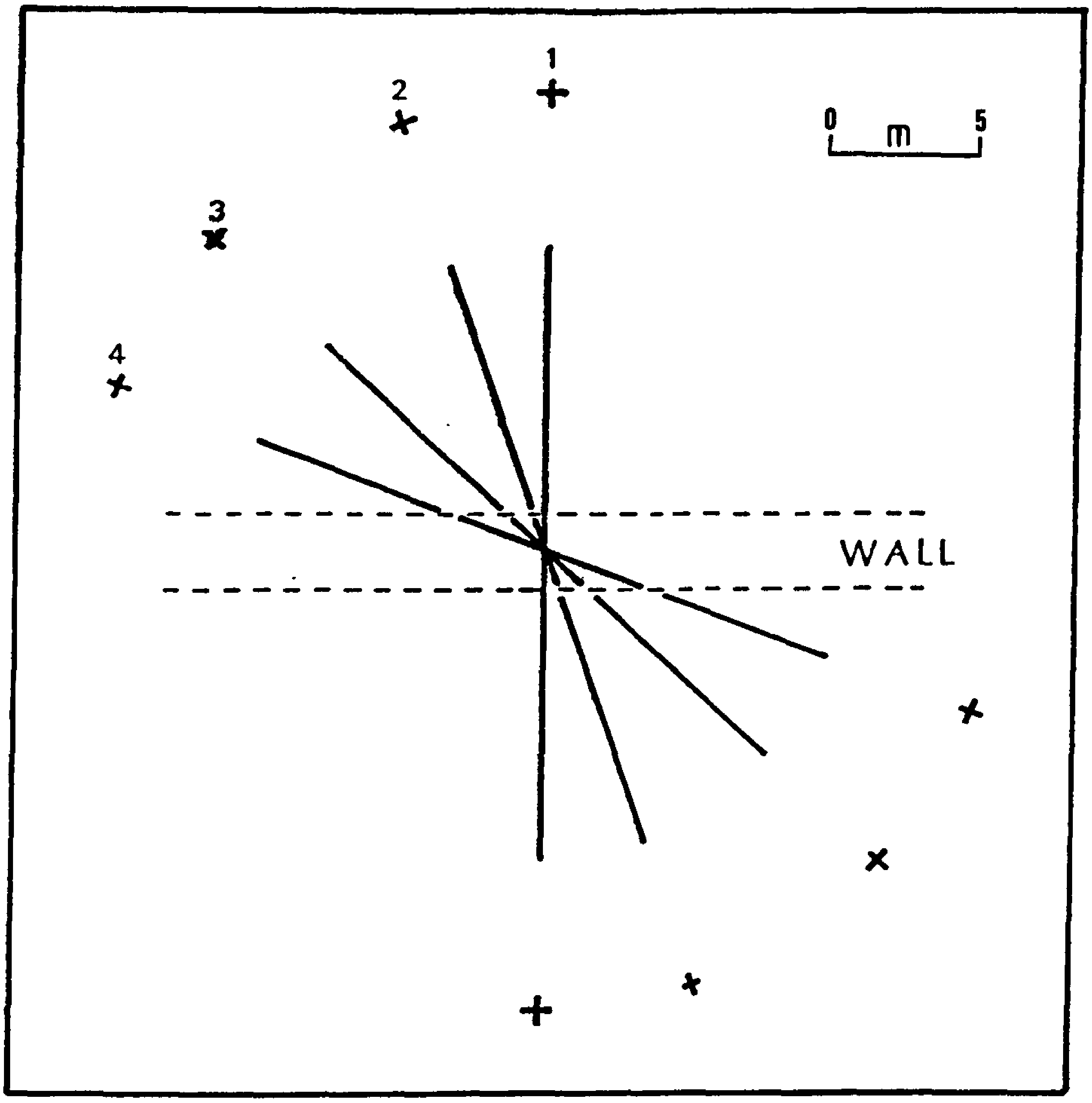


Figure 4.18. The variation in the strike angle of the Schlumberger array at Brighouse.

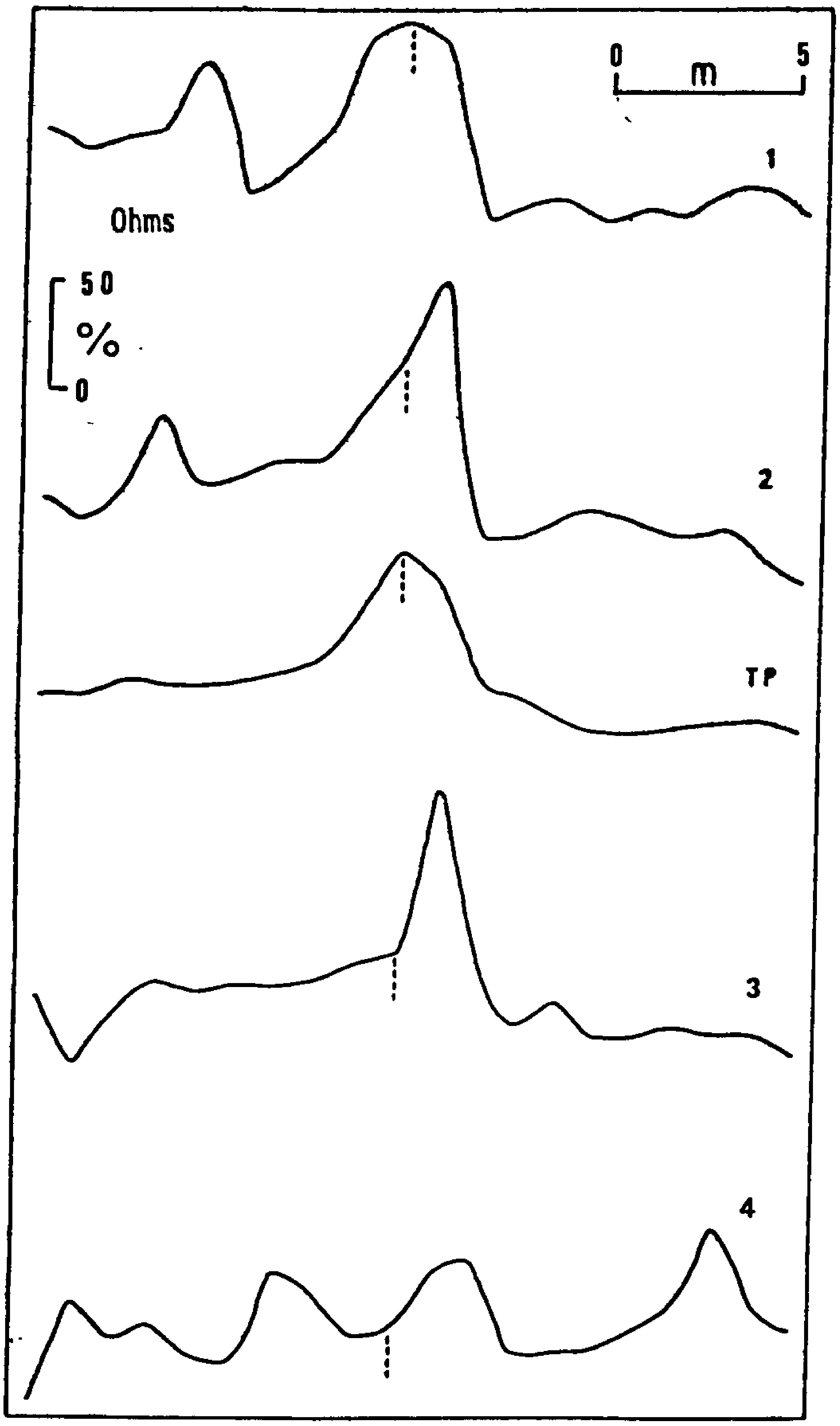


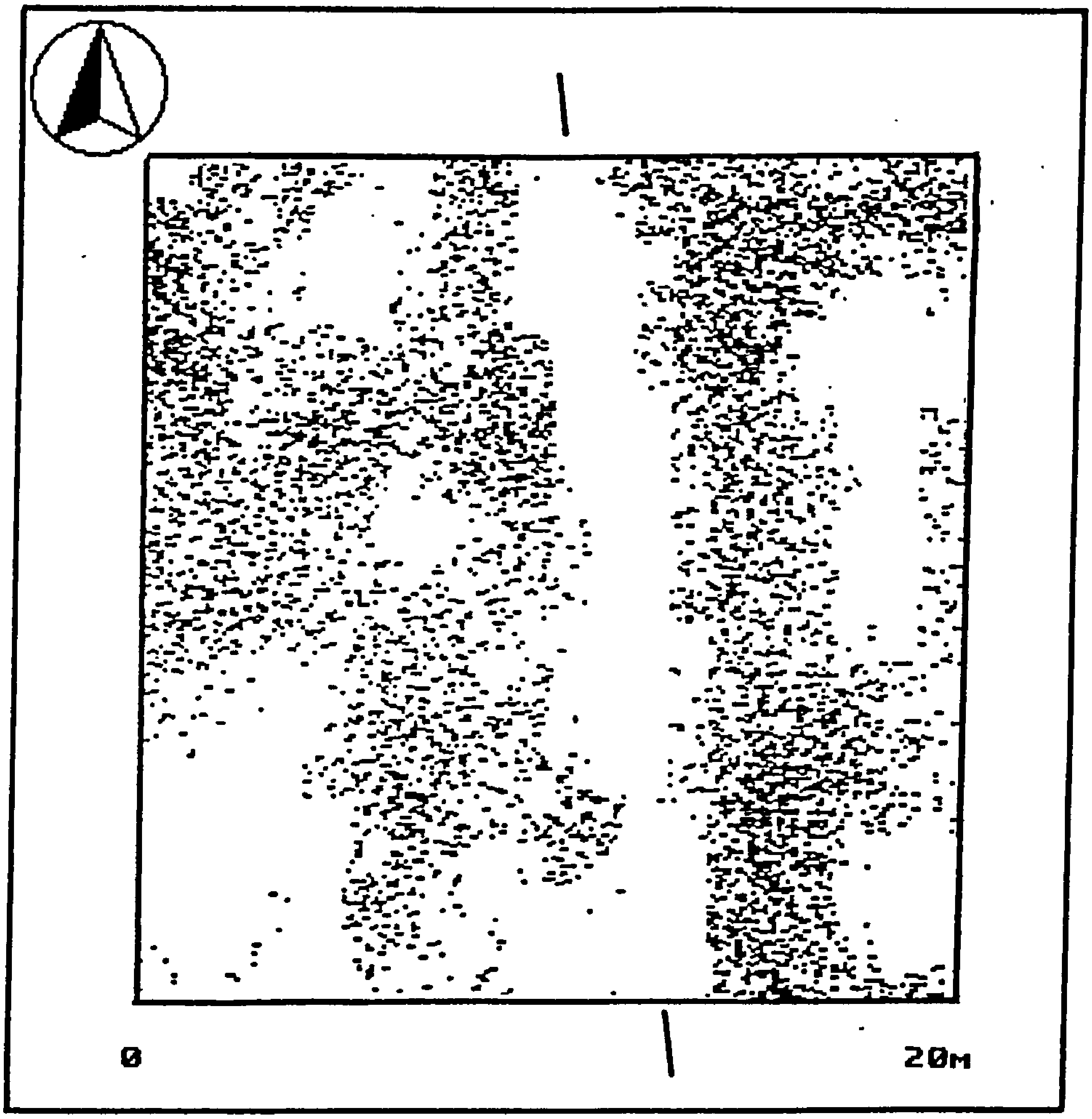
Figure 4.19. A comparison between the Twin-Probe (TP) and the Schlumberger array at Brighouse.

has conclusively shown that the results from the earlier surveys had some validity, and that any new survey in a totally unknown area would not be adequately investigated by readings from one C-C position. It is suggested that a minimum of two C-C positions are used, with central lines being placed at right angles.

4.6 Catstone Rings, West Yorkshire.

Due to the problem in simulating low resistance anomalies in the tank, it was felt that a similar experiment to that at Brighouse using a field feature exhibiting low resistance would be valuable. In an effort to investigate such a linear, low resistance feature, a 20x20m Twin Probe grid was placed over a supposed medieval ditch at Catstone Rings, West Yorkshire. The Twin Probe survey revealed a clear ditch and bank running approximately North-South (Fig. 4.20). Four linear traverses were positioned cutting across the 'ditch'. The first traverse was approximately at right-angles to the feature and was designated 0. The three other traverses were placed at angles of 30, 59, and 83 degrees respectively, and labelled accordingly. In Fig. 4.21 the relative position of these traverses can be seen. The crosses (+) represent the position of the current probes in each case (CC=30m).

For the straight through position, the Schlumberger response is seen to be very similar to the Twin Probe Fig. 4.22. The ditch covers positions 10-13 in both the Schlumberger and Twin Probe traverses. A gradual rise in the resistivity is seen to the west with both arrays, with the earthwork bank showing as a high resistance to the east. In Fig.s 4.23 and 4.24 we can see the broadening of the low resistance feature as the C-C line moves parallel to the feature. At no point does the feature become undefinable, as



Catstone Rings

Figure 4.20. Twin-Probe response. The line of the ditch is indicated.

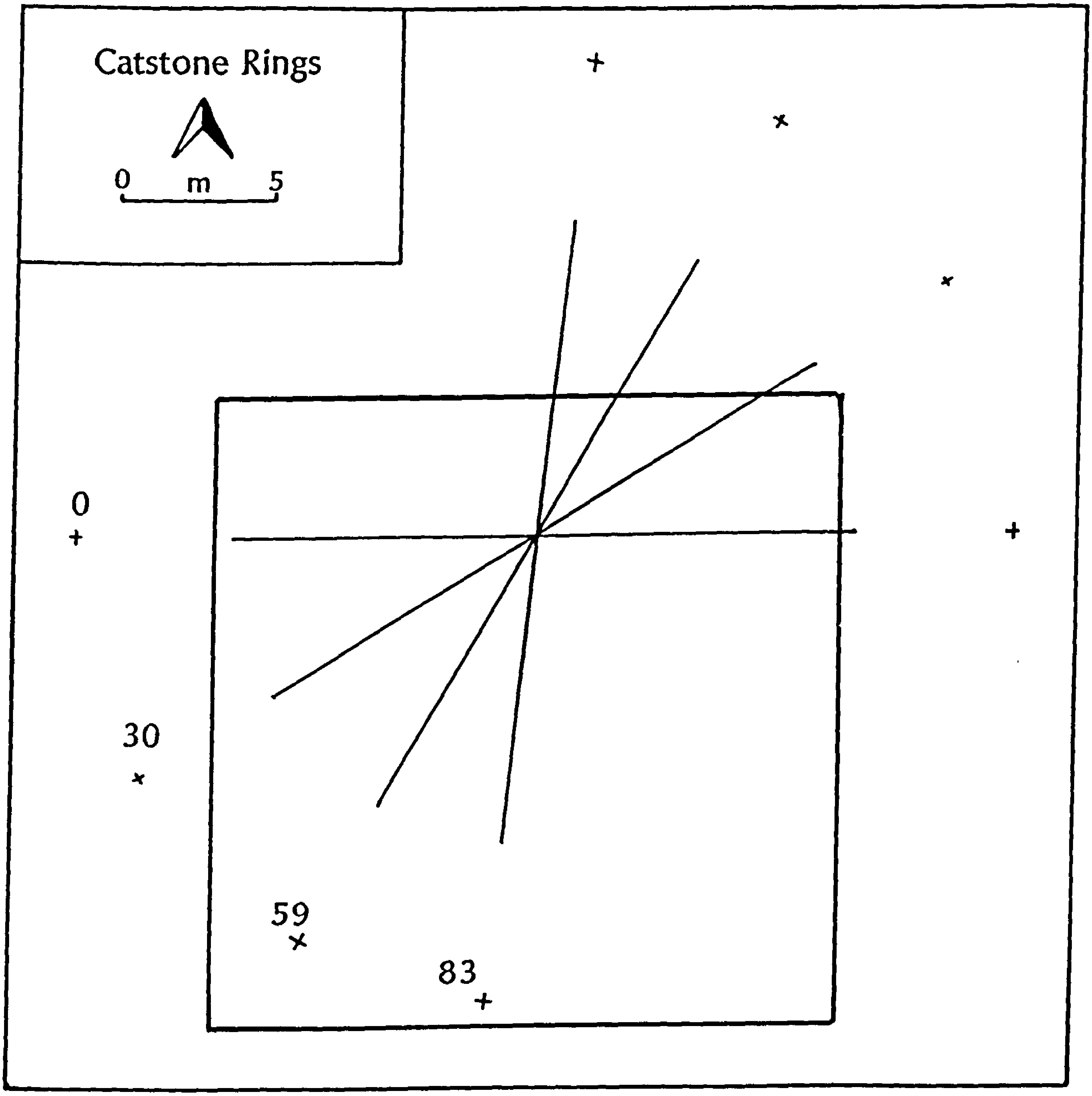


Figure 4.21. The position of the Schlumberger traverses at Catstone Rings.

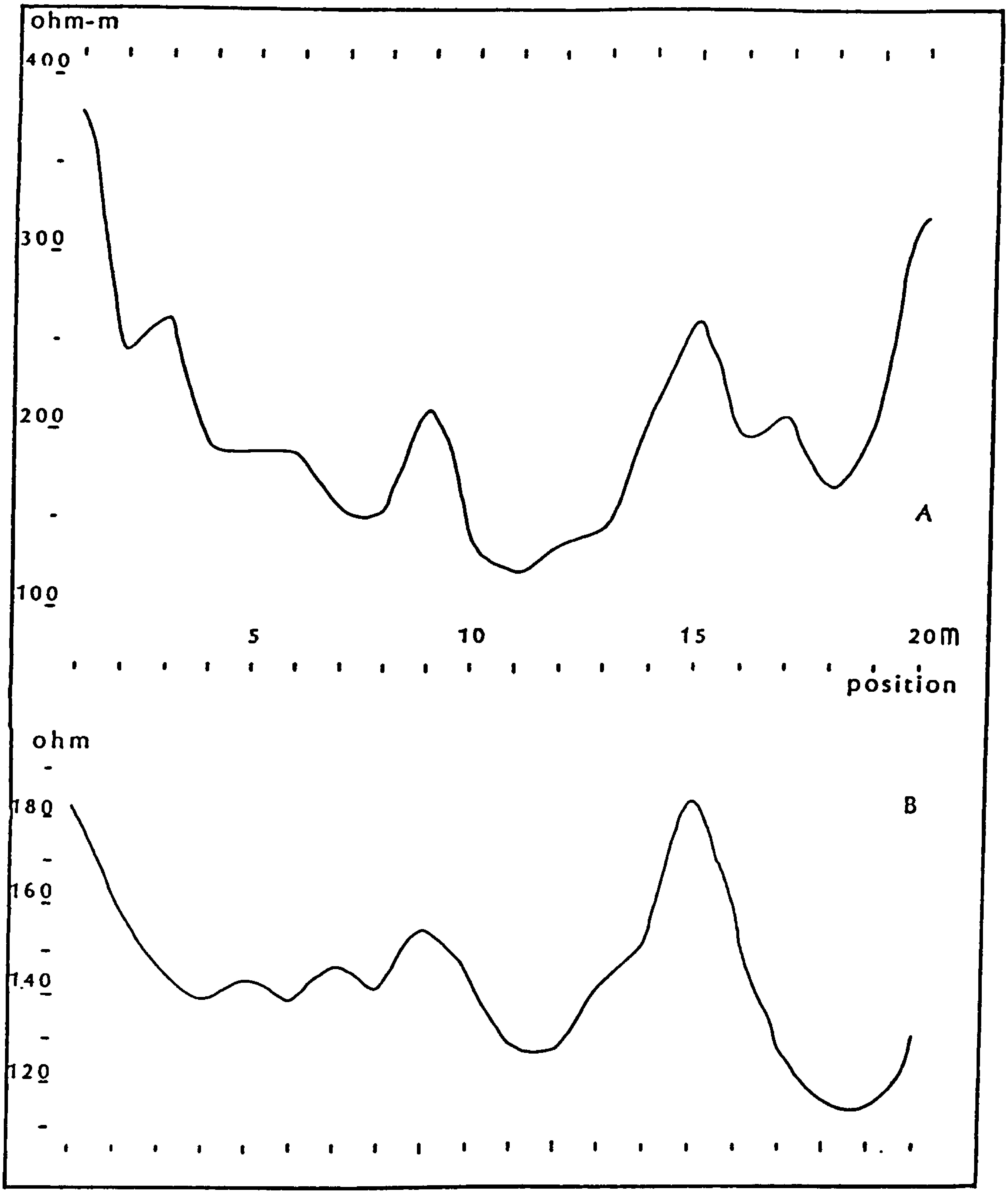


Figure 4.22. A. The 'Straight-through' (0) Schlumberger traverse at Catstone..

B. The Twin-Probe response at (0) at Catstone.

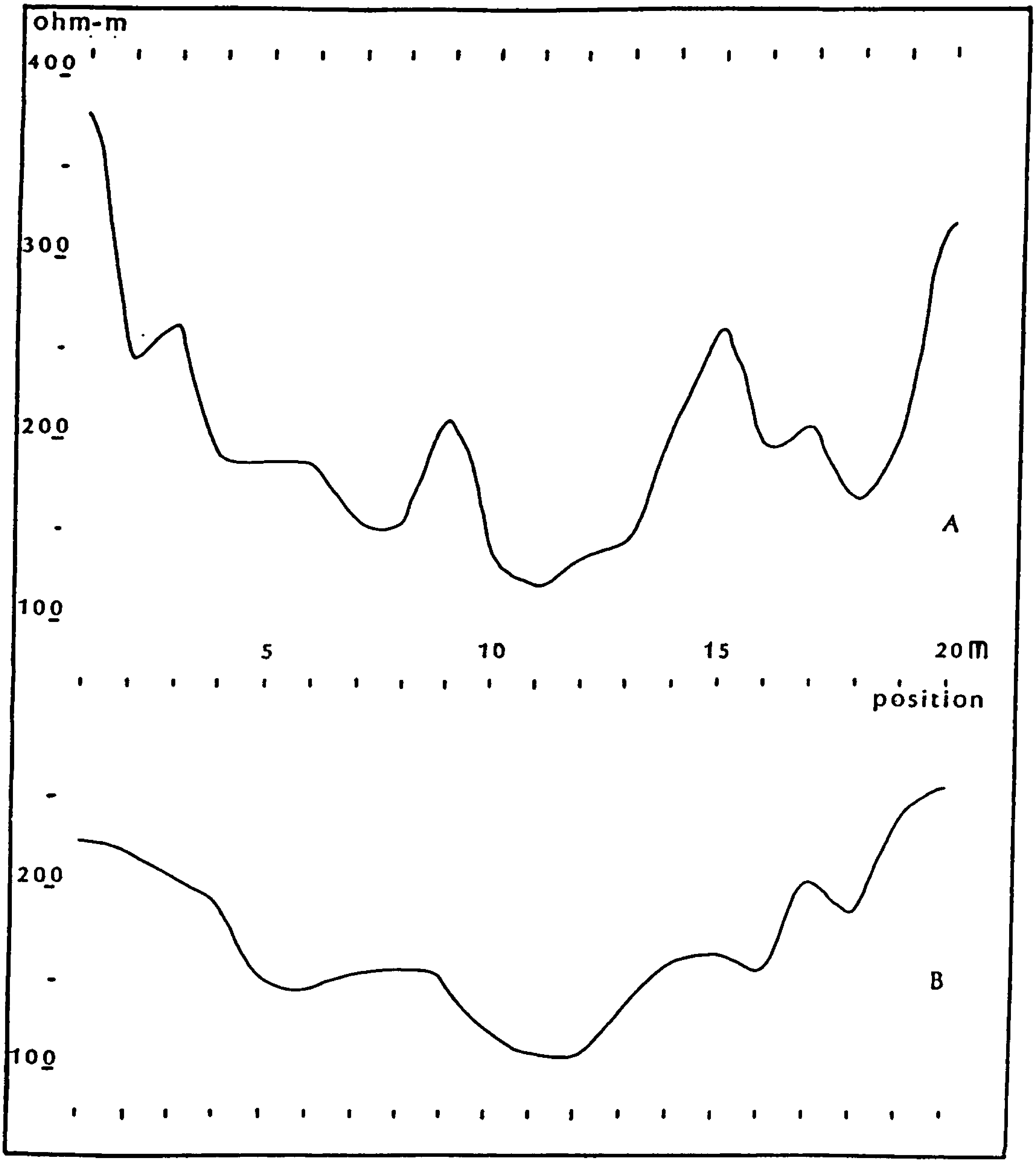


Figure 4.23. The Schlumberger response from Catstone:-
(A) at position (0)
(B) at position (30)

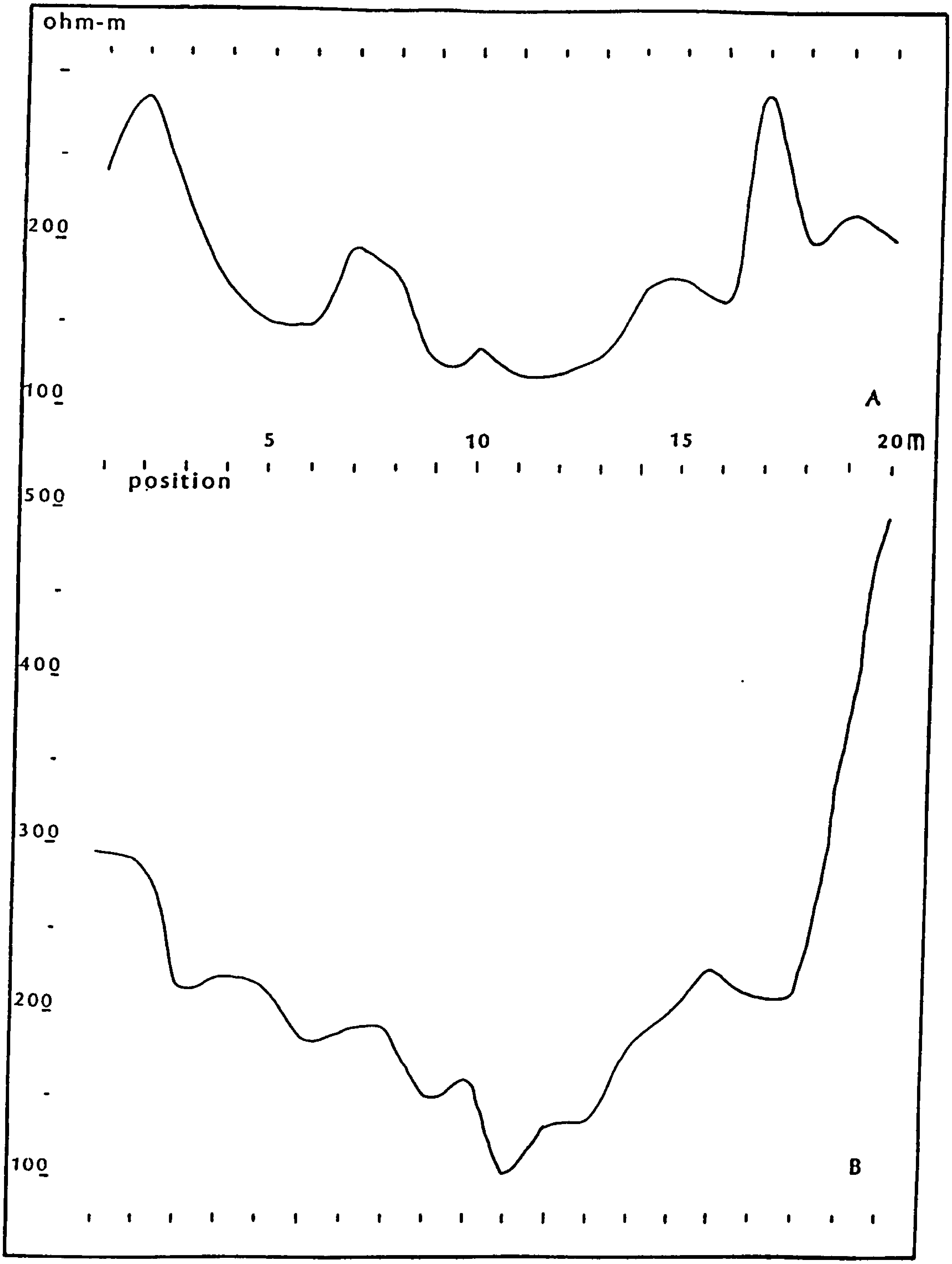


Figure 4.24. The Schlumberger response from Catstone:-
(A) at position (59)
(B) at position (83)

the similar high resistance features had at Brighouse. In comparing the Schlumberger traverses with the appropriate Twin Probe values the results are highly complementary (4.25). Although certain high resistance areas in the Schlumberger traverses are not parallelled exactly e.g. Fig. 4.23, B, position 2, the results do show a considerable degree of similarity. What again is of particular note is the change in the response for the associated high resistance bank. As the angle of strike increases the bank becomes less obvious. This experiment, whilst not surveying the ideal low resistance feature that was hoped for, gave important low resistance results and corroborated the earlier high resistance experiments.

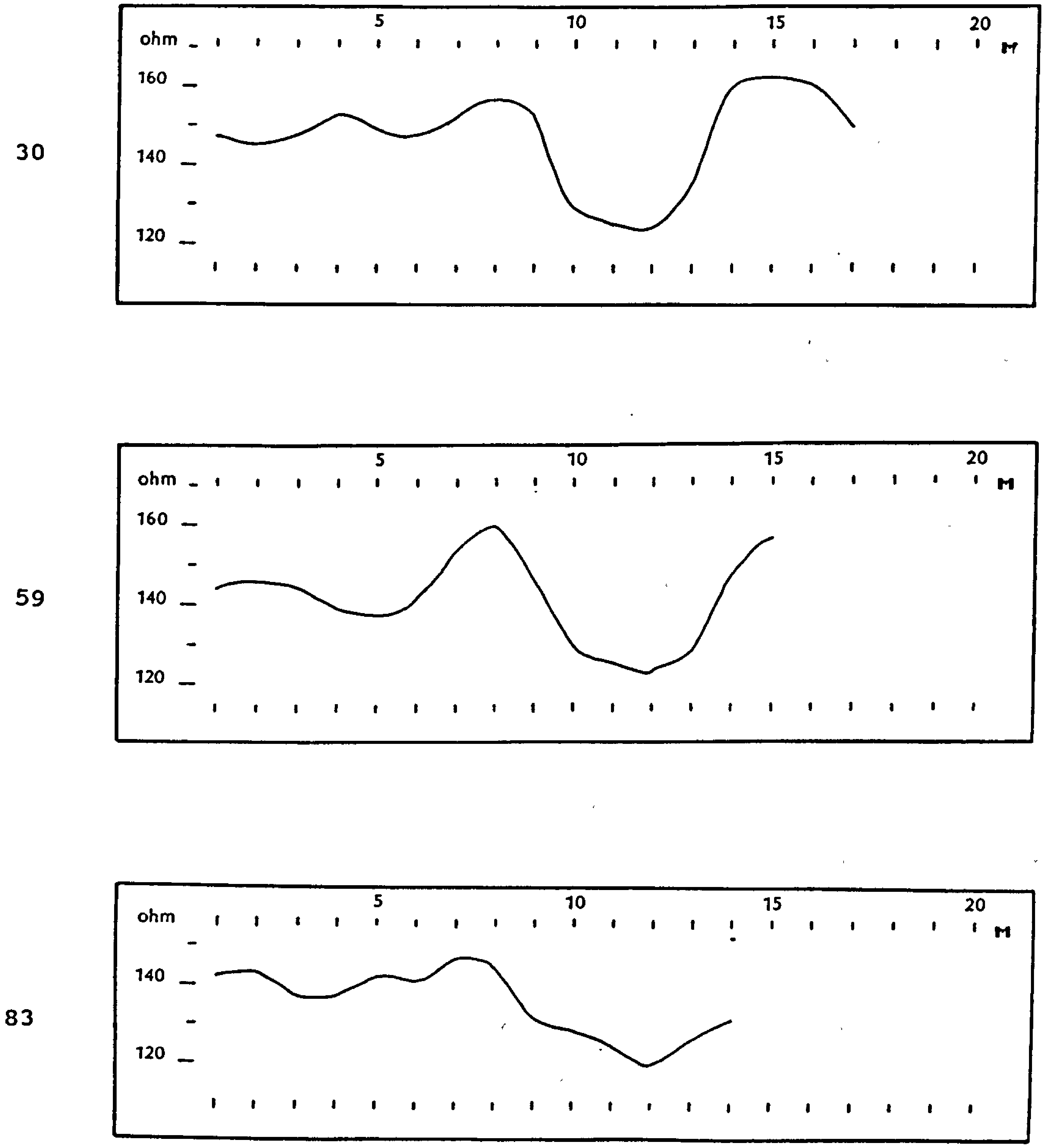


Figure 4.25 Twin-Probe traverses from Catstone Rings.

4.7 Thorpe Audlin, East Yorkshire.

A modest Twin-Probe survey was carried out over a Roman site at Thorpe Audlin near Pontefract. Of particular interest was the possibility that the site appeared to be surrounded by a ditch some ten metres wide. It was hoped that if any polarised character occurred with low resistance features then it may be more likely to see the effects on a ditch of this size. In Fig. 4.26 can be seen a Twin-Probe profile over the ditch, and into the interior of this site. As is expected, the results indicate a large drop in the resistance over the ditch, along with an increase in the resistance on a platform inside the ditch. Two Schlumberger lines were placed firstly at right angles to and secondly on the axis of the ditch. The right angled traverse appears to locate the low resistivity feature, but it is dwarfed by the high resistivity platform (Fig.4.27). The second traverse is completely within the wide ditch (Fig.4.28). The mean resistivity along its length is 65.5 +/-15 ohm-m (+/- 23%). In this case the response shows no unusual anomalies, although the variation is rather large.

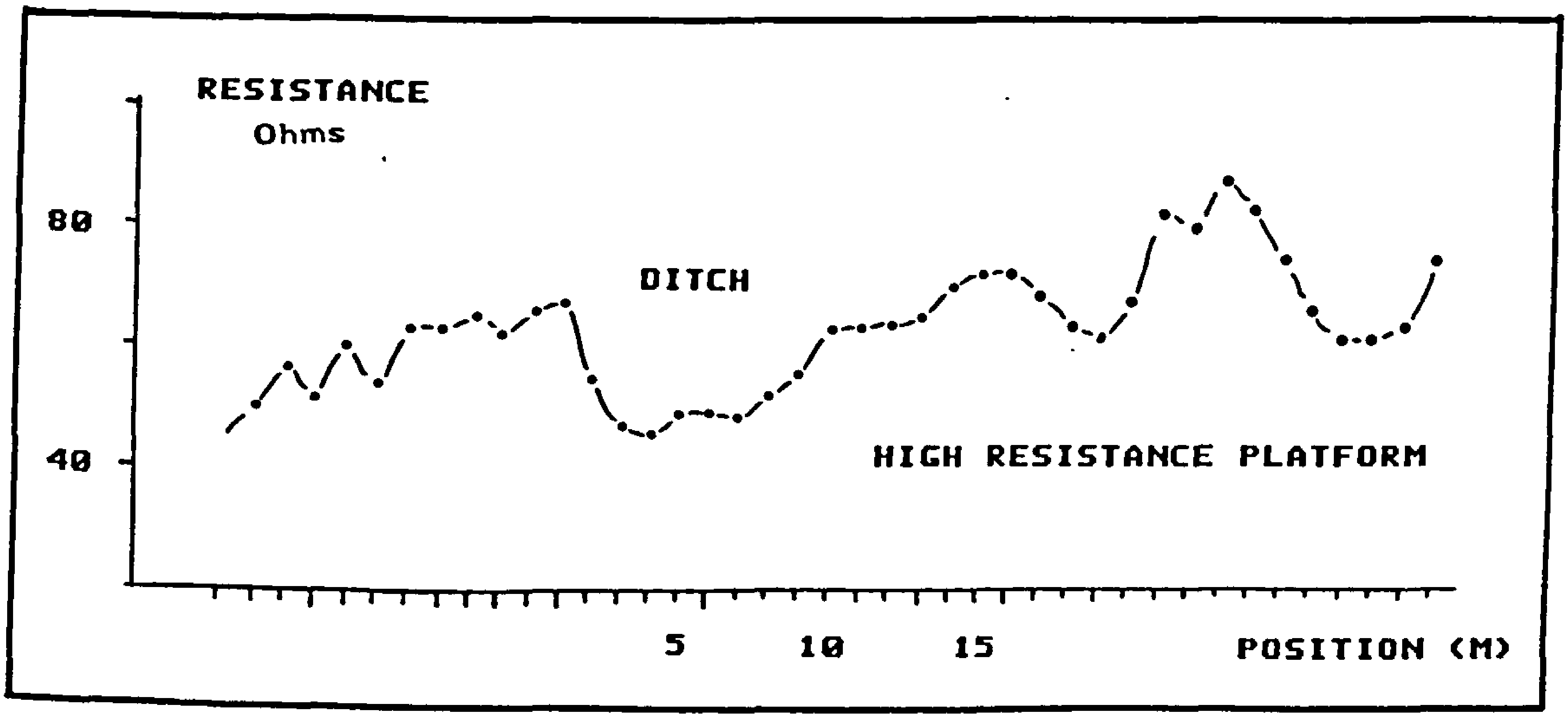
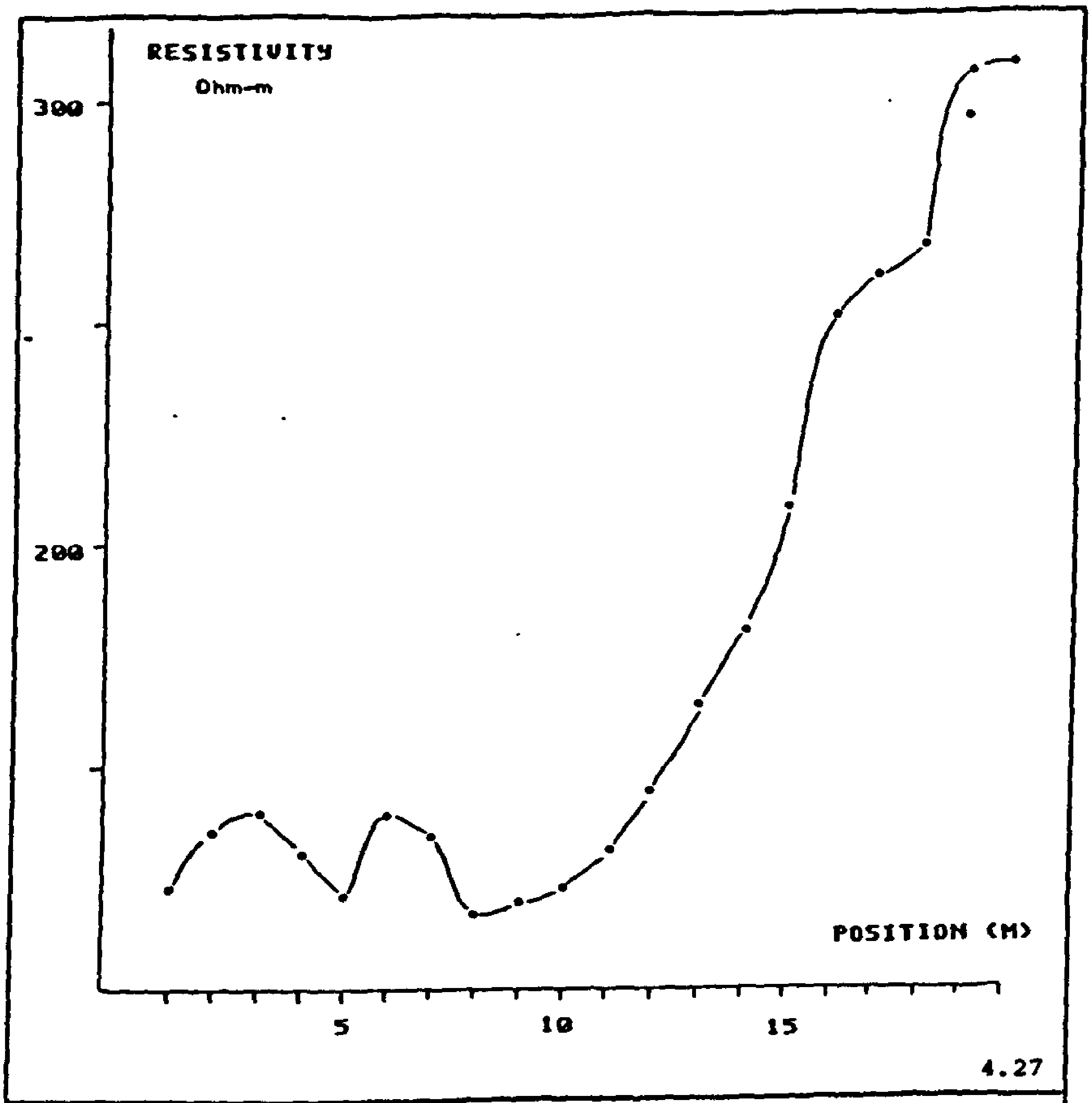


Figure 4.26. Twin-Probe response from Thorpe Audlin.



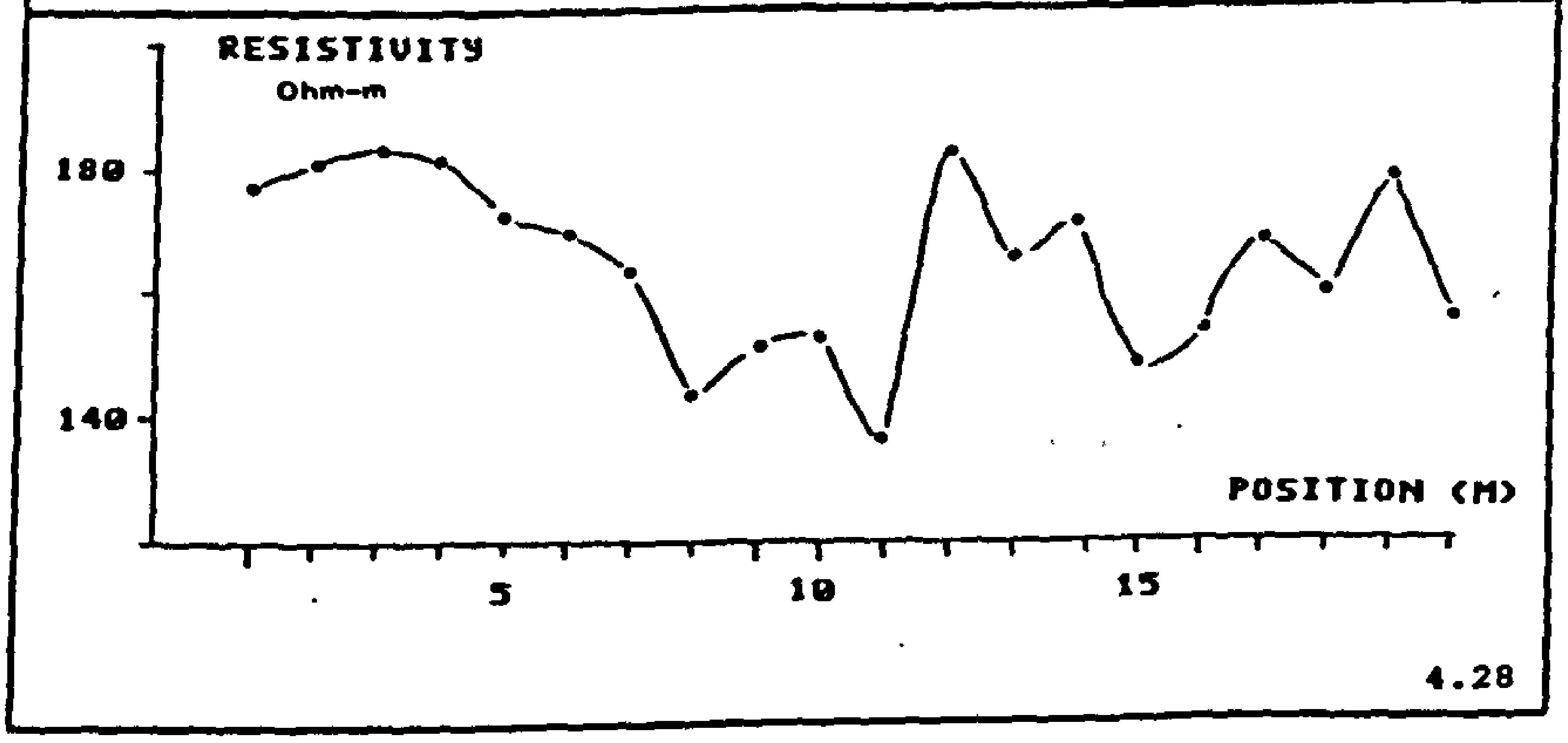


Figure 4.27. Schlumberger response with the C-C line at right angles to the ditch.

Figure 4.28. Schlumberger response with the C-C line on the line of the ditch.

4.8 A second suvey at the University of Bradford.

Although this survey was carried out at about the same time as the first survey at Bradford, it deserves a later mention because of the complexity of the response. Again, this survey took place on an area of demolished terrace buildings. The Twin-Probe survey of the 20x20m area clearly shows a number of high resistance features surrounded by low resistance areas (Fig.4.29a). For the Schlumberger survey the C-C line was again 30m long and the area was surveyed in both axial directions. Both of the individual grids contain useful information which when merged together gives important graphical information (see Fig.4.29b). One particularly important relationship is between the high and low resistance features. In Fig.4.30 can be seen a comparison for one particular traverse between the Twin, the combined Schlumberger and the two individual Schlumberger traverses. As has been seen in the earlier experiments, the combined Schlumberger response (B) is very similar to the Twin-Probe response (A). It appears to show the now characteristic changes over the high resistance feature, whilst retaining much of the clarity over the low resistance feature. The individual high resistance peak is shown to be in a slightly different place from the Twin-Probe peak. The evidence from the Brighouse experiment might lead us to conclude that this could be the result of the feature being at a strike angle of between, say 20 and 45 degrees. The individual traverses show

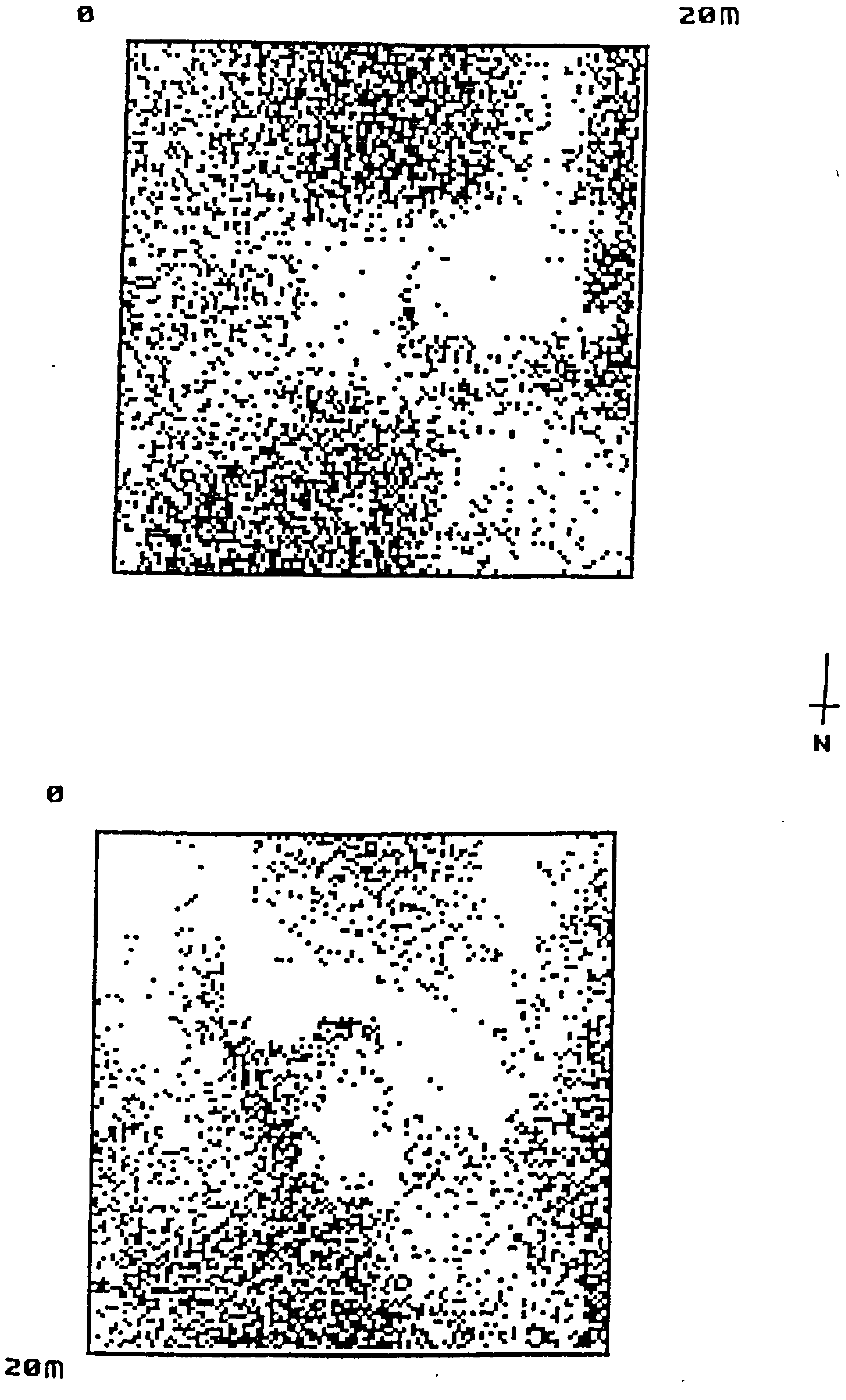


Figure 4.29. A second survey at the University of Bradford:-
(A) The Twin-Probe results
(B) The combined Schlumberger results

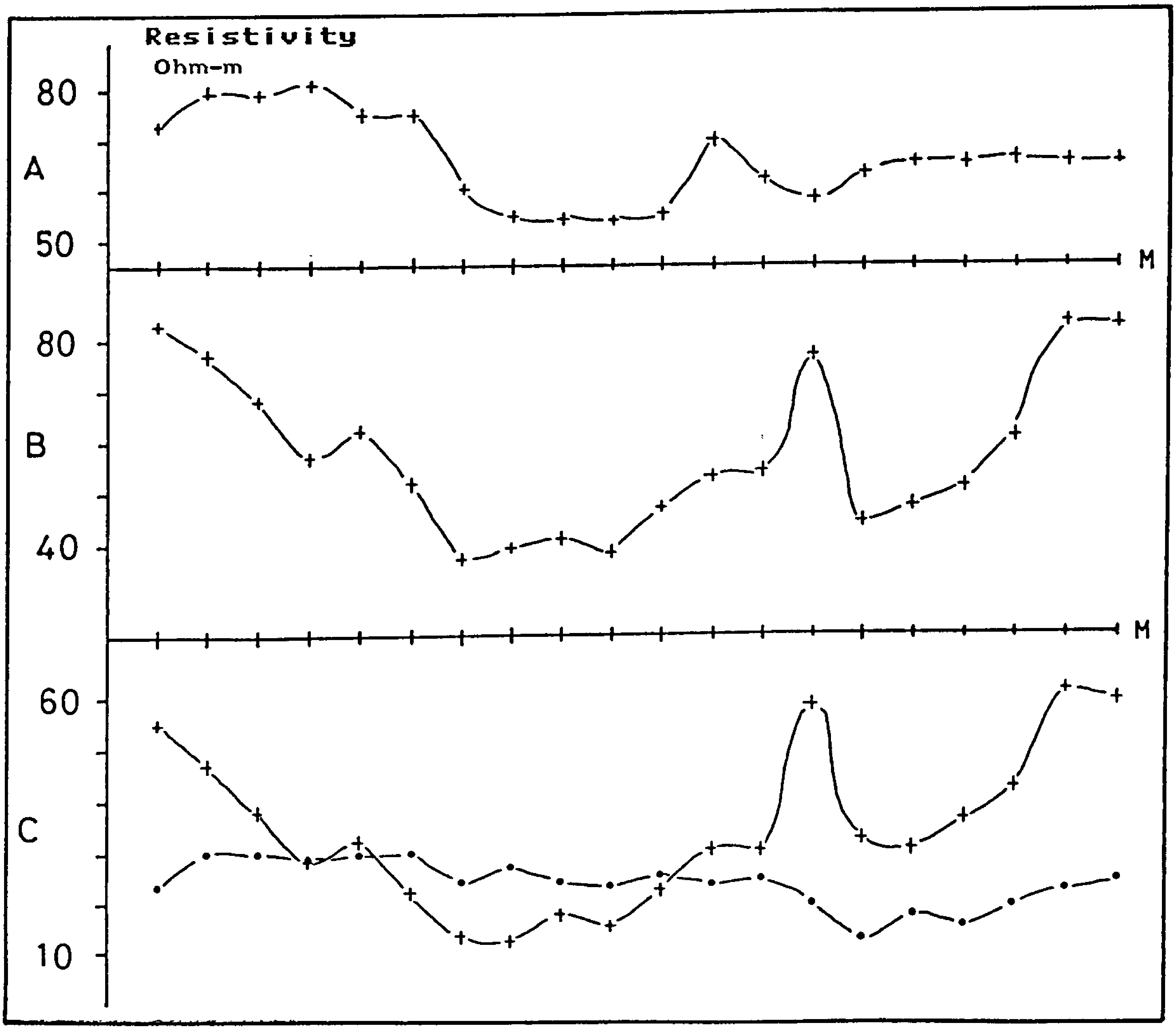


Figure 4.30. A second survey at the University of Bradford:-
(A) Twin-probe results
(B) Combined Schlumberger results
(C) Individual Schlumberger traverses

the high and low resistivity features well in only one direction.

Perhaps the best way of viewing this information is to contour the data sets. Fig.4.31 is another representation of the data in Fig.4.29, and it shows the major difference between the two surveys i.e. the clear right angle in the Schlumberger data. The contours for the individual data sets do show contrasting pictures, but some elements are present in both (Fig.4.32). In particular, both contributions appear to see a consistent depressed central area. Again, this would appear to be consistent with the preliminary findings for low resistivity features at Thorpe Audlin.

Figure 4.31. Contoured data from the University survey:-
(A) Twin-Probe results
(B) Combined Schlumberger results

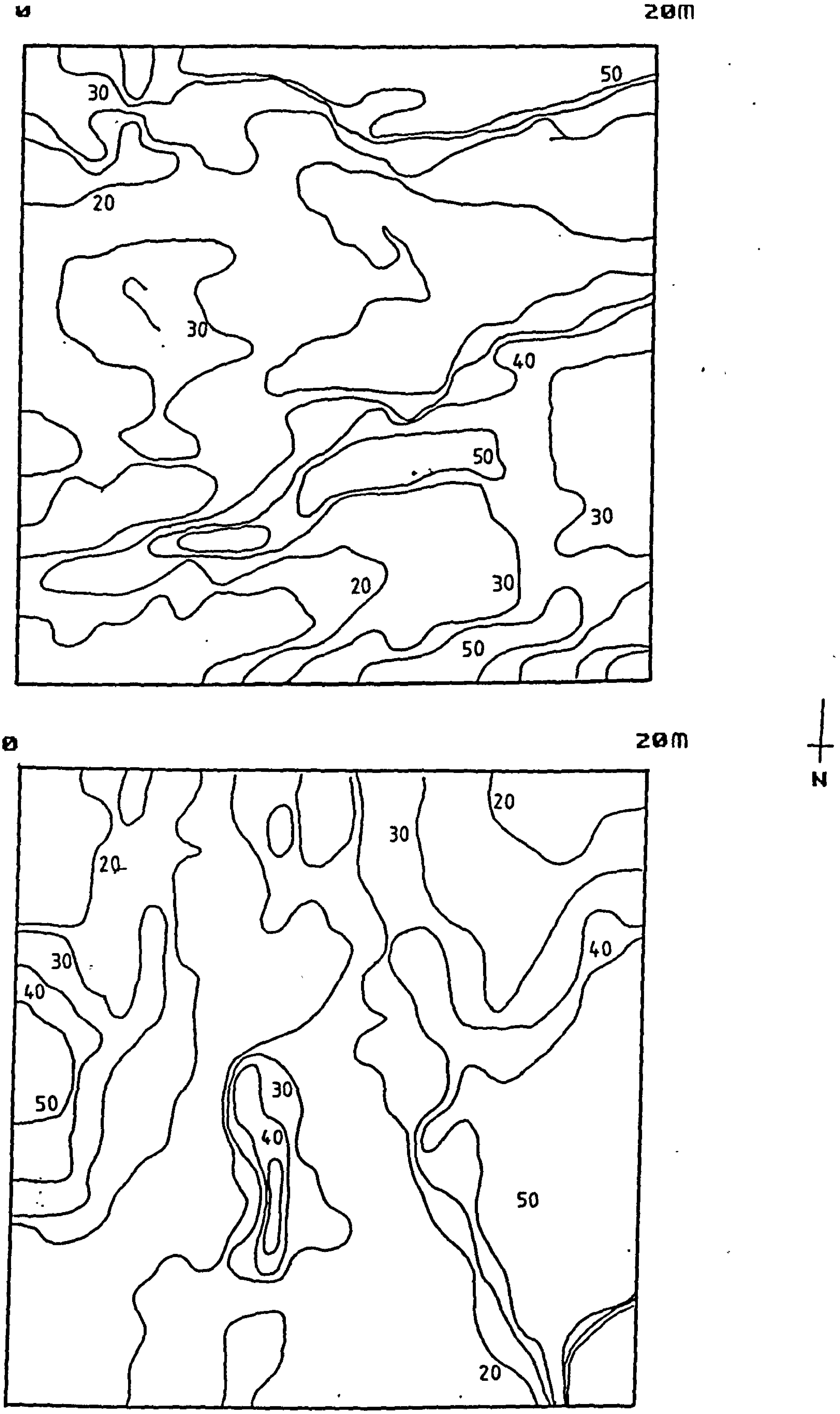


Figure 4.32 Contoured data from the University survey:-

Both Schlumberger data sets are shown.

4.9 Summary of the Field Data.

The data from the seven field trials provided a much needed empirical boost to the vital problem of anomaly interpretation. The major interpretational aspect has now apparently changed from anomaly position to array strike angle. The anomalous field patterns have not only opened up a new series of tank experiments, where the features may be set in an homogeneous medium, but have also validated the decision to change the tank to a fixed grid design. The flexibility of the anomaly position in the new system, and its close simulation of field method will be vital in assessing the spatial implications of the form of the response.

Clearly, lack of results from low resistance anomalies is very perplexing and requires further investigation. However, taken as a whole, the Schlumberger data has matched the Twin-Probe data sets. It is likely that the greater depth penetration and resolution of the Schlumberger array has aided the archaeological interpretation of the All Hallows Chapel i.e. that the increase in resistance measured using the Twin-Probe over the eastern cell is part of a broad trend, which is probably geological in origin.

Whilst it is important to reassess some aspects of the Schlumberger array in a simulation environment, in general the field responses have reiterated the conclusions drawn at the end of chapter two. That is, the Schlumberger response has proved to be both large and clear, at least in some instances. The field data have shown that it is possible to match grids, even when near surface features are present.

CHAPTER 5

FURTHER USE OF THE RIGID GRID IN TANK SIMULATION

More Schlumberger Responses to Buried Objects

5.1 Introduction.

The unexpected responses from the field tests detailed in Chapter 4 highlighted the problem of single transect simulation work. The field results proved that the variation of response encountered whilst using the Schlumberger array can be best investigated by using an off-set methodology and therefore cannot be efficiently investigated using only single traces. As outlined in section 3.5(2) a second series of tank experiments was performed using a rigid grid system.

5.2 The rigid grid system.

The rigid system was built after the initial results from the flexible system using a stationary object proved to be valid, but slow to obtain. The grid was designed on a unit of 12mm = 1m, with the C-C distance equal to 480 mm i.e. 40m. The perspex sheet was drilled with four sets of current probes, and a grid of potential probes with eight 'off-sets' from the central line (see Fig. 5.1). The probes were 6BA screws, and contact to the resistance meter was made via

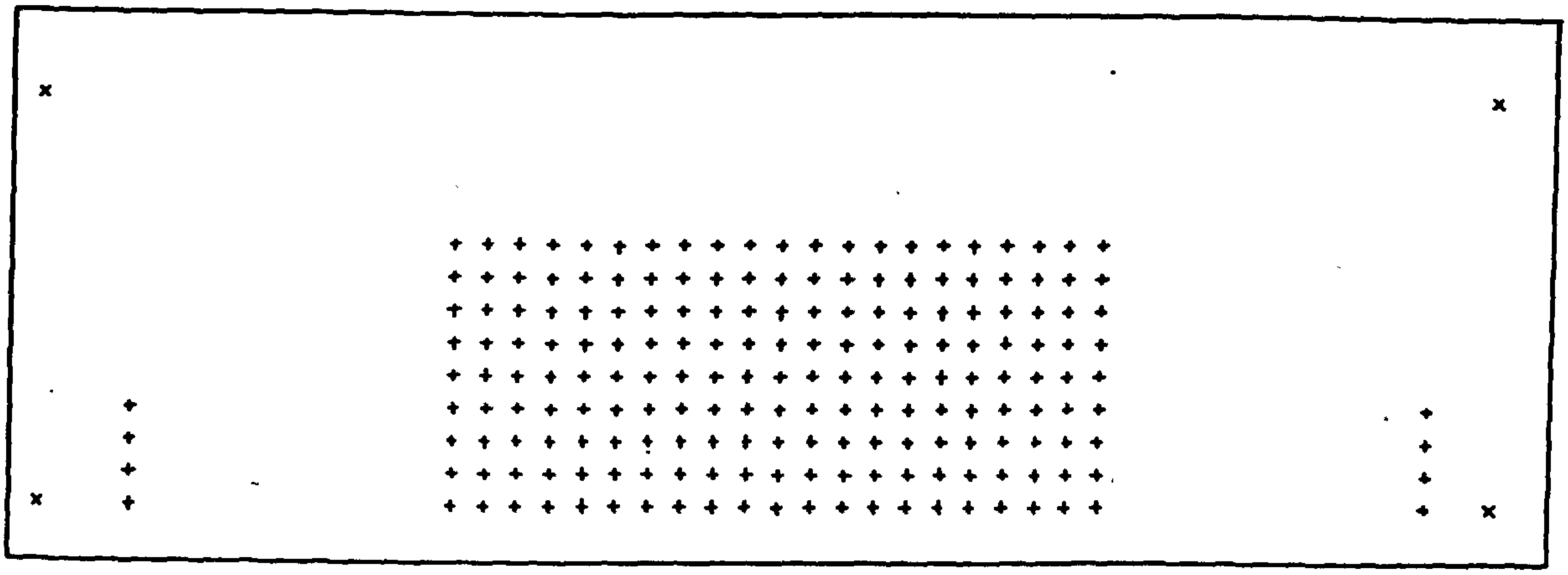


Figure 5.1 Plan view of rigid grid for Schlumberger measurements. The system consists of 4 sets of C-C positions, and 9 lines of P-P readings.

small crocodile clips. The perspex plate was lowered and levelled using corner positioned levelling screws (Fig. 5.2). The anomalies were kept in place using a perspex support that was measured as part of the background. The perspex support was placed on the bottom of the perspex trolley that was originally designed to act as part of an X-Y recording system. The support was not fixed in position, allowing the strike-angle of the straight-through C-C line to be varied.

5.3 The 'Off-Set' Methodology

One of the major aims of the research was to find some way of speeding up the collection of Schlumberger data. The suggested major improvement over past archaeological Schlumberger work was that as the potential gradient can be corrected for off-set values from the straight through line, then a whole grid of readings may be taken without moving the current probes. Further investigation into this suggestion has revealed similar methodologies in the geological literature (e.g Kearey and Brooks, Bertin 1976). Although, due to current considerations, most of the geological methodologies involved a rectangular grid, it was decided, if possible, to work within a square grid to fit in with existing software and procedures. Theoretical arguments outlined in section 2.5 suggested that a square collection area was valid.

Iliceto (1971) has reported that an area may be surveyed by the setting out of parallel rows of current probes, and

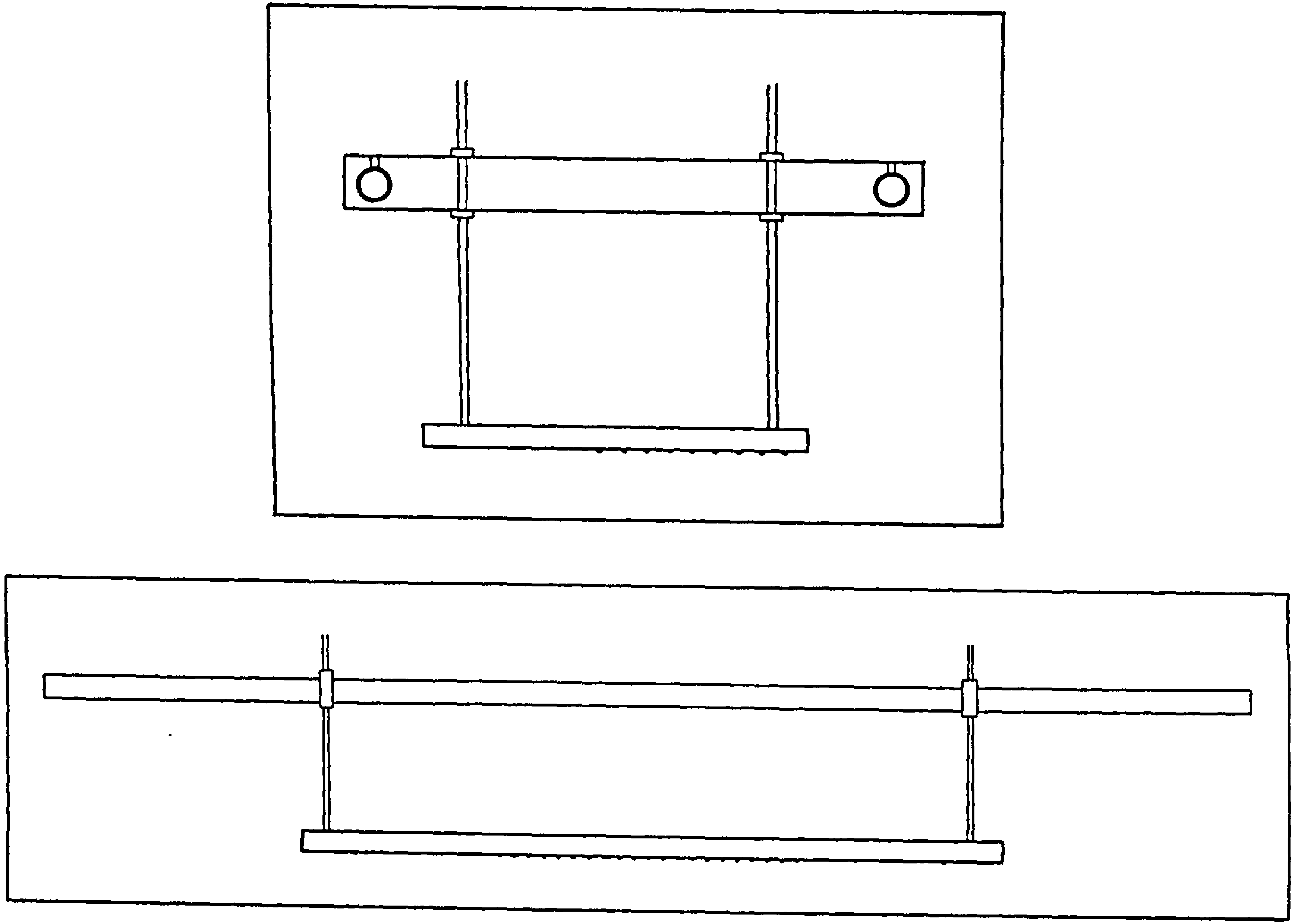


Figure 5.2 Sections of rigid grid systems.

applying a constant current. Using this technique, the only correction required is along the current axis, as theoretically the electric field is homogeneous between the two sets of current electrodes. Although there are some problems concerning the stability of a direct current source, the methodology is adopted from the classic geological Schlumberger tradition. The apparently asymmetric responses reported by Iliceto, confirmed by reference to earlier work by Parasnis, is regarded as an important interpretational problem for the Schlumberger. Another issue highlighted by Iliceto is the side reverse peaks which may also potentially confuse the interpretation of a complex archaeological situation. It was these theoretical and practical problems that this second suite of experiments was intended to investigate.

The mean and standard deviation of the host medium, measured with the new rig, were not as good as the flexible system. This was due to slight variation in inter-probe distances caused by inaccuracies whilst drilling the perspex. This resulted in a decision to 'normalise' all of the simulation data. The procedure followed in all the following experiments was to take a set of readings with the object in place and then remeasure the resistance without the object present. The percentage change due to the object was then evaluated.

5.4 High Resistance Objects

1. Central line experiments.

The central line experiments in section 3.8(b) were repeated for two other anomaly shapes and sizes to re-establish the basic anomaly response. It was this response that was now under question after the field tests reported in Chapter 4. In these experiments the anomaly position was kept constant and the potential probes were moved across the grid of probes. This was done first of all with a large high resistance cylinder and secondly with a polystyrene sphere. The former was measured with a rod of 51mm diameter perspex. The results are summarised in Fig.5.3. Clearly, the object is very well discriminated against the background. The average percentage change due to the object is 105% (+/- 4.9%), whilst the Peak:Reverse Peak remained a constant 5.7 +/- .3 (5.1%). This would again clearly demonstrate the constant response of an object positioned at different points across the central line.

In an effort to reduce the Schlumberger response for a given object to its most basic form, it was decided to repeat the experiment with an insulating sphere. This was achieved using a polystyrene sphere of 25mm diameter. This is the most simple shaped object to simulate with, and with the C-C line

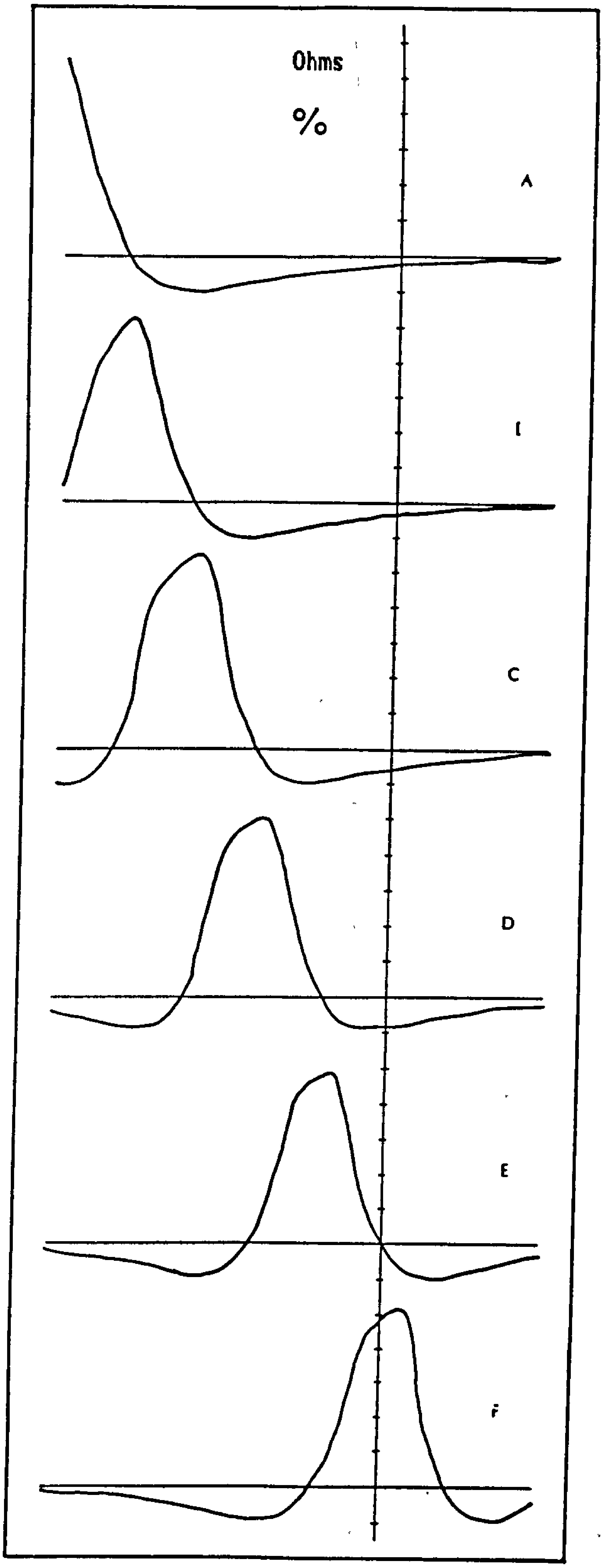


Figure 5.3 The response from a 51mm diameter perspex rod at 6 positions along the C-C line. The gradations are 20% increments. Position A is at the edge of the grid, and position F is at the centre.

positioned directly over the centre of the sphere, then the Bipolar Model is valid Lynam (1970). The results should be directly compatible with previously computed Schlumberger forms (e.g. Houlder 1983), as well as the previous experimental data from section 3.8(b). Again, the results are summarised in Fig.s 5.4 and 5.5. As the object was repositioned at various places along the straight through line, the average change for the central peak was 21.6+/-2.3 (10.6%), whilst the Peak:Reverse Peak ratio was 7.6+/- 1.6 (20.9%). These should be compared with Houlder's theoretical value of 4.5:1. These statistics are highly illuminating to the nature of Schlumberger survey. By comparison with the previous experiment, the object size had decreased, whilst the error associated with the Peak:Reverse Peak ratio and the central peak had both greatly increased. As the errors associated with each individual probe-pair are normally very low, see (Fig. 5.6), then the variation must be due to the positioning of the object. Indeed, a lateral shift could explain the low ratio obtained in section 3.8(b) i.e. the sphere may have been positioned slightly away from the maximum positive response. In such a case a small change in the position of the object with respect to the potential probes could prove vital in a field situation. However, the field target is most likely to be far from spherical in shape. However, the individual curves 1-9 show an interesting shape factor. The resistivity is clearly distorted in the area between the object and probe C2. However, the maximum deviation is only 2% above background. This is not as great

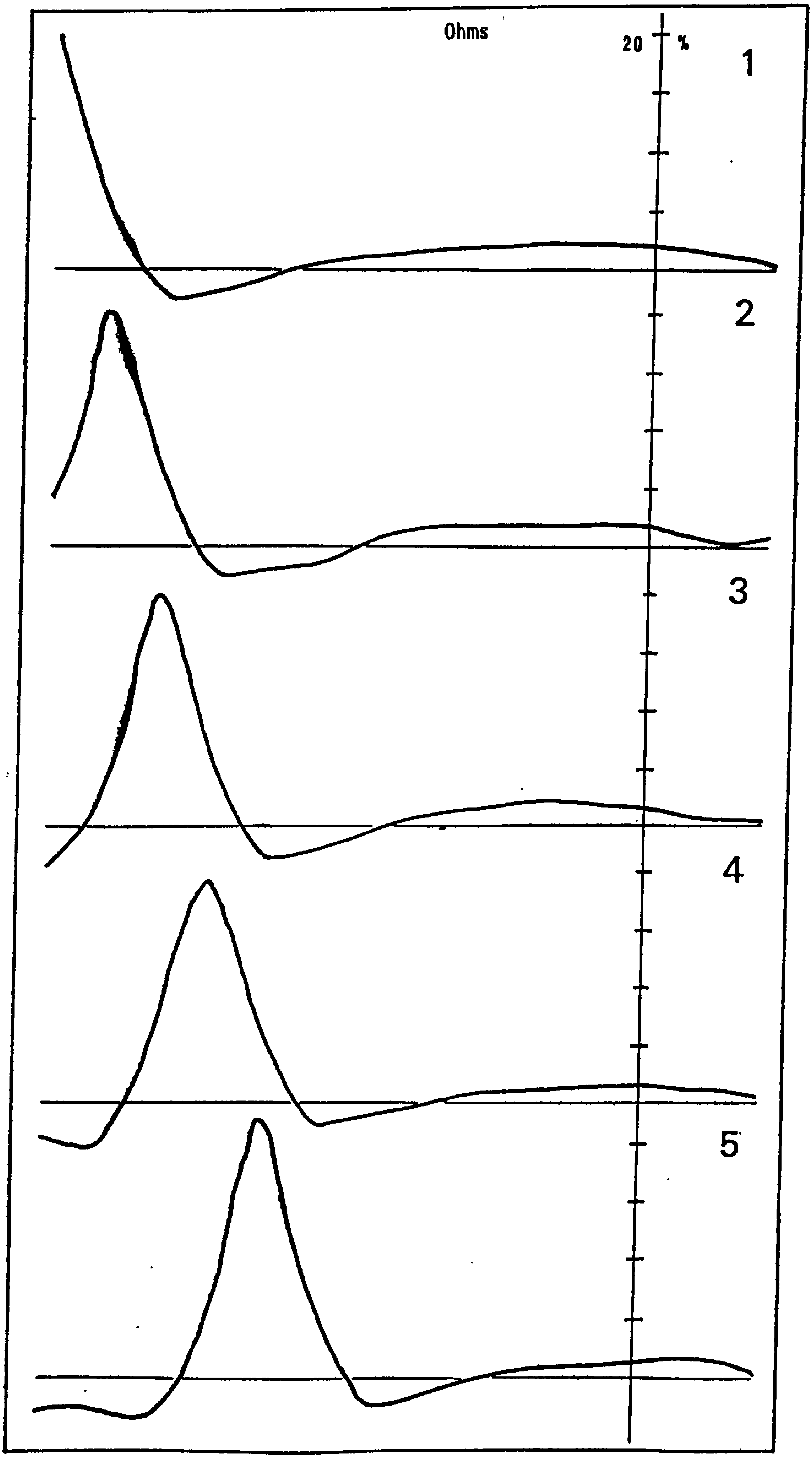


Figure 5.4 The response from a sphere at constant depth. Numbers indicate probe pairs. Position 1 is at the edge of the grid.

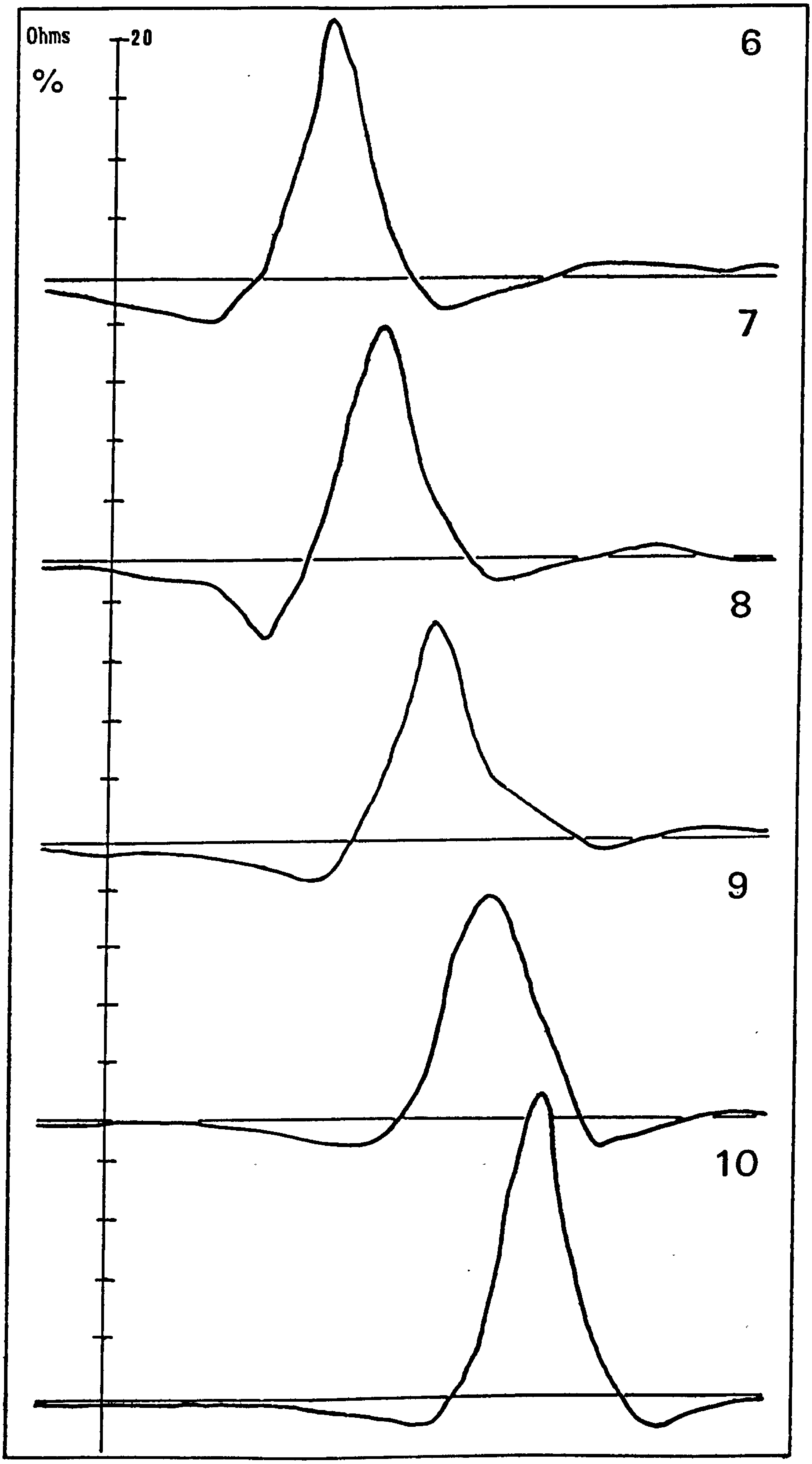


Figure 5.5 Continuation of Fig.5.4. Position 10 is at the centre of the array.

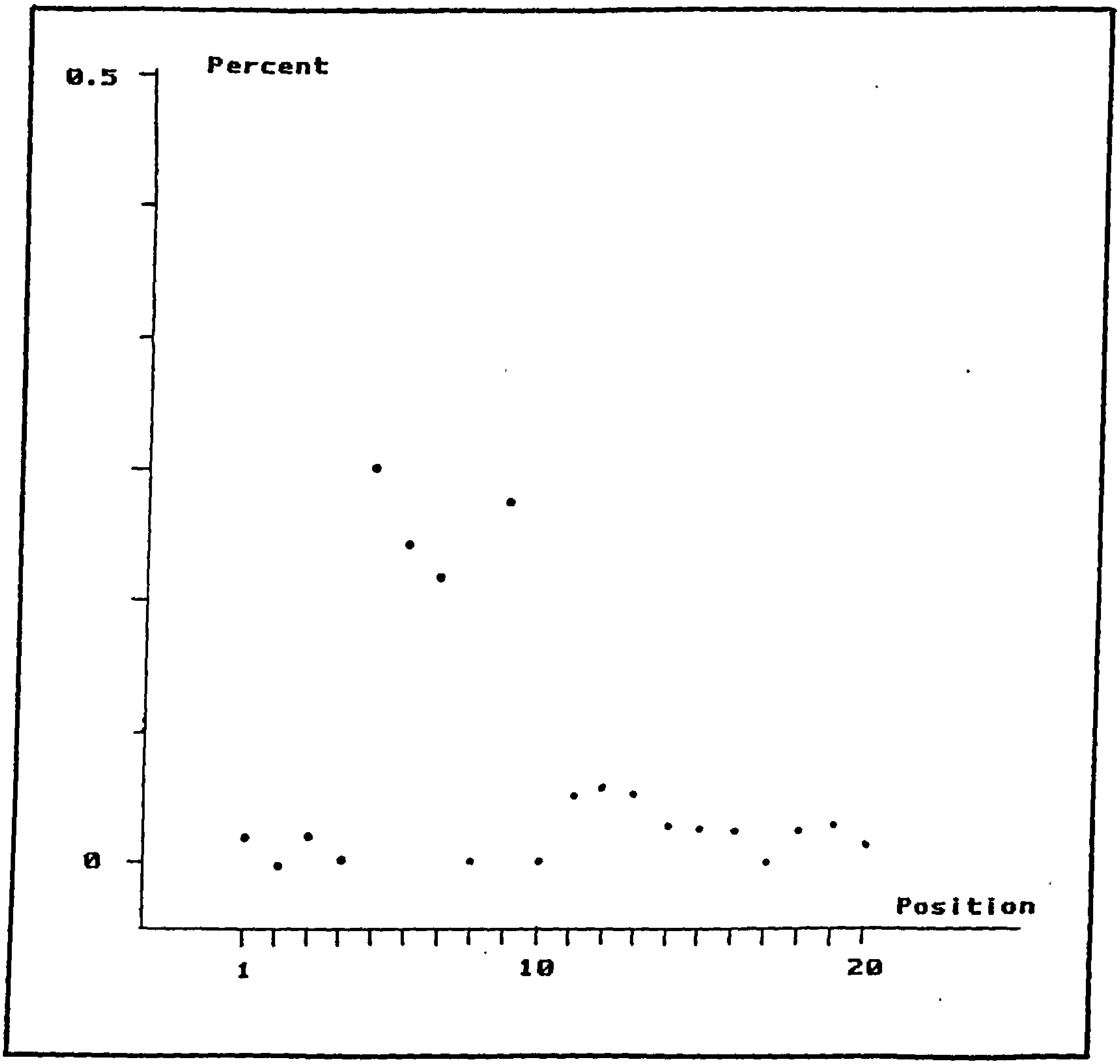


Figure 5.6 Typical errors associated with each probe pair.

as the distortion measured at the edge of the grid, when the sphere was placed under the C1 probe(5%) - see Fig.5.7. Although this is supporting the work of Parasnis, at least in the form of shape, the amount of distortion is minor. However, another important aspect that this experiment sheds some light on is that of matching grids. As an object under the current probe C1 would increase the background at the edge of the grid by 5%, and the object at the centre of the grid would have no affect on the edge of the grid, then this supports the possibility that large objects may cause matching problems. However, in field terms the change of 5% is very small and probably would be within the background noise.

A second series of experiments were performed using a second polystyrene sphere of the same size. This time the object was situated in two places on the central line and the depth to the object was varied. This was to see how, if at all, the depth aspect varied the response to an object depending on position on the grid. The sphere was positioned under probe pair 3 and 10. A summary of the results may be seen in Fig. 5.8. The similarities between the two sets of profiles are notable. Certainly, for a feature of similar dimensions to this sphere there would be no significant change in response depending on depth or position. There is no reason to suggest that the form of response should be any different when the depth to the object is varied.

In terms of the overall response to depth, the 40:1 ratio Schlumberger performs well when the target is within the

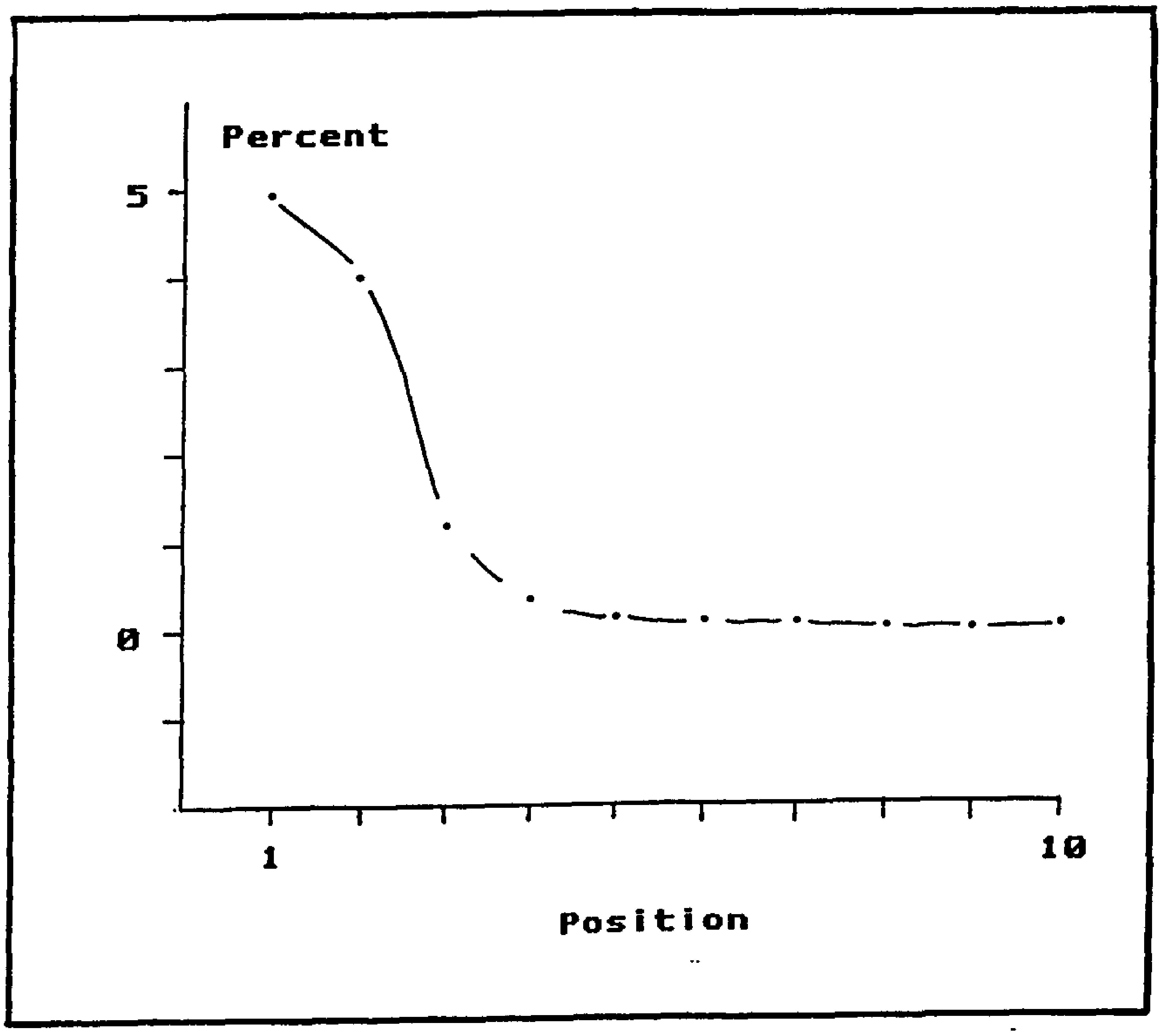


Figure 5.7

Polystyrene sphere (25mm diameter) positioned 3mm beneath the current probe.

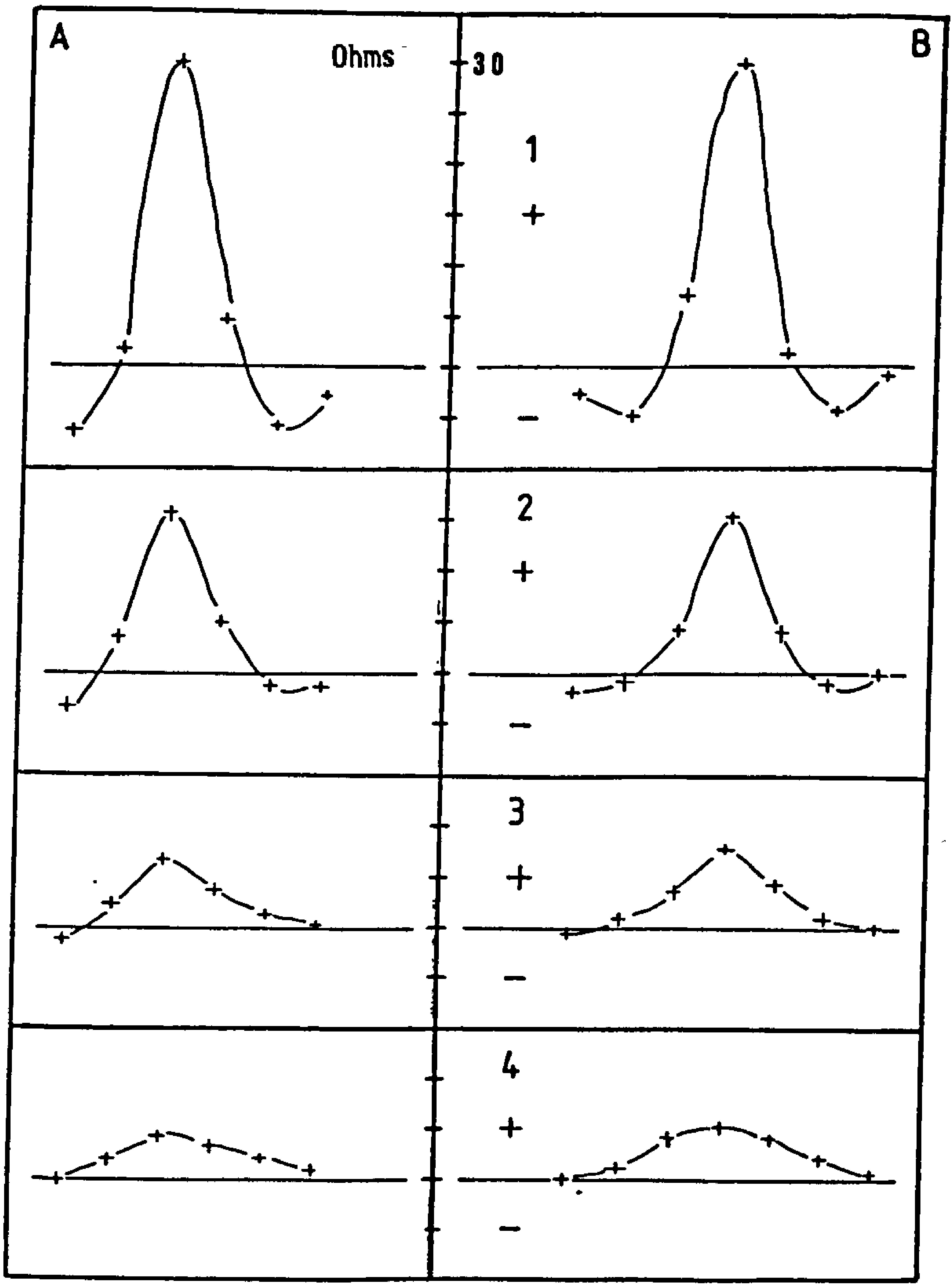


Figure 5.8 Investigation of response due to depth at two positions along the C-C line. Position A is at the edge of the grid, position B is at the centre of the array.

Depth 1 = 0.1m

Depth 2 = 0.5m

Depth 3 = 1.1m

Depth 4 = 1.6m

first metre. However, below this depth the response for the 2m diameter sphere decreases to approximately within the noise associated with the background i.e. circa 5%.

5.5 Low Resistance Objects

Resistance methods of archaeological prospection have often proved an inefficient way of locating low resistance anomalies e.g. Clark 1975, Papamarinopoulos et al 1985. Indeed, during an earlier set of experiments the determination of low resistance features in the tank proved most unsatisfactory. In the earlier simulations steel cylinders had been placed perpendicular to the C-C line. Despite vigorous attempts at scouring the surface of the object and cleaning any remaining grease, very little stable response was ever achieved. The method adopted for the production of stable objects is outlined in Appendix 1. The first experiment was to assess the effect due to a large diameter, low resistance cylindrical anomaly placed perpendicular to the C-C line. The cylindrical object was 108mm long and 51mm diameter. The graphical summary (Fig. 5.9) shows a consistent change in the response. The negative change in the peak averaged at 41.8 +/- 1.6 (+/- 3.9%). Although the Peak:Reverse Peak ratio shows a slight increase as the object nears the centre of the array, the average ratio is 4.7:1 +/- .3 (+/-8%). This is a good tank simulation

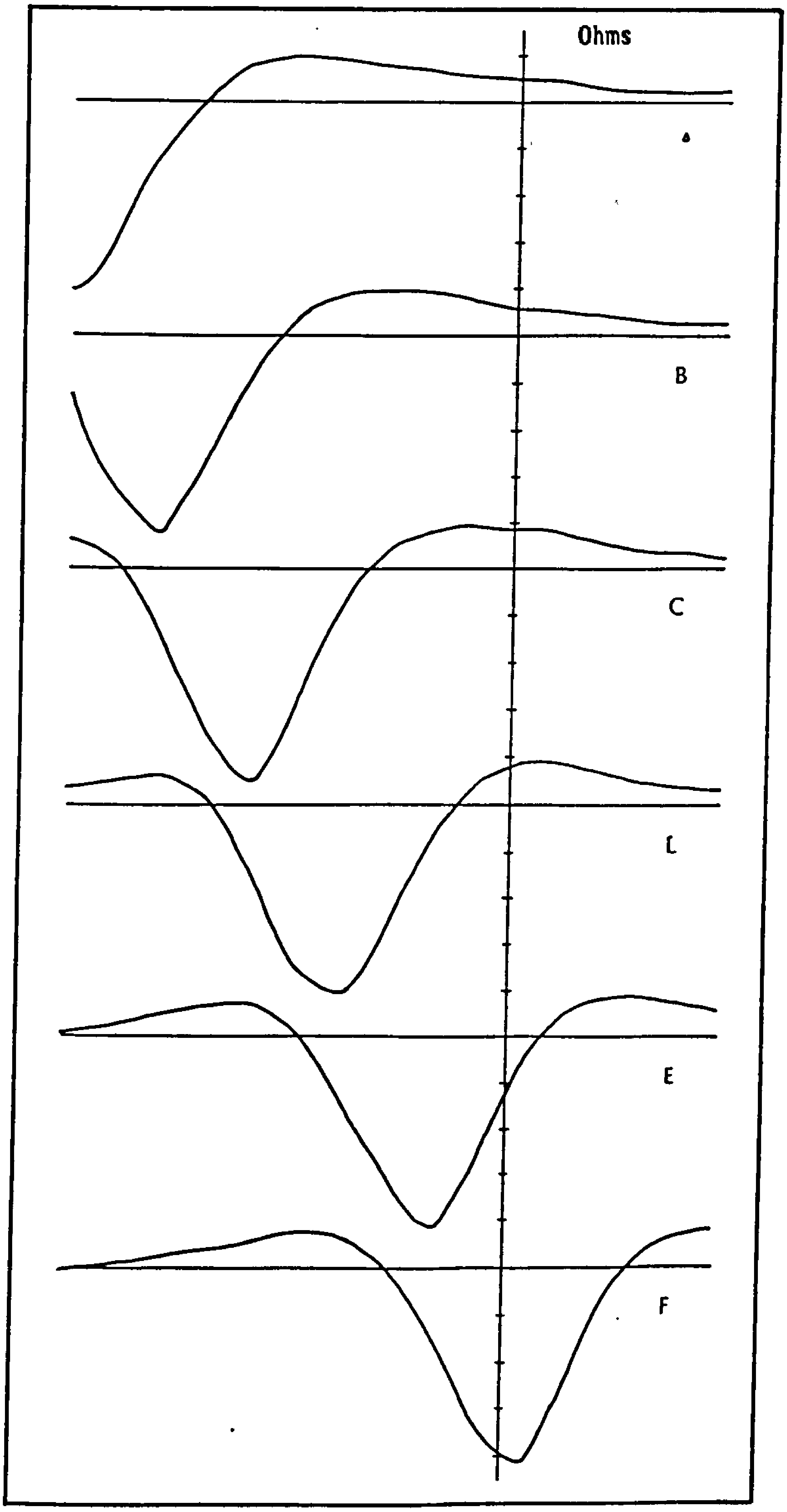


Figure 5.9 The response due to a large conducting rod. The gradations represent 10% increments. Position A represent the rod at the edge of the grid, position F is at the centre of the array.

of the theoretical situation described by Parasnis. In keeping with the archaeological nature of our data, in this case the C-C distance is 9.6 times the size of the object, rather than 3.5 times the object reported by Parasnis. In contrast, in the present experimental tank case, the inverse side peaks are quite pronounced when the object is positioned at both the edge and the centre of the array. In effect they form a tail which shows a change of up to 10%.

5.6 Buried Features and the Off-Set Rig

A series of experiments were devised to simulate the polarised affects first observed in the field trials at All Hallows, Tickhill. The objects were positioned on the straight-through line so that the spatial charateristics of the response could be studied. As detailed above (section 5.3), the values plotted in this series of experiments are normalised to take out minor positional errors and reduce contact problems due to tank ripple effects.

A. High Resistance Features.

In this experiment two objects, one (0.75m dia.) was placed at right angles to the C-C line and a second(1.0m dia.) was placed parallel to the C-C line (Fig. 5.10). It is clear that this tank experiment completely upholds the

TWO HIGH RESISTANCE FEATURES

A -0.75M AT 0.5M
B - 1M AT 0.5M

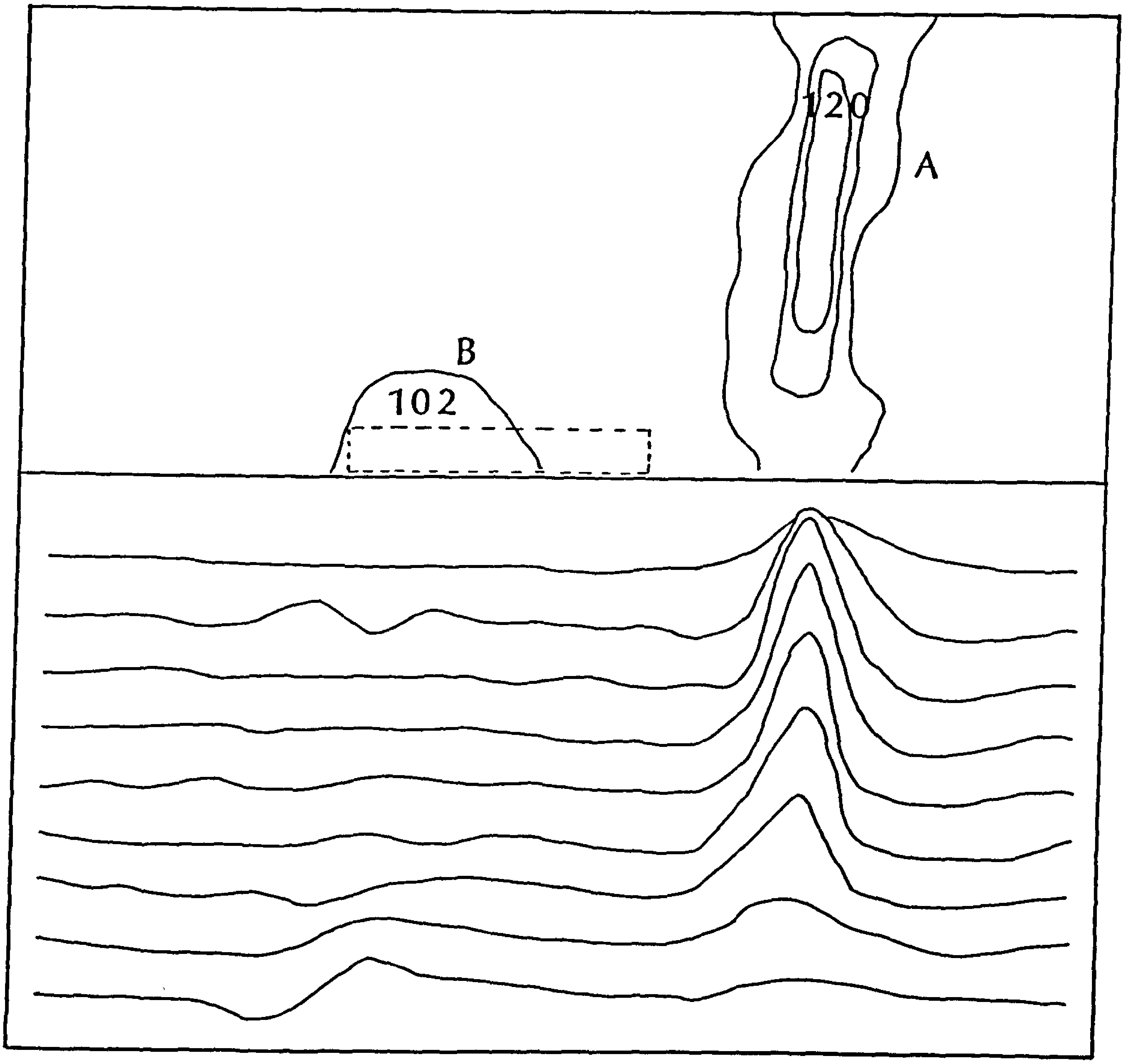


Figure 5.10 The response due to two high resistance cylinders. Position A is perpendicular to the C-C line, position B is parallel to the C-C line.

empirical observations made at All Hallows. The smaller object at A, perpendicular to the C-C line, produced a large response, circa 25% increase above the background. The larger perspex cylinder at B, parallel with the C-C line, only produced a minor (2%) increase at one end of the object. This slight increase may be due to an edge effect produced by the object being tilted. Both objects were measured at the same time to avoid any critical instrument change, although none had been recorded previously. The third position for a high resistance object was at 45 degrees to the C-C line (Fig.5.11). In this position a curious effect may be discerned, as the object is best 'seen' at the ends of the cylinder. This is a similar response to that obtained in the Brighouse field test; section 4.5, Fig.4.19. However, although the central part of the cylinder is barely above the normalised background, it is noticeable that the object's shape is still recognisable. This is because the values around the object are to some extent depressed. This would suggest that depending on the angle of the axis of the object to the C-C line, the array becomes almost an 'end' detector i.e. it is only measuring the areas where the change in voltage is greatest.

B. Low Resistance Features.

In view of the apparent directional properties of the high resistance anomalies, it was decided to experiment with

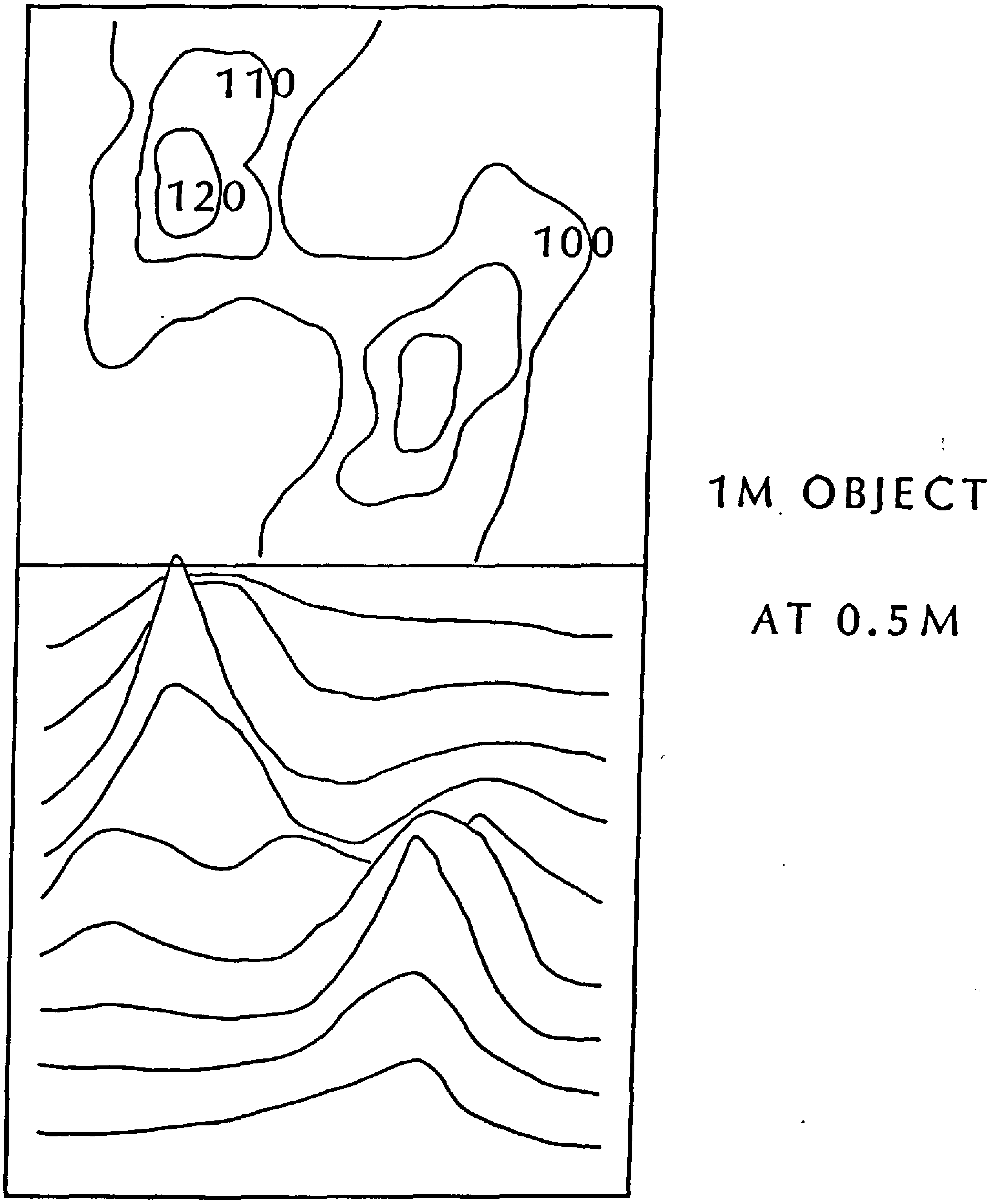


Figure 5.11 The response due to a perspex rod positioned approximately 45 degrees from the C-C line.

the low resistance objects parallel with the C-C line. The result of this experiment was a positive identification of the low resistance body (Fig.5.12). The form of the response, however, does call for some discussion. Although at the centre of the anomaly the change was great, we see very large reverse peaks at the ends of the cylinder. Although this was an expected form of response for the Schlumberger, it was sufficiently different from the high resistance response. In this case the width of anomaly response is very broad, not in keeping with the hoped for resolution of the array. In some respects the response for this object could be almost regarded as circular, with the equipotentials being severely distorted all around the object. A longer iron object was also investigated to see if the circular response form was still evident. In fact an elongated response was obtained Fig.5.13. This 'broad front' of readings is considered in more detail later.

Once a standard procedure had been achieved for the preparation of low resistance anomalies (see Appendix 1), a response pattern was obtained for anomalies both parallel to and perpendicular with the C-C line. A first test using anomalies of the same dimensions showed that the form of response is different for the two extreme cases. It would also appear that the low resistance object positioned on the central line would be easier to detect. Although this is in contradiction to most field cases in resistance survey, theoretically a conducting sphere will give twice the response of a non-conducting sphere (Lynam 1970).

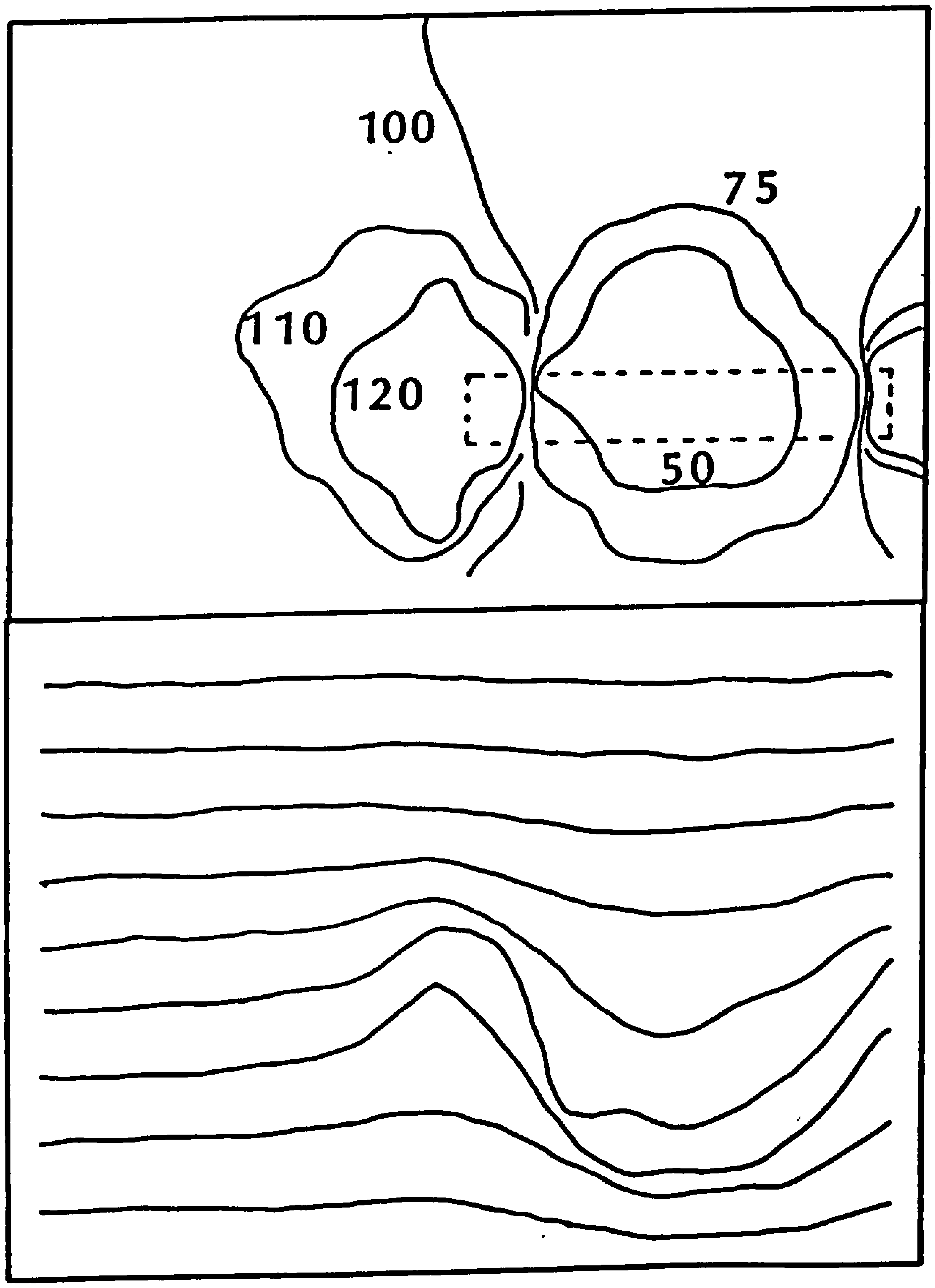

1M OBJECT AT 0.5M

Figure 5.12 The response due to a conducting cylinder positioned parallel to the C-C line. The position of the object is indicated by the dashed line.

The object is equivalent to a 1.0m wide feature.

1M OBJECT AT 0.5M

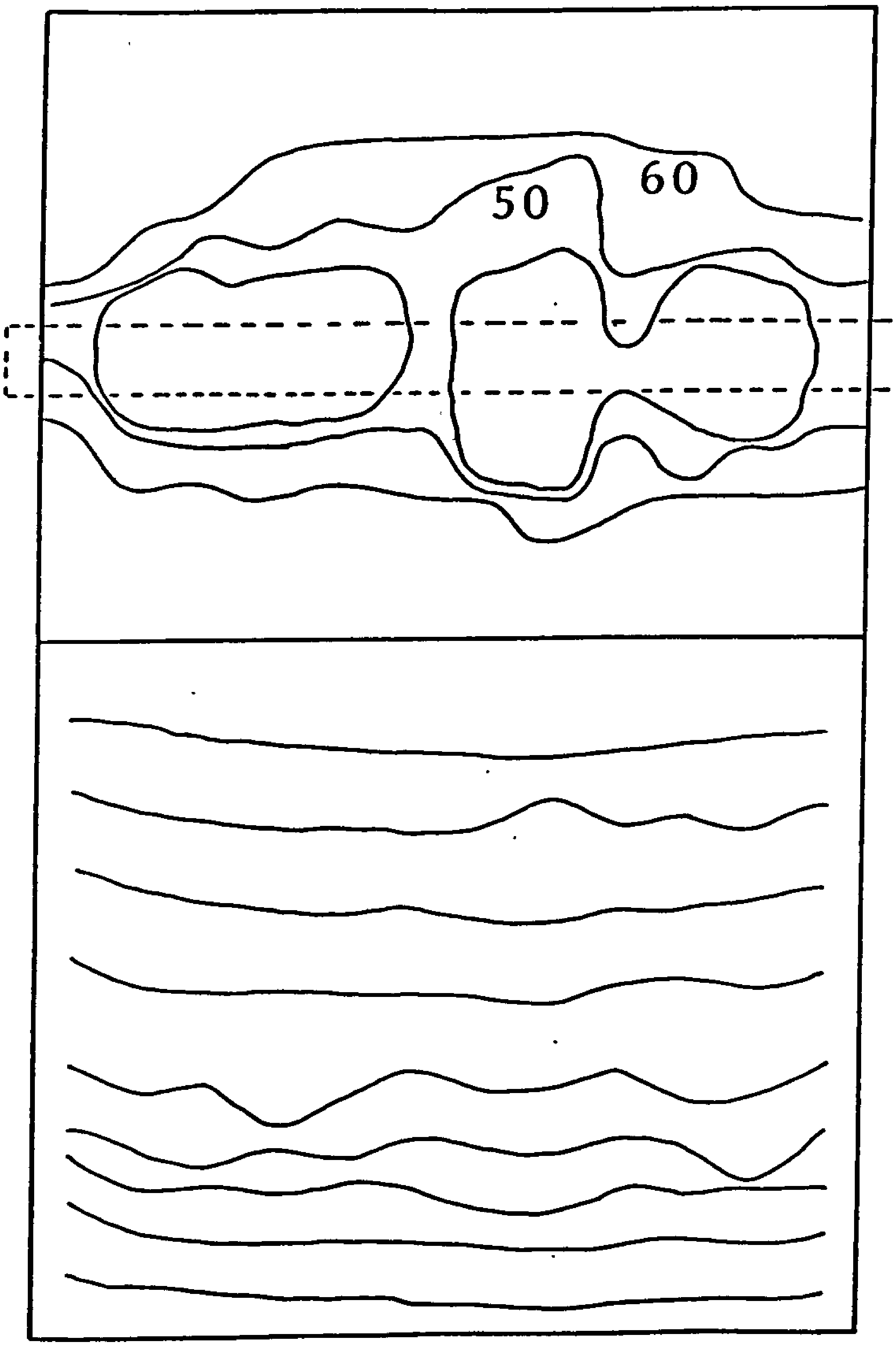


Figure 5.13 the response due to a long conducting cylinder (the position of the object is marked). The object is positioned parallel to the C-C line.

A similar experiment to that shown in Fig.s 5.10 and 5.11 above was tried for a low resistance object. This time a 12mm diameter rod was set a depth of 3mm (eqivalent to 0.25m) and the position varied as shown in Fig.s 5.14, 5.15 and 5.16. It is clear that in all three positions the anomaly was clearly detected. In terms of percentage change the least obvious anomaly is when the object is perpendicular to the C-C line, with a maximum change of 25.5% below background. The greatest percentage change was when the object was parallel with the C-C line (84.4%). The maximum change with the object in the middle position was 58.8%. Interestingly, although the parallel position gave the greatest response it was not necessarily the easiest position to interpret. The perpendicular position shows a very clear single peak feature with small reverse peaks. Both of the other positions show not only large reverse peaks, but also a corridor of low readings noticed above. This would clearly cause a number of problems in interpreting several features in close proximity.

It is clear from the above experiment that to investigate even the apparently simple case of a rod parallel with the C-C line, the results must be viewed in a wider spatial context. To investigate the effect of a long, low resistance anomaly positioned on the central line, a similar grid was used. In Fig.5.17 the response due to the progression of the rod across the central line is seen. In the first position the response is somewhat contradictory, as the low resistance response is overwhelmed by the reverse peak, which is as

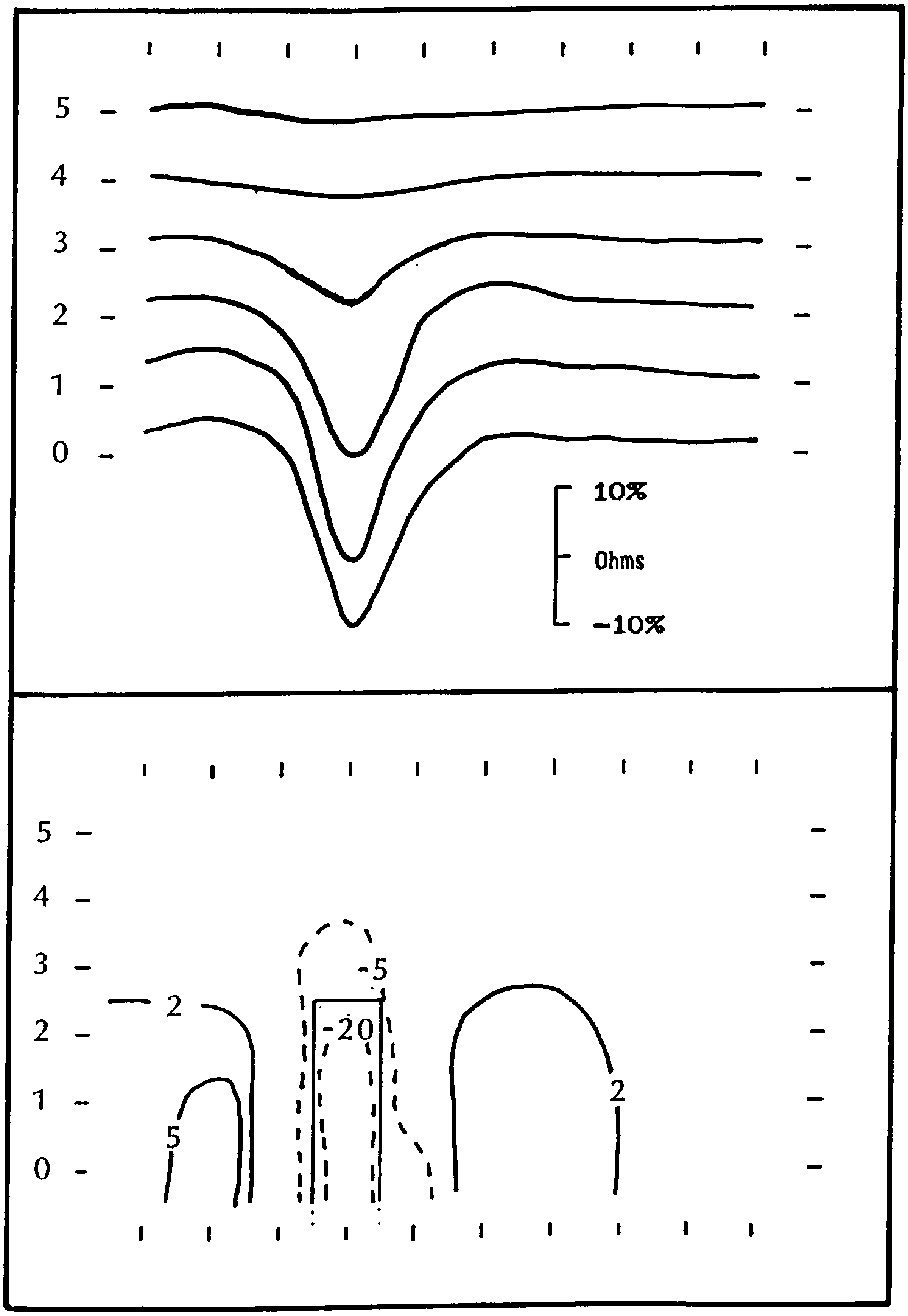


Figure 5.14 The response due to a conducting cylinder positioned perpendicular to the C-C line.

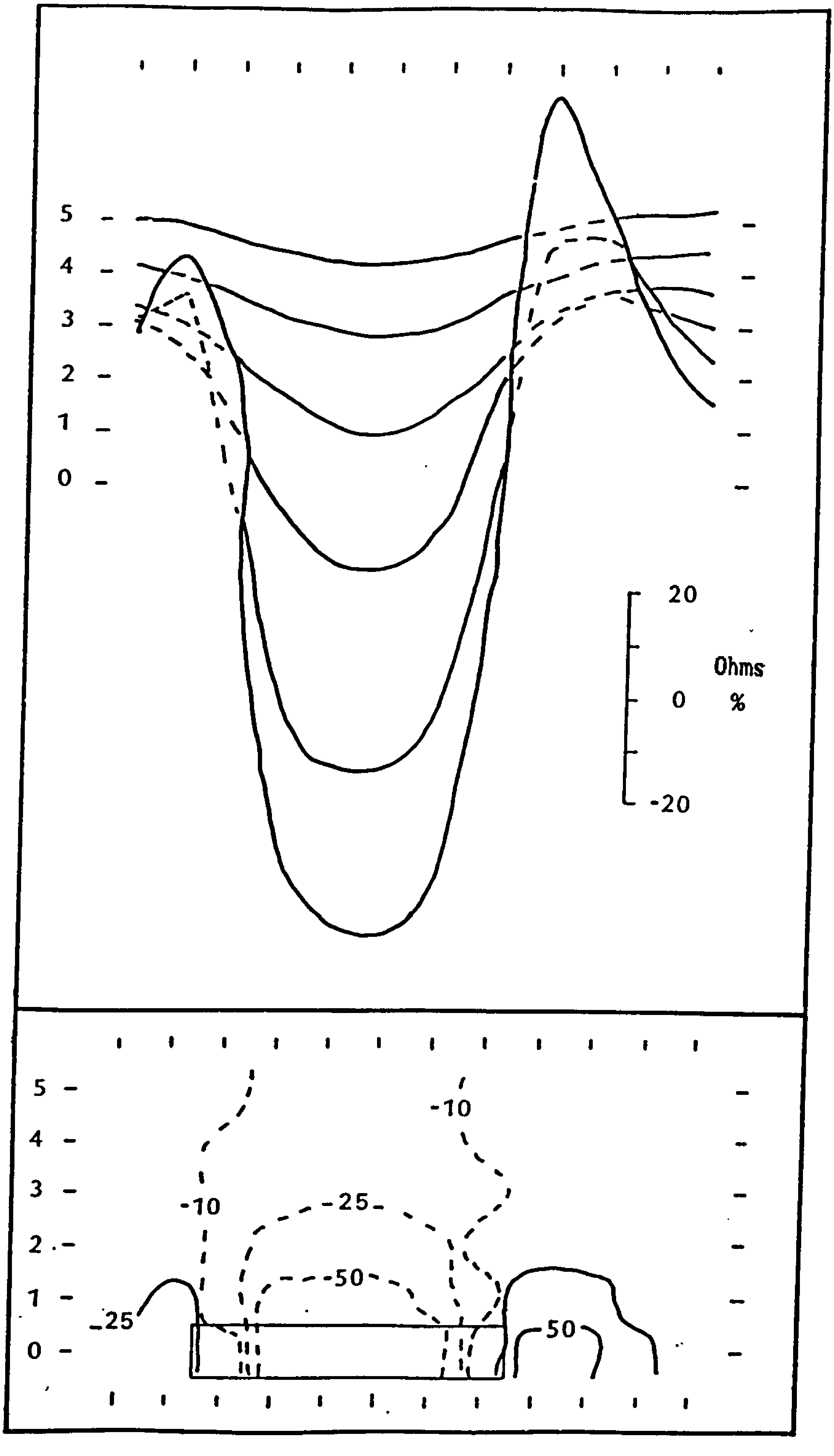


Figure 5.15 The response due to a conducting cylinder positioned parallel with the C-C line.

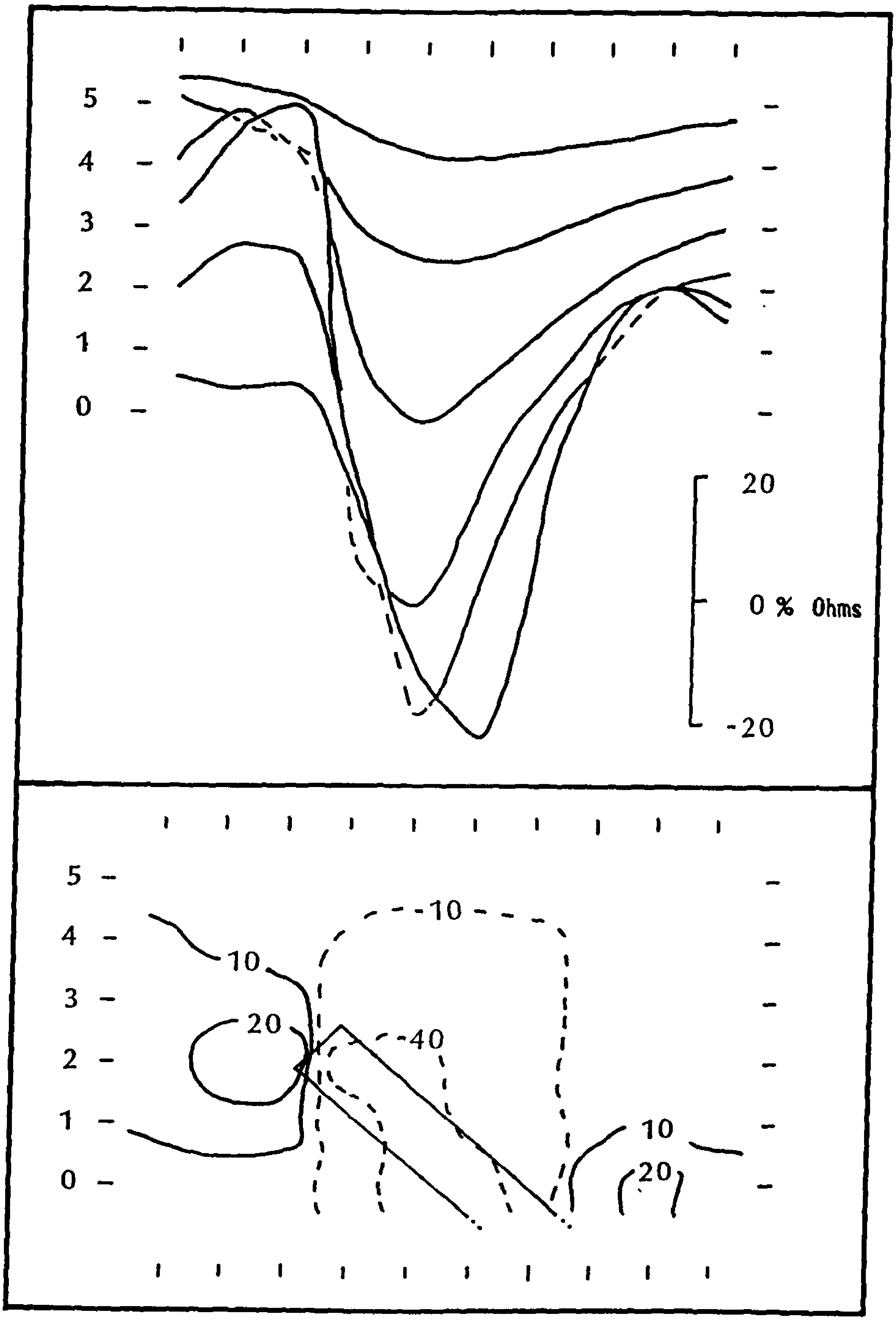


Figure 5.16 The response due to a conducting cylinder positioned at approximately 45 degrees with the C-C line.

large as a normal peak. Of course in this case the major part of the negative peak is set off the grid. However, the reverse peak is not only disproportionately greater than the measured major peak, but also its real change is very large. This is due totally to the presence of the rod in close vicinity to the current probe C1. The major peak and reverse peak changes for the three positions are tabulated below.

Table 5.1 Changes in Resistivity due to the Presence of a Low Resistivity Feature (a long rod).

Position	Major change	Major reverse change
A	28.6%	58.9%
B	23.0%	17.8%
C	10.6%	10.8%

Again from all three positions there are clear indications of the 'corridor' effect. It is probably true to say that in all three cases it may be difficult to identify the presence, and interpret the nature, of low resistance objects, without the use of spatial information. The data gathered in this experiment indicates that the field response

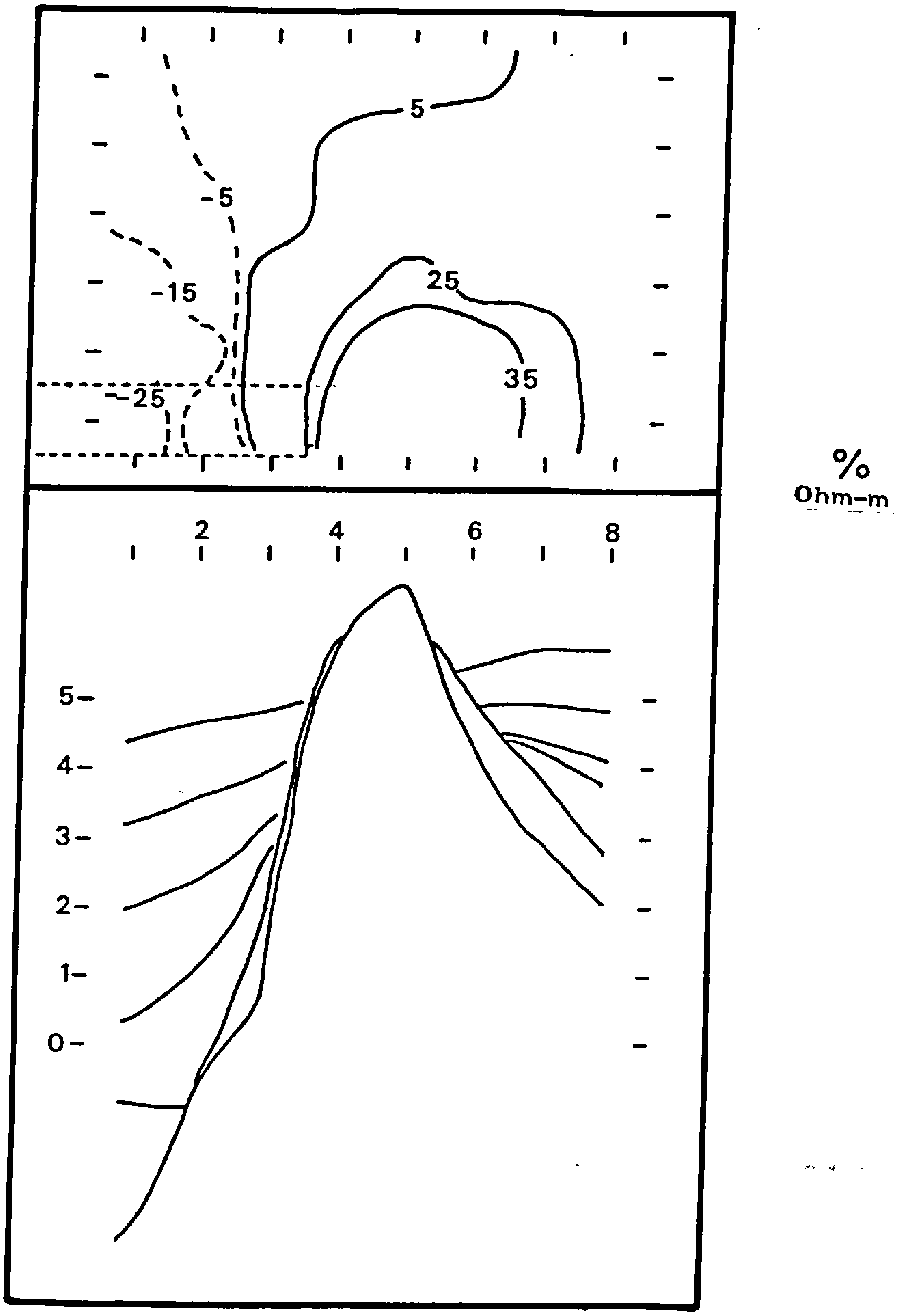


Figure 5.17a The response due to a long conducting cylinder positioned parallel with the C-C line. Probe positions 1-8 are shown.

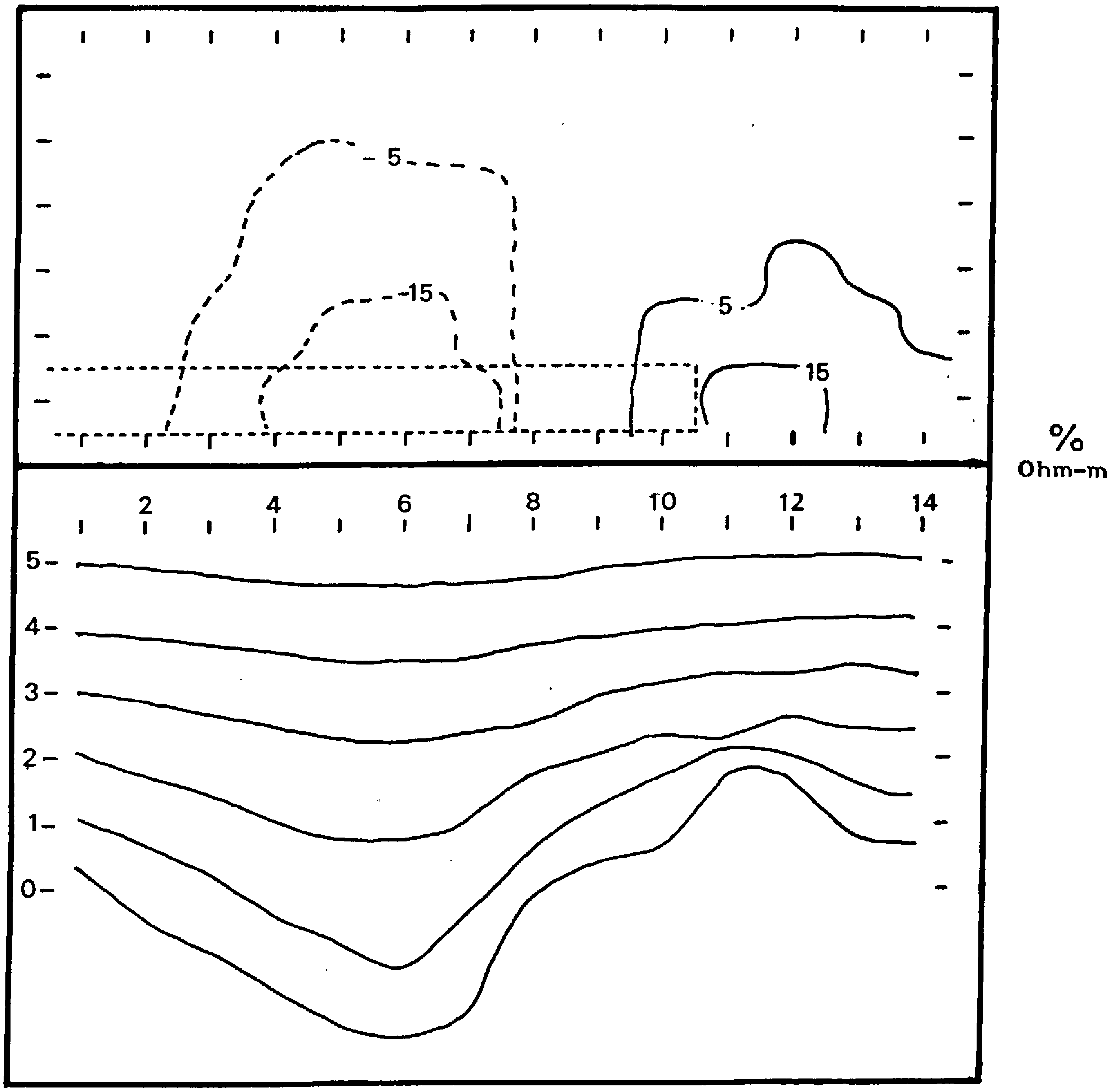


Figure 5.17b The response due to a long conducting cylinder positioned parallel with the C-C line. Probe positions 1-14 are shown.

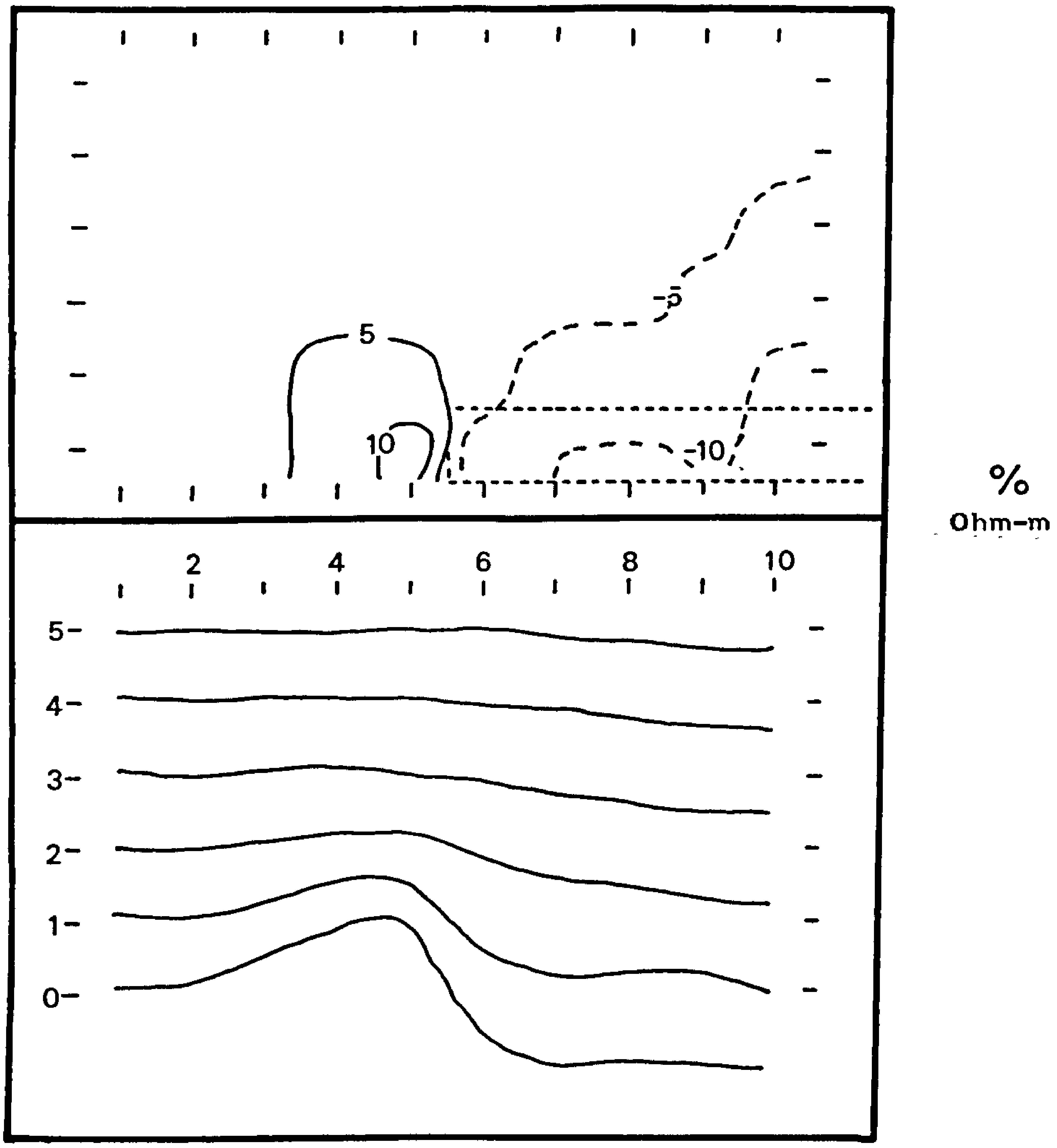


Figure 5.17c The reponse due to a long conducting cylinder positioned parallel with the C-C line. Probe positions 1-10 are shown.

from Thorpe Audlin are similar i.e. the fact that the ditch extended between C_1 and C_2 should give us a depressed value along its whole length. It is only through the identification of gridded patterns that the resolution of such an array may be tested. Although no radically complicated response forms were obtained (i.e. like Clark's), single line simulations would have been most discouraging. Single line simulations may also have produced misleading traces i.e. suggesting that the targets at an angle to the C-C line could not be identified.

However, the above simulation was based on a very large conducting anomaly, which may, especially in position (A), have influenced the current most uncharacteristically in terms of archaeological targets. The experiment was repeated using a shorter object of the same diameter. The grid results may be seen in Fig.s 5.18 and 5.19. The major and reverse peak response are tabulated below.

Table 5.2 The changes in Resistivity due to the Presence of a Low Resistivity Feature (a short rod).

Table 5.3. Position	Major change	Major reverse change
A	56.5%	31.8%
B	67.3%	32.9%
C	59.3%	22.2%

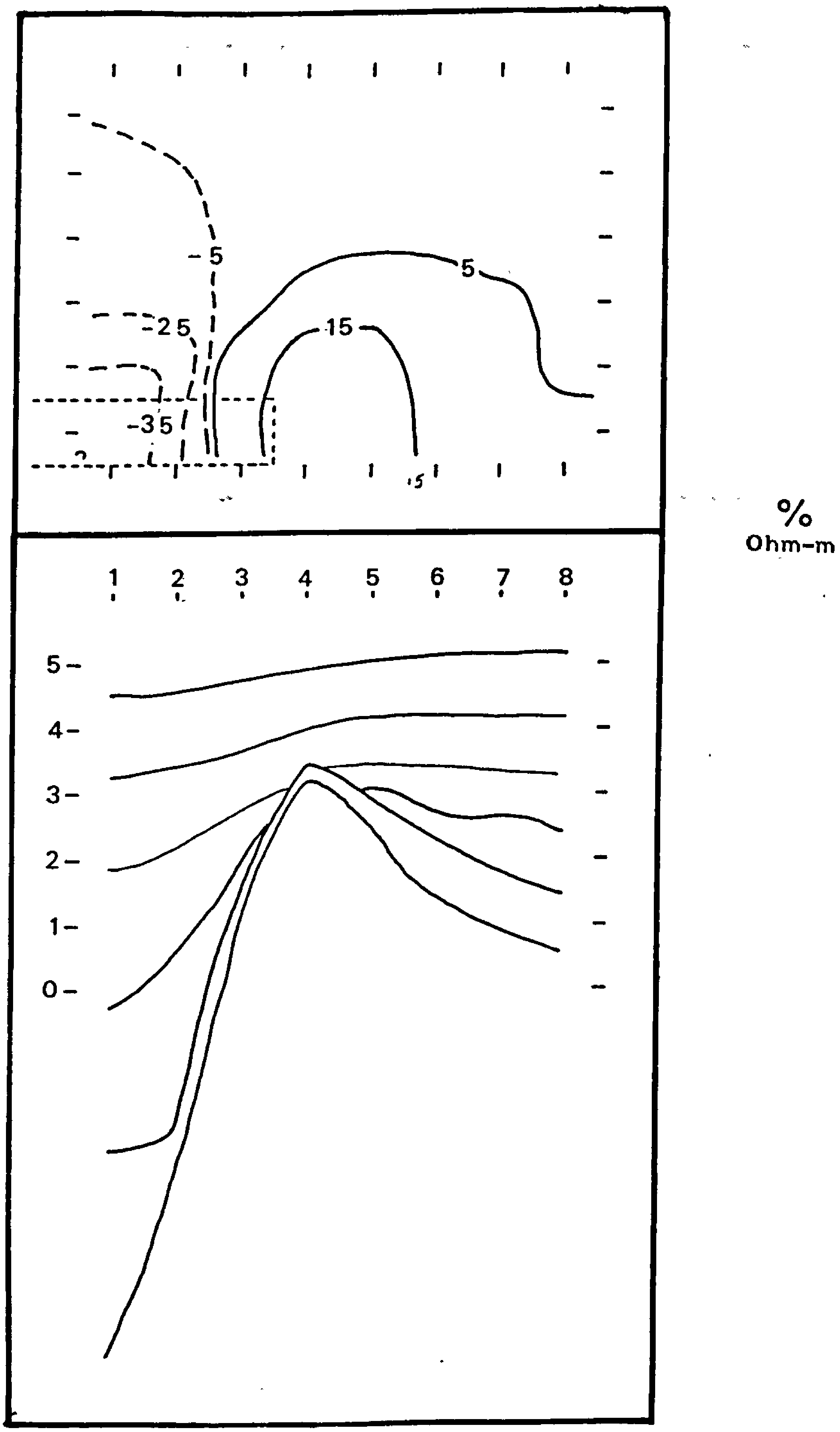


Figure 5.18 The response due to a short conducting cylinder positioned parallel with the C-C line. Probe positions 1-8 are shown.

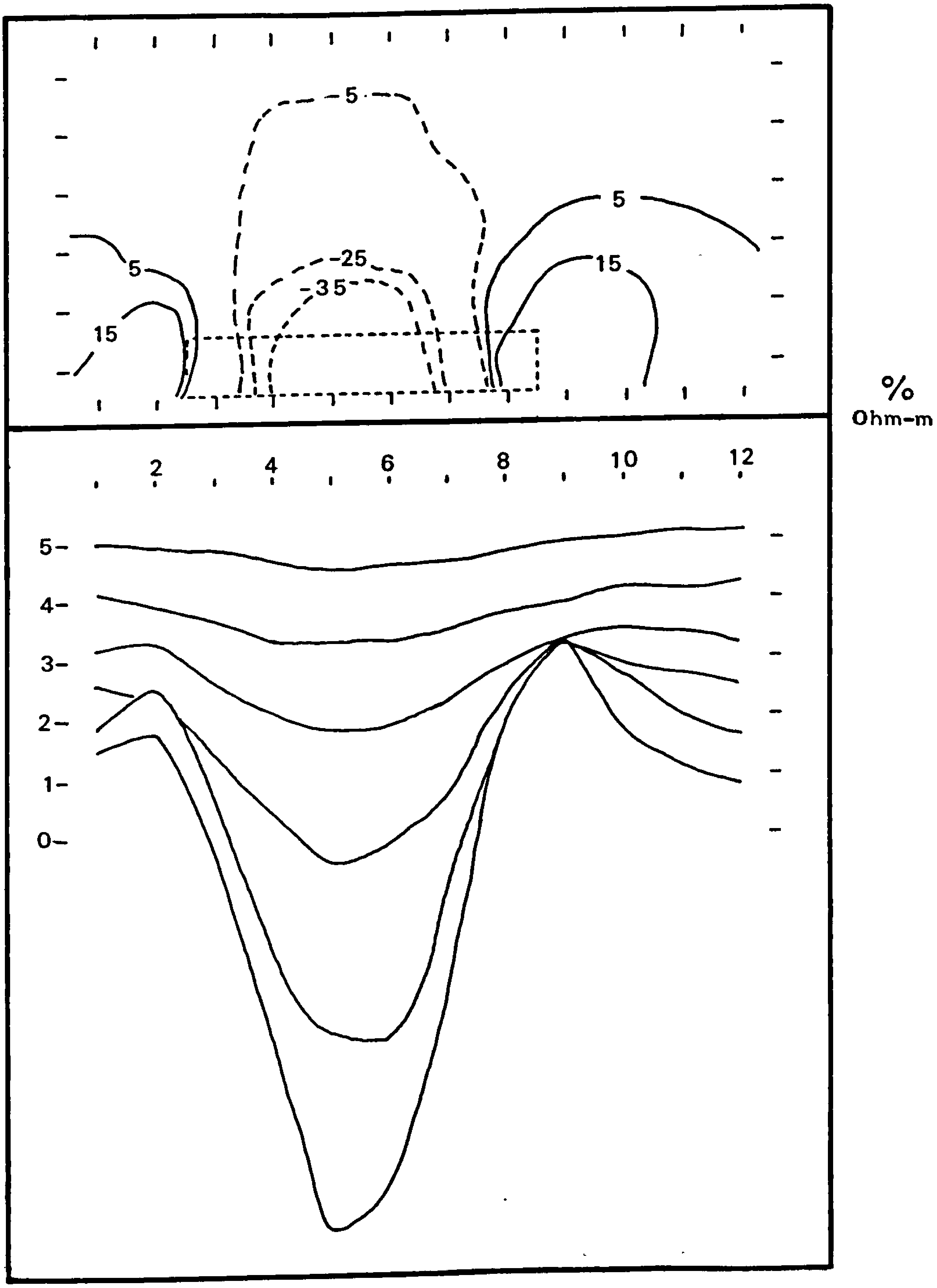


Figure 5.19 The response due to a short conducting cylinder positioned parallel with the C-C line. Probe positions 1-12 are shown.

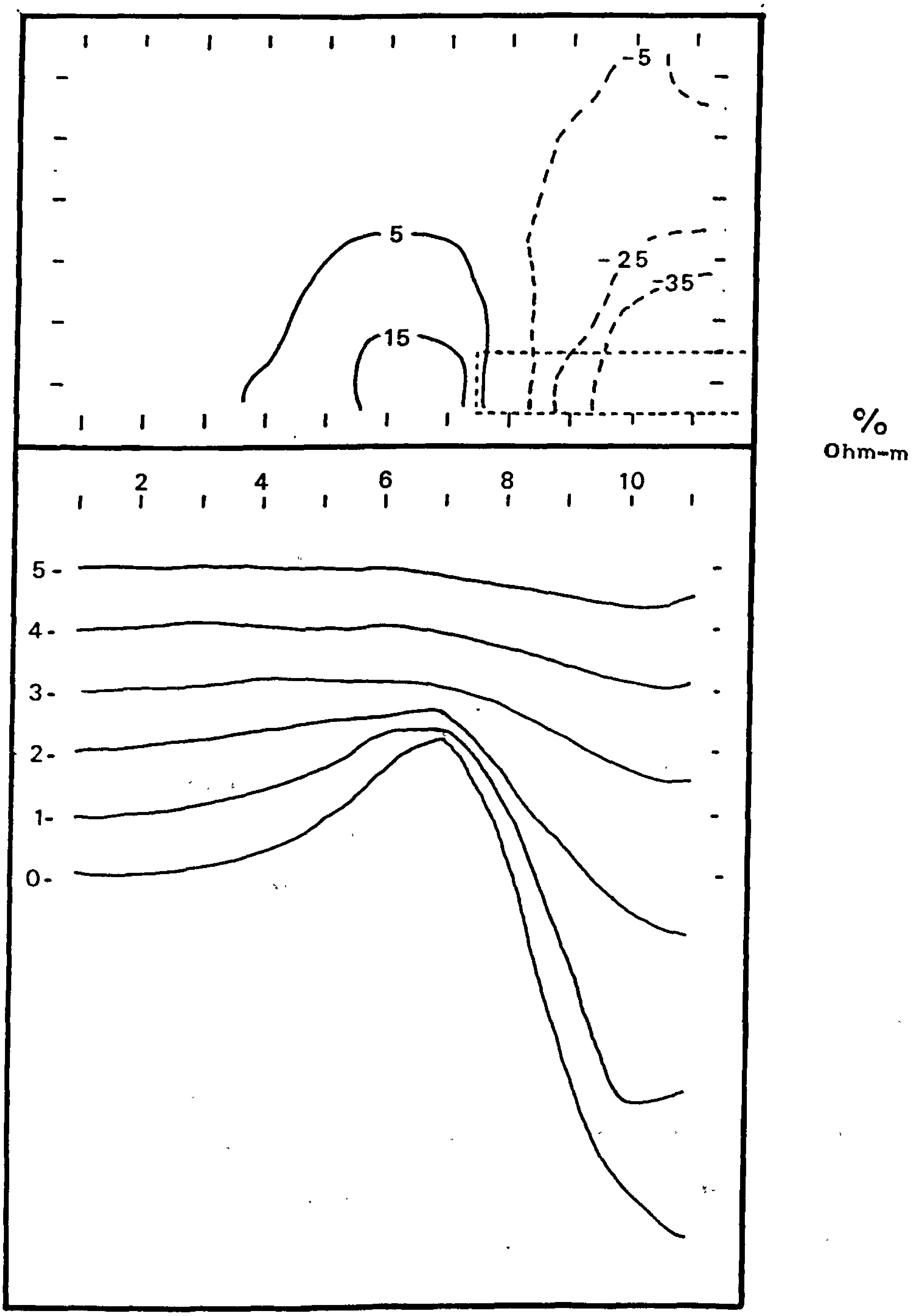


Figure 5.20 The response due to a short conducting cylinder positioned parallel with the C-C line. Probe positions 1-11 are shown.

Under these cicumstances the object can be discriminated in a much more convincing manner. In all cases the major peak easily overwhelms the reverse peaks. In fact, the position of the object appears to have little effect on the maximum anomaly response. Although the apparently classic 'corridor' effect is seen in all cases, the anomaly is clearly defined.

C. An Investigation into the Corridor Effect.

A clear pattern has been seen and described above when low resistance anomalies are positioned parallel to the C-C line. To investigate this phenomenon 4 low resistance cylinders L_1-L_4 were used. In the first experiment the object with the largest diameter (L_4) was placed parallel to the C-C line. The centre of the object was placed directly under the central potential probes. A transect of readings was taken moving away from the object using the off-sets i.e. the readings were taken perpendicular to the straight through line. The background was measured without the anomaly present and the percentage change calculated. The anomaly was then replaced with one with a smaller diameter and the measurements repeated. A diagram of the percentage change along the corridor of influence with the bottom of the feature at a constant level is seen in Fig. 5.20.

The curves showing the change in response away from the C-C line clearly demonstrate the large affect that even a small conducting body may have c.f. object L_1. Naturally, the maximum response at the centre of the array is greatest for the largest object

The experiment was repeated with the same objects, but the depth to the top of the object was kept constant (Fig.5.21). The response curves are very different under these conditions. The largest object still gave the greatest response, however, the other three smaller cylinders also gave a substantial decrease. It would therefore appear that any conducting cylinder buried close to the surface would give a similar maximum response. The 'corridor' effect is particularly strong when the objects are buried at shallow depth.

In neither of these experiments is there any suggestion of reverse peaks as, presumably, the current has been distorted in a regular manner. If the full width at half maximum is considered, then the response from the smallest object (L_1 = 0.25m) covers an area of 4m in the first experiment and 2.5m in the second. The largest object (L_4 = 1.5m) gave a response over 3.5-4m in both cases.

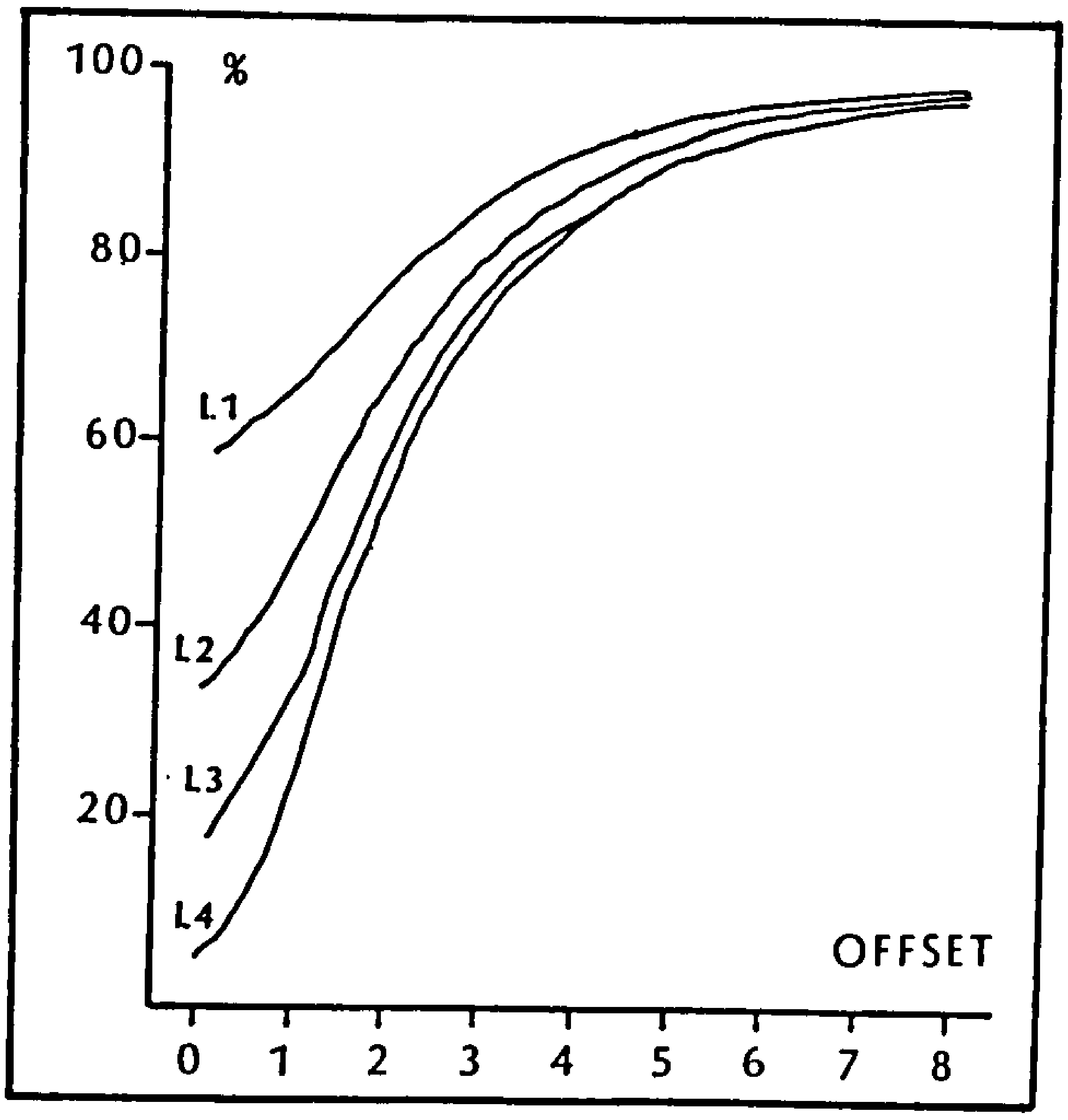


Figure 5.21 The percentage change due to conducting cylinders L_1=0.25dia; L_2=0.5m; L_3=1.0m; L_4=1.5m. The bottom of each object was kept constant at c.1.6m equivalent.

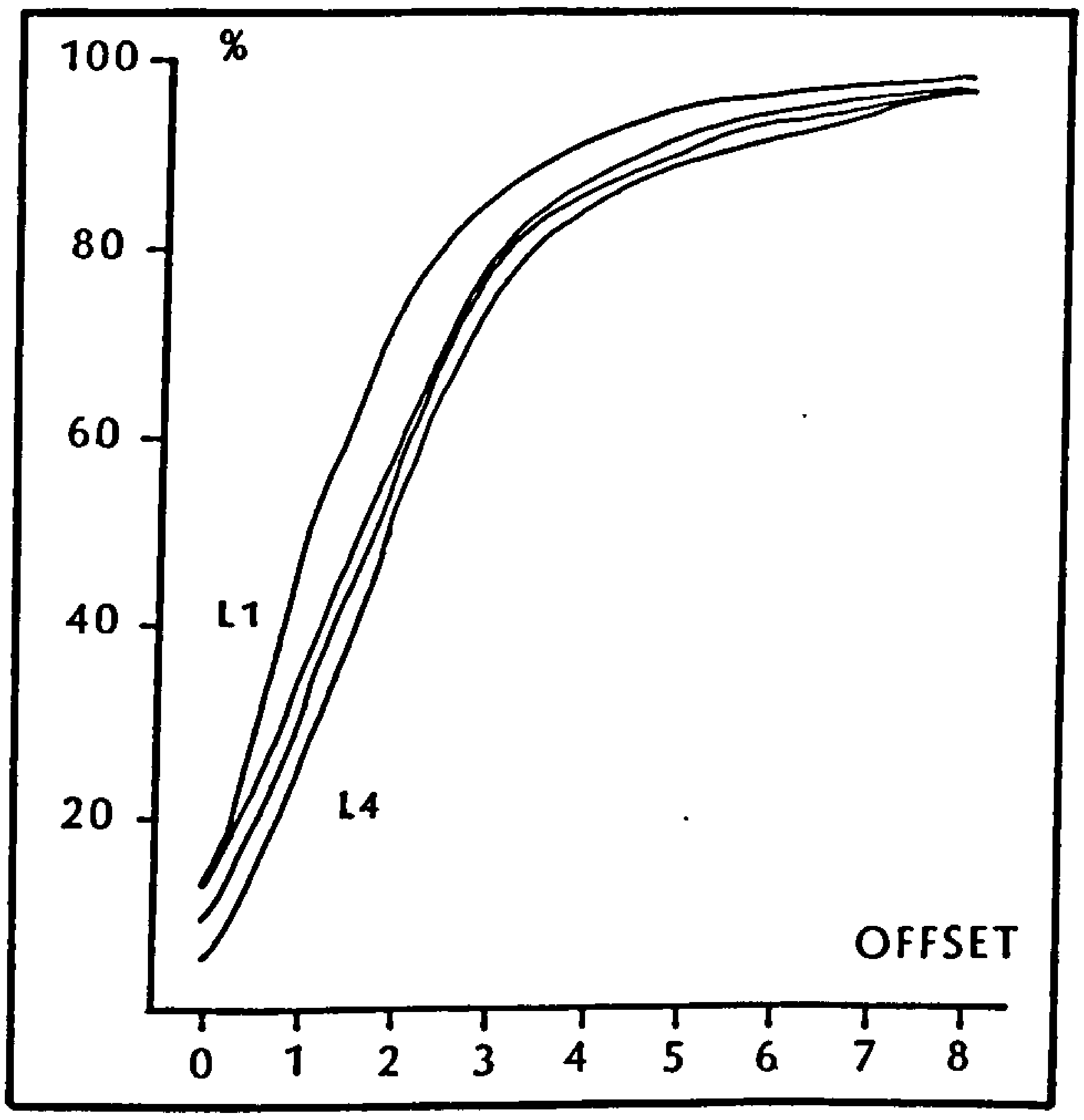


Figure 5.22 The percentage change due to conducting cylinders The top of each object was kept constant at c.0.1m.

5.7 Conclusions to the experimental work

It is clear from the experiments detailed in this chapter, that to use the Schlumberger in the desired way, i.e. in a 20 x 20m grid and with the current probes 40m apart, will cause some interpretational problems. In both the field and the laboratory it has been shown that different responses can be achieved depending upon the direction of linear anomalies.

For the present, field procedure must entail the double surveying of any grid. This should indicate the likely nature of the buried remains.

CHAPTER 6

The aims and procedures in modern field survey in Greece.

6.1 Introduction

The 1960s saw a new orientation in both research strategies and methodologies in academic field archaeology. In keeping with the rise of a more secure data base, which contained information not only on site-based archaeological landscapes, but also inter-site data from the surface of modern fields, was the continuous development of ever more rigorous survey strategies. Important work by American scholars had already shown that meaningful patterns could be extracted from the modern field surface, conveying interpretable past cultural information (c.f. Binford 1964; Binford et al 1970). The euphoria exhibited by the ready practitioners of this new art resulted in a conscious attempt to quantify and therefore minimise the blurring of the many post-depositional factors. Indeed, theoretical stances were built on such changes (c.f. Schiffer 1976, 1983) and as a result the quality as well as the quantity of the information increased many times in the 1970s. Recent studies have attempted to analyse the patterning due to ploughing, which is regarded as the major interpretational problem, using repeated artefact collections (c.f. Odell and Cowan 1987;

Hoffman 1982; Riordan 1982). This access to post-depositional information has resulted in a surer data-base, especially on-site where simulated archaeological distributions could be subjected to regular ploughing. The ploughing could take the form of field based investigations (c.f. Ammerman 1985; Reynolds 1982), or computer modelling based on the latter (Yorston et al 1990). In many instances a major problem concerns the devastation of topsoil patterns by modern intensive agricultural methods. Luckily, in many parts of the Mediterranean, the field systems have been maintained as small units, making them unavailable to large machinery. This situation will not last for very much longer.

In the Mediterranean the new technique of intensive field survey was readily taken up, and the idea of integrated research programmes has become common place (c.f. Keller and Rupp 1983). However, the apparent achievement of recent Mediterranean surveys must be seen against the historical development of the surface survey technique.

Traditionally the Greco-Roman world has intrigued the academic due to the enormous breadth of the ancient written record. This initially stimulated scholars in the 17th to 19th centuries to travel widely in Greece, noting the presence of any remains that either were mentioned in the ancient texts or were locally believed to be ancient. Ironically, not only did this set a trend in the solo methodology that still, on occasions permeates some research in Greece, but in themselves these studies have now become important gazetteers of information for modern field workers

(Snodgrass 1987). In particular, they often give exact locations for sites that were recently upstanding monuments, but are now destroyed. The travelogues are often so precise that individual sherd collections may be identified with named sites. Naturally, the basic flaw in this information collection strategy is that it produces a biased sample based on what were the most 'obvious' of sites.

6.2 What are 'New Wave' surveys?

Although elaborate survey strategies were being implemented in the United States in the 60s, in Greece the methodological components of the new survey strategies were not notably quantitative. Indeed, the major impact was the adoption of the concept of regional survey. The new regional survey was readily adopted with large areas being quickly scanned by a small number of people on foot or in a Landrover. The pinnacle of the work achieved by the early 70s is the 'University of Minnesota Messenia Expedition' (McDonald and Rapp 1972), which while using fairly traditional survey techniques proved seminal not only in its complete consideration of a large area, but also in its inclusion of specialist contributors to form a holistic approach to the territory. It is on this sound foundation that the 'New Wave' surveys of the late 70s and 80s have been built.

The new wave surveys have concentrated on examining the entire surface area of a region, or some statistical sample of a region (c.f. Cherry 1983). The techniques are dedicated to the quantitative analysis of cultural material. In most cases this involves material from any period that is present on the modern surface of the fields. Although the methodology of each project is particularly 'individual', due to the diverse environments and research questions to be answered, a number of common denominators tend to be present. Perhaps the most obvious and important is the pragmatic attempt to apply quantifiable field survey strategies over total landscapes. In the Mediterranean the diverse environments often include terrain that may be difficult to survey in a systematic manner. The difficulties involved include uncompromising topography and rapidly changing land cover. The surveying and interpretation of difficult and often hazardous terrain is a fundamental point of all of the modern so-called intensive field surveys in the Mediterranean.

It has to be noted, however, that in an area such as the Mediterranean where historical accounts can give a written history to the archaeological material culture, the concept of <u>site</u> survey has always been prevalent. The ability to match a site with historical acts or figures is a natural by-product of good field survey (c.f. Snodgrass 1985; Osborne 1987). However, in most cases these are major sites that would usually be located using the most extensive survey design. Again the effective 'non-sample' used by intensive surveys over any given area encouraged the assumption that all major sites were being located that lay in that sample area. Another major reason for concentrating on 'site' survey is due to the quantity of ancient material on Greek fields; as such, initial work on 'site-less' survey gave little hope to the field worker in a country where the sherd density on-site may be as high as 40 sherds /100m^2 (Bintliff and Snodgrass 1985). Quite simply, in Greek conditions it was regarded a 'Yes or No' decision as to whether a site exists on the soil surface and, therefore, at least within the topsoil (e.g. Keller 1983). The parallel with an earlier American debate is worth noting (Plog et al 1978).

It is only through the collection of large data bases that problems of inference have been seen to have some substance. In particular, the 'visibility', or otherwise, of sites of all periods has come under question. From the Boeotian data base it was argued that historically attested population estimates could not have been housed in the number of sites located within the survey area. From this it was deduced that the apparent re-burying of sites by plough action was causing a serious under-representation of the data base (Bintliff 1985). The acceptance of this fact does not imply discredit, either to the results obtained from, or the technique used by current surveys, but merely focusses on some of the inherent distortions in the data base. In short then, a priority for the new intensive surveys has been the quantification of the number of sites across a whole landscape, not only to give a hopefully representative sample of the past settlement plan, but a complete picture of common types of past settlement locations. The latter can be argued with some confidence from the evidence collected via survey of all environments within the research area.

The absolute quantification of the data base has suggested areas of complication that may be accounted for by, for example, the action of the plough. This quantification also offers some means to circumvent this distortion, as in the Boeotian population argument above. As the new wave surveys are essentially diachronic in nature, this allows in many cases for the accent of interpretation to be on the evolution of the modern settlement pattern, rather than an artificial fossilised snap-shot of a particular chronological age. Indeed, the gross dating of surface material requires that such an overview should be taken.

Despite this concentration on the location of sites the new intensive surveys clearly possessed the methodologies to monitor the content of the background ceramic component. As the focus for the surveys went beyond the familiar 'site spotting' to an investigation of this background, so the questions that the surveyors were proposing became less concerned with social issues and more concerned with economic ones. In Britain the acknowledgement that ephemeral spreads of Roman ceramic material could represent the location of past manuring activities has been of major importance to the success of artefact recovery, or non-site surveys as a whole(c.f. Crowther 1983, Williamson 1984, Gaffney et al 1985). As part of the refinement of the interpretation of archaeological information, rural sites could be placed with another element of their total systemic context, involving the study of the remnants of economic decisions. This information can then be usefully incorporated into the overall site density of an area to assess how much of an area may have been cultivated, and, given information on the agricultural regime, how many people could have been supported by the site. Prior to the realisation of the importance of 'off-site' information, the only other way to approach 'how much was being farmed' was via theoretical models based on ideal land-use such as Site Catchment Analysis (S.C.A) or Thiessen-Polygon Analysis (T.P.A.). In fact, the information from such surveys has given clear evidence that the major tenets of S.C.A. and T.P.A. were correct.

Nearer to Greece, other surveys have produced evidence for the existence of manuring activities using a radial sampling design on sites in Syria and Oman (Wilkinson 1982, 1989). Although the sampling methodology used is now perhaps out-dated, the work has helped to highlight the possible interpretation of off-site material. The material gathered by the 'New Wave' surveys in Greece, in contrast, is consistently of good quality and can be used to interpret the link between all the sites in a complex rural landscape. Indeed, the quality of 'New Wave' data is such that comparisons can be made between surveys that are separated by the physical environments that they are investigating, but are similar due to rigorous research strategies c.f. Bintliff and Snodgrass 1988, who compare the absolute sherd values associated with off-site manuring from Britain to Oman. A few surveys with particularly sensitive data collection designs have also recognised the presence of site 'haloes' which are part of the intensive farming around the edge of rural communities (Bintliff and Snodgrass 1985; Cavanagh et al 1988). The acknowledgement that large scale manuring is readily defined spatially by using the correct methodology is very important, not just for the interpretation of past farming systems, but also for the implementation of novel scientific techniques to help identify such systems. The latter is particularly important in zones where either ceramic materials do not survive, or were never spread as part of the manuring process.

Recently, an attempt has been made to find local enhancement of trace elements in the soil that can be attributed to manuring. Just as ceramic debris would have been mixed into farmyard middens, transported to the fields and distributed in the pattern of the manuring activity, so would the inorganic elements concentrated by human and animal waste. In particular the amount of lead and copper in the soil was shown to be directly associated with the density of the ceramic surface component. By using the surface record, it was therefore possible to show the use of elemental analysis in the area of largely theory-bound off-site archaeology (Davies et al 1989, see Chapter 8 below).

6.3 New Wave Surveys and Intra-Site Analysis

The investigation of the environs of archaeological sites is a recent development by comparison to the intra-site analysis of archaeological material. However, the conservative nature of most archaeological work has meant that even this latter kind of analysis has normally been associated with excavated assemblages. Nonetheless, attention has now focussed on the plough soil in an effort to define not only chronological differences across the site but also the possibility of different use areas within the site. In Greece this work has been little practised due to overemphasis on the importance in Greek field archaeology of the location of sites. Yet, there has been a long-standing interest in defining site character, principally in an effort to create a hierarchy of settlement (c.f. Renfrew and Wagstaff 1982). Many different ways have been suggested for the definition of sites (see Keller and Rupp 1983). In one of the rapid but perhaps over-simplistic examples for site definition used in the Mediterranean, the supposed centre of the site is located and two transects are placed at right angles to one another (Gallant 1982). A sherd count is maintained every X metres until some level of background is found, at which point the site is judged to have ended. The information gathered by this sort of technique can be used as a rough estimate of a site's ceramic extent, but can give no spatial information on the variability of the material across the site. The only way to gather credible results from the surface is to search intensively the whole of the possible site's surface and beyond. This usually involves the laying out of a grid based on either square or rectangular collection units. However, in many ways the recording of the distribution of the total ceramic counts across the site is the minimum level of spatial inquiry. As in the question of manuring beyond the archaeological sites, both ceramics and inorganic materials cannot be assumed to concentrate solely inside 'the site'. Also, organic material may be altered due to cultural factors that may be important to either use or part use of the site. It is work within this framework of research that can divide the site hierarchy into something more plausible than a settlement hierarchy based on presumed site size.

6.4 New Wave Surveys and New Specialists

The contribution that can be made by archaeological field survey investigation in Greece is dependent not only upon the quality of the surface evidence, but also on the collaboration of other, non-ceramic, specialists. Perhaps more than any other change of emphasis in Mediterranean surveys, the integration of many different specialists has brought a fresh and realistic approach to problems both old and new. The trend for this approach was however set in Greece by the pioneering Minnesota Messenia project of the sixties (McDonald and Rapp 1972), and has been re-inforced by virtually every large survey since (see Keller and Rupp 1983, Dyson 1982). The exceptions to this are probably the so-called 'one-man' surveys (e.g. Rolland 1983, Fotiadis

1983). However, even the smallest of survey teams often depend upon a broad spectrum of information to interpret the field survey data-base (e.g. Gallant 1982, 1986). Although the trend has been away from the lone fieldworker in Mediterranean archaeology, those who have continued this tradition have, in light of research interests, also changed. The stereotype of an individual traversing the countryside, book in hand, trying to locate sites described by the ancient writers has been replaced by more methodical exercises. The challenge now, perhaps, is for individuals to explore difficult terrain that in previous times would have been regarded as bereft of past cultural remains.

The work of the new wave surveys may therefore be divided into two areas:-

(1) The precise mapping of all cultural artefacts across the landscape (a specific development of the 'New Wave'), and

(2) Collaborative projects with often non-archaeological specialists (a concept typical for most Mediterranean field surveys from the 1960s onwards). The specialists can include statisticians, geomorphologists, sedimentologists, botanists, anthropologists, chemists, geophysicists, etc.

However, although it may be convenient to break down a typical project by such a division, the inferences made from the archaeological survey work can often only be tested with reference to collaborative data and as such the division is an unnatural one. The reverse argument is also true. The change to regional analysis in Greece provided the archaeologist with much needed raw data, at a time when politically and financially the importance of excavation by overseas-based projects was, inevitably, on the decline. Indeed, a reaction has taken place against the purely statistical approach of some of the surveys, especially in terms of surveying poorer soil areas, and also the problem of archaeological inference from surface finds. Although it is natural to agree with the criticism that field survey is not an end in itself, and that there are inherent limitations in all survey work (c.f. Hope-Simpson 1983), it is impossible to agree with the statement that only excavation can solve any interpretative problems.

It is in fact in the area of problematic non-excavation interpretation where the strictly non-archaeological survey techniques may be of great importance. The topic of intra-site analysis has become one of the most vibrant parts of archaeological research (c.f Hietela 1984, Carr 1986, Schofield forth). In Greek survey the problems have been focussed more toward the simple definition of site boundaries for site size determination, than to the identification of functional or structural units within sites (c.f. Gallant 1986). It is perhaps worth noting that Cherry's (1983) strong advocation of field survey in the Mediterranean does not contain any explicit recommendations on the use of intra-site techniques. The new importance of the internal order of small scatters has proved critical, not only to rebuff pessimistic declarations like Hope-Simpson's, but also to emphasize the ability of the survey methodology to open access to vital theoretical issues (see Chapter 8, below).

It is now commonplace to undertake at least some form of intra-site work on most Greek surveys. In many cases this has involved the most basic random 'information' gathering, complete with all its problems. Beyond this crude method of sampling, two levels of sophistication exist. For many this has entailed sampling designs to give some idea of site size and chronological extent, this is usually accompanied with 'grab' samples to give a firmer hold on the chronological element(s) of the site. However, many surveys now have a much fuller policy of total grid collection, although few have the funding or can justify the need to plot accurately the position of every sherd. The prominence of site 'haloes' is becoming an increasingly important problem in the definition of a site. It is primarily because of this phenomenon that non-archaeological methods have to be evaluated. The archaeological potential, in terms of interpretation and assessment, of these new techniques will be of great importance. Traditional methods are at present defining the limits of our inferences rather than the archaeology. For example, pilot studies by one major project has attempted to define the site using phosphate analysis (the Laconia Survey: Cavanagh et al 1988, Buck et al forth). The results have indicated a divergence in the interpretation of site limits between the phosphates and ceramic data. Suitable techniques and methodologies will help solve these problems. However, on a cautionary note, in many cases we will be investigating 'activity' rather than solid cultural remnants. Activity is a particularly difficult area to define archaeologically, and will be equally difficult in the future if incorrect methodologies are pursued.

CHAPTER 7

The Boeotia Survey and the Rural Problem.

7.1 Introduction.

During the 1980s the Boeotian project in central Greece has intensively surveyed about 40 Km^2 of the modern rural landscape (see Fig.7.1 for general survey area). The standard fieldwalking method developed by this project (Bintliff and Snodgrass 1985, 1988b) , is to employ teams of fieldwalkers walking in a line and spaced 15m apart. Transects of land are then walked, with a mechanical counting device used to register all of the ancient objects seen on the surface within a measured distance. The length of the transects are typically 50-100m long, and are usually dependent on the terrain, the frequency of the finds and the ground cover. Each surveyor can be expected to scan a corridor of circa 2-4m.

The variation in the background count of ceramics from area to area suggests that it is impossible to suggest any absolute value above which a 'site' is said to exist. However, from empirical knowledge of a given area it is possible to judge a limit above which the counts are thought to be associated with areas of archaeological interest i.e. a 'site'. Once such an area has been located an attempt is first made roughly to define the edges of the ceramic peak

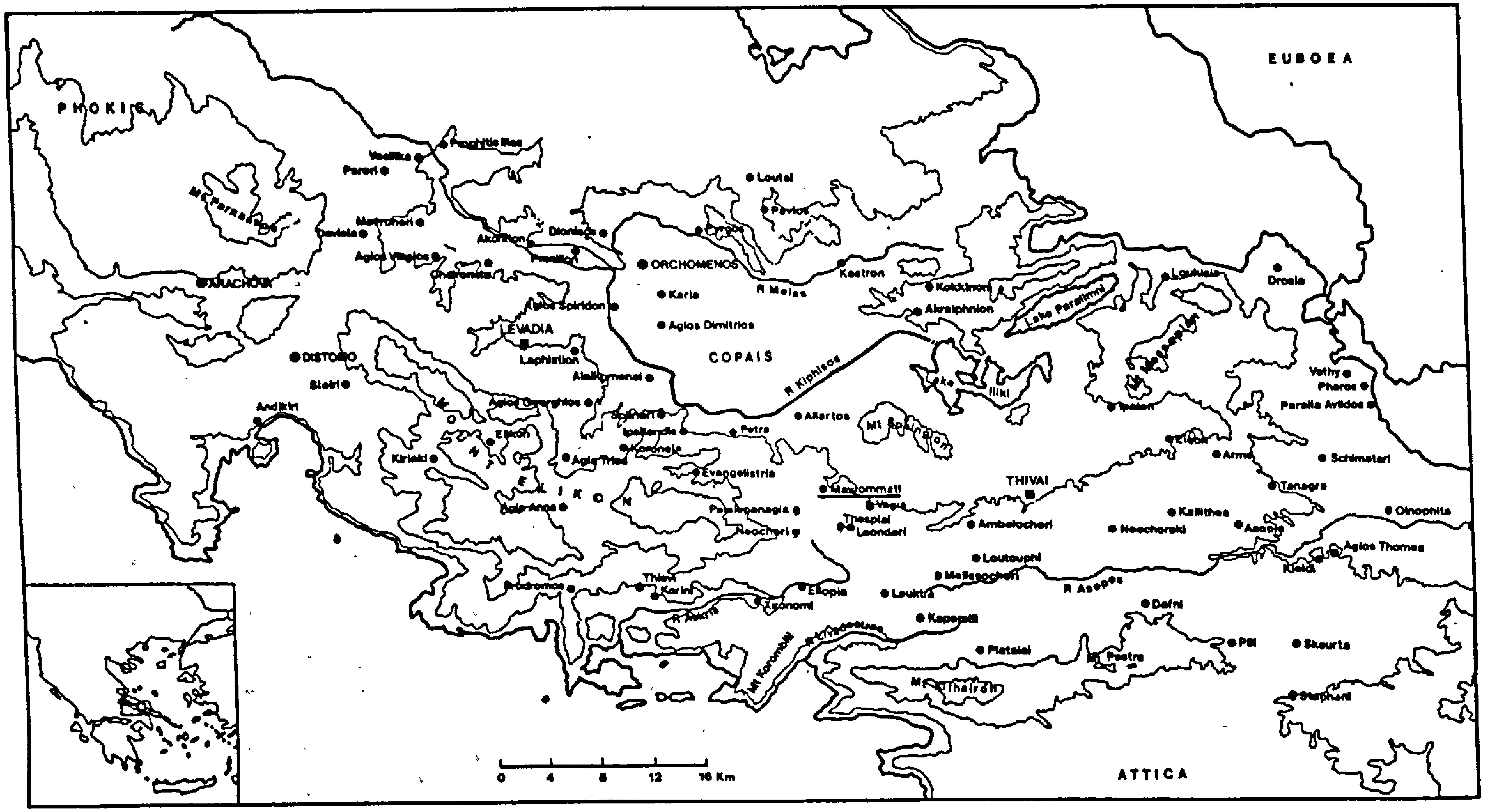


Figure 7.1 The modern province of Boeotia, central Greece. The survey is centred on Mavrommati. (After Bintliff 1985)

using short transects. Detailed information is then collected using contiguous collection units (see next Chapter). When chronological data become available from the collected diagnostic material it is possible to prepare maps that summarise the position and extent of centres of activity across the landsape for each archaeological period.

The nature of survey data, and the longevity of the ceramic material styles and use is such that it is not possible to date surface material with great precision. To circumvent the problems due to chronological imprecision the dating of the sites is in broad time categories. The following chapter will deal with this in greater depth. It is apparent that for the majority of the Greco-Roman period the landscape appears to be densely populated with 'rural' and the occasional 'urban' sites.

For the Archaic-Classical and Early Hellenistic period (c.600 BC to 200 BC), we can see a full landscape (Fig.7.2), which is in complete harmony with the robust picture suggested for the classical Greek civilisation. The interpretation of the majority of these sites has been of small farms intensively working land around each focus, whilst other, less intensive agricultural work, may be conducted further away from the sites. Naturally, these rural sites do not exist in a vacuum; much larger, historically attested settlements are known throughout the survey area e.g. Thespiae, Haliartos, Askra. A number of the smaller sites have also given evidence for special use such as religious sites and cemeteries. However, sites that give

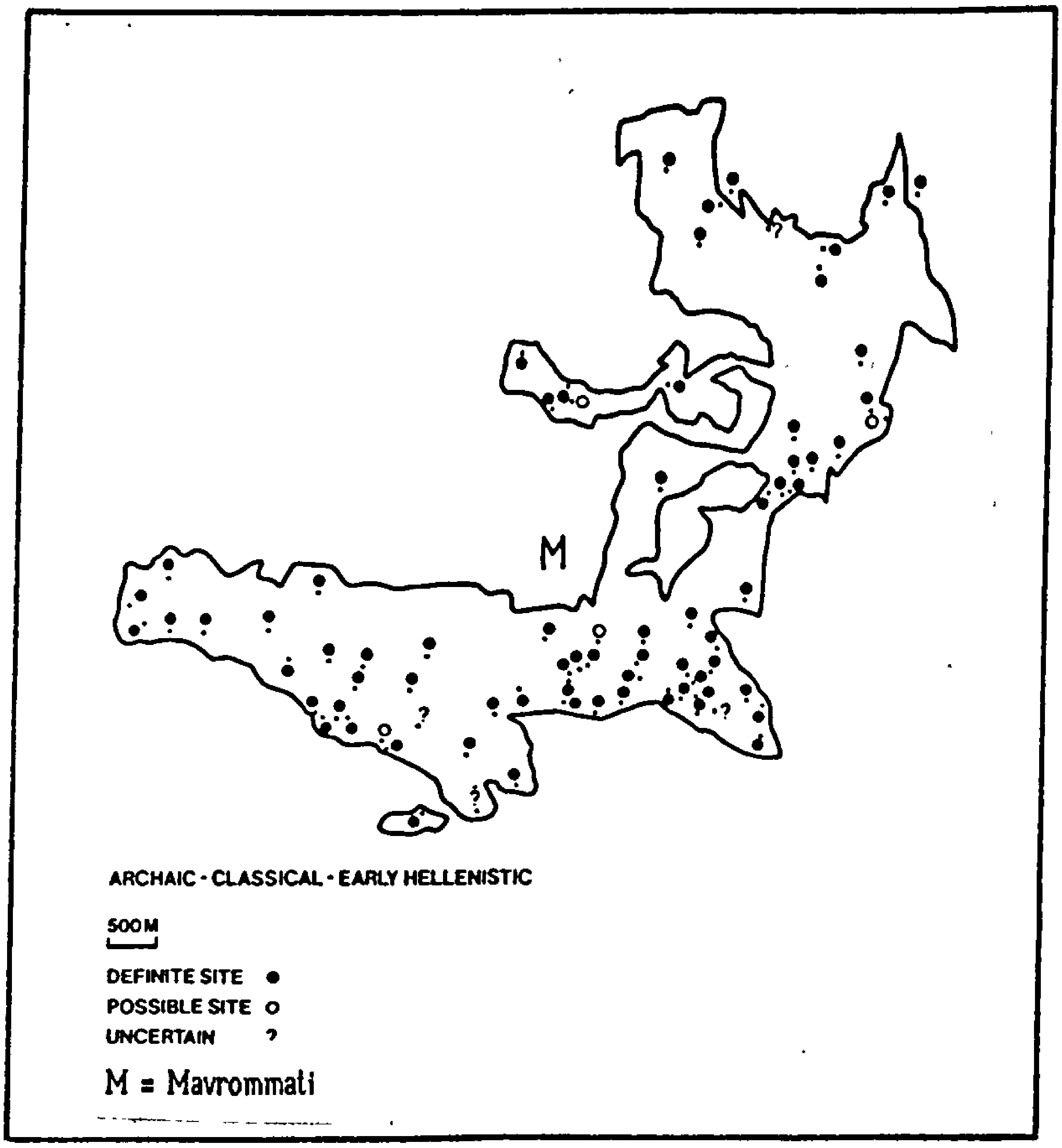


Figure 7.2 Distribution of Archaic - Early Hellenistic sites located by the survey.

(After Bintliff 1985)

clear responses that indicate past function are, due to the nature and the frequency of the tasks carried out on-site and to the ceramic evidence itself, seldom to be found in Mediterranean survey data.

For the Late Hellenistic and Early Roman period (c. 200 BC to 300 AD), survey evidence from both the landscape and townscape points to a great reduction in the number of sites (Fig. 7.3). This apparent drop in the total population for the region fits in well with the previous period being such a florescent time for the Greek city state system. In fact, human utilisation of the landscape during the peak period may have been over stretching the capacity of the well used soils (Bintliff 1985; Bintliff and Snodgrass 1985). The Late Roman period (c. 300 AD to 650 AD) again shows a rise in the number of sites (Fig. 7.4), which are predominantly of 5-6th century in date.

The general picture of the past, recovered from the surface record, is one of boom and decline in both the rural and city components. At the height of the city-state the landscape would have been fully used, with evidence of activity throughout. One of the most important questions is whether the site activity, as described by the peaks in ceramic distribution really represents past settlement. This is particularly important in the case of the smaller sites. Certain factors identified from the site data-base appear to give a positive answer to this question. Firstly, the presence of artefact haloes around most of the sites would suggest an intensive area of farming, which would be in

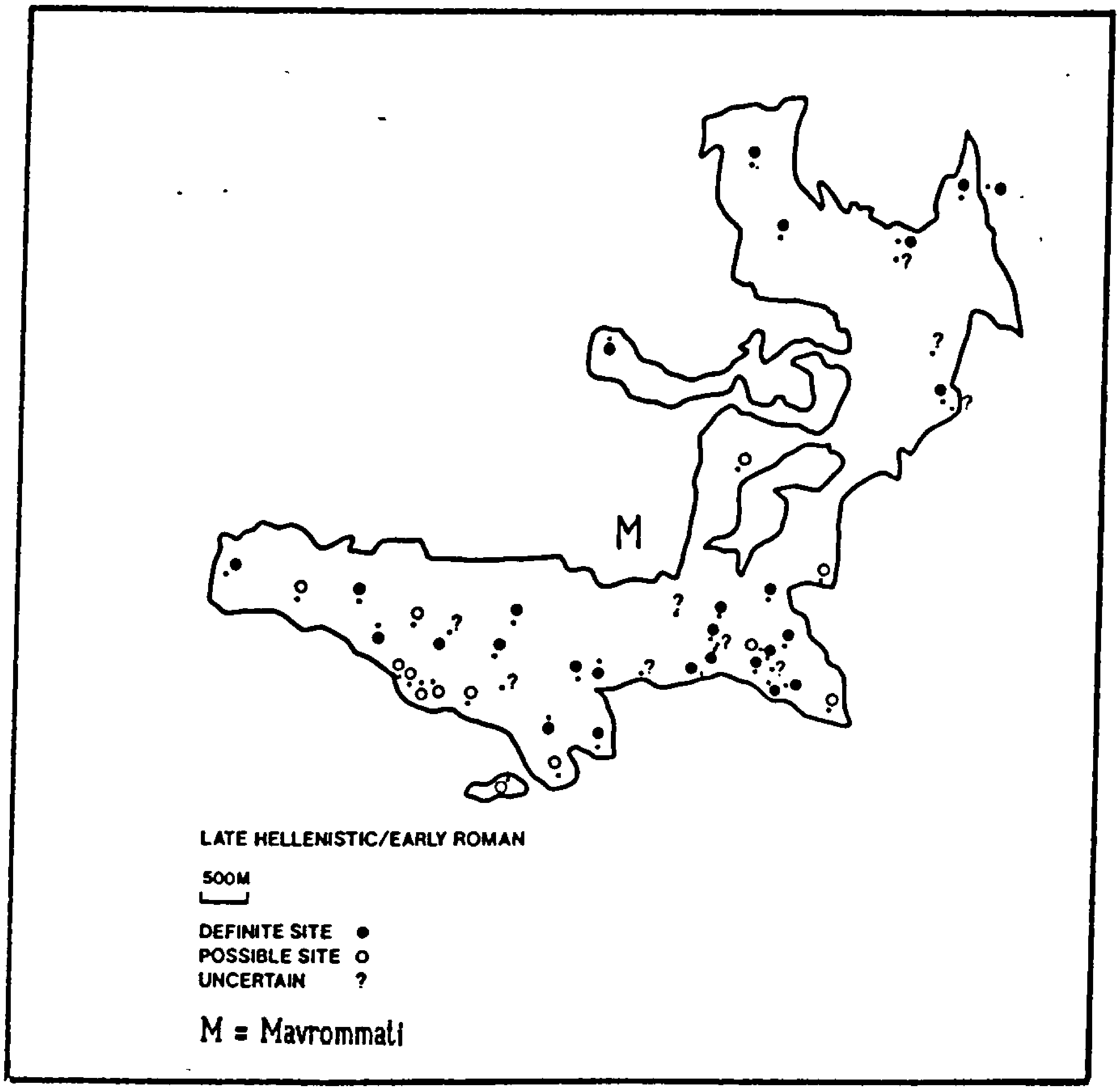


Figure 7.3 Distribution of Late Hellenistic and Early Roman sites located by the survey.

(After Bintliff 1985)

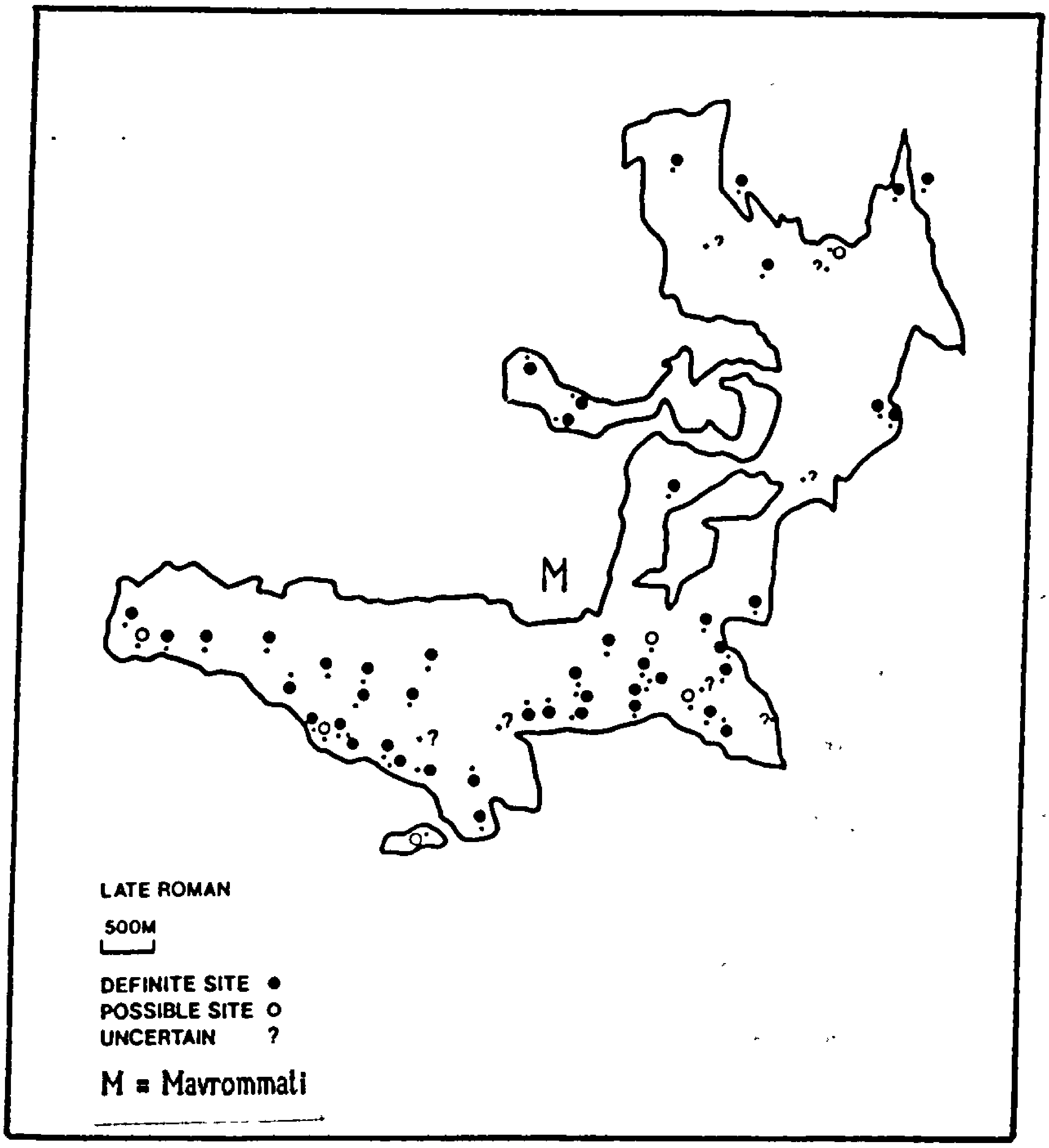


Figure 7.4 Distribution of Late Roman sites located by the survey.

(After Bintliff 1985)

keeping with settled agricultural practices. Secondly, it is inconceivable that ceramics of the quality and quantity that have been located at these sites should be the debris from a system of agricultural sheds. The fact that so much of the surface material comes from permanent roofing material also suggest some massive and permanent investment in the buildings themselves.

7.2 Past work on Greek Rural Landscapes.

A recent summary of the archaeological, literary and epigraphic evidence for Attica has caused a re-think of some of the evidence that has suggested large scale rural population (Osborne 1985a, 1985b). Osborne's epigraphic survey has revealed many contradictory views concerning the 'essential' city life of the Athenians, although the pre-eminence of the city was never doubted. Osborne describes a situation where the rich invariably had some toe-hold in the major settlement in the polis. He notes :-

> "...wealth remained based on the land and that leases clearly indicate that it could be expected that there would be a building of some sort on any substantial plot of land. This building is likely to have been multi-purpose, and certainly not to be considered a 'farmhouse', but for part of the year it is likely to have sheltered the workforce employed on the land, whether that included the landholder and his family or not."
>
> Osborne 1985b, p.127

Osborne clearly and carefully argues the case against the possibility of a mass rural existence based on isolated farmsteads. With increasing confidence he feels able to disregard the term farm with connection with the sites in his area, only occasionally admitting to the direct evidence of economic activity in the form of 'beehive sherds', olive presses or threshing floors. Even then the 'isolation' of these sites is deemed not appropriate. Whilst an argument can be formulated against the criteria Osborne chooses to apply to the sites, for example rooms so small that only animals would be housed (the 'Lauter' House ibid p27; Lauter 1980), or the existance of other economic/pedological factors, the case for the farmsteads is not proven.

The archaeological evidence, such as exists, appears to support the written evidence, with few small rural sites known in the Athenian 'chora' or territory. It could be argued that the sites are clearly of a different character to the Boeotian sites. On the other hand, this is probably a function of the one-man surveys that have identified the majority of the more obvious sites in the evidence from Attica. The sites from Attica show far more signs of wealth than any of the sites in Boeotia. However, they still appear to lack any archaeological evidence that would prove year-round occupation (Jones et al 1973). Although the excavation evidence for year round occupation is rarely conclusive, other factors such as the position and size of the settlement may also be used to argue for some sort of seasonal use for the villa. Interestingly, the evidence for specialisation at the Vari villa, where the role of beekeeping was fundamental to the interpretation of the site, suggests a large investment of time at the villa, no matter how seasonal.

Whilst the archaeological evidence described above may be meshed with the surviving Attic epigraphy and literature without great difficulty, it is obvious from the results of the most recent surveys in Greece that the data-base elsewhere can be, and usually is, radically different. Although the lack of modern site survey in Osborne's region (exempting the recent German S.W. Attica Survey, Lohmann (1983, 1985)), means that the archaeological evidence could be illusory, the total picture for Attica still provides a contrast with the information gathered by modern intensive surveys for other regions. Indeed, prelimary evidence from the Lohmann surveys suggest a previously unrecorded landscape in Attica. The sites contain the full suite of small agricultural farm buildings, including threshing floors and evidence for water control. The surviving field systems suggest an intensive use of the countryside, by permanant residents in the farms. As nearly every intensive survey in Greece mirrors the rural landscape as described in Boeotia above (Cherry 1983), the evidence from Lohmann surveys would appear to be in total agreement with other modern surveys.

Despite the plethora of evidence for the existence of small sites, there are very few published examples of excavations on such sites. The paucity of excavated and published farmsteads in the Greek world may be accounted for in two ways. Firstly, until recently the legacy of Greece has been viewed by archaeologists and related academics within an art-historical framework (Cartledge 1986; Snodgrass 1987; Gibson 1985). A result of this policy has been that excavation has investigated rich unique sites, rather than the more mundane, yet more prolific 'rural' sites. Secondly, much of the evidence has been collected using excavation methodologies that are now regarded as less than adequate; in most cases only the ground plan of the sites survive, along with a note on the presence of the largest economic indicators, such as fragments of olive presses.

However, three case studies are particularly important in the study of rural Greek farm sites. The first study comes from the Sounion area of South Attica. In 1956 Young investigated the ground plans of six "tower like structures" and compared them with similar structures in the Greek world. After dismissing several fanciful interpretations for the structures, he suggested that the towers formed part of a country estate 'package'. The structural components of the estate are a tower, a court and a house. The idea of an estate is further enhanced by the recognition of a field wall, apparently containing 20 ha of land surrounding the Cliff Top Tower. For Osborne, in his general study of Attica, the enclosure of a quarry and two mines within this area postulates a reason for the site's position. The need for industrial gain, therefore, outweighs the strong bond between man and town.

Despite the closeness of the mines and the siting of the sites on often poor ground, a practical farming interpretation still seems valid. With some of the alleged site-sizes appearing similar to the Boeotian data-base, the data suffer only from being confined to the plans of upstanding monuments. The data have general application throughout Greece, and would benefit from a modern reappraisal. In particular, the information that could be retrieved on site-size could be highly relevant to surface surface studies. Also, the positioning of these sites is very important. The fact that they are not situated on the best agricultural ground suggests that the logistics of farming such a well defined territory could be theoretically mapped, again influencing the interpretation of other agricultural systems identified by surface survey.

A major synthesis that is particularly relevant to rural studies involved the mapping of 'homestead farms' in the Crimea, which came under Greek influence in the sixth century B.C.. In identifying and defining 'homestead farms' Pecirka importantly dismisses the class-conscious bias of ancient and modern classical scholars.

> "It is immaterial whether the living quarters were
> occupied by the owner, by a tenant, or by free or
> unfree labourers."
>
> (Pecirka 1973, p.115)

Instead as Pecirka points out

> "...we must also take into account the social and political aspect: the status and wealth of the landlord, of the tenant and of the workers, in connection with the fact that all political activity was concentrated in the town and that not all social groups would or could take part in it.
>
> (Pecirka 1973, p.119)

Pecirka's own assessment of the evidence of isolated rural settlement in the Classical period was that it was not a common phenomenon in Ancient Greece, but at times could, indeed did occur. By the Hellenistic period many favourable technical and economic conditions may have resulted in increased rural settlement. Again, Percirka notes the survival of farm sites with towers, but does not assume that all towers have an agricultural function, nor do all farms have towers. In the chora (territory) of Chersonesos an ancient landscape of ruins has been preserved that covers over 10,000 ha (i.e. 100 km^2). The farms are arranged in two systems; in the smallest and oldest system, at Lighthouse Point, about 80 farms were recorded, each covering on average about 4.5ha of land. This quality and quantity of evidence for land division associated with mapped farmsteads is almost unique in the Greek world, and clearly indicates an early form of land division (Boyd and Jameson 1981).

Clearly there is ample evidence for the existence of farms in ancient Greece outside of the Attica area. Indeed, enough evidence now exists within the region of Attica itself to show just how productive the classical landscape was. As noted above, publications by Lohmann (1983, 1985), have shown that by the intensive scouring of now uneconomic lands in South-West Attica there is a wealth of small working farms from the Classical period. The upstanding remains lie in ancient terraced fields and show ample evidence of fulltime agricultural occupation. For example the site at Hagia Photini 2 shows that the agricultural buildings (complete with tower) were associated with large scale terracing and water control. There was also primary agricultural evidence such as an olive press and a large semi-circular threshing floor which were still surviving (Lohmann 1985, Fig.11). The quality of these remains is due to the positioning of the sites on marginal land; it is thought that these lands may not have been used intensively during post-Classical times and have therefore avoided the ravages of the plough. As this limestone and schist area was always easy to exhaust it is difficult to understand why these buildings were situated in this type of location. Lohmann (pers comm) has suggested that the location was probably due to the exploitation of extensive pockets of good, schist derived soil.

7.3 Small surface scatters and intra-site geophysical prospecting.

Given the fact that very little new evidence is forthcoming from excavation, what then is the role of geophysical and other related survey techniques in the investigation of small localised scatters? As has been shown in the three case studies above, the local tradition is to build structures or at least foundations in stone. This form of structure, along with the substantial threshing floors usually offers a large contrast to the surrounding soils and is therefore ideal for detection using the resistivity prospection technique. Resistivity survey in the Mediterranean does have some major problems during the hot summer months, but still provides a surer way of assessing buried structural remains than magnetic prospection, due to the general lack of magnetic contrast between local stone and the surrounding medium. The evidence from all of the direct archaeological work suggests that it would be improper to investigate only the largest of structural elements at rural sites as a host of activities appear to have taken place on these sites. The resistivity survey ought therefore to be used in conjunction with other techniques to try firstly to pin-point the site of any activity and then to try to assess what sort of activity was practised.

It is hoped that the fusion of geophysical techniques with basic archaeological data can offer new insights into the problem of settlement and activity that have produced the small ceramic scatters that are so common in modern intensive field survey. In the case of the Boeotian sites, many of the presumed settlements are away from marginal land and offer good conditions for geophysical survey.

CHAPTER 8

Site Investigation on the Boeotian Project.

8.1 Primary site investigation

When an area surveyed using the field walking technique produced anomalous readings above the local background artefact level, then the suspected area would be investigated using smaller transects. Once the approximate edges of the ceramic scatter had been roughly identified, the delimited area was surveyed using specific site procedures.

The site investigation usually involved the surveying of the whole site in small spits with a standard minimum block size of 10x7.5m. Using this area as a standard unit, a count was made of all of the ceramic objects within each individual 10x7.5m block. With a field team of four, at any one time a larger area of 4 units (10x30m) would be laid out. Any 'feature', or indeed fabric, sherd that might be chronologically identifiable through a diagnostic feature such as a style of rim or fabric is also collected and 'bagged' within the larger block i.e. the 10x30m area. Within each area an assessment is made of the ground conditions on a scale of 0-10. 10 represents perfect ground visibility with no vegetation cover, whilst 0 represents the poorest conditions, where none of the soil surface is visible. This parameter is measured to assess any possible anomalous ceramic counts within the data-set. Each site is then conventionally surveyed, noting the relief of the land and the position of modern field boundaries.

8.2 Site choice for secondary investigations.

The major contribution that the use of geophysical prospection could give to the investigation of the small Boeotian sites would be the elucidation of any ground plans associated with a ceramic scatter. This would incidentally prove that the surface assemblages were associated with buried structures. In reality, there was little doubt of this connection, as a large percentage of the ceramic count was known to be due to the presence of roof tiles.

As the sites under investigation are, by definition, at least partially plough damaged, it is important to choose which sites to survey very carefully. Experience of field survey conditions in Greece has suggested that the following three criteria are important in this decision.

(1) Sites that contain large, relatively unabraded ceramic material on the surface may be indicative of recent deep ploughing. The reason why this may be crucial to the choice of sites is the fact that the sherds are large, and this suggests that they have been disturbed infrequently. In such a case it is more likely that the relationship between

the material on the surface and the original buried archaeological context would be a more direct one.

(2) Sites that have complex overlapping chronological data are prone to distortion due to secondary and even tertiary re-use of the same areas. Although single period sites are something of a rarity in the Boeotian database, it is possible to select sites with a reduced time span. The quality of the surface data on short-period sites should be of the greatest spatial clarity.

(3) The research design followed in the secondary intra-site investigation on the Boeotian project was based on the premise that for a great number of sites geophysical prospection, due to the degree of preservation, or rather destruction, may only give information of reduced quality. In fact, it is argued that in order to gain vital information that may help indicate any functional aspects of a site, the geophysical information must be viewed in conjunction with other aspects of a site's archaeological character. This approach involves the use of a battery of techniques that will obtain a series of complementary signals from a site.

As has been described above, in the Mediterranean area a site is often defined as a high concentration of ceramic sherds on the soil surface, a classic monothetic determination. Using a secondary 'battery' approach to some of the sites it was hoped that the ultimate end point would be a polythetic site definition. Such a definition would help to assess similarities and dissimilarities between sites, and this discussion should rise above the simplistic level of site size and relative chronology. The components considered as part of a secondary approach by the Boeotian project may be seen in Table 8.1.

The methods of intra-site variation chosen by this study may be broken down into two types. For convenience these may be labelled direct or indirect methods. For this research a direct method is one that measures a value that has some direct cultural significance e.g. the counting of tile sherds, or the spatial distribution of worked stone. The indirect methods are those which measure naturally occurring properties that have been changed via cultural activity e.g. resistivity data, trace element levels.

Table 8.1 A summary of the types of techniques used in Boeotia.

TECHNIQUE	TYPE OF MEASUREMENT
Ceramic count	Direct
Tile count	Direct
Rubble Plan	Direct
Resistivity measurement	Indirect
Magnetic susceptibility	Indirect
Magnetic viscosity	Indirect
Trace element analysis	Indirect

One important interpretational factor linking both the indirect and the direct techniques listed in Table 8.1 is that measurements taken from the topsoil, rarely reflect isolated cultural instances. For example, geological or topographical problems may always be expected to blur any man-made patterning. The fact that certain techniques may occasionally measure similar aspects of the site is important in terms of clarification of hypotheses and research design. To put this in some perspective, Carr (1982) has argued that the changes in chemical and physical conditions in an organically enriched soil may give changes in resistivity. On archaeological sites where the form of pedological alteration involves the incorporation of organic residues of anthropic origin within the soil, physical and chemical changes in the soil occur jointly. The resistivity will decrease if chemical and physical alterations complement each other, and increase if the alterations oppose each other. Carr has argued that changes in nutrient and humus levels and the resulting changes in resistivity, could be used to identify use areas within simple earthern sites. Such changes could be measured using a number of techniques. Indeed, for a particular technique there may be more than one method capable of measuring the required changes i.e. the Barnes Layer method for cancelling the effect of part of the topsoil in resistivity measurement (Barnes 1952) was not the only technique/method available, but was thought to be the most suitable by Carr. However, resistivity does not simply measure habitation type changes, such as were present in Carr's sites, but also the contribution from structural elements. Therefore, due to the presumed presence of major structural features, the Boeotian sites are even more difficult to investigate using this 'explanatory' method. Due to the overlapping products from a complex archaeological situation, the use of a battery method approach to measure many attributes from a site and involving many different techniques would, therefore, seem more appropriate in this case.

Of course, in field survey there is always the constant problem of measurement distortion due to post-depositional factors. Although this is often a constant factor, its effect can be variable across a landscape, or even a site. Whilst work will undoubtedly continue on this vital research topic, the chosen measurement unit used in this research for the second stage of intensive investigation is compatible with computed values for surface studies (i.e. Cogbill and Lane 1985). It is hoped that this unit size, whilst chosen as a convenient sub-unit of the geophysical grid, will also act to minimise any 'noise' caused by post-depositional factors.

8.3 Procedure for secondary, on-site investigation.

Once a site had been chosen for further work, a grid on which the battery techniques are based was set up in the field. A Twin-Probe survey would be carried out where appropriate, and then followed by a Schlumberger survey in both axial directions, as indicated at the end of Chapter 5. Where appropriate, soil samples would be collected at 5m intervals across each 20m grid, giving 16 sample points per grid. The soils were then measured for their magnetic susceptibility and viscosity, and were later analysed for a series of trace elements. The trace element analysis was done by Prof. Brian Davies and Andy Waters. If there was judged to be a significant amount of putative building material on the soil surface then a plan would be made to show the distribution of the material. Which techniques were used depended upon two factors:-

(1) whether it was felt that the conditions were correct for a particular technique e.g. the limitations of resistance measurement on recently ploughed fields were noted.

(2) a limitation, inevitably, was due to the late implementation of new ideas and techniques, which could not be used on sites previously surveyed. Therefore a technological change may be seen in the data set, with more

techniques being used on more recently discovered sites. Although studies in the field survey environment are "reproducible", the short time available for the field work meant that little time could be allocated to revisiting old sites.

8.4 What do we measure and why?

Working on the premise that a polythetic site definition or function is feasible, it is possible to suggest a large number of parameters that could be measured. However, it is inevitable that the parameters chosen must be limited due to time, cost and most importantly the specific research questions being asked. It is this link between archaeological theory and practice that defines a framework for success. In this research it is important to assess the behaviour on site that might give rise to physical or chemical changes that could be measured 2000 years after the site was used.

Inevitably, the chronological resolution that is lacking in surface survey means that the parameters that we choose to measure are one of two types. Firstly, we can try to measure actions that are often only carried out once with one major outlay of energy, but leave solid, durable remains, such as house or kiln production. Secondly, we can measure those actions that are repeated many times at a site, and are the product of the function of that site e.g. long-term industrial processes or regular middening of waste material.

Whilst it is acknowledged that the interpretation of the evidence for the latter actions is often the most contentious, it is still within the possibility of archaeological research design to combine a number of techniques that will measure past actions.

From our knowledge of past work on rural settlement and evidence of economic indicators from traditional field survey it is possible to suggest what activities could have taken place on these ancient sites. Firstly, and foremost, due to the nature and quality of the ceramic evidence we would expect some signs of permanent building structure within the area designated as the 'site'. This should be confirmed by :-

(a) Tile Counts. Wherever possible the site was gridded out in 5x5m squares and the quantity of tile roofing material within each unit was counted with the help of a mechanical counting device. It is argued that well defined peaks in the data can then be equated with roofed structures (Gaffney and Gaffney 1986). Occasionally, this information could be used to design subsequent research steps e.g. as in the case of site TPW2 (section 8.5, below).

(b) Geophysical Prospection. It is clear that the actual building structures, which in known cases elsewhere to have been found built at least at foundation level of stone, should be detected using the resistivity technique (e.g. Lohmann 1983, 1985; Pecirka 1973). A question that this research has asked is whether the Schlumberger is any better suited than the Twin-Probe array to the detection of stone walled structures beneath ceramic scatters. This assumes that the structures may survive to some degree the destructive tendencies of the plough. This qualifier is particularly important in field survey, as the sites are discovered because they are partially plough damaged. In the small scale surveys whose discussion will follow, the reason for doing the surveys was not always to see if a complete plan of a rural settlement could be obtained, but to see if any larger structural elements still exist. Especially interesting are those elements that may be linked to chronologically differentiated areas of the site. Patterning of the latter is very hard to describe on many of the Boeotian sites due to few datable sherds having been recorded.

Although the Twin-Probe resistivity array was used most often, its function was primarily as a quick method to check out a large primary area. Where appropriate Schlumberger surveys were used to confirm particular features of the site or, alternatively, on one occasion it was used as the major subsurface investigator.

(c) Building Rubble. Again, from the larger building structures one would expect to see evidence of local worked stone brought to the surface by the plough. The recording of this material can be very time consuming. This evidence was recorded on only a small number of sites to verify a rough image that was suggested by a visual scan of the field. The 5x5m grid that was used for the tile counts was also used for this measurement, although an actual plan was usually made of the individual items rather than a bulk count.

None of the three items listed above will really give any clear information on the regular activities that could have taken place on a particular site, unless a particular type of plan could be traced from the resistance results. To identify this form of activity we must use techniques that can measure cultural alterations of naturally occurring properties.

(a) Magnetic Susceptibilty. The magnetic susceptibility of a material is simply the ability of a material to be magnetised. The magnetic susceptibility, X, is defined as the ratio of the total induced magnetic moment or magnetisation per unit volume to the strength of the applied field. Due to the difficulty in producing standard volumes of soil, the measurements taken in this research were for mass susceptibility. Topsoils tend to have higher magnetic susceptibility than the subsoils from which they are derived. Le Borgne (1955, 1960) explained this in terms of the conversion of weakly magnetic forms of iron oxides to more magnetic forms. That is, haematite is first reduced to magnetite and then reoxidised to maghaemite. Le Borgne suggested two mechanisms for this . Firstly, there is the effect of burning on the soil, which can be produced from domestic contexts. Secondly, there is the so-called fermentation mechanism, which is produced by the rotting of organic matter under specific aerobic conditions. Although the first mechanism has been well documented in laboratory conditions (c.f. Graham and Scollar 1976, Le Borgne 1955), the second process has not been successfully simulated. For this research, therefore, we would expect to interpret any positive results as traces of processes that would have required any great heat e.g. domestic fires or industrial processes. In all of the following cases soil samples were taken every 5m over the major grid, and the soils were air dried and sieved before separating into 50g samples.

(b) Magnetic Viscosity. The magnetic viscosity is simply the measure of how long it takes the magnetic domains in a material to realign along an external field. The out-of-phase component of the susceptibility was measured using a laboratory based Pulsed Induction Meter (PIM), the viscosity being calculated as the out-of-phase measurement as a percentage of the quadrature component. As archaeological industrial samples have been found to have high susceptibility and low viscosity, then measurement of magnetic viscosity could help identify the function of a site that had been suggested by magnetic susceptibility measurements. The soil samples used for the susceptibility measurements were also used for the viscosity determinations.

(c) Trace Element Analysis. This is a particularly interesting new line of intra-site research (Davies et al 1989, in press). Modern evidence has shown that wherever people work or live the concentrations of heavy metals rise in adjacent soils and these accumulations may survive for a long period of time. In short there is a 'habitation' effect where both industrial and domestic site occupation can give rise to heavy metal contamination of soils (Davies 1978). At this stage of research it may be that the amount of metal on a particular site may be more useful as an inter-site comparison, rather than the intra-site spatial aspect. Hopefully, this situation will be rectified when more analyses have been completed on a range of sites. The trace element evidence given in this thesis comes from a larger project based on the Boeotian material and supervised by Prof. B. Davies of the Environmental Science department, Bradford University and Dr J. L. Bintliff of the Department of Archaeological Sciences, Bradford University (see Davies et al forth.). Whilst much of their pilot study was to try to see if the ancient residuals were still present on the larger regional scale, their most recent work is now based on the same grid as the rest of the secondary investigation work. The later material can be analysed in the same way as the other intra-site material. Although a whole suite of trace elements were measured, only Cu and Pb were highlighted in this thesis. It is felt that these are particularly important for identification of habitation affects. Initial work involved the assessment of regional means via a number of transects. These values were used used as indicators of enhanced trace element levels.

8.5 A summary of the techniques used on the Boeotian sites.

As was mentioned above, it was not possible to do every technique on all of the sites. The field work was limited to two three week seasons, only during the second of which was the full Schlumberger set-up available. A summary of the techniques used on particular sites is given in Table 8.2.

Table 8.2. A summary of the use of techniques on the Boeotian sites.

	TECHNIQUE							
	CERAMIC	TWIN	SCHLUM	MAG	MAG	RUBBLE	T.E.A.	TILE
	COUNT	SURVEYS		SUS	VIS	PLAN		COUNT
SITE								
MPA2	X	X		X				X
PP17	X	X	X				X	X
PP27	X	X	X	X			X	X
VM64	X	X	X	X	X	X	X	X
VM70	X	X		X		X		X
VM89	X	X	X	X	X	X	X	X
VM95	X			X			X	X
TPW2	X		X	X	X	X	X	X
TPW11	X			X	X			X

SITE CODE: MPA2

DATE RANGE: Classical-Hellenistic

DATE RECORDED: 1981

TECHNIQUES: Ceramic count; Twin-Probe; Magnetic Susceptibility.

This site was located in 1981 using an early form of the Boeotian surface survey method. As can be seen from Fig.8.1 the site is a typical small site apparently covering an area of approximately 60x40m. MPA2 is an unusual site as it is a clear ceramic peak situated in a very low density of background. Despite the large count of ceramic material over the site, the actual number of diagnostic sherds was very low. Nonetheless, the site is very closely dated to the Classical period. The approximate area of the site was divided into six grids, which produced the Twin-Probe results in Fig.8.2a. The results show a large high resistance anomaly stretching through grids 2,3,5 and 6. The magnetic susceptibility samples show an enhancement of this property, roughly coinciding with the outline of this anomaly (Fig.8.2b.). Within the area of the 'structure' is a relative high susceptibility by comparison to the exterior.

The latter patterning, and the problems of explanation of

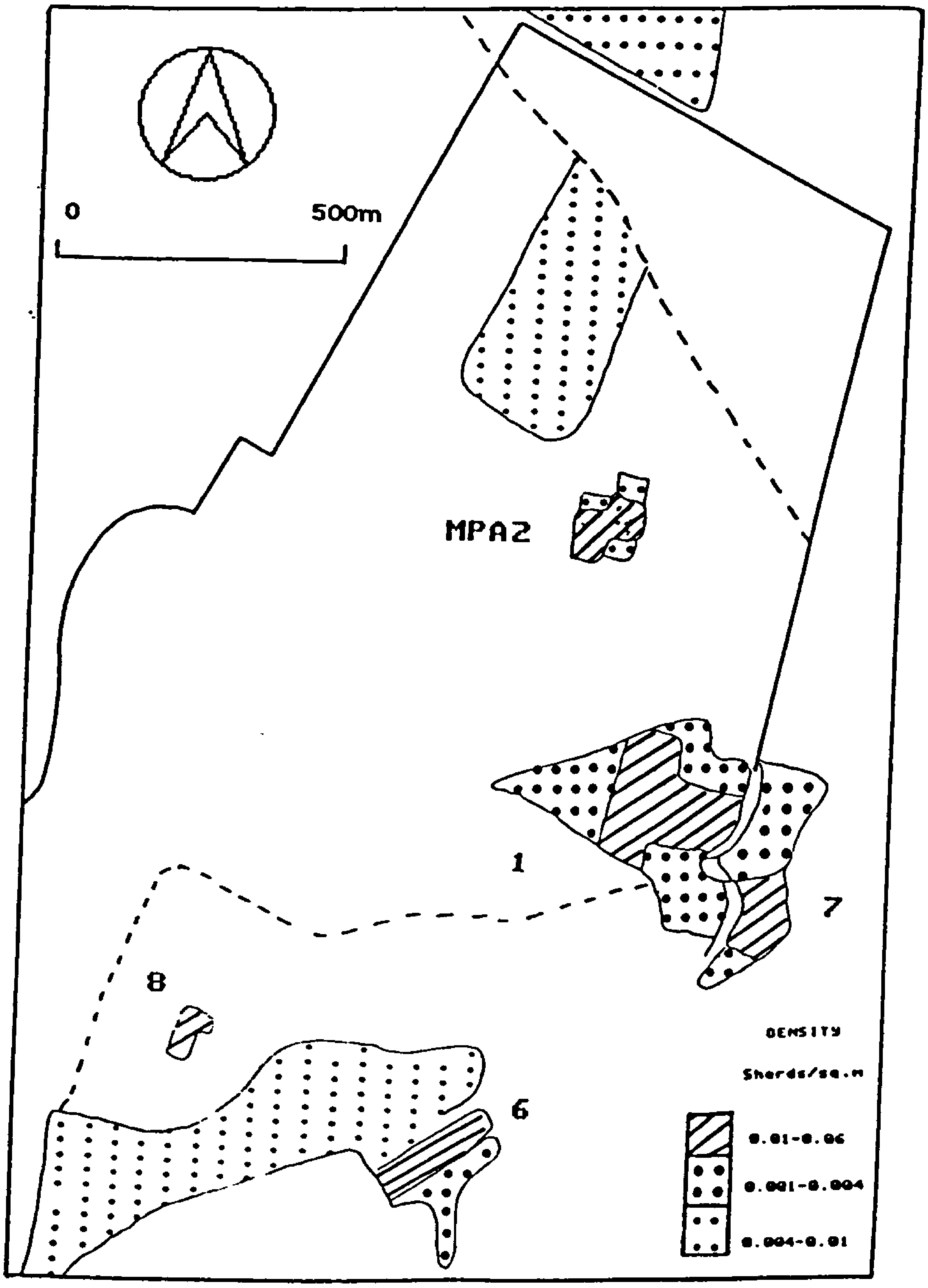
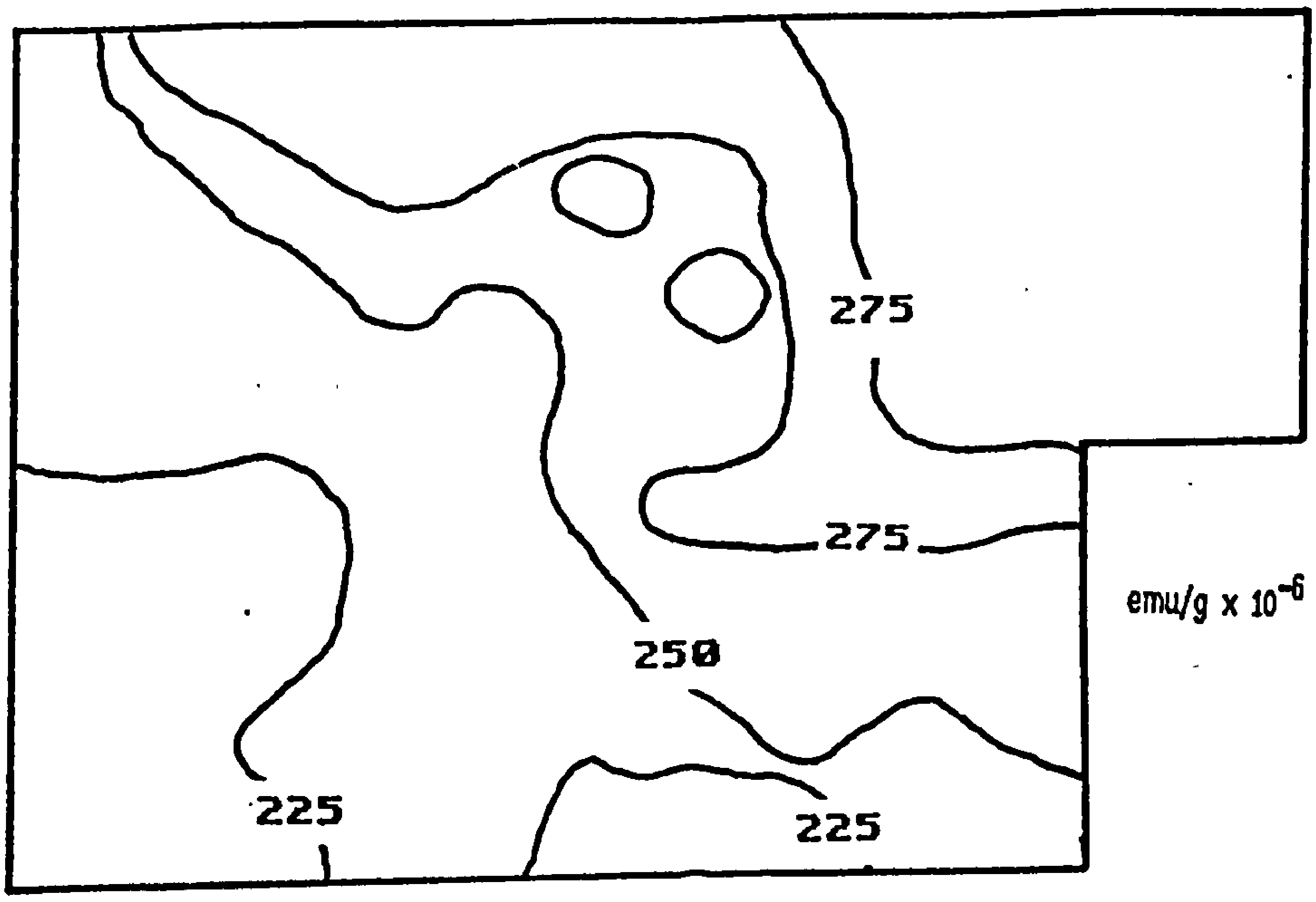
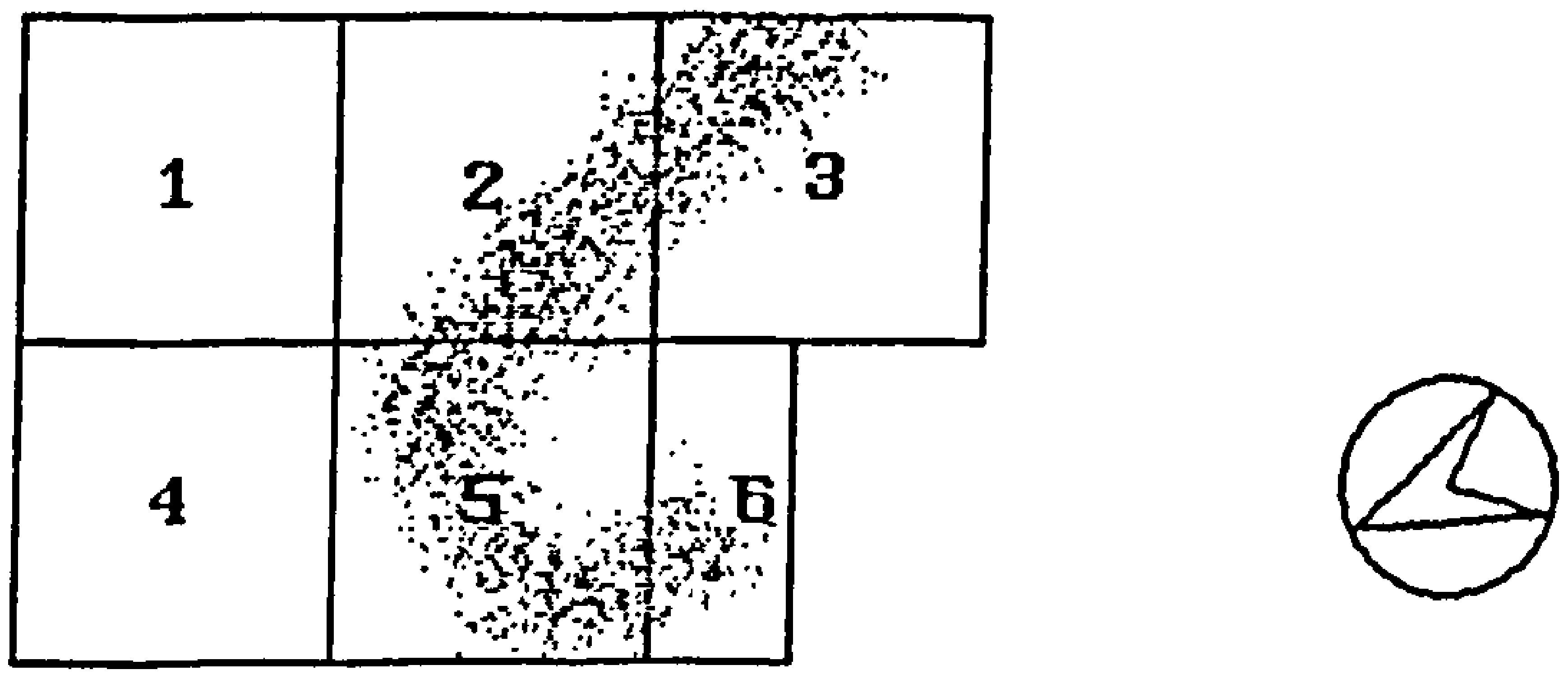


Figure 8.1. Sherd densities in the vicinity of MPA2.

0 The magnetic susceptibility from MPA2. 60m





Grid numbering and tentative interpretation

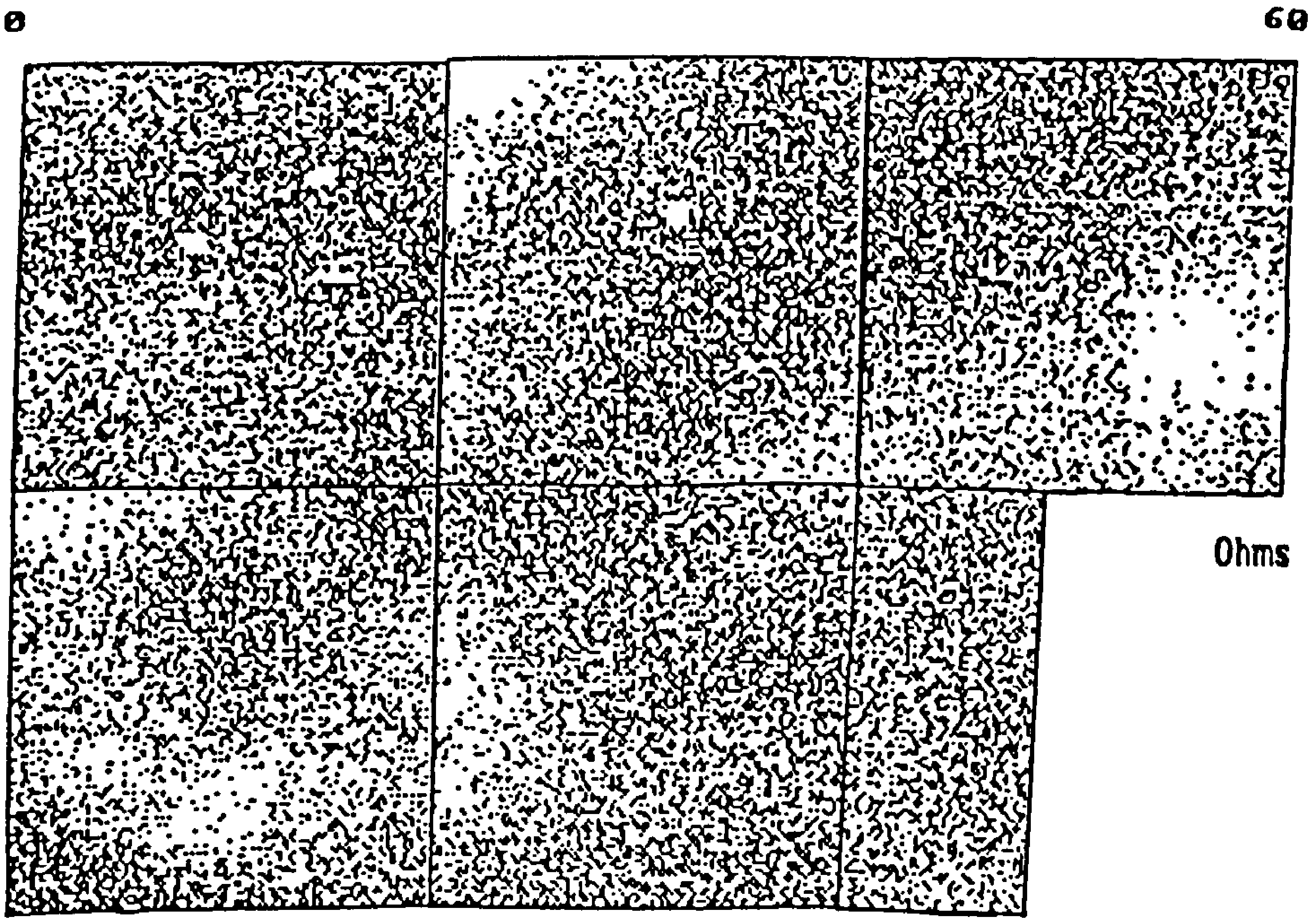


Figure 8.2 Twin-Probe resistance from MPA2.

such patterning is unfortunately characteristic of intra-site study on the Greek sites. In short, the coding of the information often reveals the large gaps in our interpretative capability, even when viewed with the other archaeological evidence. On this site the supplementary information is very limited, despite the fact that the resistivity survey proved valuable. This is principally due to the lack of resolution in the original ceramic method. The inability to define closely the site edges proved a hindrance in decision making for the other studies. Whilst in sherd density terms the site contrasted very clearly from the background noise, the extensive transects were too coarse to identify useful areas for further study. In general, however, there is some agreement between the ceramic peak and the information from the secondary investigation (see Fig. 8.2). A result is that the resistivity and, hence, the magnetic susceptibility surveys do not necessarily cover the best possible area for the intra-site analysis.

Whilst the conditions were good for studying this unusual site, it was decided that a return trip would not be undertaken. This was due to 'shooting-practice' by the landowner. This severely curtailed the secondary investigation, whilst speeding up the Twin-Probe survey.

Conclusions of analysis at MPA2.

The limited tests available on this site have not particularly helped to explain the true nature of this site. Indeed, there is a hint that this site could provide a good case study if further work was undertaken at the site. However, the interpretation of the survey over this portion of the site is highly debatable, with the secondary evidence merely highlighting future research questions. The magnetic susceptibility, although definite peaks are prominent on the site, merely suggests that the overall values are high by comparison to most topsoils. Whilst it is possible that the modern intensive agriculture used on the site may have contributed to the spatial patterning of the susceptibility results, the fact that the resistivity survey does locate some apparently archaeological features suggests that the plough damage is not great.

In terms of the overall interpretation of the site, very little may be said apart from the validation that a possible stone structure is associated with the ceramic scatter. The imprecision of the early intra-site work means that the precise association cannot be identified. The unavailability of the land for future work resulted in this site producing a confusing picture of possible associations. Further work on the site might resolve many of the problems associated with the analysis.

Table 8.3 MPA2. The date of the diagnostic material.

	DATE			
	C-H	H	Prehistoric	TOTAL
SAMPLE				
4.5	1			1
4.6	1	2		3
4.7	3			3
4.8	2		1	3
TOTAL	7	2	1	10
'GRAB' SAMPLE	5	1		6
TOTAL	12	3	2	16

The ceramic evidence appears to indicate a small site with a relatively tight chronological time span.

SITE: PP17

DATE RANGE: Hellenistic-Early Roman

DATE RECORDED: 1984

TECHNIQUES: Ceramic counts; Tile counts; Twin-probe; Schlumberger; Trace Element Analysis.

This site was discovered in 1984 and sampled with a series of eight 10x30m samples. Again, the site was defined by a number of very high ceramic counts. The intensive collection on this site showed evidence for major occupation during the Late Hellenistic and Early Roman periods. An important observation was that the relatively short life span of the site and the fresh, unabraded character of the large ceramic sherds indicated that the site was likely to be relatively undamaged by plough action. Furthermore, the diagnostic material suggested that the site indicated a minimum interference from other periods. A result of these ideal conditions is that this site provided a most complete analysis of a farm establishment. The relationship between the grids used by the different techniqes may be seen in Fig.8.4, whilst its association with the 'landscape' indicated by the field survey data can be seen in Fig.8.3.

The results from the Twin-Probe (Gaffney and Gaffney 1984), although blurred by the presence of vegetational changes, give a good representation of the plan of a buried structure (Fig.8.5.). The buried structure, B_1, was apparently surrounded by an enclosing wall, C_1, whilst two

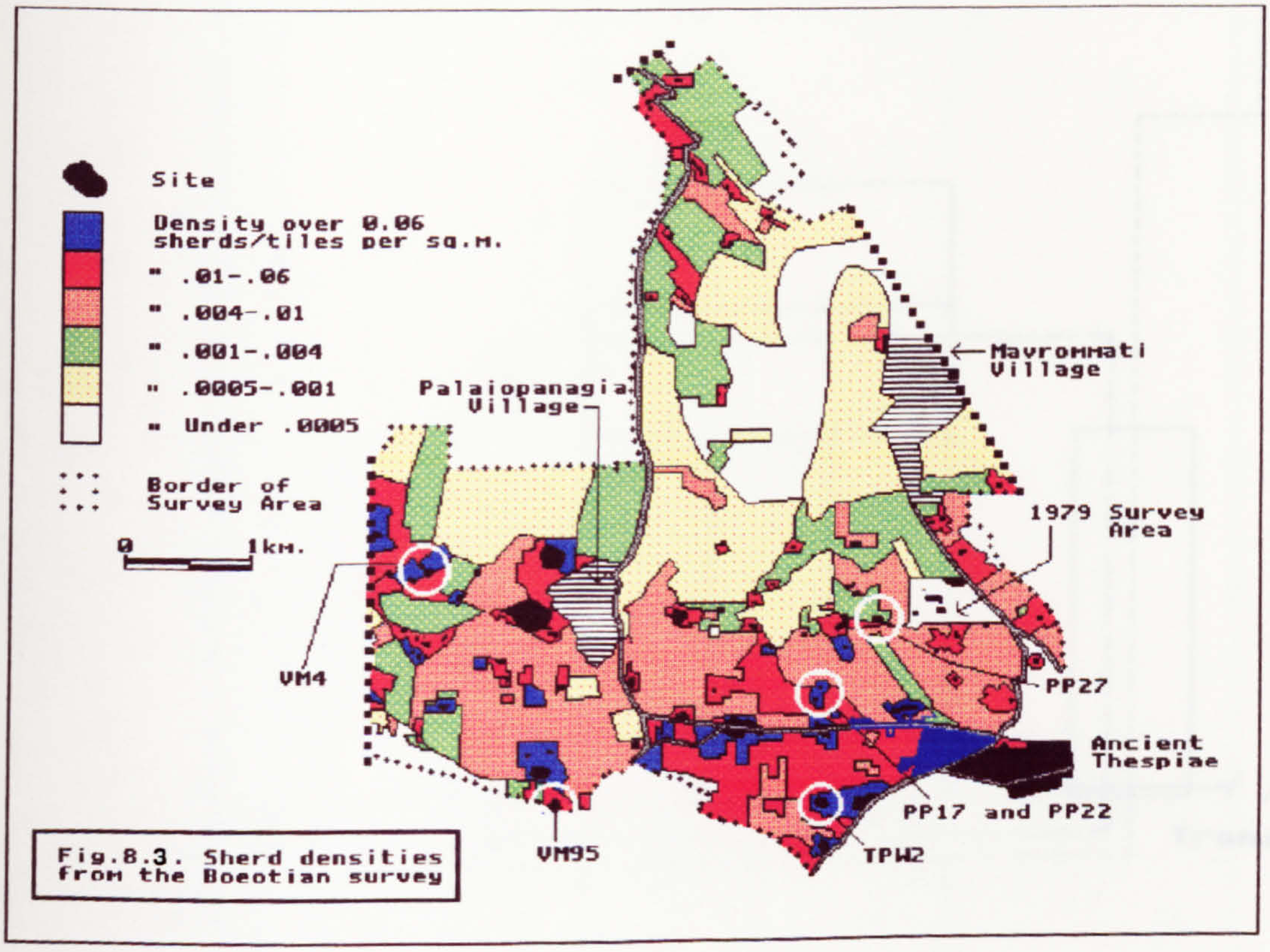


Fig.8.3. Sherd densities from the Boeotian survey

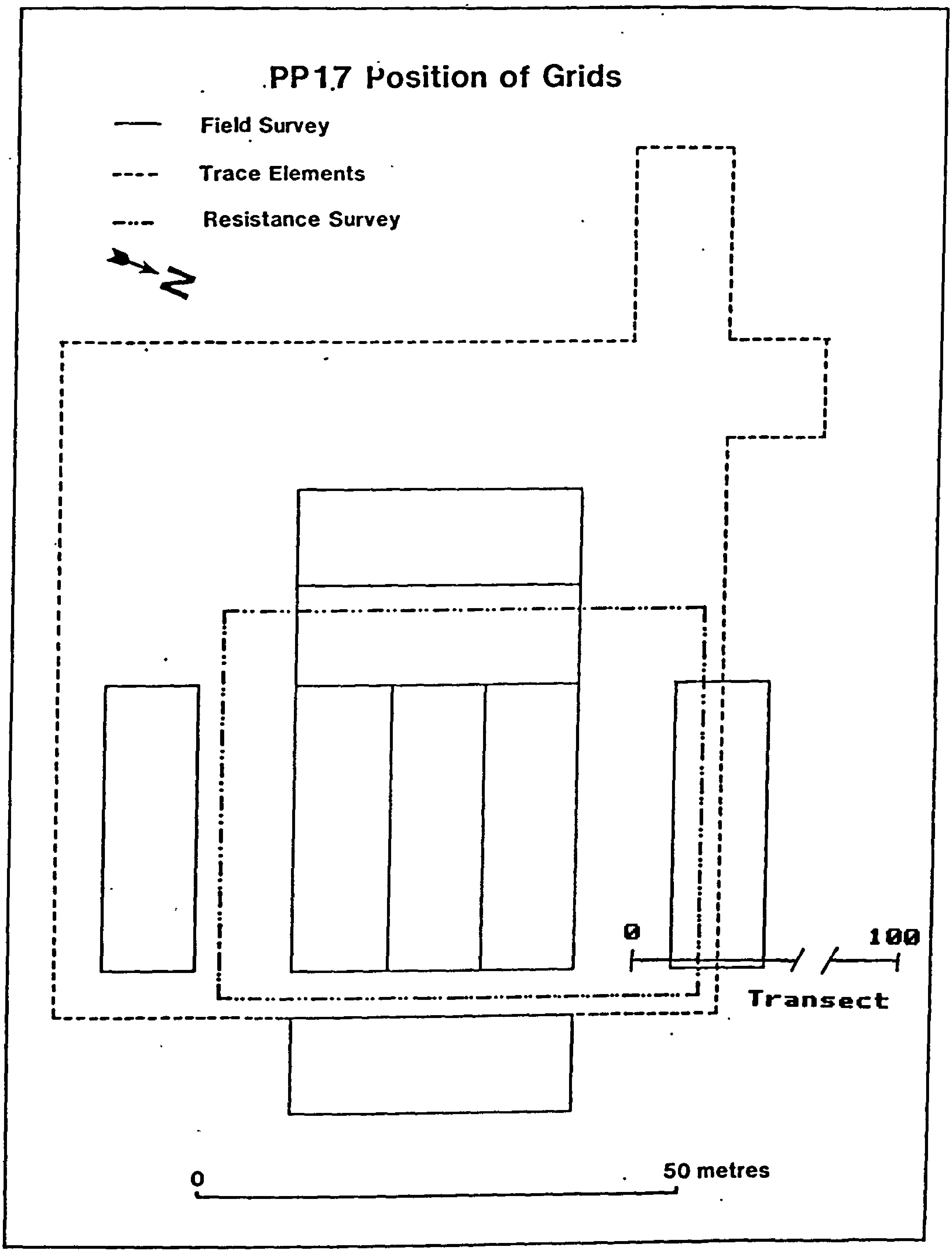


Figure 8.4. Site PP17.

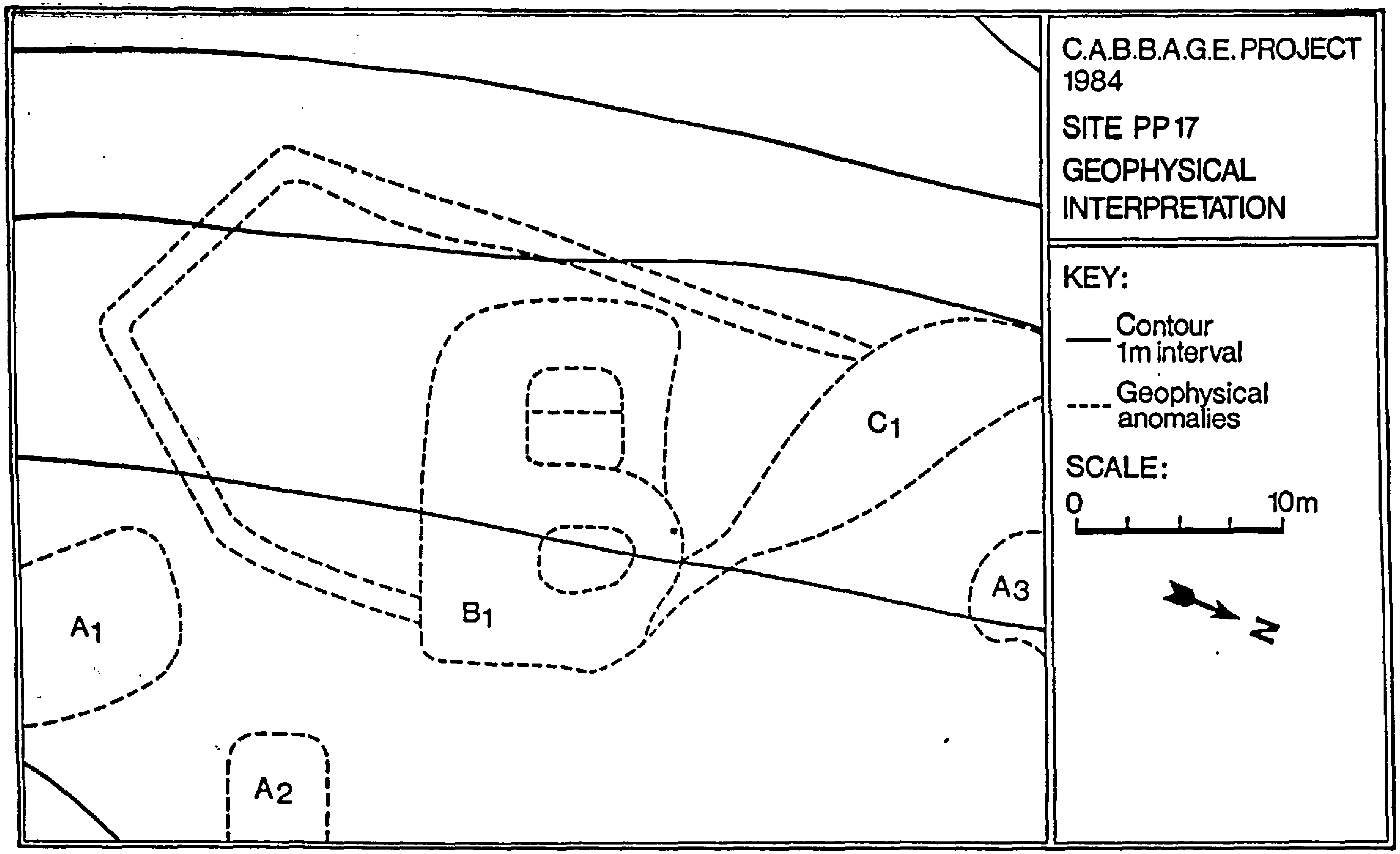


Figure 8.5 Interpretation of the Twin-Probe survey from PP17.

other high resistance features, A_1 and A_2 were not readily explainable from the geophysics alone.

By comparison with the other archaeological components, it was clear that there was a marked coincidence between the peak in tile material and a possible two roomed structure located by the Twin-Probe survey (Fig.8.6.). Indeed, it is clear that the major peak in general ceramic evidence is situated uphill of the buried structure. This probably reflects some form of refuse dumping, whilst the tile is indicative of primary use areas. The anomalies at A_1 and A_2 may, therefore, be explained as middens relating to the formal refuse disposal that is suggested by the ceramic distribution. An implication for survey methodology in the Mediterranean is that one must realise that the location of a site could be by the identification of refuse areas, and not primary use areas. The uncritical use of such information for the quantification of site size, for example, must be avoided at all cost.

The information gathered by the Trace Element Analysis has also proved illuminating, with the relationship with the geophysical grid shown in Fig.8.4. The Trace Elements suggest that at least two elements were well above the regional background. This is thought to be due to a 'habitation' effect (Davies et al 1989,forth. Fig.8.7). The lowest copper content at PP17 was 8.4 mg/kg compared with a regional mean of 5.7mg/kg and a regional high of 12 mg/kg. The lowest lead concentration at the site was found to be 22 mg/kg, whilst the regional mean was 6.6 mg/kg. This was initially

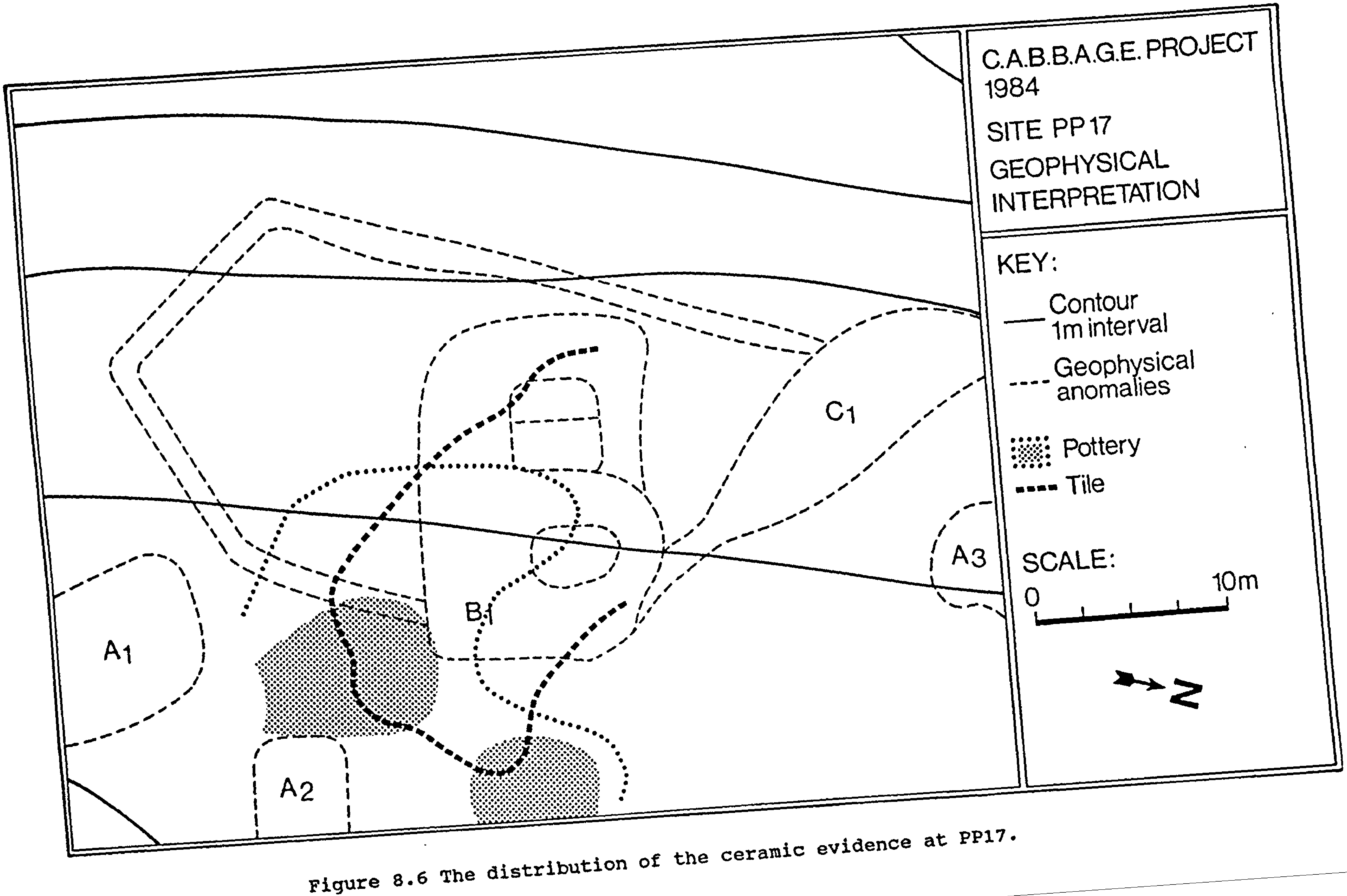
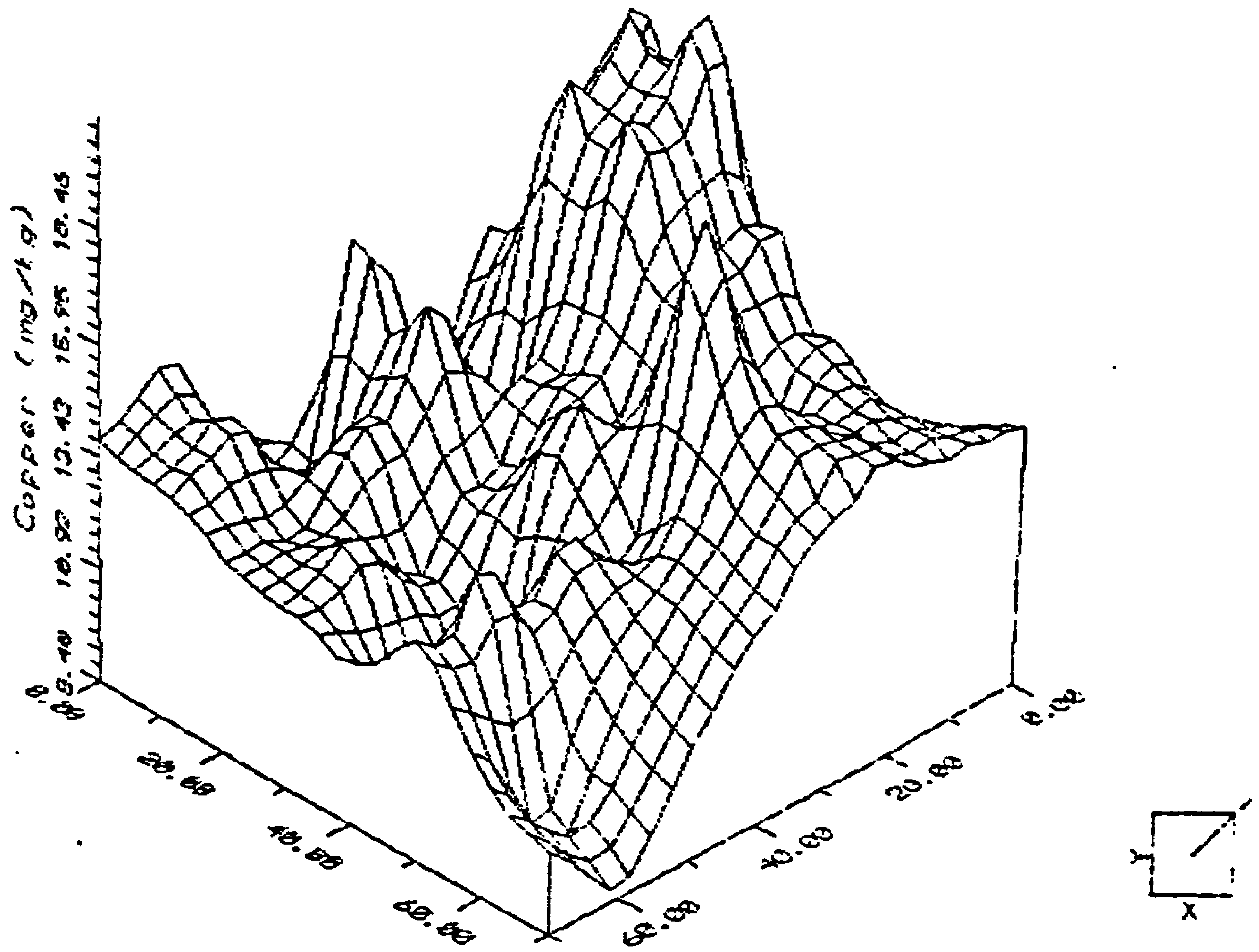
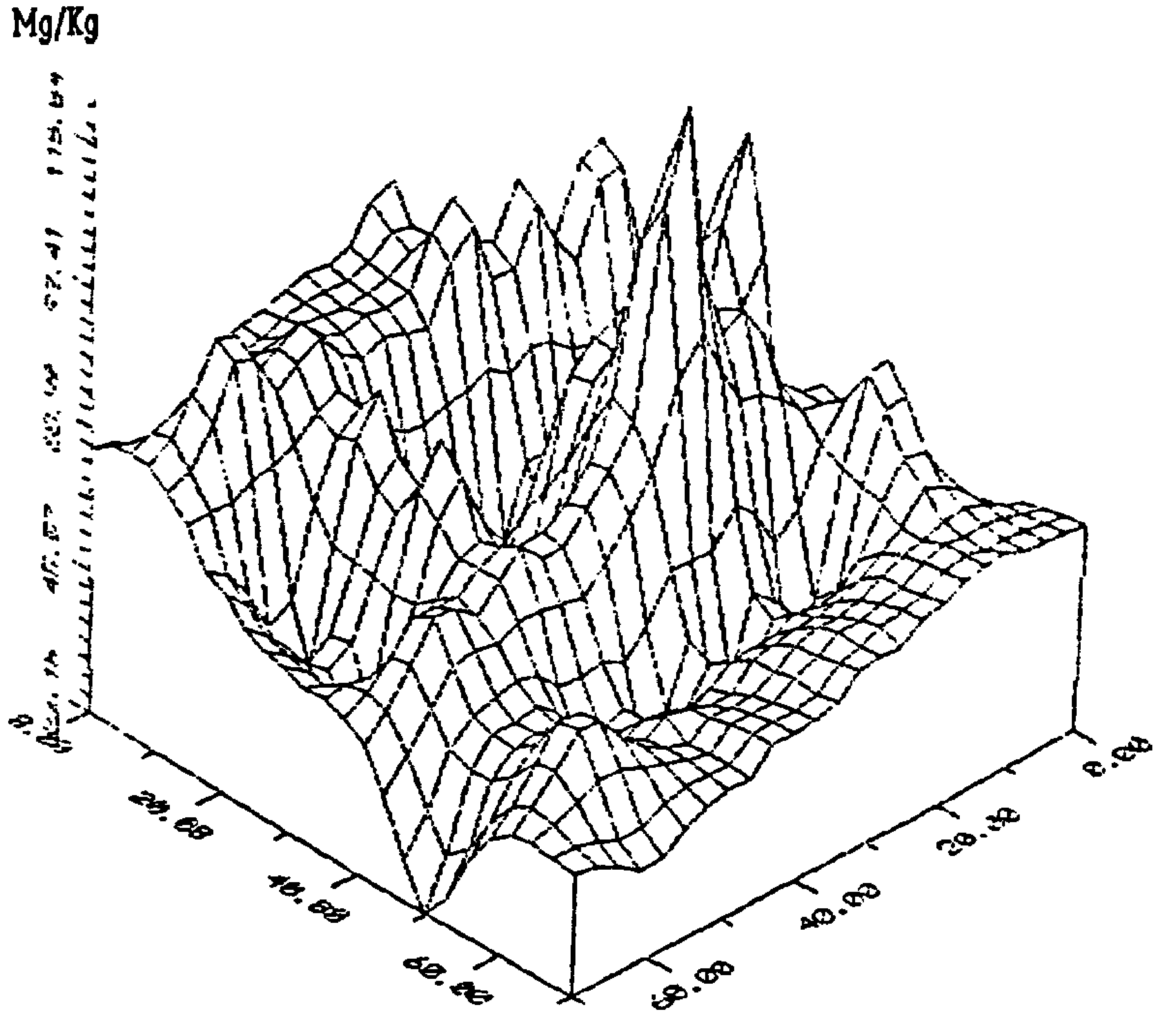


Figure 8.6 The distribution of the ceramic evidence at PP17.



SITE PP17 COPPER



PP17 LEAD

Figure 8.7 The distribution of Copper and Lead at PP17.

considered to be due to an accumulation of lead from petrol vehicles using the road at the site. Later wider sampling around this site suggested that modern petrol vehicles were not the cause of the build up (Fig.8.8). Both the susceptibility and the viscosity show a decrease away from the site, with a major increase 100m to the north. The accumulation of copper and lead are best interpreted by the 'habitation' effect noted by Davies (1978). In particular the copper has a major peak over the buried structure, whilst the lead more or less 'rings' the structure (Fig.8.9.). Whilst this apparently differential accumulation of the trace elements is probably due to behavioural variations, research still has to prove exactly what sort of archaeological activities may be represented by such variation.

However, it is also clear that the evidence from the trace elements is suggesting a wider area of human activity than that defined by the other techniques. Recent results of phosphate analysis in Greece show a similar 'non-site' trend with, perhaps, both techniques measuring activity rather than core habitation. Alternatively, some massive post-depositional changes could be smearing site material off-site. This could have the effect of producing a non-site characteristic. However, in the case of the results from the trace elements, the latter explanation would seem unlikely as there is a known regional level for each element. Consequently, we are seeing site definition criteria that would be based on activity rather than structural evidence. Therefore, these overall enhanced values for both of the

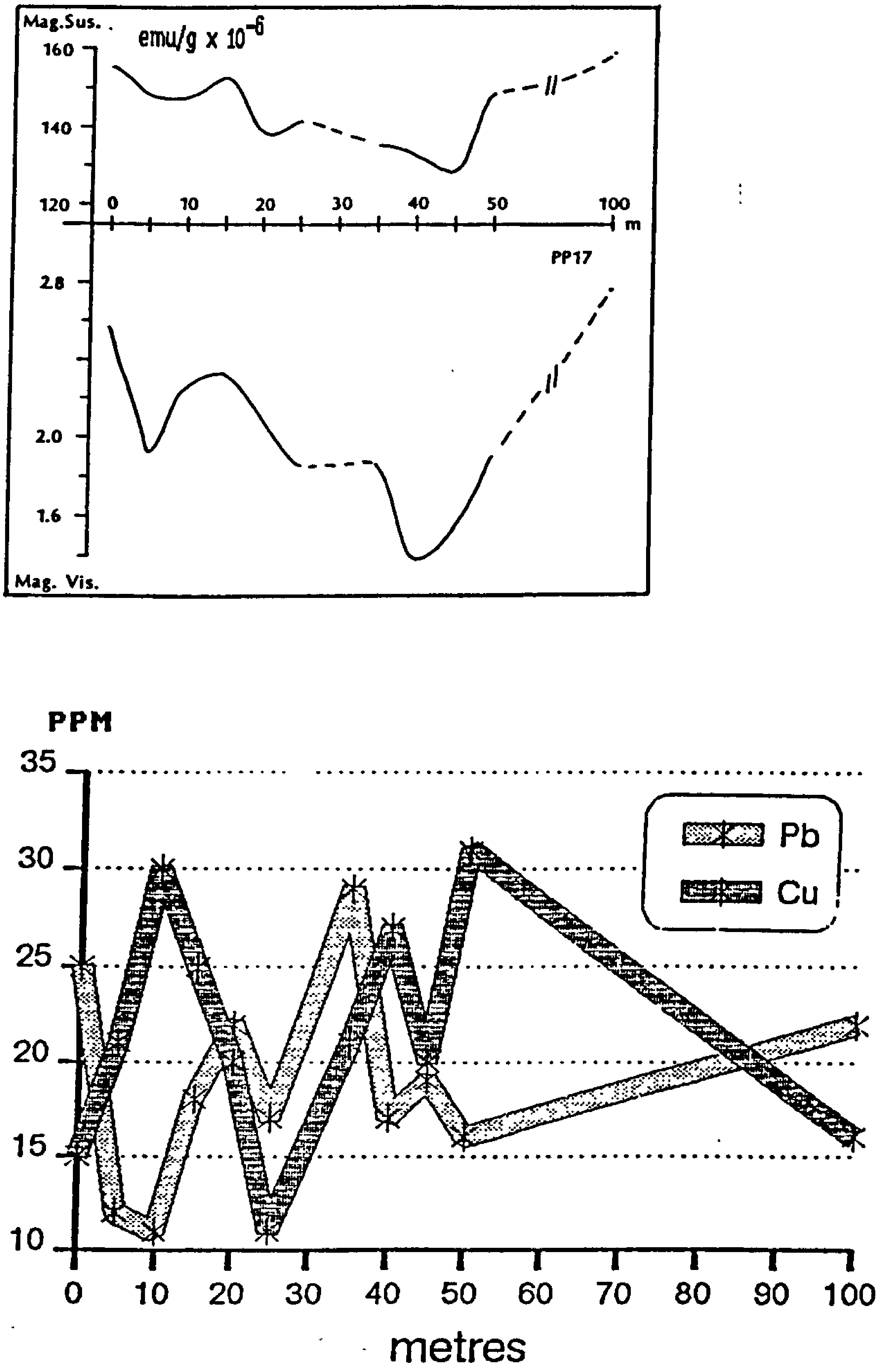


Figure 8.8 The Trace Element and Magnetic components measured in the transect at PP17.

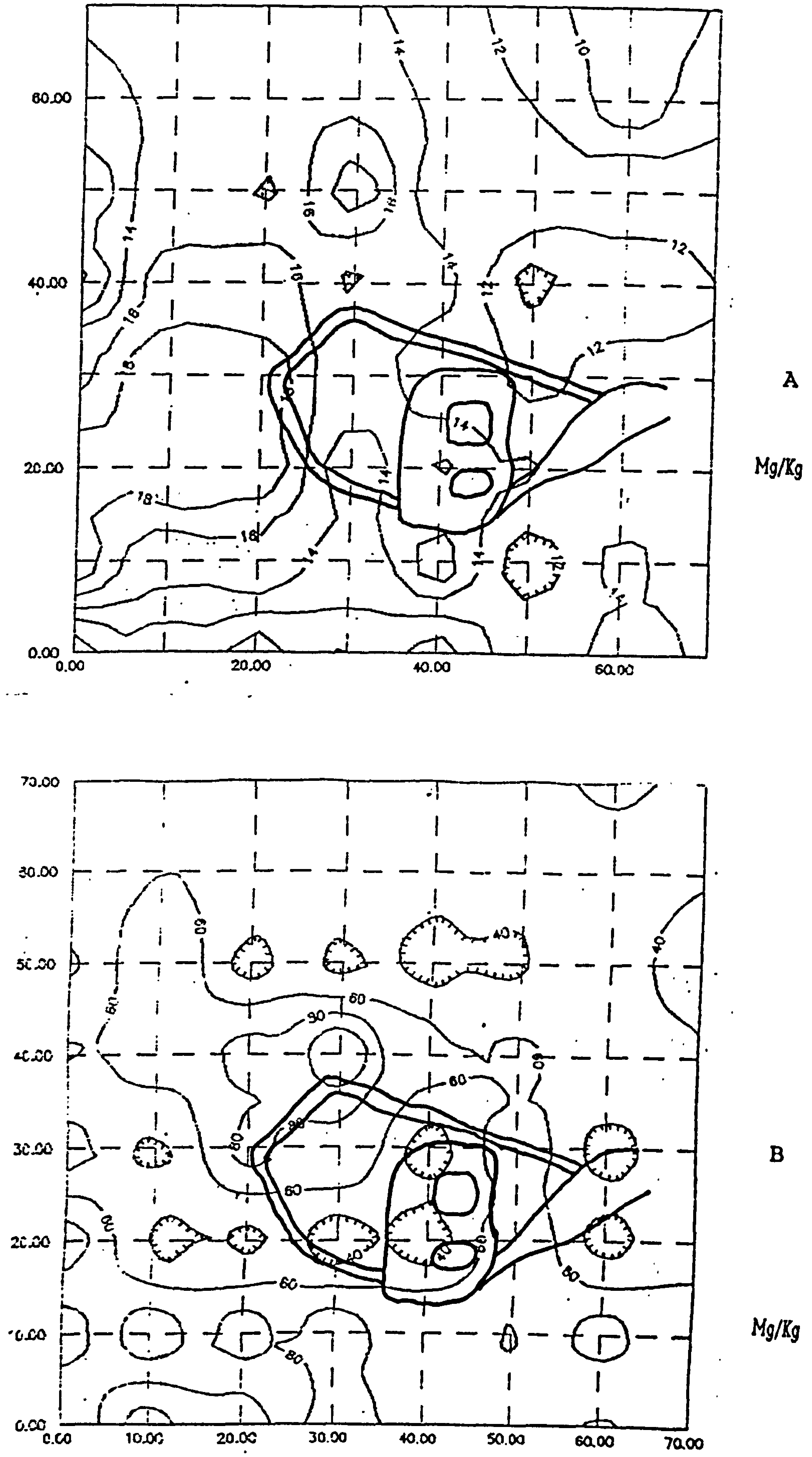


Figure 8.9. The geophysical interpretation and the distribution of A) Copper, and B) Lead.

elements may be further linked to the 'halo' effect around the site. Indeed, further analysis of the ceramic counts at PP17 reveals that the site is part of a broad continuum of high ceramic counts focussing on the 'site' (see Fig.8.3). The combined analysis from all of the available evidence has suggested that an intensive infield activity was based on the farm, and probably indicated the use of animals, rubbish deposits and specific manuring activity.

Table 8.4 Date of diagnostic material for PP17.

Sample	Ceram.	C-H	H	LH	H-ER	ER	R-LR	TOTAL
				DATE				
1	1120	1	4		15	2		22
2	975			3	5		1	9
3	376							0
4	33							0
5	259		1		3			4
6	155				3	2	2	7
7	43					1		1
8	36		1					1
TOTAL	2997	1	6	3	26	5	3	44
'GRAB' SAMPLE				5	10	2	2	19
TOTAL	2997	1	6	8	36	7	5	63

SITE: PP27

DATE RANGE: Early to Late Roman.

DATE RECORDED: 1984

TECHNIQUES: Ceramic count; Tile count; Magnetic Susceptibility; Trace Element; Twin-Probe; Schlumberger.

The area which was delimited by 13 sample units, is probably not an accurate representation of the whole of the archaeological site, PP27. This is due to a change in vegetation from ploughed soil in the southern part of the site, to a shrubby area covering the supposed northern limits of the site. The northern area was not surveyed using the intensive surface survey technique as the remains had not been exposed by the plough. A resistivity survey was not attempted here either due to the compact nature of the soil. The spatial patterning suggested by the ceramic samples was also followed closely by the tile distribution. The latter distribution also peaks in the northern part of the sampled area. The Twin-Probe survey provided some structural information, although the survey also had to be kept to the ploughed area of the site, as the uncultivated land was too hard to insert the probes. Initial interpretation of the Twin-Probe resistivity results indicated that the area surveyed was indeed only part and not the whole of the site.

A discrepancy exists between the northern edges of the secondary sampling grid and the ceramic area. This may be accounted for in one of two ways. Firstly, as the secondary sampling was completed a year after the original site sampling, it is possible that a greater amount of land had been ploughed in the first year. Secondly, it is possible that the pacing for the ceramic samples was inaccurate. The southern boundary of the grids have therefore been used to superimpose the data (Fig.8.10).

The tile count at PP27 (Fig.8.11) suggested that the most likely area for a tiled structure would have been in the northern half of grids 1 and 5, where counts greater than 32 were noted i.e. values over the mean + (2 x S.D). This is complemented by the evidence from the ceramic counts which suggested peaks consistently down the northern edge of the survey grid (see Fig.8.12). It is possible that this northern distribution is a result of this strip being ploughed for the first time in recent years (see above). Alternatively, some form of field clearance may have taken place, moving the larger ceramics to the side of the field. The latter is unlikely as the soil itself still contained a good proportion of stones. The ceramic distribution indicates a second peak to the west of the two tile peaks. This could be indicating a selected area of refuse disposal.

Although the Twin-Probe survey provides a number of probable archaeological features (Fig.8.13), the survey design could not provide a definitive plan of associated

Figure 8.10. Relationship between the two grids used at PP27

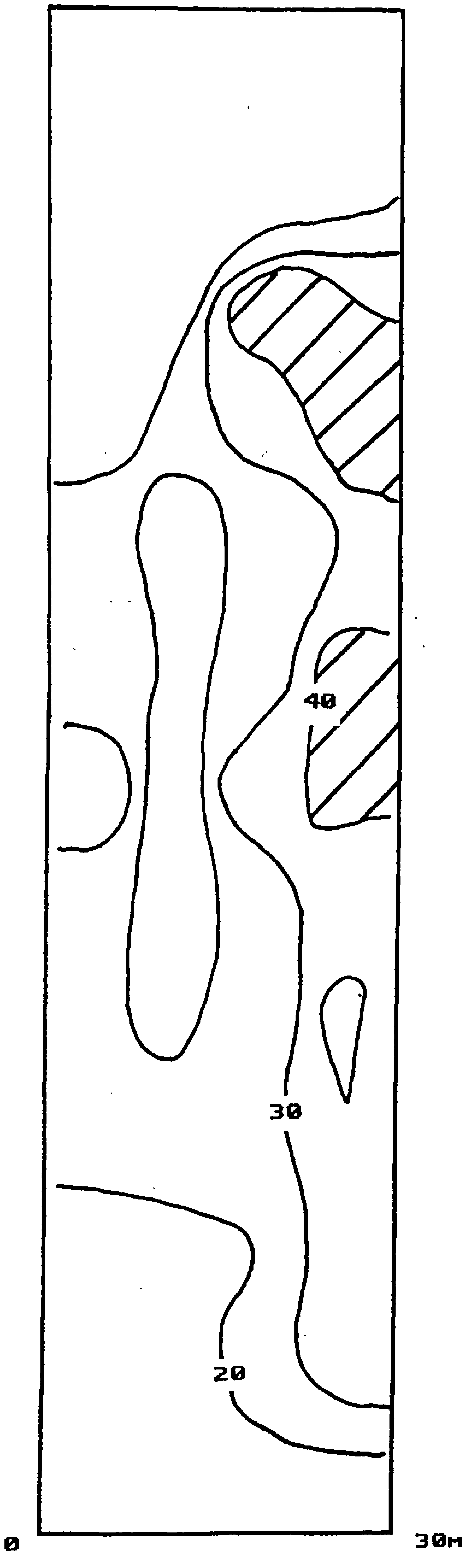


Figure 8.12

The ceramic distribution at PP27.

features. However, features A, B and C are all possibly associated with the tile scatter. Interestingly, a re-visit to the site after a particularly heavy ploughing event in 1989, suggested that the focus for the tile may lie slightly to the south of the areas indicated in Fig. 8.11. This may suggest that anomalies A, B and C form part of farm structure. The only other major anomalies are D and E, which do not appear to fit in with any of the other secondary evidence. It is possible to suggest that D may be part of a boundary wall around the site. A number of linear features running E-W, ie in the direction of the measurements must be regarded as suspect - not only is this following the slope of the hill, but also indicates the direction of the plough action, the ruts of which were still clearly visible.

An early version of the field Schlumberger unit was used at this site (using the modified Bradphys meter, see section 3.8). Tests had revealed that with a P-P distance of 0.5m it was only possible to extend the C-C distance to 12m i.e. a CC:PP ratio of 24:1. This resulted in the Bradphys measuring resistances as low as 0.2 ohm, which is at the limit of its detection. For this set of tests all four of the probes were moved and then watered in position. No offset survey was tried as the meter readings were too small. The results from the Schlumberger indicate a poor response over what is the major resistance feature at the site. Coupled with this is a complex response form over the high resistance anomaly (see Fig.8.14). This result is not unexpected as the study using tank simulations indicated that complicated responses may be

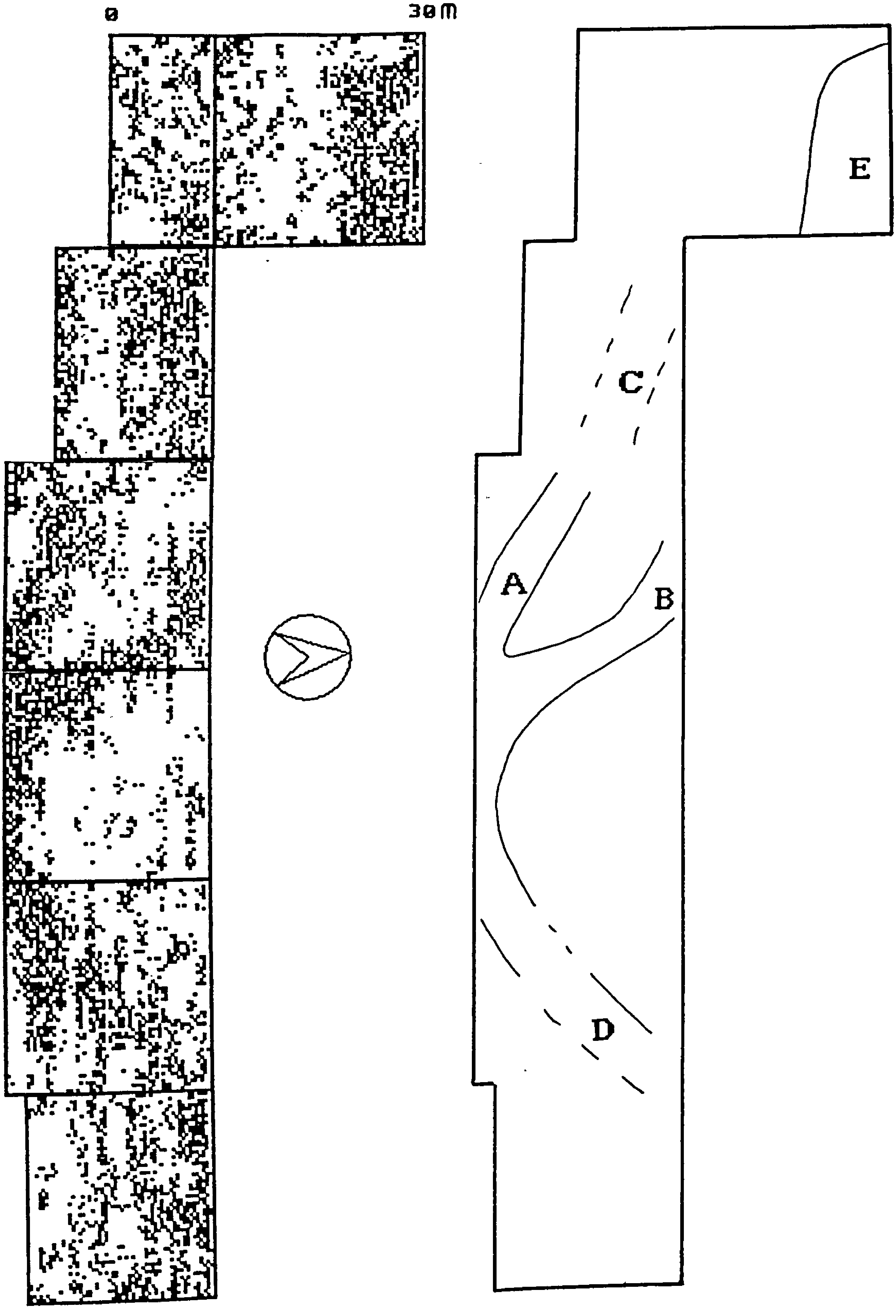


Figure 8.13 The Twin-Probe survey from PP27.

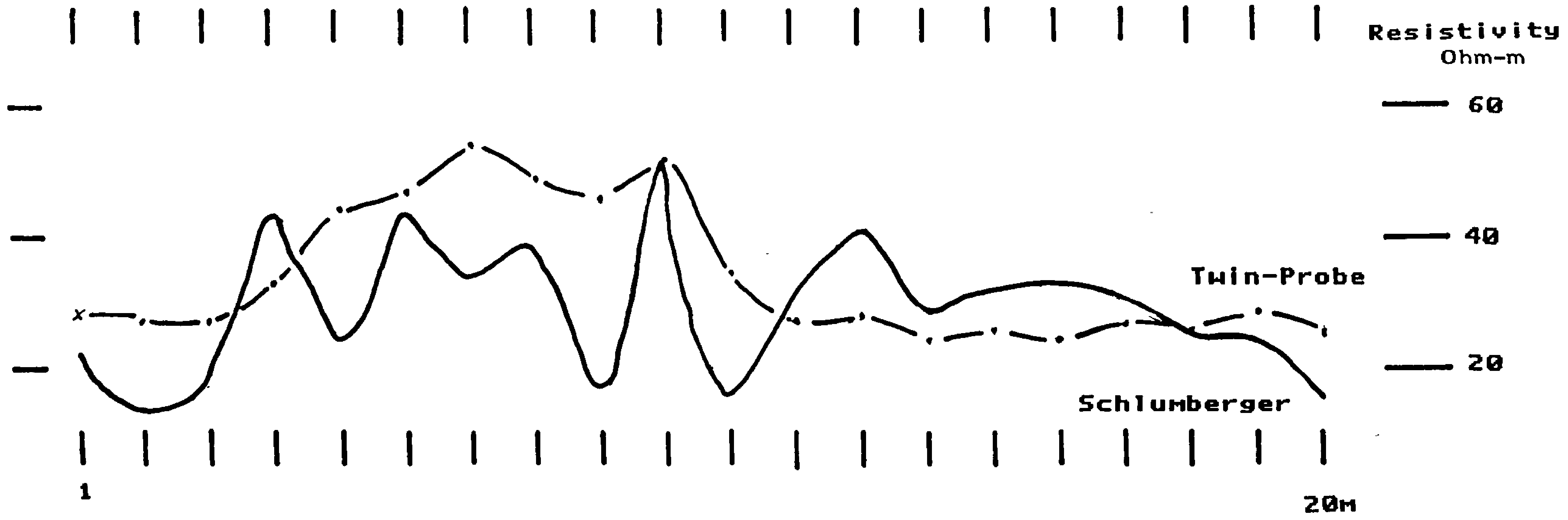


Figure 8.14 A comparison of the Schlumberger response with the Twin-Probe at PP27.

obtained when the CC:PP ratio is low.

In general the susceptibility pattern over the survey area is confusing (Fig.8.15.). The 100 samples processed from the site reveal a high average susceptibility (151 e.m.u./g x 10^{-6}), but form no coherent pattern. In this case the peak in the data would suggest that the major activity on the site is along the edge of the modern road. This is in clear contradiction to the conclusions drawn from the tile and ceramic evidence.

Conclusions

This site has broadly followed the trend set by PP17. A series of large resistance anomalies appear to be associated with a high concentration of tile fragments. The other elements of the battery investigation are less indicative of any 'structure' within the site data, with the susceptibility suggesting a different, perhaps complementary, spatial picture.

The evidence at PP27 would suggest that we have investigated part of a site that contains a small structure surrounded by a boundary wall. It is not clear what the magnetic susceptibility distribution represents. However, the site as a whole would appear to be ideal for further study using trace elements.

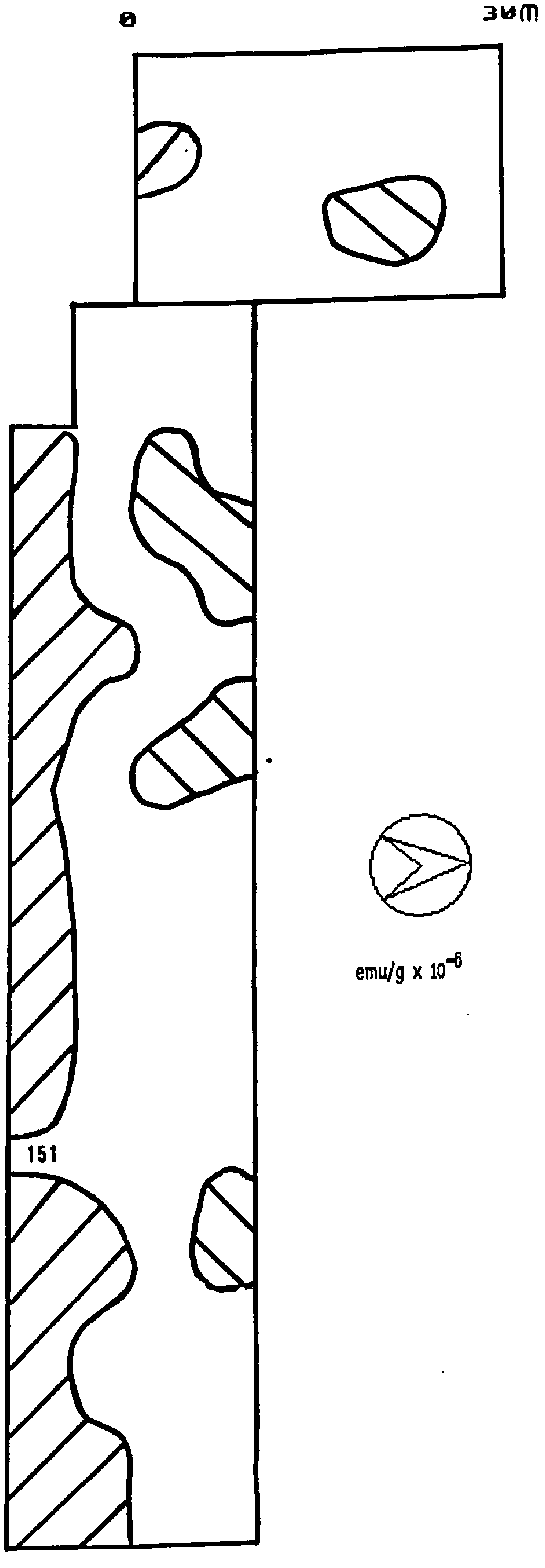


Figure 8.15 The Magnetic susceptibility measurements from PP27.

Table 8.5 Diagnostic material at PP27

			Date			
	Cearmic	C-H	C-R	ER	R-LR	LR
Sample						
1	34					2
2	92		5	3	1	
3	91		1	1	4	
4	114		1		2	
5	111					
6	87		2	1		
7	131	1	2			4
8	112	1		2		1
9	86				2	
10	106		2			
11	119		2			
12	58					
13	18		1			
TOTAL	1159	2	16	7	9	7

SITE: VM64

DATE RANGE: Roman-Late Roman

DATE RECORDED: 1984

TECHNIQUES: Ceramic count; Tile count; Twin-Probe; Schlumberger; Magnetic Susceptibility; Magnetic Viscosity; Rubble Plan; T.E..

This site is a typical small site situated in the 'Valley of the Muses', one of the most fertile valleys in the survey area. The site was initially assessed using eight ceramic count samples (Fig8.16), and the diagnostic breakdown may be seen in Table 8.6..

Given the conditions outlined in the preceding case studies, the tile counts seen in Fig.8.17 would appear to give a clear indication of a possible area for a building structure. The anomalous concentration of tile appears to cover an area of about 150m^2 and is abruptly stopped at the southern edge of the grid due to the presence of a large terrace. The patterning from the magnetic susceptibility enhancement is very similar to the tile distribution, with all the values greater than one standard deviation from the mean at the southern grid edge. The magnetic viscosity also peaks in this area (Fig.8.17). Interestingly, the trend in both of the magnetic responses, showing a corridor of higher values to the north, might be due to soil movement downhill. In an effort to try and verify the concise size of this site an extra set of information was collected from eight

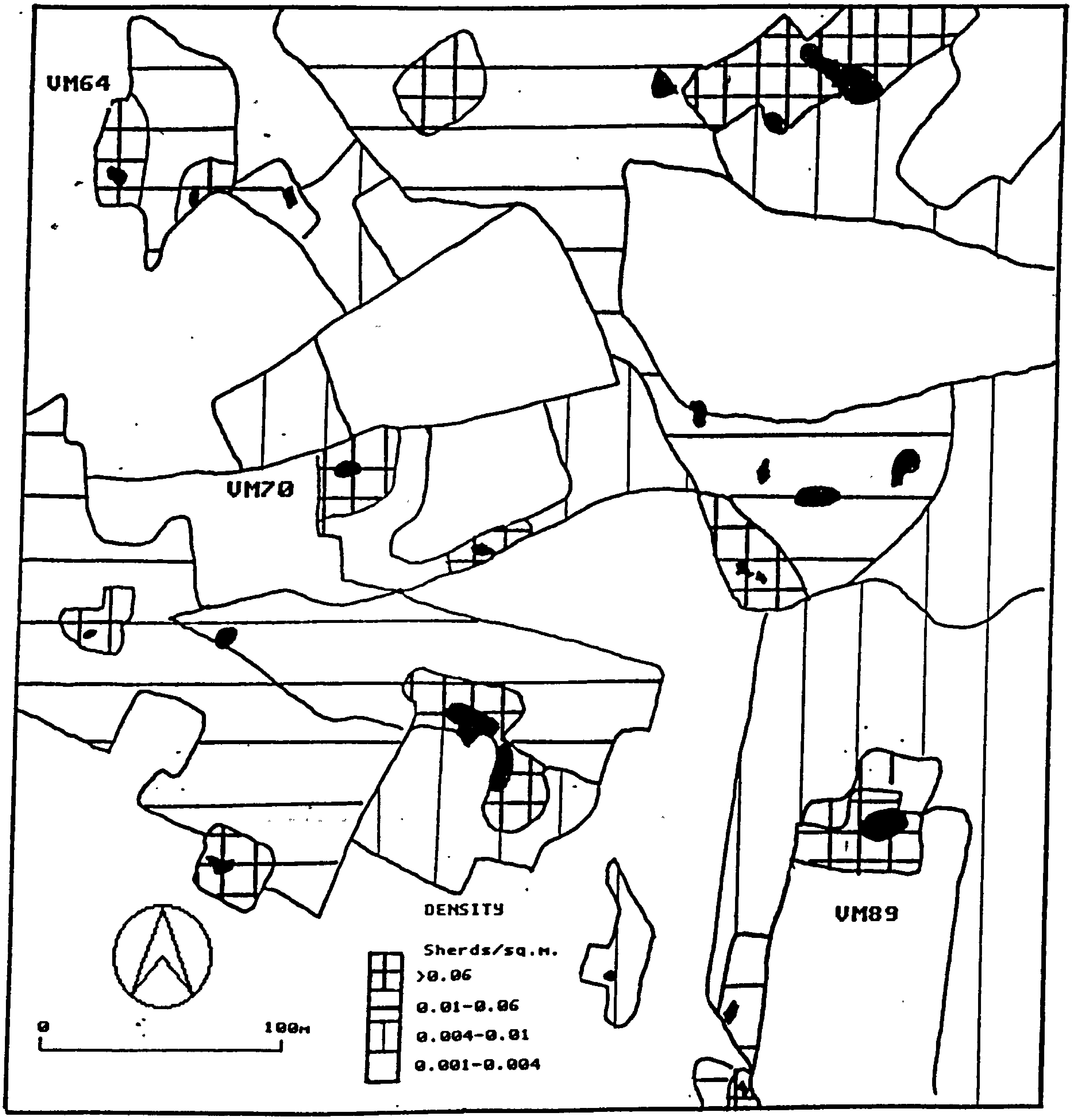
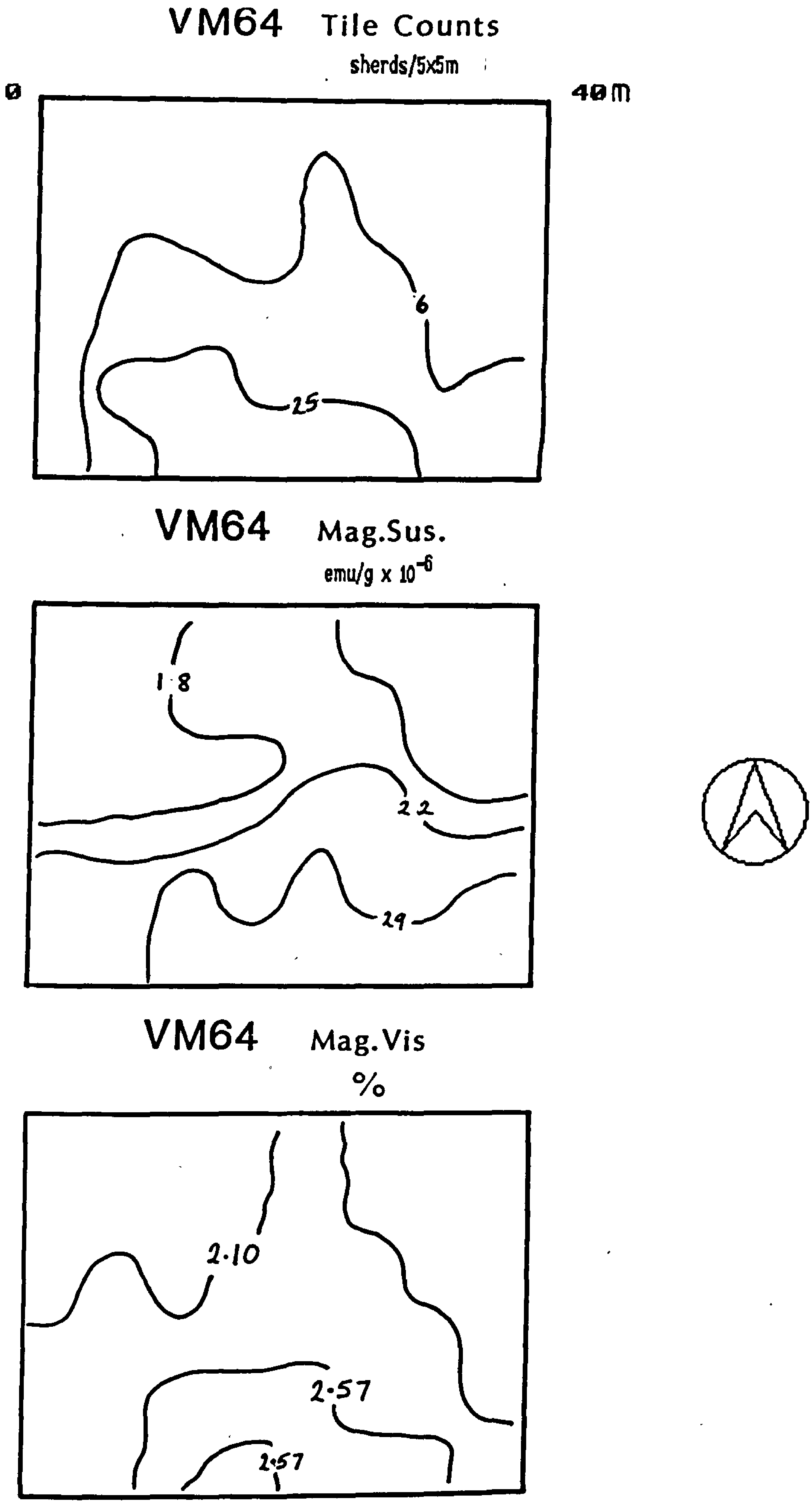


Figure 8.16. Sherd densities in part of the Valley of the Muses. Indicating sites VM64, VM70 and VM89.



VM64 Tile Counts

sherds/5x5m

VM64 Mag.Sus.

emu/g x 10^{-6}

VM64 Mag.Vis

%

Figure 8.17 The distribution of Tile Counts, Magnetic Susceptibility and Magnetic Viscosity at VM64.

transects radiating from the edge of the grid (Fig.8.18 and 8.19) Transect one was situated in the southerly direction i.e. going uphill and showed an increase in susceptibility and a decrease in the viscosity on the thin soil. Transect two which was situated on the southern edge of the site and showed a slight decrease in susceptibility and a large variation in the viscosity. Transect three was positioned to the north of the site, and was largely in the enhanced 'corridor' assumed to be due to soil movement. Neither transect 3A nor 3B showed any significant increase over the average grid susceptibility. The viscosity also remained low. The susceptibilty measurements in Transect four show a significant drop after 10m, although the values increase again after 40m. This could be due to a change in agricultural practice, or a localised change in geology. The viscosity component remains relatively low.

Perhaps one of the most obvious points to arise from the transect information is that the site itself is hard to delimit from the transect evidence alone. Although this is partially due to changes in topography, etc, it must also in part be due to the sampling strategy. The gridded information, however, is highly compatible with the tile evidence (Fig.8.20 and 8.21). The rubble plan of the gridded area is not particularly informative, with the majority of the material being of very small size (Fig8.22).

A comparison between the ceramic/tile evidence and the magnetic information is both confusing and intriguing. The variation in the tile counts by comparison with the

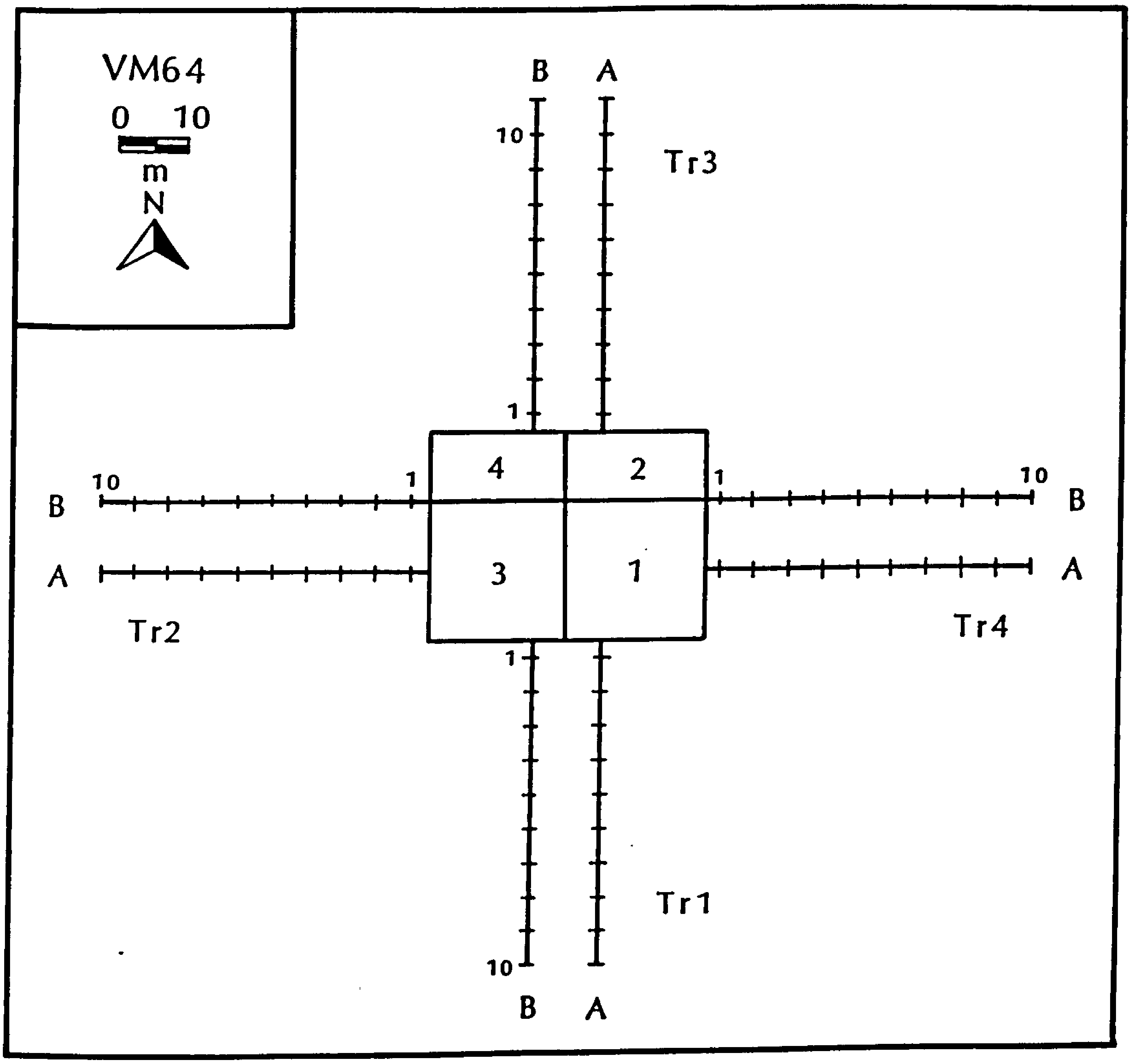


Figure 8.18 The position of the transects at VM64.

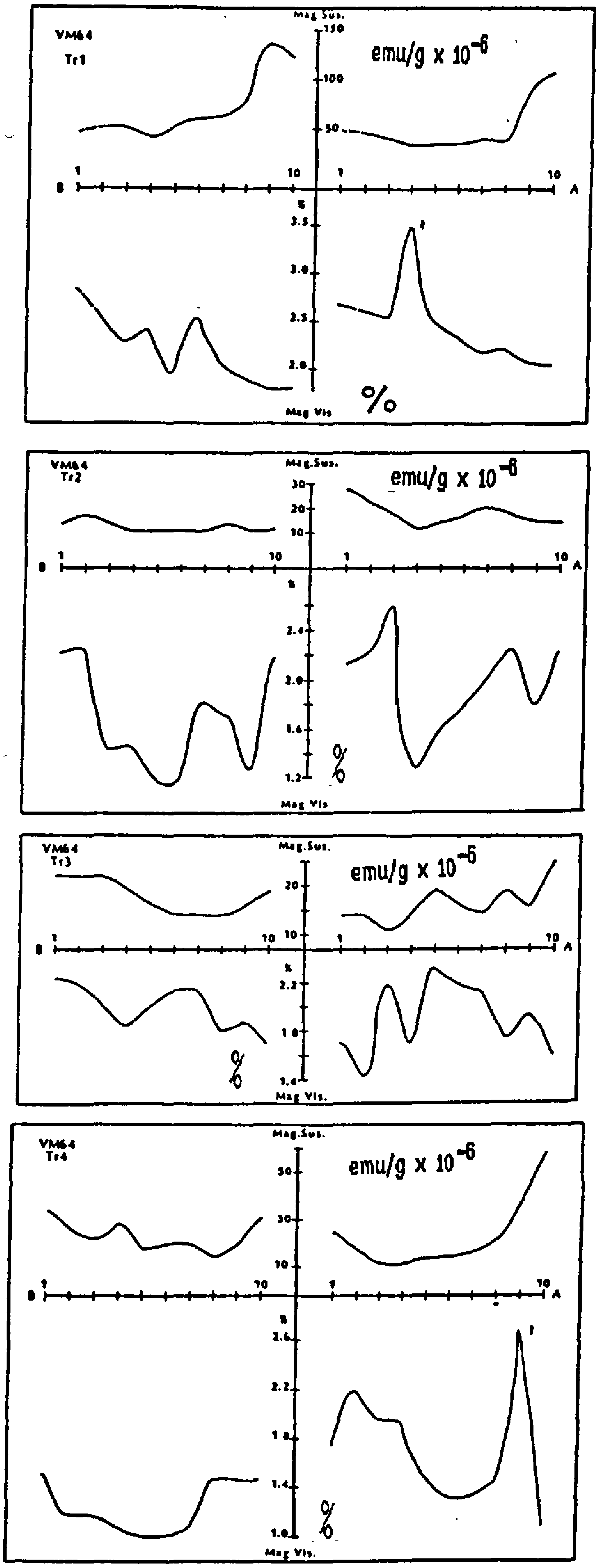


Figure 8.19 Viscosity and Susceptibilty measurements along the transects at VM64.

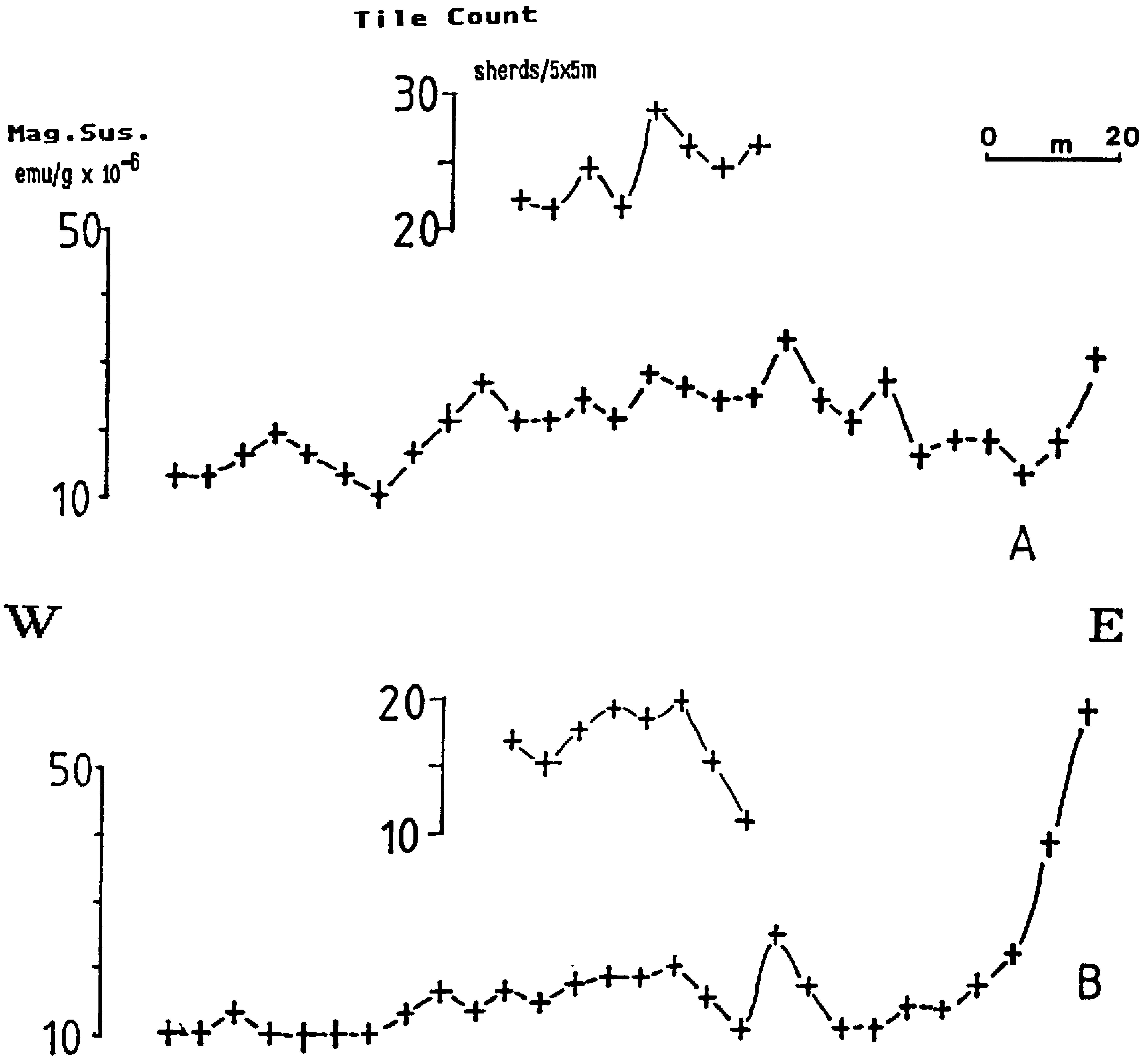


Figure 8.20 Susceptibility measurements west to east i.e. Tr.2-Tr.4, including those on the site. For comparison, the tile data is shown.

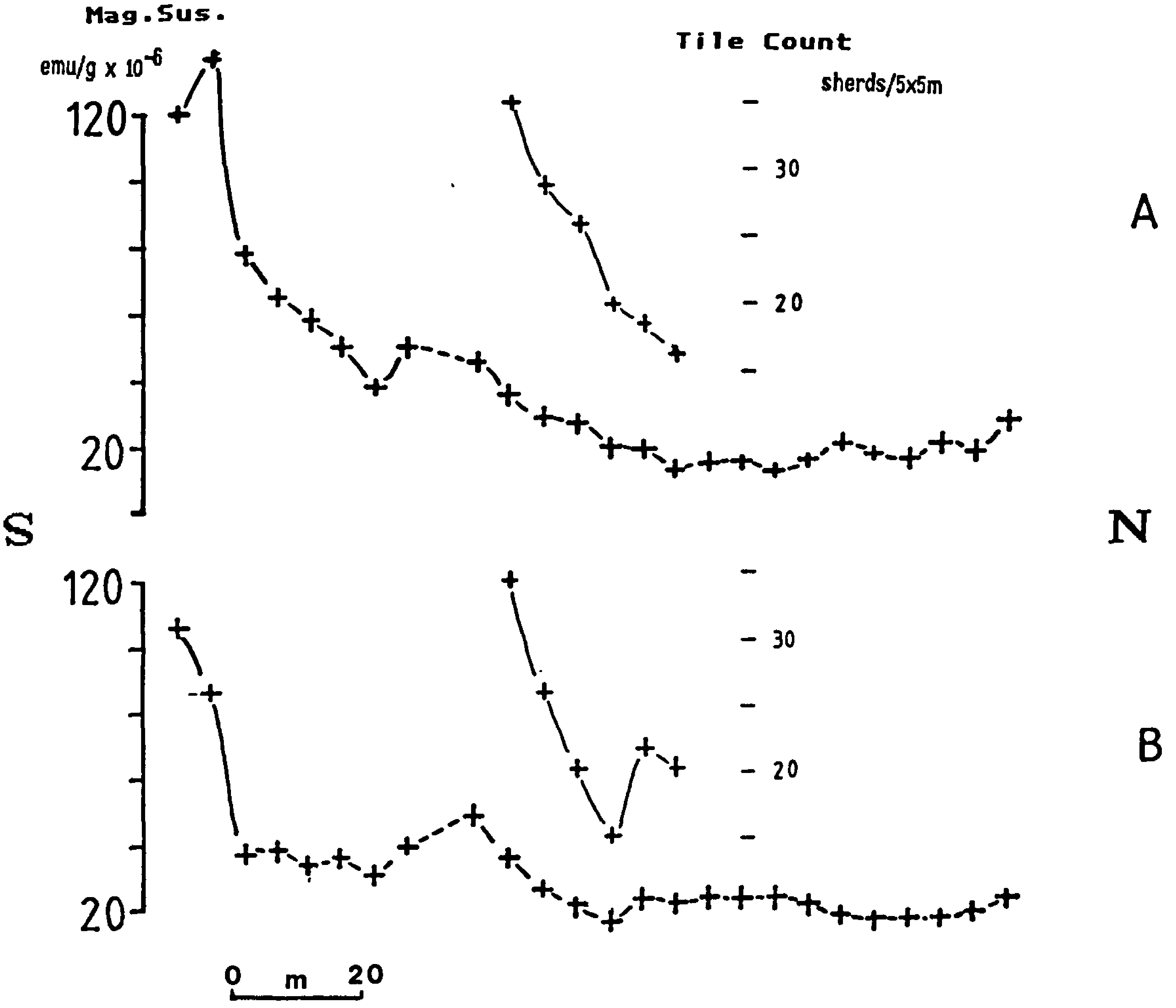


Figure 8.21 Susceptibilty measurements south to north i.e. Tr.1-Tr.3, including those on the site. For comparison, the tile data is shown.

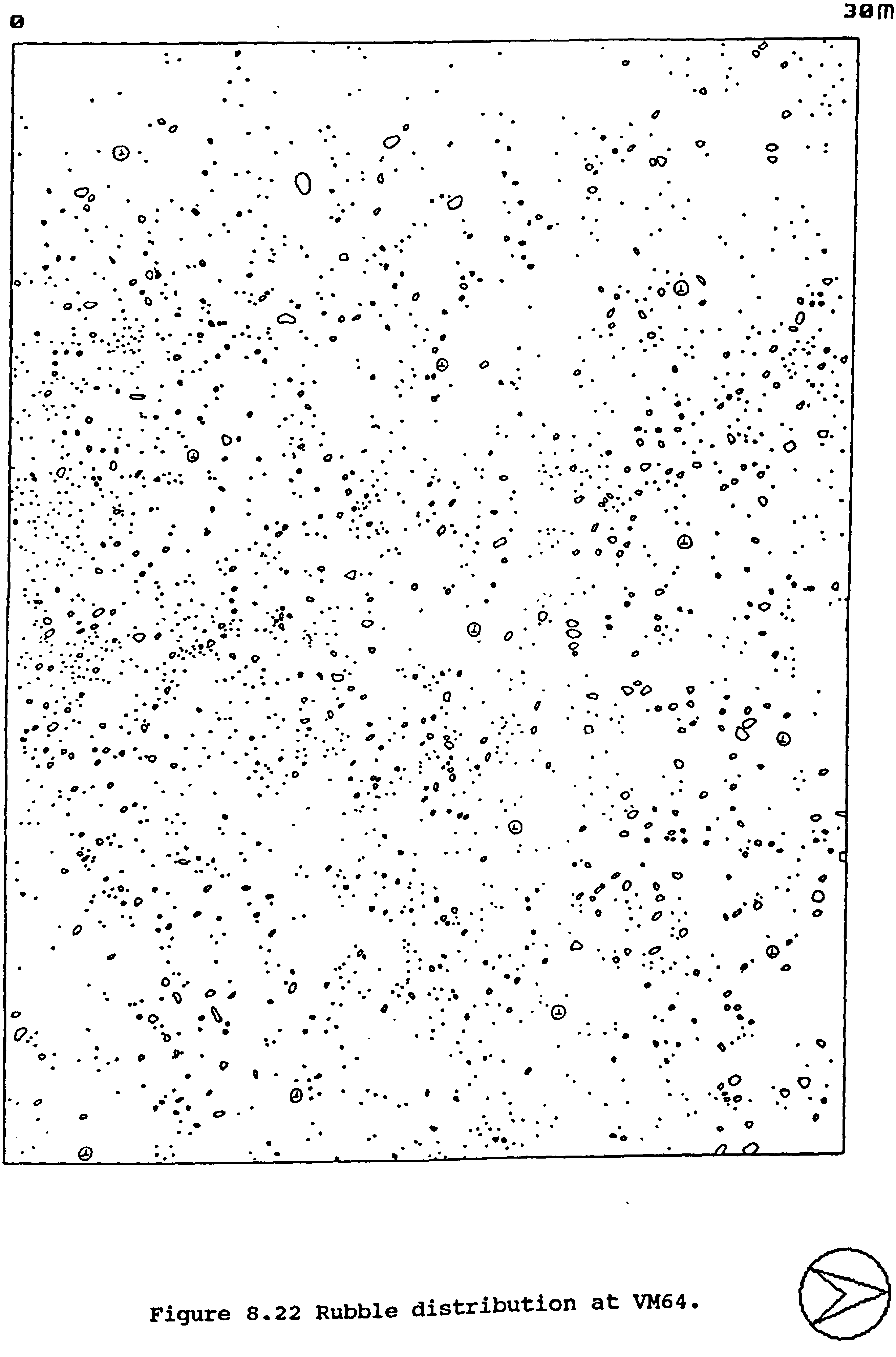
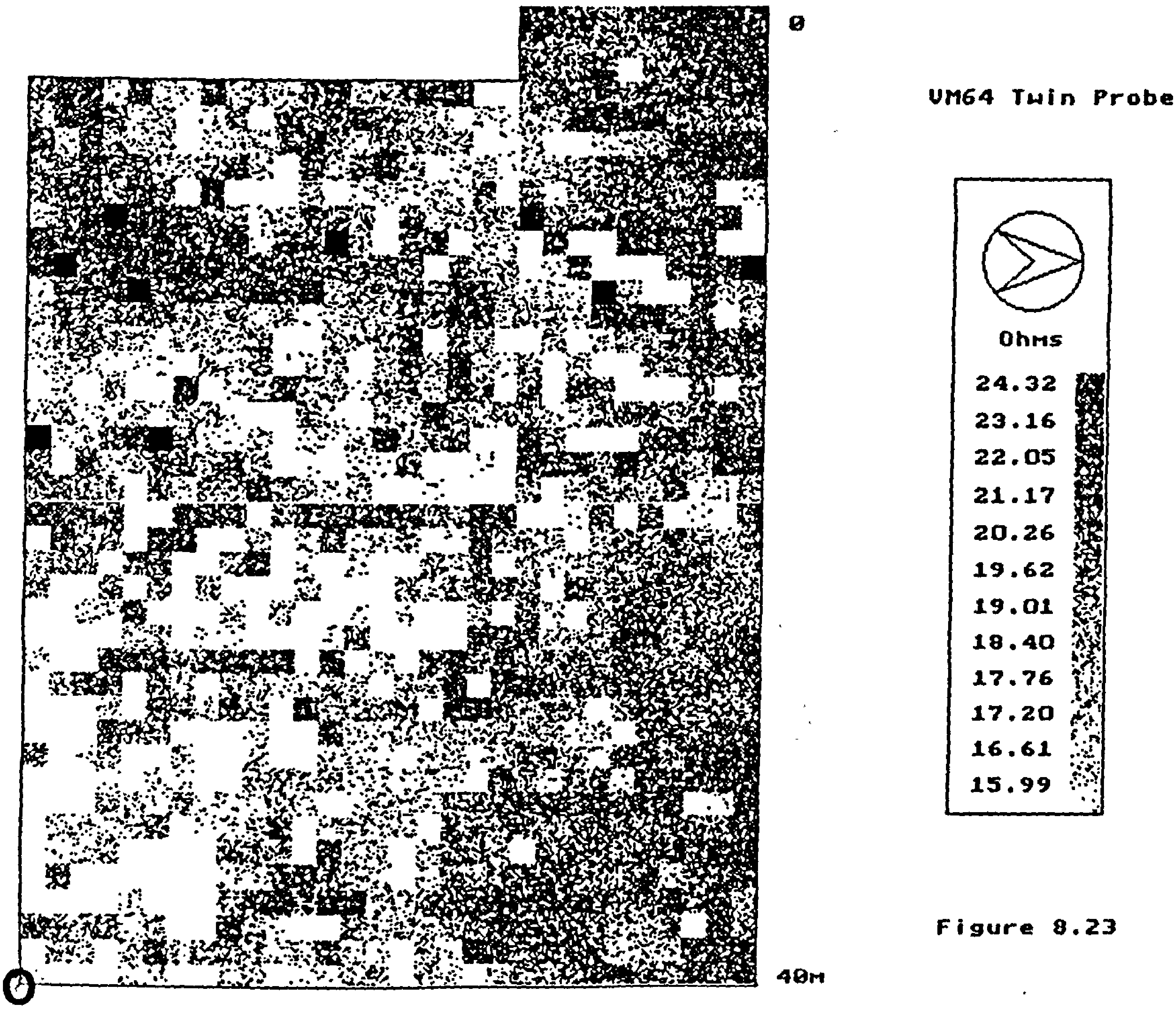


Figure 8.22 Rubble distribution at VM64.

susceptibility is high correlated. Moreover, the site is 'visible' within the larger magnetic susceptibilty trend, even if natural effects, such as slope, do confuse the interpretation. Whilst the ceramic/tile evidence suggest clear archaeological centres, the magnetic evidence indicates only a minor enhancement. Obviously, any structure that was roofed could be represented on the field surface by tile fragments, no matter what functions were performed inside it. However, the minor enhancement of the susceptibility may be due to the infrequent use of the site for occupational activity, or the spreading of domestic rubbish across the infield activity area.

The Twin-Probe survey indicated a few interesting anomalies especially in the region of the highest tile counts, where there appeared to exist traces of a square, high resistance feature (Fig.8.23). Considering that the soil samples showed a suspicion of soil movement that may have been due to plough action, it is most unlikely that minor features should exist at this site. There are some anomalies in grid 2 which may possibly be the result of minor structural features. The anomalies, however, are most ephemeral.

The Schlumberger survey was done over the complete gridded area to see if any detail could be provided concerning the possible ephemeral features. With the current probes situated E-W, the now typical, slightly 'streaky' response is obtained with the strongest high resistance features aligning N-S (Fig.8.24). Although this picture is



VM64 Twin Probe

Figure 8.23

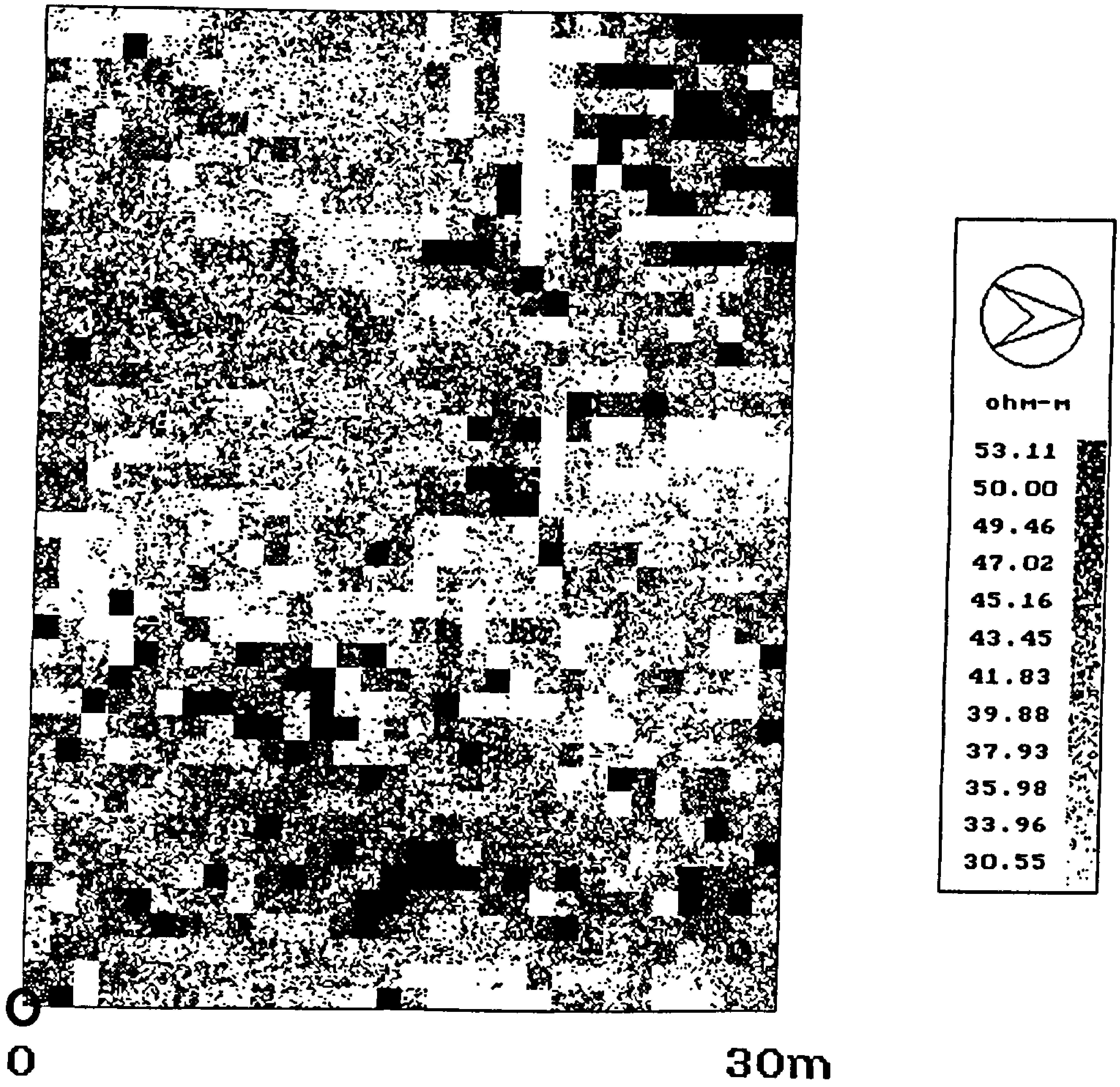


Figure 8.24. VM64 - Current probes E-W.

biassed due to the directional property of the array, it is apparent that there is continuity between grids 1 and 2, which suggests that the stripes have some non-random cause. When the probes were switched to the second position (N-S, Fig.8.25) then a complementary picture is obtained. This second position suggests that there a number of strong responses, possibly due to the anomaly edge effects outlined in Chapter 5.

The combined Schlumberger resistivity picture shows a broader high resistivity response for the Twin-Probe feature in grid 3, whilst also higlighting other high resistance features (Fig.8.26). In particular there can be seen some specific continuity through grids 1 and 2. If the high resistivity response in grid three may be interpreted as some form of agricultural structure, then the faint traces of high resistivity to the east may be some associated yard, or even a shed ?

The trace element evidence again suggests that the soils in the area of the site show significant levels of chemical build up (Fig.8.27). One peak in the copper distribution coincides with the major resistivity feature, as seen in the Schlumberger survey. Other copper peaks are situated in more peripheral areas, with some suggestions that resistance anomalies are associated. The lead concentration shows a wide and dispersed distribution.

The soil samples that were collected in the four transects were also measured for trace element composition

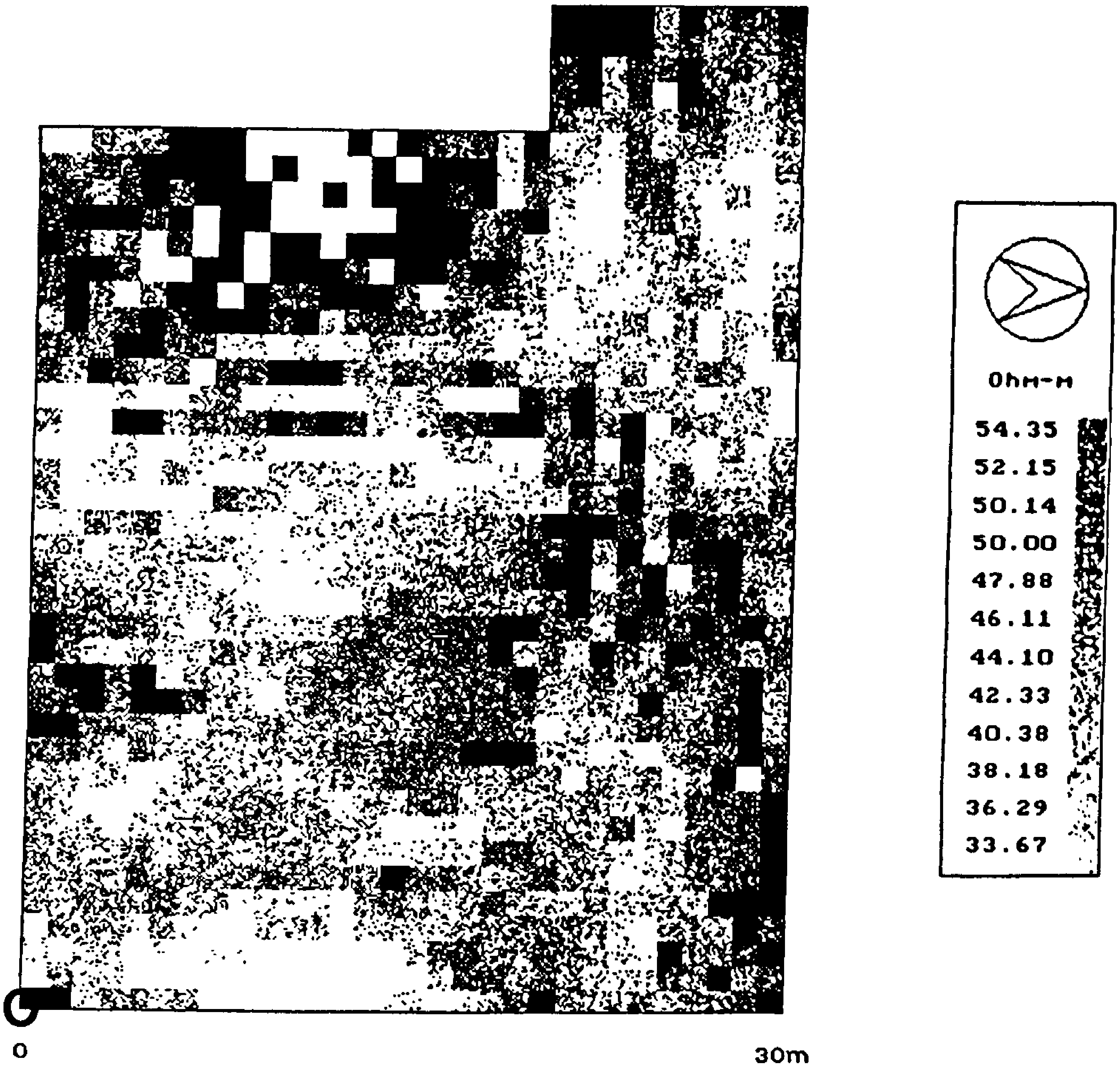


Figure 8.25. Vm64 - Current probes N-S.

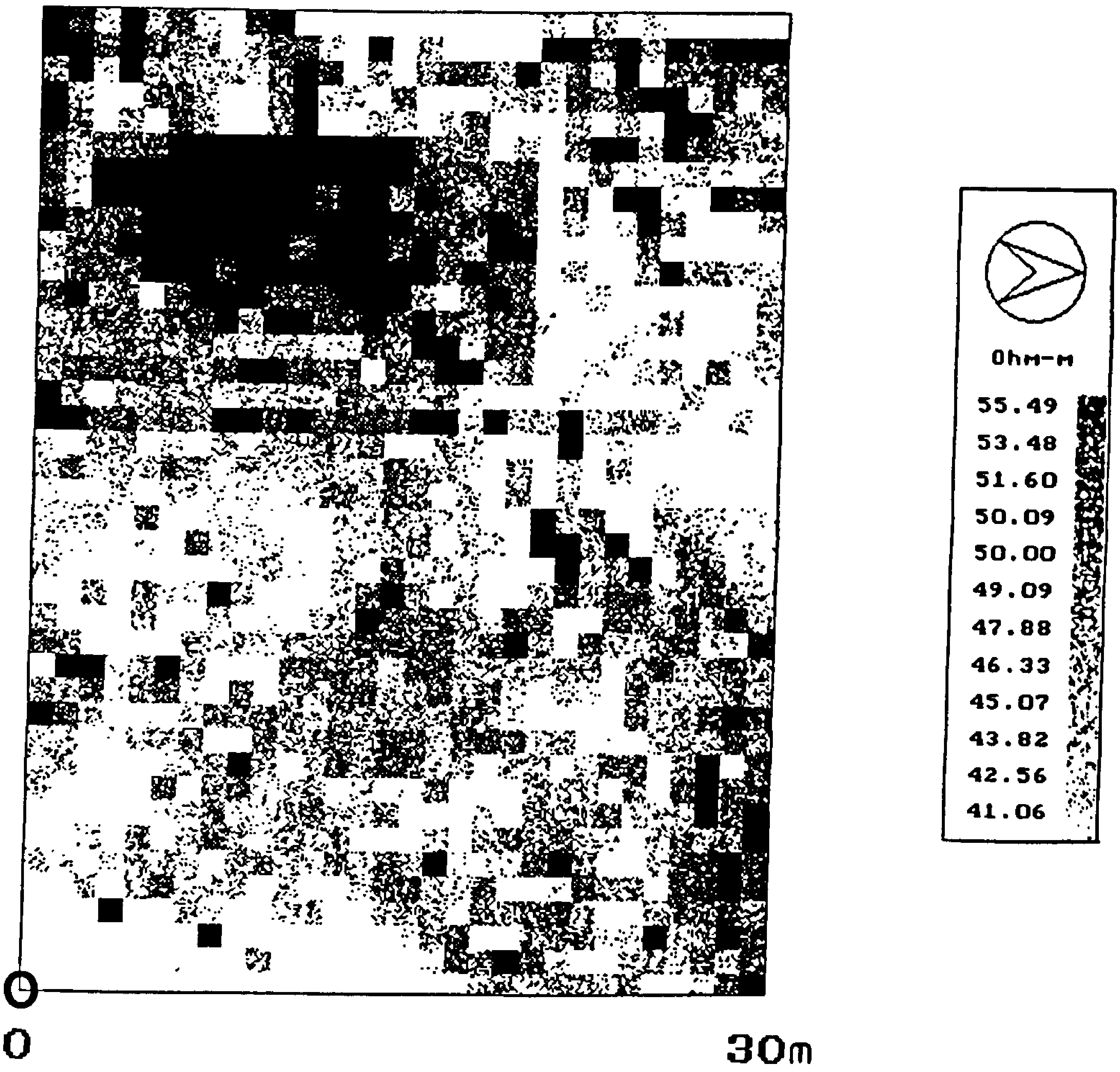


Figure 8.26. VM64 - Combined Schlumberger.

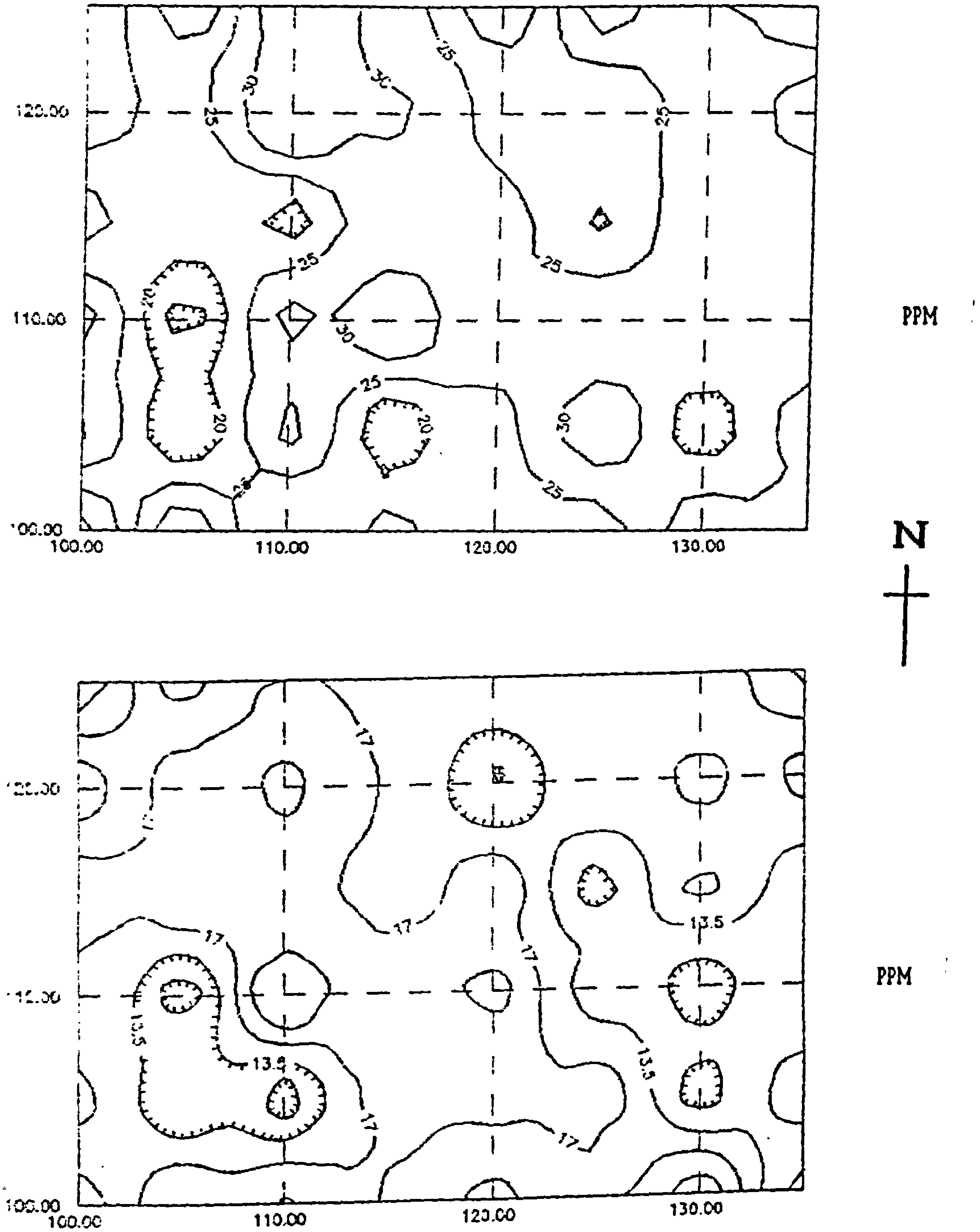


Figure 8.27 Copper and Lead distributions at VM64.

(Fig.8.28. and 8.29). In both the N-S and the E-W transects, a good agreement can be seen between the trace elements and the susceptibility measurements. However, whilst the copper concentrations at the site are well above the regional levels, it is also true that there are peaks just off the 'site' that match and exceed peaks on the site. A similar situation may be seen in the lead data. However, although the site itself may be a relative 'low' within the confines of the site and its halo area, it is still clearly 'high' by comparison with the regional levels. This is totally compatible with the model for an intensively farmed 'halo', with the greatest agricultural activity occurring in the environs of the site.

Conclusion

This site has given quite a characteristic pattern from the measurements of the topsoil. The overlapping nature of the tile, susceptibility and viscosity measurements are very encouraging. However, the results from the resistivity surveys are not so clear. Although there are some general similarities between the Twin-Probe and the Schlumberger responses, the detail is largely different. This could be due to the fine tilth of the topsoil at the site. Occasionally, it was difficult to know if a good contact had been achieved before each measurement was logged. For both resistance arrays the data logger was switched to its manual mode, leaving the operator to judge when a satisfactory reading had been achieved. However, neither data set is error free, and

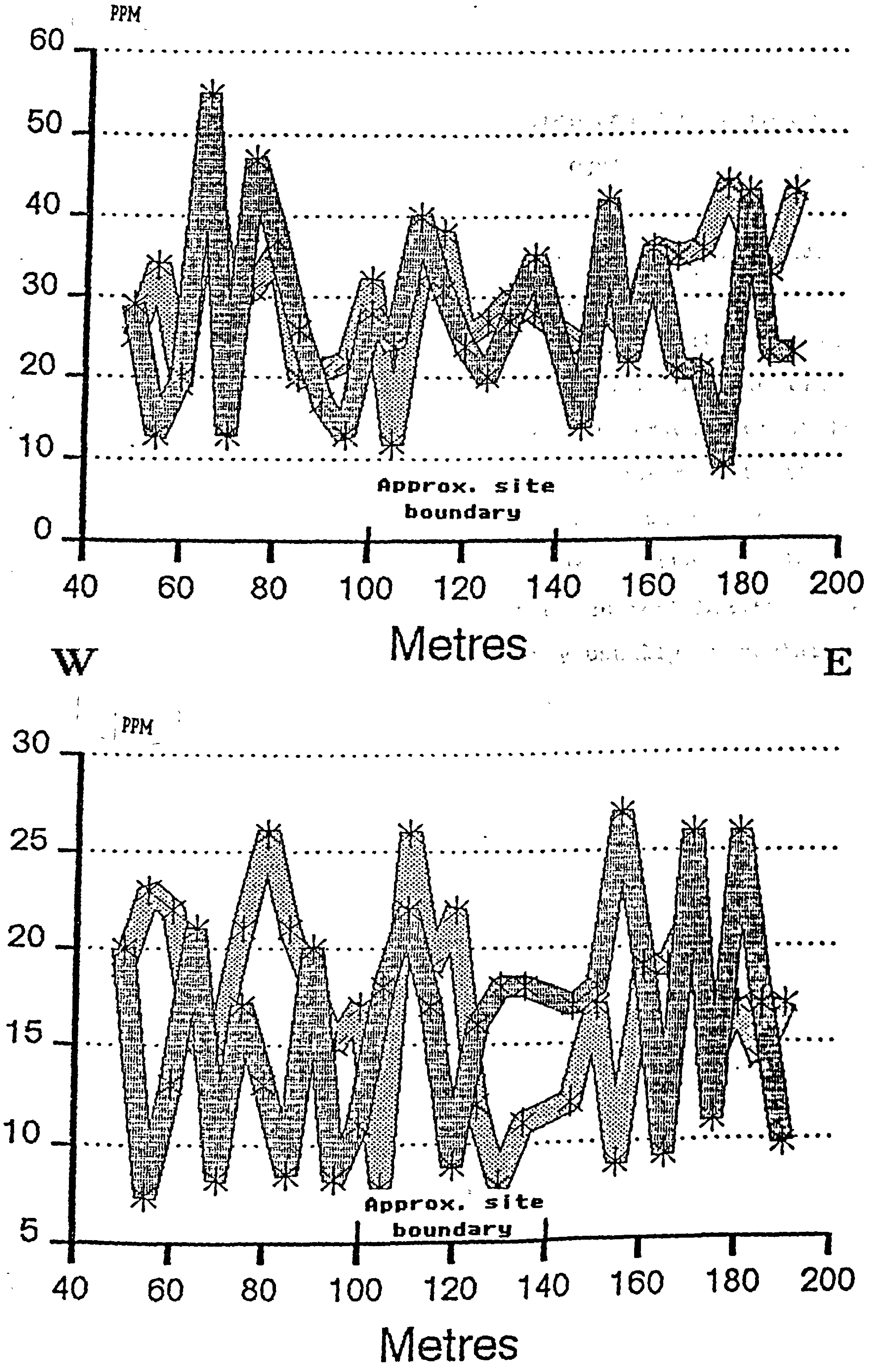


Figure 8.29 West to east transects of copper and lead concentrations at VM64.

some way of reducing this problem would have to be found if the Schlumberger is to be used regularly on poor contact soils.

Given the nature of many of the Boeotian sites, invariably surrounded by a high density of sherds, it seems likely that the sites, as defined by traditional means, may be difficult to delimit at the secondary investigation level. Indeed, the evidence from the regional trace element levels , which suggests that there is a clear increase at the 'site' foci, may be important in the discussion of activity around the site. The high trace elements around the ceramic 'site', coupled with the high magnetic susceptibility level may substantiate the intensive activity usually associated with the interpretation of a site halo.

Table 8.6. The diagnostic sherd collection from VM64.

			DATE			
	Ceramic	Prehis	ER	R-LR	LR	TOTAL
SAMPLE						
1	54			1	1	2
2	110		1	1	1	3
3	275			1	3	4
4	244		1	6	2	9
5	56				1	1
6	110			1		1
7	77					0
8	56					0
TOTAL	975	0	2	10	8	20
'GRAB' SAMPLE		1	1		3	5
TOTAL		1	3	10	11	25

SITE: VM70

DATE RANGE: Classical (plus)

DATE RECORDED: 1984

TECHNIQUES: Ceramic count; Tile count; Twin-Probe;
Magnetic Susceptibility; Rubble Plan.

This site is situated on the south-east slope of the Strongali hill, in the fertile Valley of the Muses. The date range of the site is predominantly 4th-3rd century B.C., although there may be some earlier and later occupation (see Table 8.7). In Fig.8.30 may be seen the relationship between the various measurements taken at this site. Although the majority of the ceramic sherds were concentrated in samples 9-12, which is at the south of the site, a visual inspection of the surface suggested that the building material was concentrated to the north of the stone field wall. A second grid of 40x40m dimensions was then laid out over the most promising area to the north. The relevant ceramic distribution is shown in Fig.8.31.

The tile counts (Fig.8.32) showed a clear concentration in the S-W corner of the intensively surveyed area. Evidence from earlier investigations of other sites suggested that such a concentration would be indicative of a building structure e.g.PP17. The magnetic susceptibility measurements that were taken on the same grid also show a coherent distribution, with a response that appears to be correlated

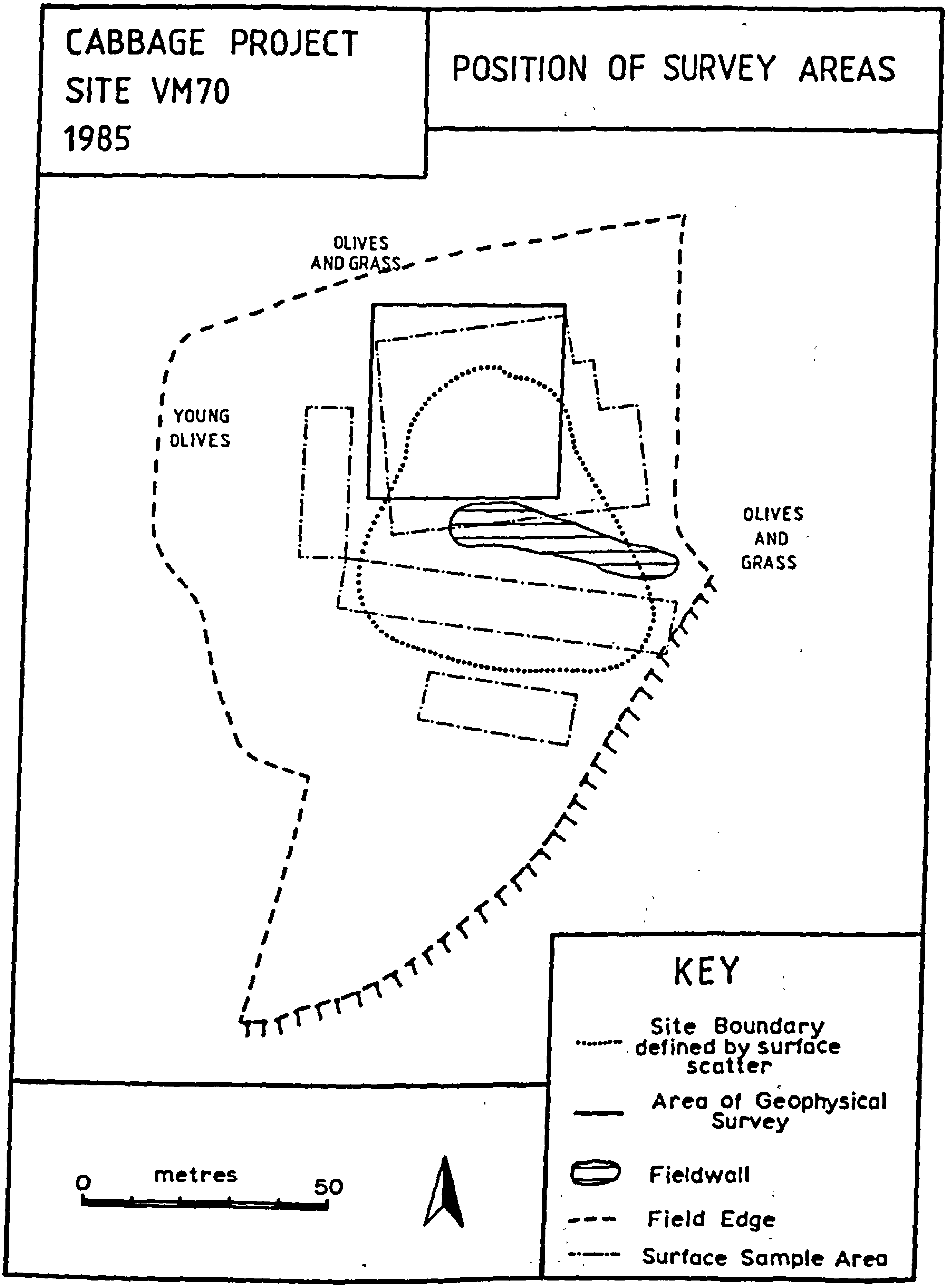


Figure 8.30 Position of survey areas at VM70.

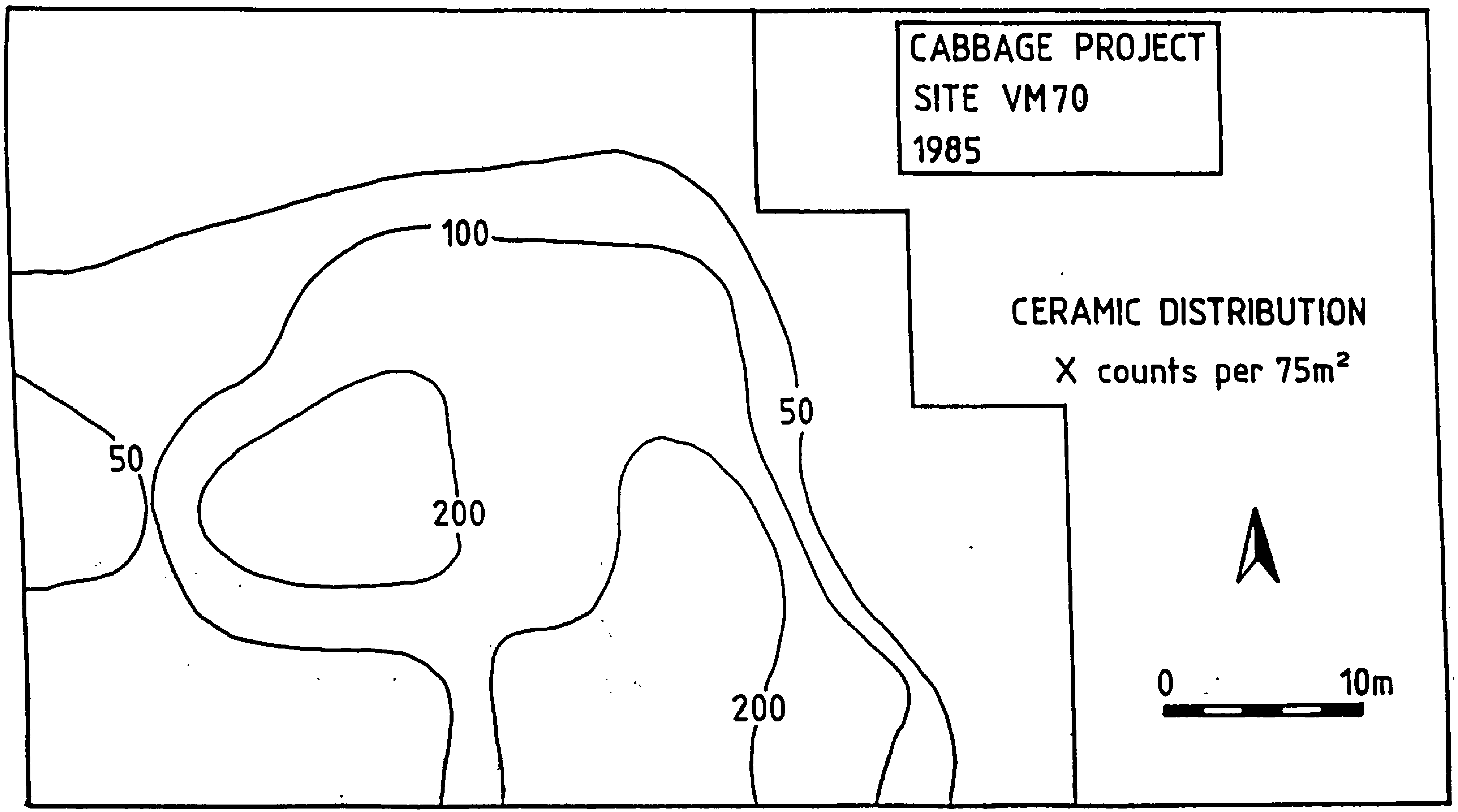


Figure 8.31 Ceramic distribution at VM70.

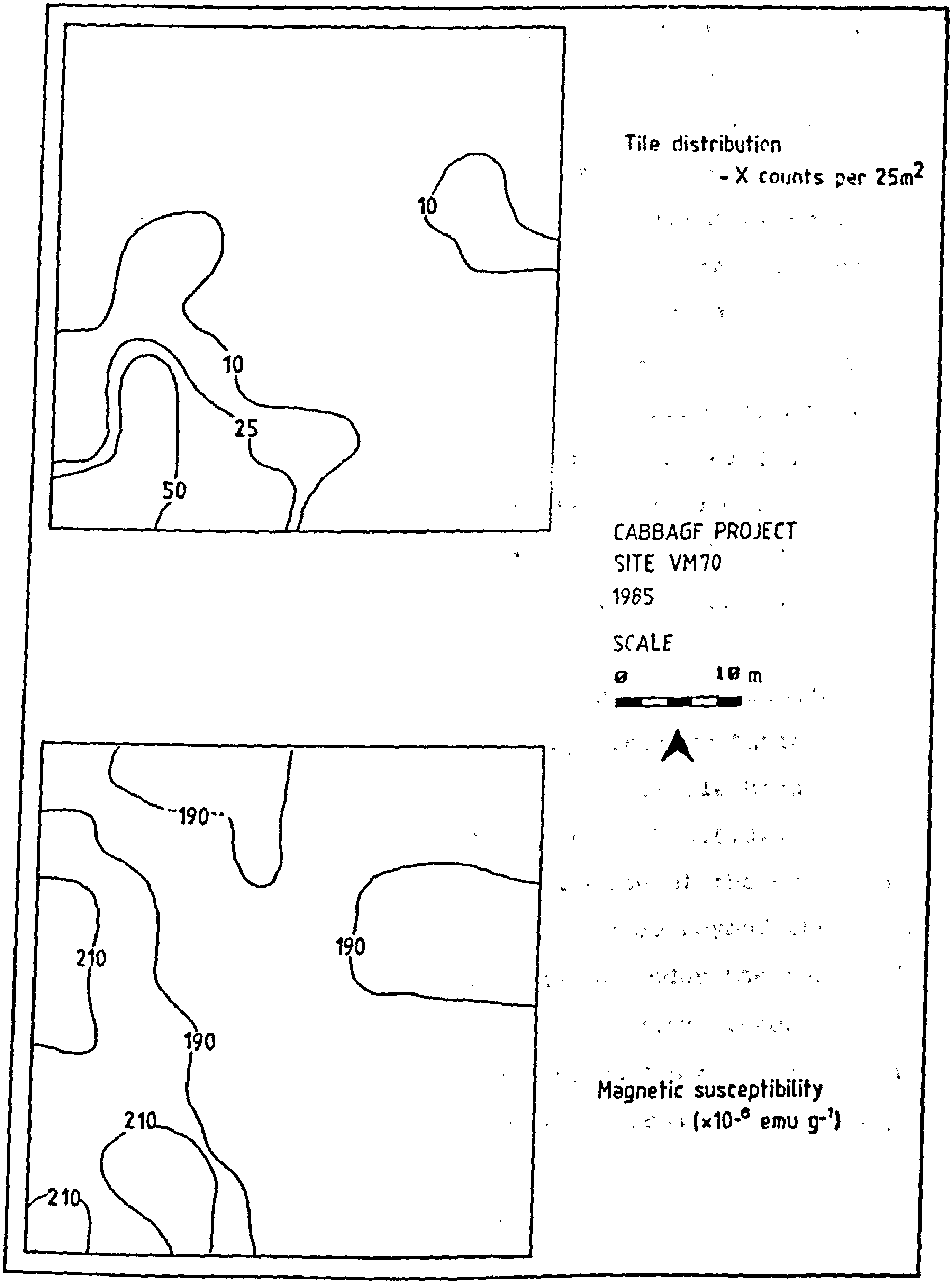


Figure 8.32 Tile and magnetic susceptibilty distribution at VM70.

with the tile distribution. The two major magnetic enhancements appear to be directly associated with the tile concentrations. This is particularly interesting as this suggests that an increase in susceptibility at another site, may indicate some form of otherwise unrecognisable activity, perhaps even the presence of ancient structures that were not roofed with ceramic material. Again, the evidence from the rubble plan which shows a high concentration in the S-W corner of the intensively surveyed area, is presumably indicative of a previous structure (Fig.8.33).

All of the above evidence from the secondary on-site investigation is highly correlated and appears, as at PP17, to be negatively correlated with the evidence from the ceramic totals. This would indicate some agreement with the interpretation that the tile equates with structural elements and total ceramic count may be related with more general refuse disposal.

Ideally the Twin-Probe survey should show similar results to PP17. However, the dot-density representation shows a confused picture, although there are possible high resistance features in the S-W corner of the grid (Fig.8.34). Yet it is not possible to suggest the exact course of the anomalies. It is quite likely that the anomalies may go beyond the southern edge of the grid and may continue under the rubble field wall. A return visit to this site a year later to do a Schlumberger survey proved abortive. Very recent ploughing had provided unsuitable conditions for resistivity surveying.

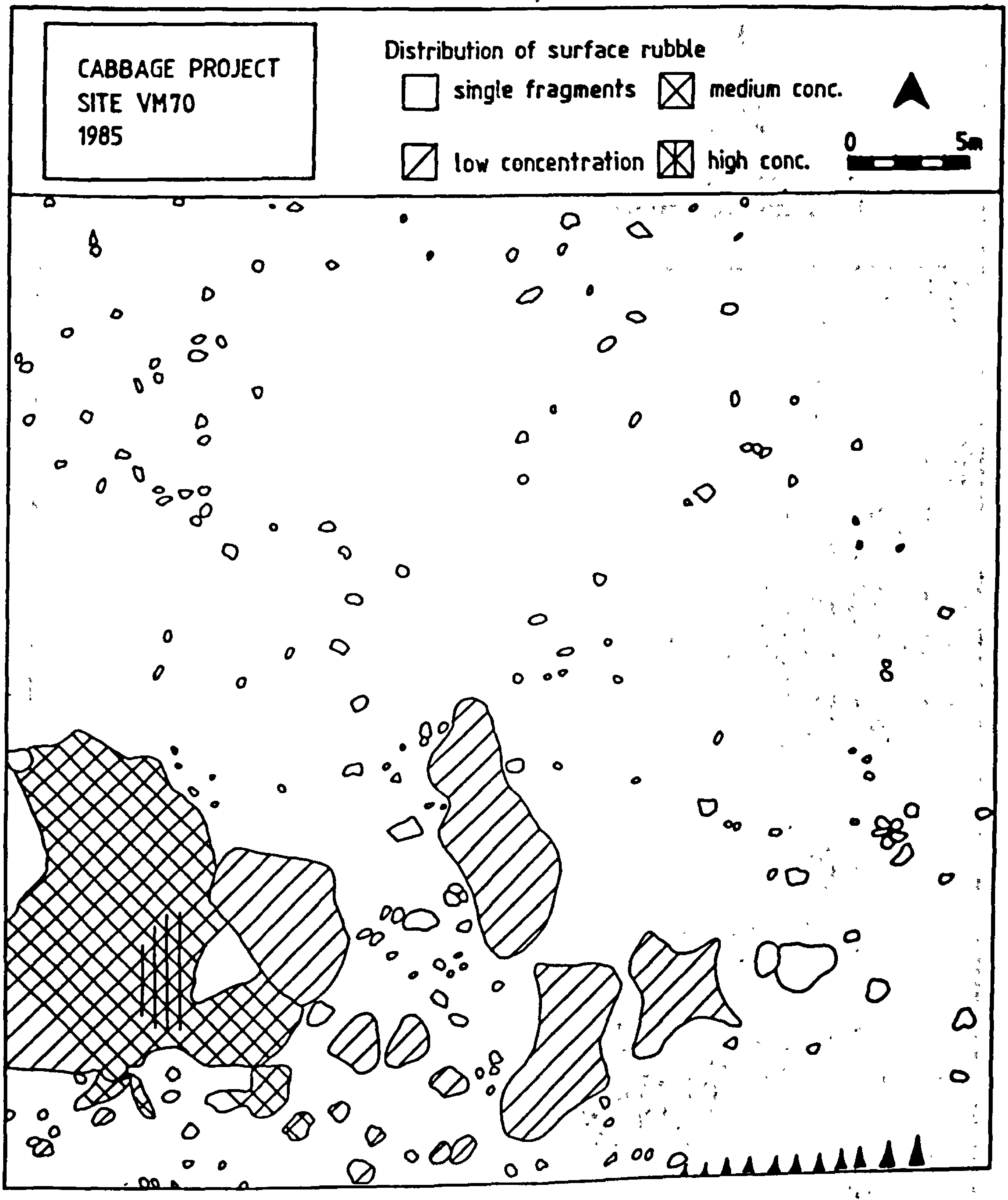


Figure 8.33 Rubble distribution at VM70.

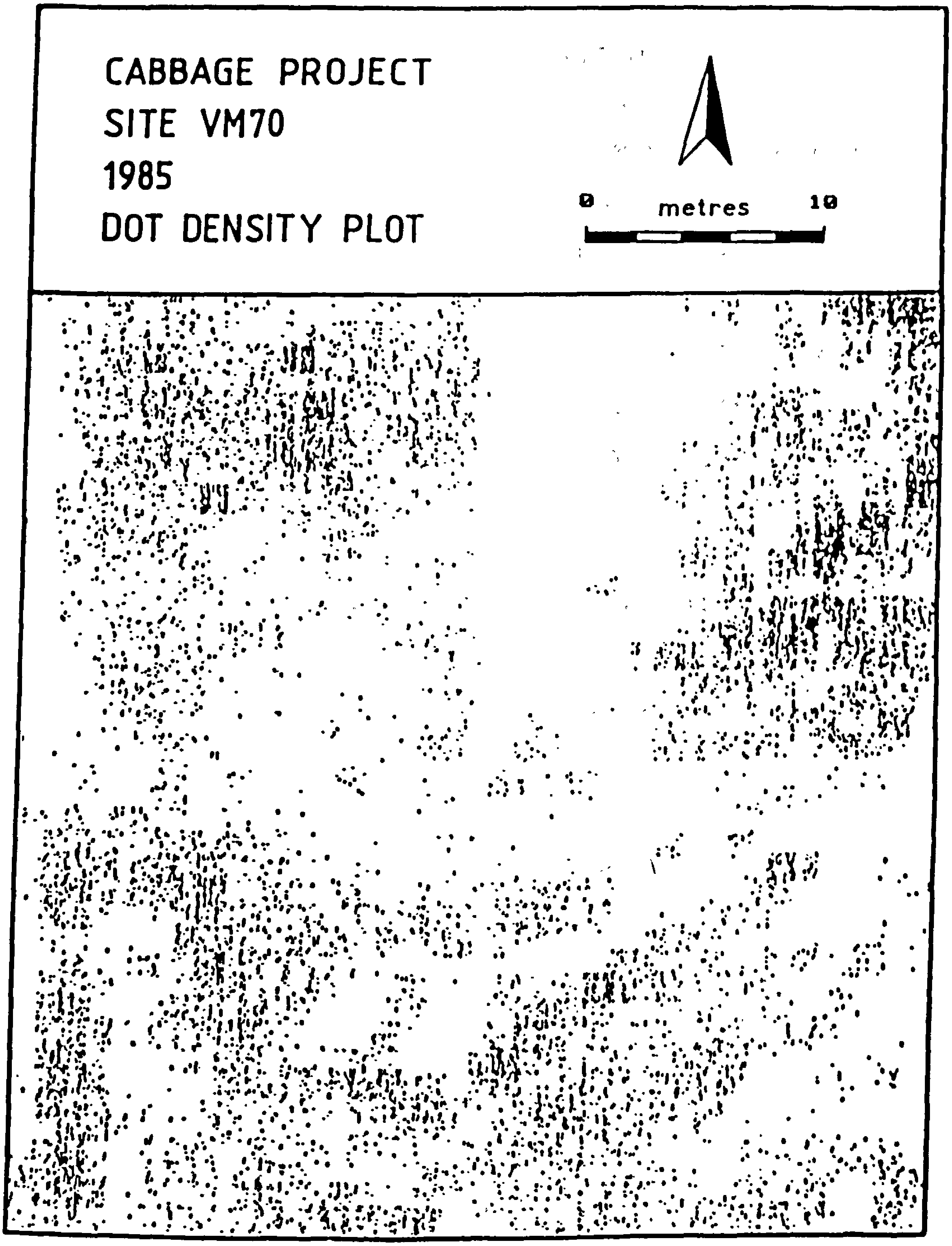


Figure 8.34 Dot density plot of Twin-Probe resistance data from VM70.

Conclusion

The major dating evidence which is in samples 5 and 6 contains some very fine pieces of Classical sherds. Apart from the increased magnetic susceptibility and the massive ceramic counts, the secondary investigation revealed nothing that would suggest intensive occupation at the site. However, the long term use of the site may be suggested by the enhanced susceptibility measurement over the possible structural area.

It is likely that this site is being significantly destroyed by the present agricultural regime - the only archaeological evidence now appears to exist in the topsoil. Trace element work at this site could help indicate any remaining activity foci, especially with respect to the tile and magnetic susceptibility peaks. As this site is badly plough damaged, it is impossible to say much about the function of the site without such information.

Table 8.7. Diagnostic material from VM70.

		DATE							
	CERAMIC	G-A	A-H	C-H	C	H-ER	ER-LR	LR	TOTAL
SAMPLE									
1	550		5						5
2	281	1		2					3
3	58								0
4	20								0
5	519	1		4	4	1			10
6	237			2	10				12
7	55								0
8	806				3				3
9	225								0
10	249						1		1
11	199		1						1
12	146			1					1
13	47			1				2	3
TOTAL	3392	2	6	10	17	1	1	2	39
'GRAB' SAMPLE				1					1
TOTAL	1088	2	6	11	17	1	1	2	40

SITE: VM89

DATE RANGE: (Classical?) Early Roman (Late Roman?)

DATE RECORDED: 1984

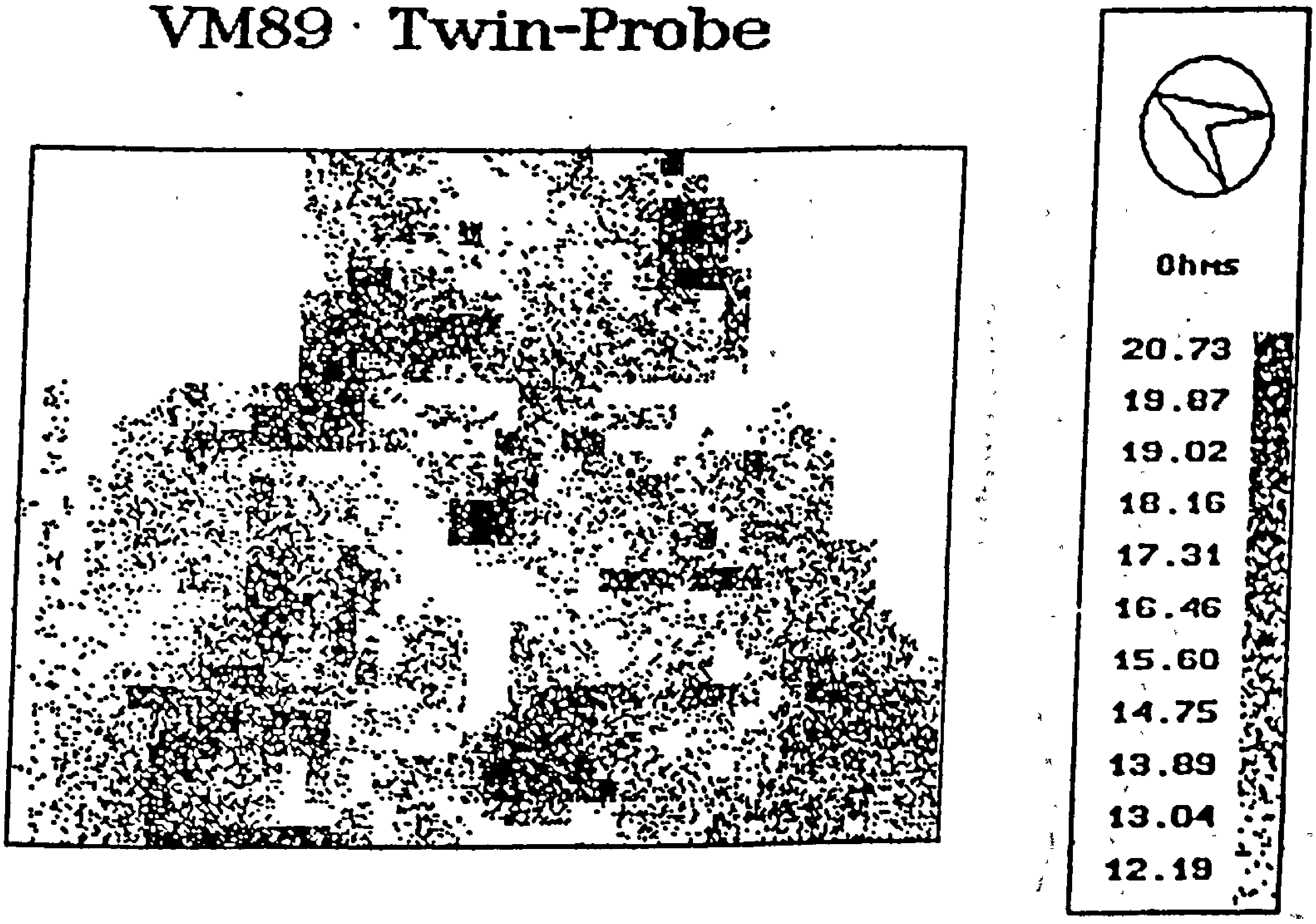
TECHNIQUES: Ceramic count; Tile count; Twin-Probe; Schlumberger; Magnetic Susceptibility; Rubble Plan; T.E.A.

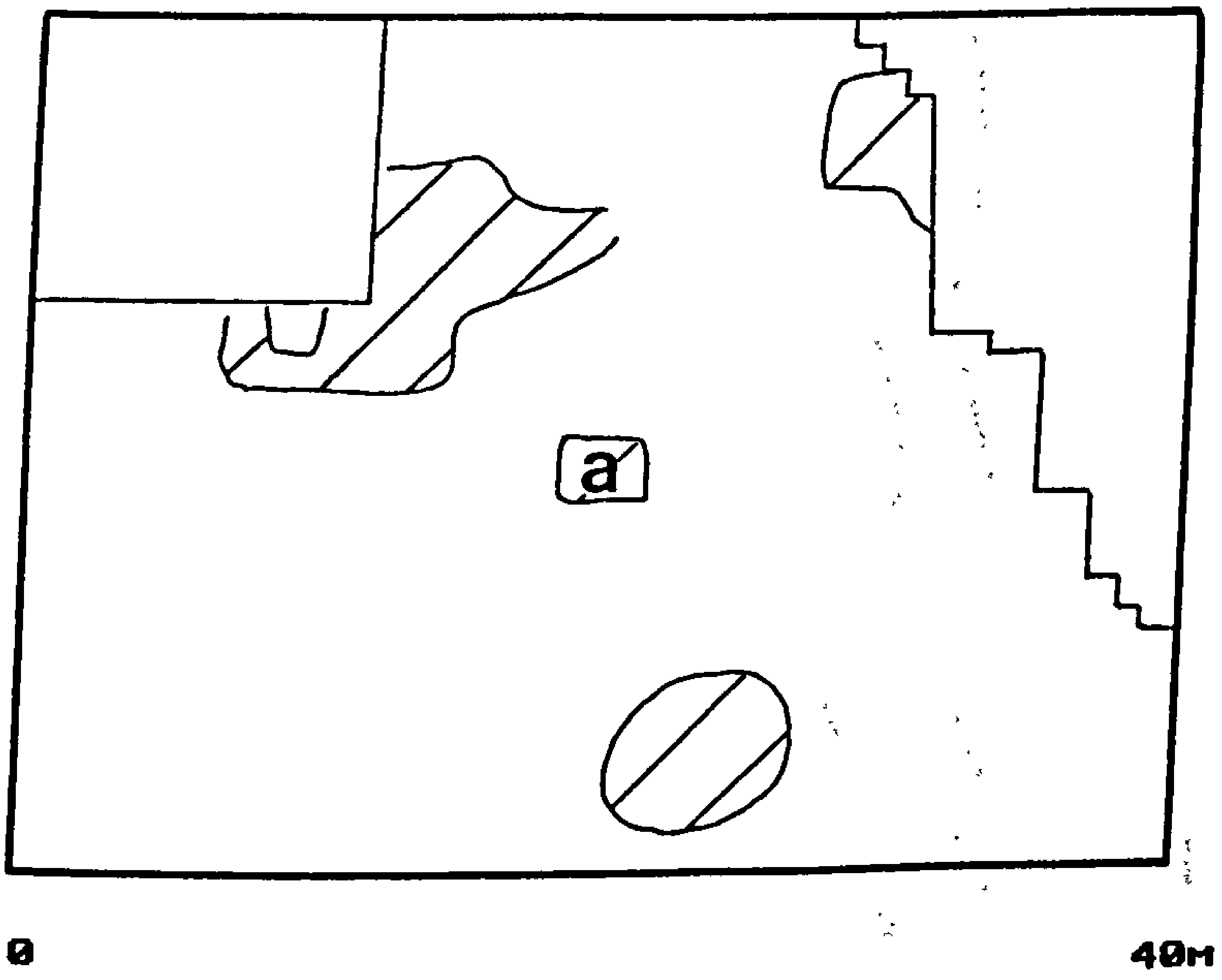
This is a large site covering some 2 ha and is situated in the Valley of the Muses. The site itself is not single period in date. The area of the site that is highlighted in Table 8.8 illustrates the problem of low recovery rate of identifiable sherd material. The samples 45-47 lie near the eastern edge of the site. Intra-site work initially concentrated on this area, and them moved to a second area directly to the east. Although the second area was initially thought to be outside of the site, surface inspection at a later date suggested that this was not so.

Area 1

An area of $1000m^2$ was initially surveyed with a Bradphys instrument, using the the Twin-Probe configuration. The survey suggested that several high resistance anomalies were present (see Fig.8.35). In the small area surveyed there are a number of discrete anomalies that may represent structural features. In the area labelled 'A', some Schlumberger tests were carried out. In this case the measurements were taken with the modified Bradphys meter.

VM89 · Twin-Probe





Shading indicates high resistance areas

Figure 8.35

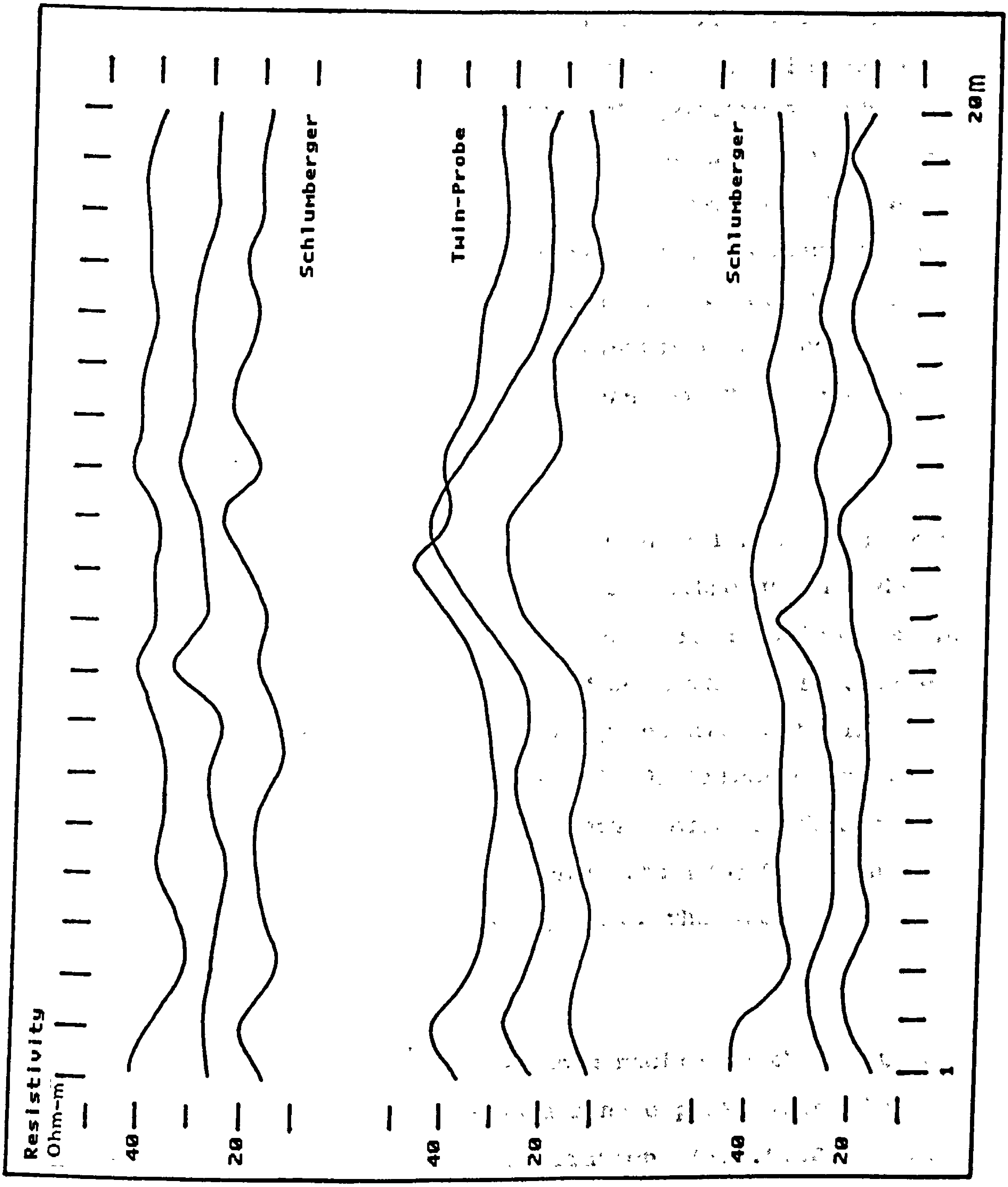


Figure 8.36. Comparison of Twin-Probe and Schlumberger responses from Vm89.

For the Schlumberger survey the C-C distance was set at 8m, whilst the P-P distance was 0.5m i.e. CC:PP = 16:1. For these tests only the three most central values were collected (that is, the values at 3, 4 and 5m from C_1), in both the straight through and first off-set positions. When the measurements had been collected, the whole array was turned through 90 degrees and the measurements repeated. The results may be seen in Fig.8.36. The high resistance feature is quite clearly seen in the Twin-Probe results. However, this is not so in either of the Schlumberger orientations. Again, this may be a similar response as seen at PP27, and must be attributed to the small CC:PP ratio.

All three high resistance areas in grid 1 and 2 appear to be within high areas of tile counts, although they do not have an exact correlation. Although there is a slight slope of this field, from the south to the north, it is unlikely that plough movement is particularly significant in this case. The evidence from the rubble distribution shows no particular concentration, with a general spread throughout. The magnetic susceptibility from this site (Fig 8.37) shows a possible increase in the southern part of the site.

Area 2

The second area at this site was directly to the east of area 1. The tile counts indicated a single peak, which is not matched by the soil magnetic information (Fig.8.38.). The trace element levels are much higher than the regional means.

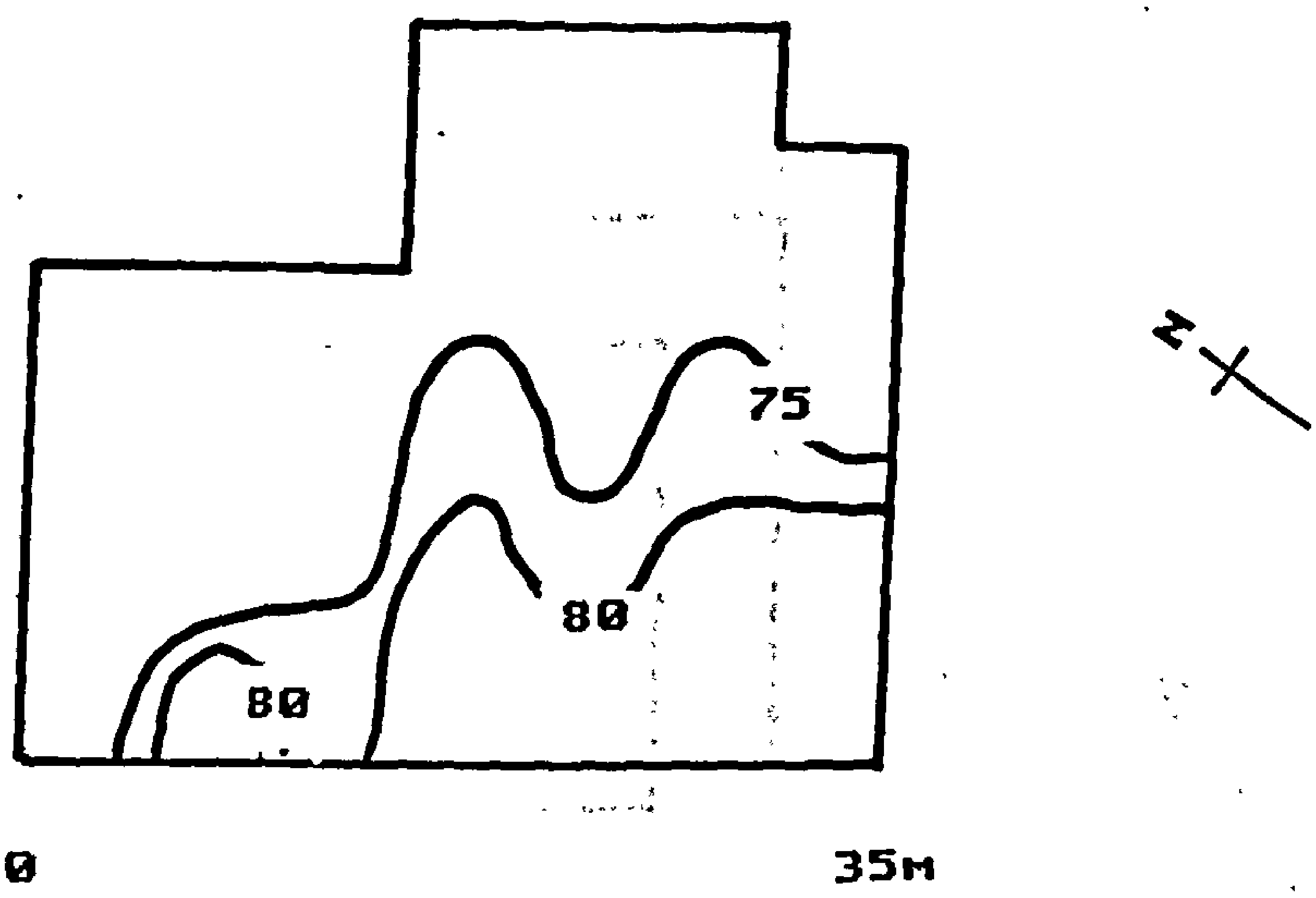


Figure 8.37. VM89 - Area 1. Magnetic susceptibility.

emu/g x 10^{-6}

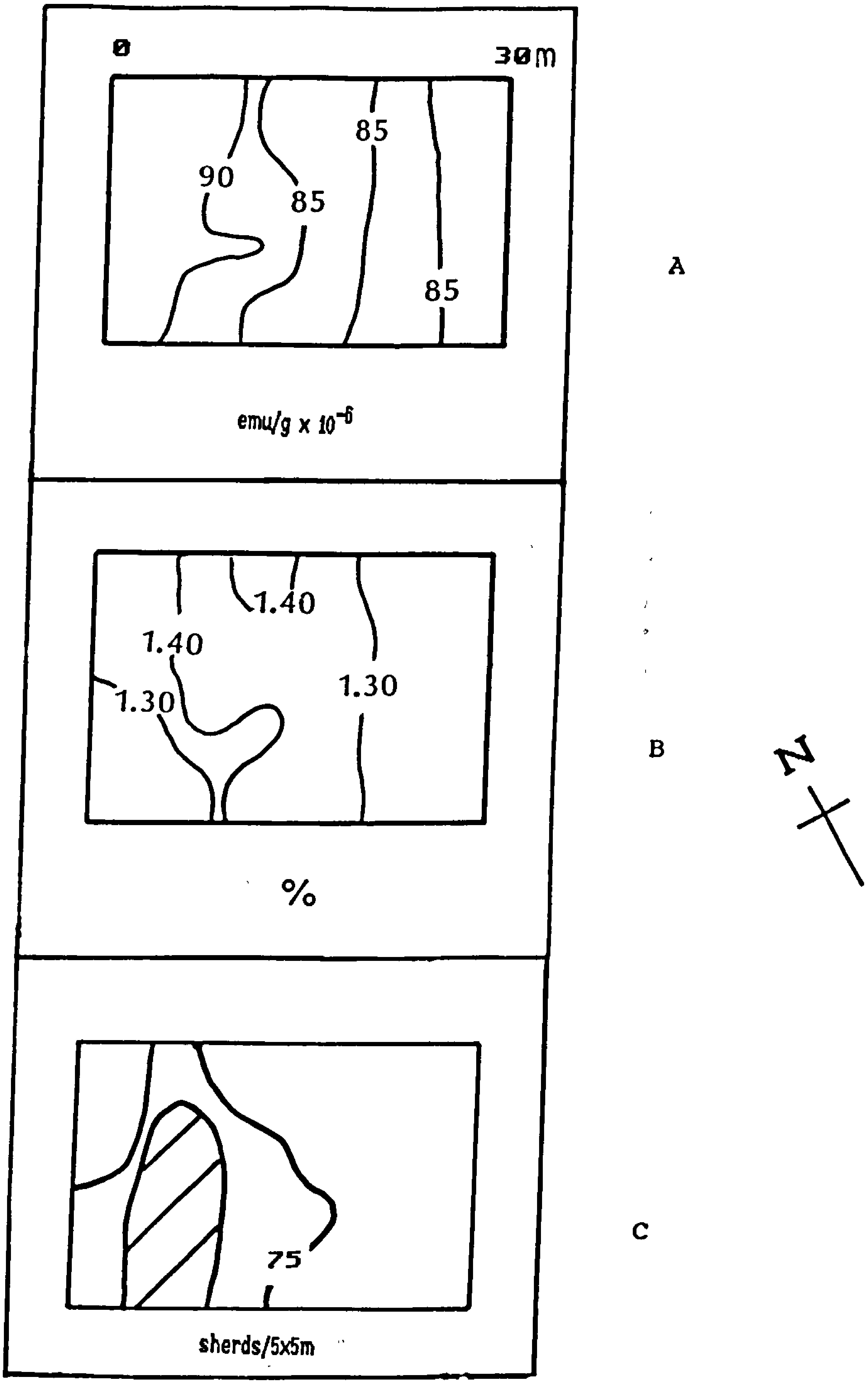


Figure 8.38. VM89 - Area 2. A) Magnetic Susceptibility B) Viscosity C) Tile Counts.

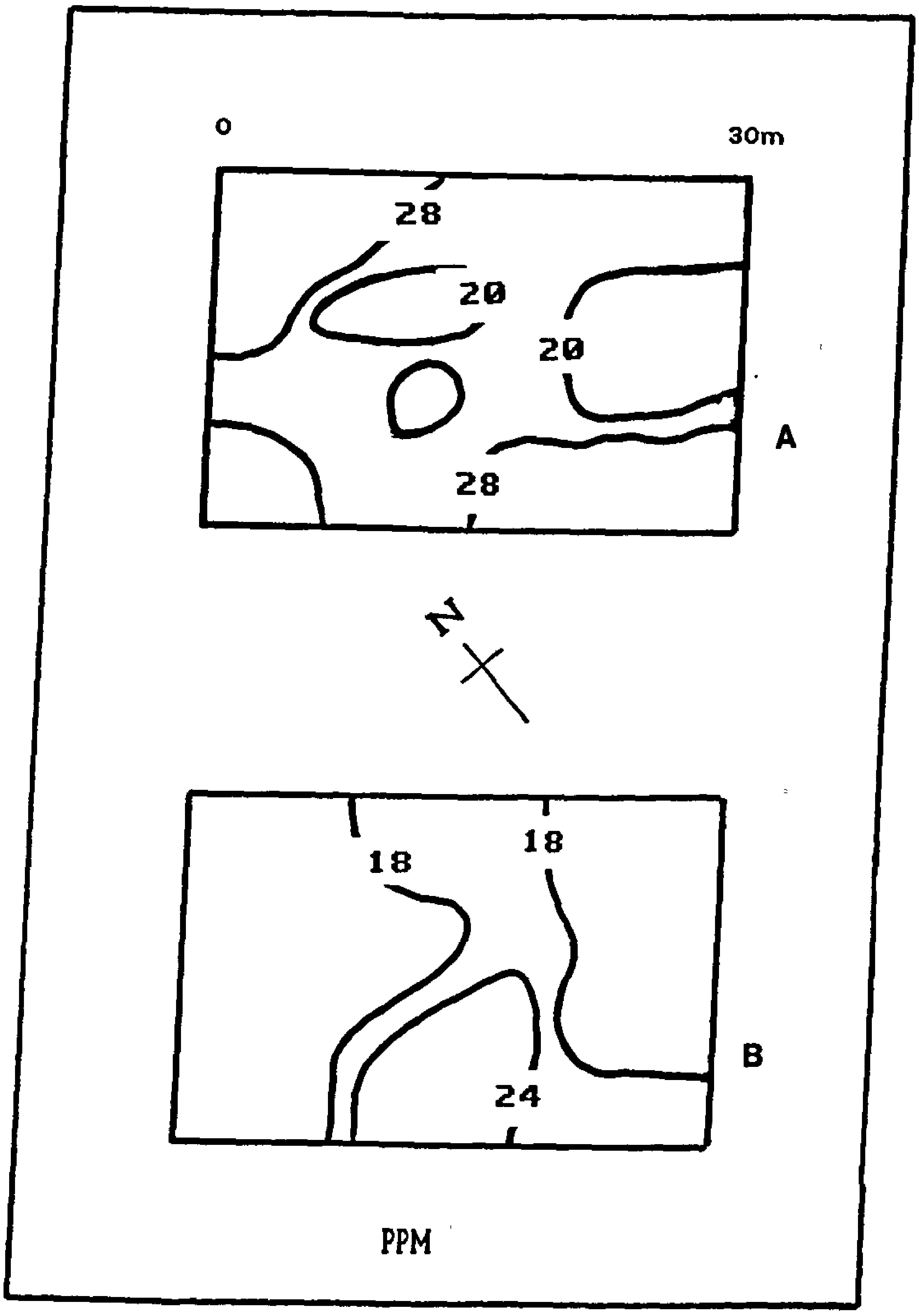


Figure 8.39. VM89 - Area 2. A) Copper distribution
B) Lead distribution.

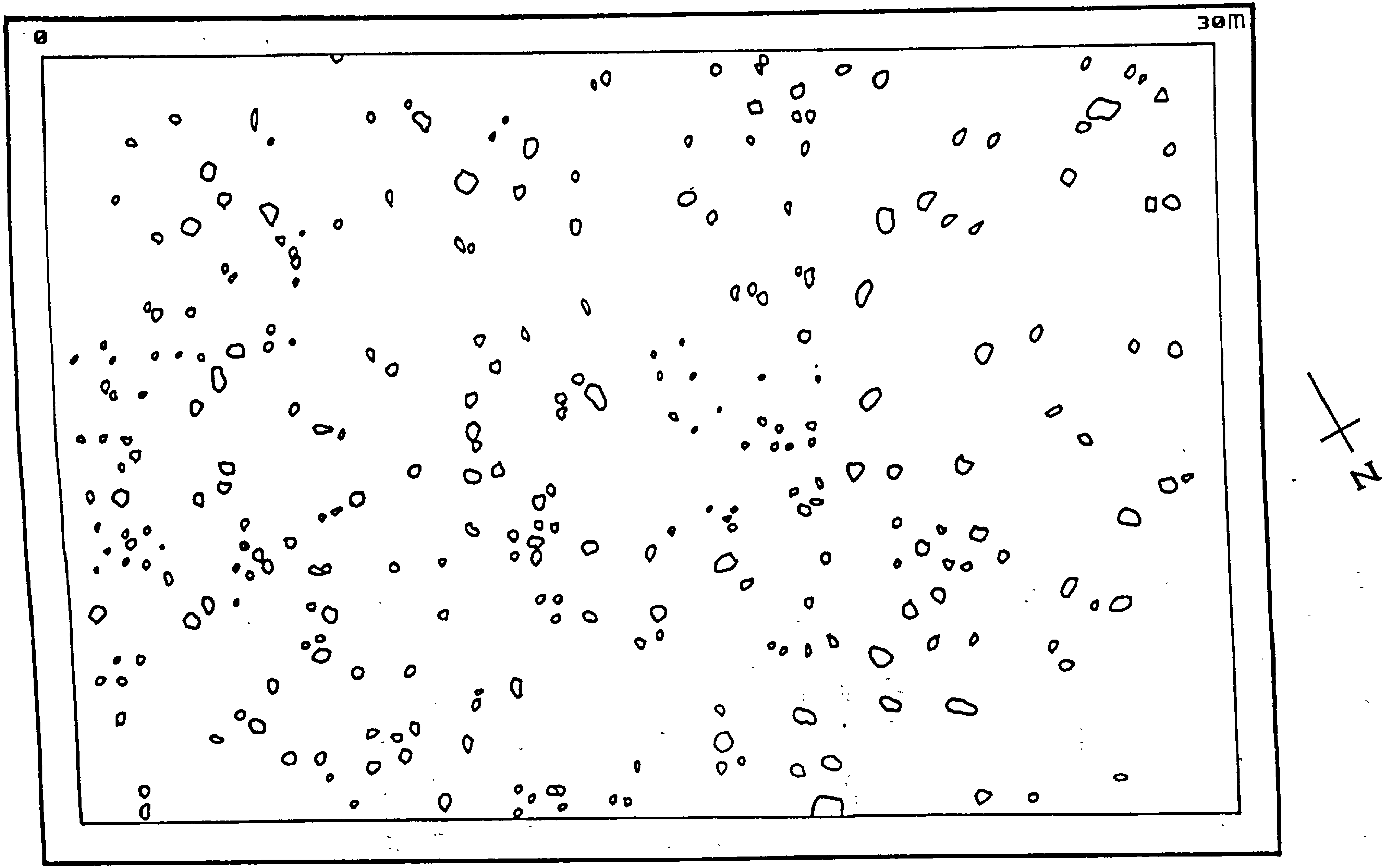


Figure 8.40. VM89 - Area 2. Rubble Distribution.

However, the spatial variation is very slight, with the only significant peak being in the lead distribution. The latter is slightly off-set from the tile peak.

It is possible that this area lies outside of the main part of the site. The presence of the tile in significant amounts, however, should indicate the presence of some substantial structure. It was not possible to confirm this using resistivity, as the ground was baked hard, making it impossible to achieve adequate contact.

Conclusions

The site of VM89 is somewhat larger than the majority of the sites investigated in this thesis. One would expect a range of activity to be undertaken on such a site. The conclusions that can be drawn from the results, are that a number of high resistance anomalies have been located using the Twin-Probe arrangement, and that these may be indicative of buried structural remains.

Clearly, it would be of some value to continue the secondary investigation work within Area 1. The lack of variation in the trace elements in Area 2 may be significant if this area does lie outside of the 'site'. Again, to be able to contrast this variation with an area inside of the site would be valuable.

TABLE 8.8 Diagnostic material from VM89.

		DATE					
	CERAMIC	C-H	H-R	ER	R-LR	LR	TOTAL
SAMPLE							
45	924	3	1	3		1	8
46	882	1		1	2	2	6
47	730	1	1	2		1	5
		---	---	---	---	--	--
TOTAL		5	2	6	2	4	19
		---	---	---	---	--	--

SITE: VM95
DATE RANGE: 4th-3rd century B.C.
TECHNIQUES: Ceramic count; Tile count; T.E.A.
Magnetic Susceptibilty; viscosity.

The site at VM95 provides one of the least informative data sets in the Boeotian data-base. Whilst both the ceramic counts and the dated material indicate a compact site, the magnetic investigations provide nothing of note (Fig.8.41.). However, the fact that we have located a site using traditional survey techniques, that shows so litle variation for the individual magnetic elements in the secondary investigation, could be significant. It could be that a different sort of activity has taken place at this site by comparison to, say, VM70 or VM64. Indeed, the size of the site, suggested by ceramic counts is very small. It could be argued that the evidence represents a very short lived minor site, which could have been used for some specific function. The latter may have left no trace that we could detect.

The trace elements in particular (Fig.8.41., D and E), show major enhancements in both lead and copper (regional means 6.6 ppm and 6.7 ppm respectively). The question that must be addressed, therefore, is why do we get such a clear trace element enhancement when other parameters we are using to describe the site are low ? It is unlikely that the post depositional factors at the site have destroyed some of the parameters and not others. Therefore, further research should focus onto the trace element variation around a site such as

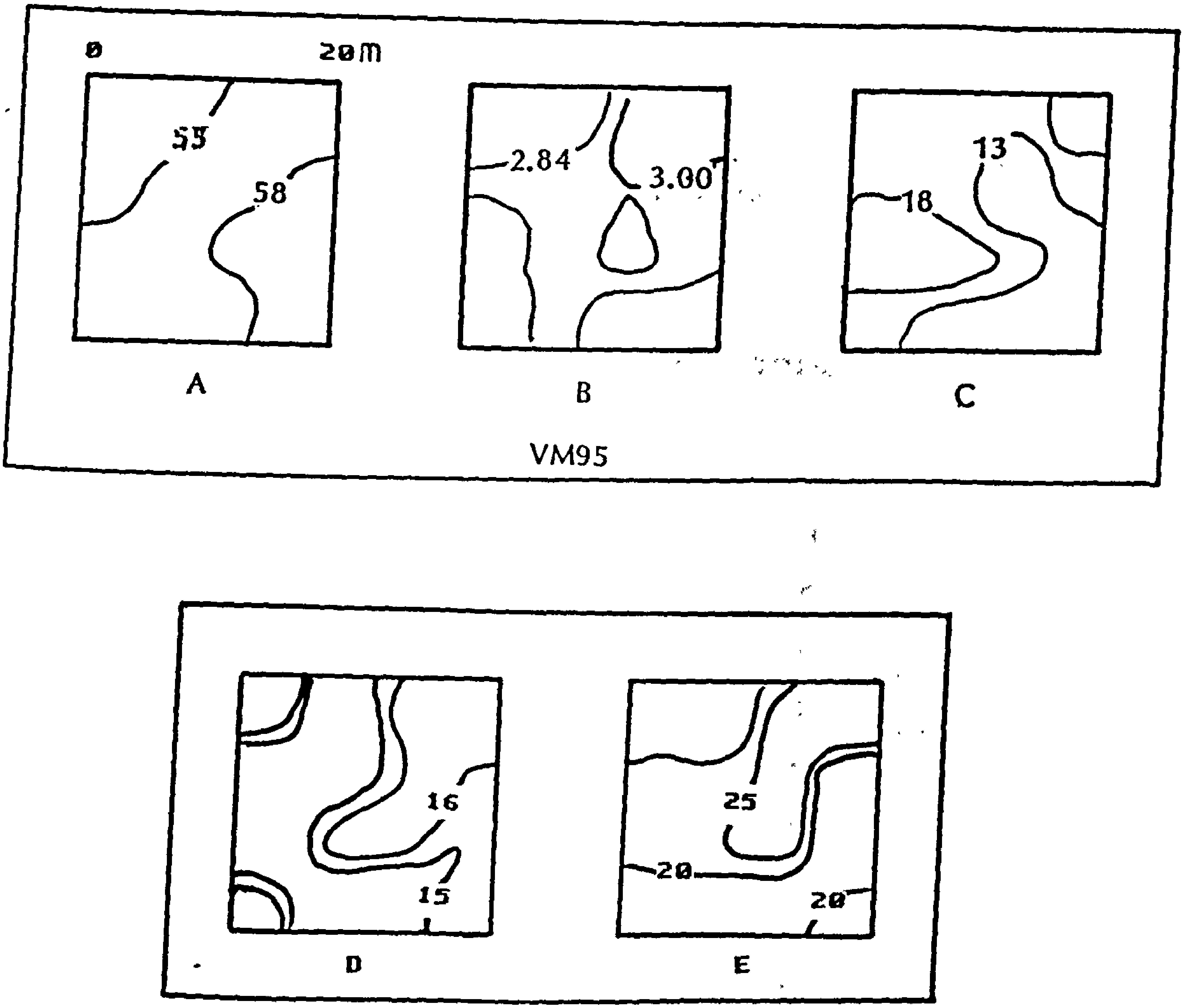


Figure 8.41. VM95 - A) Magnetic susceptibilty emu/g x 10^{-6}
B) Magnetic viscosity %
C) Tile counts sherds/5x5m
D) Lead distribution
E) Copper distribution. } PPM

VM95. By comparison with a site that has offered all the 'signals' of habitation, we could then tell if the patterning at VM95 is significant, or simply the product of natural factors. The evidence remains that increased trace element levels are present at this site, and that they probably reflect archaeological activity.

TABLE 8.8. Diagnostic material from VM95.

		DATE			
	CERAMIC	C-H	C	EH	TOTAL
SAMPLE					
1	281	14	1	1	16
2	263	3			3
3	244	6			6
4	83				0
5	59		1		1
6	68	3	1		4
7	21				0
TOTAL	1019	26	3	1	30
'GRAB' SAMPLE			6		6
TOTAL	1019	26	9	1	36

SITE: <u>TPW2</u>

DATE RANGE: <u>Late Roman</u>

DATE RECORDED: 1985

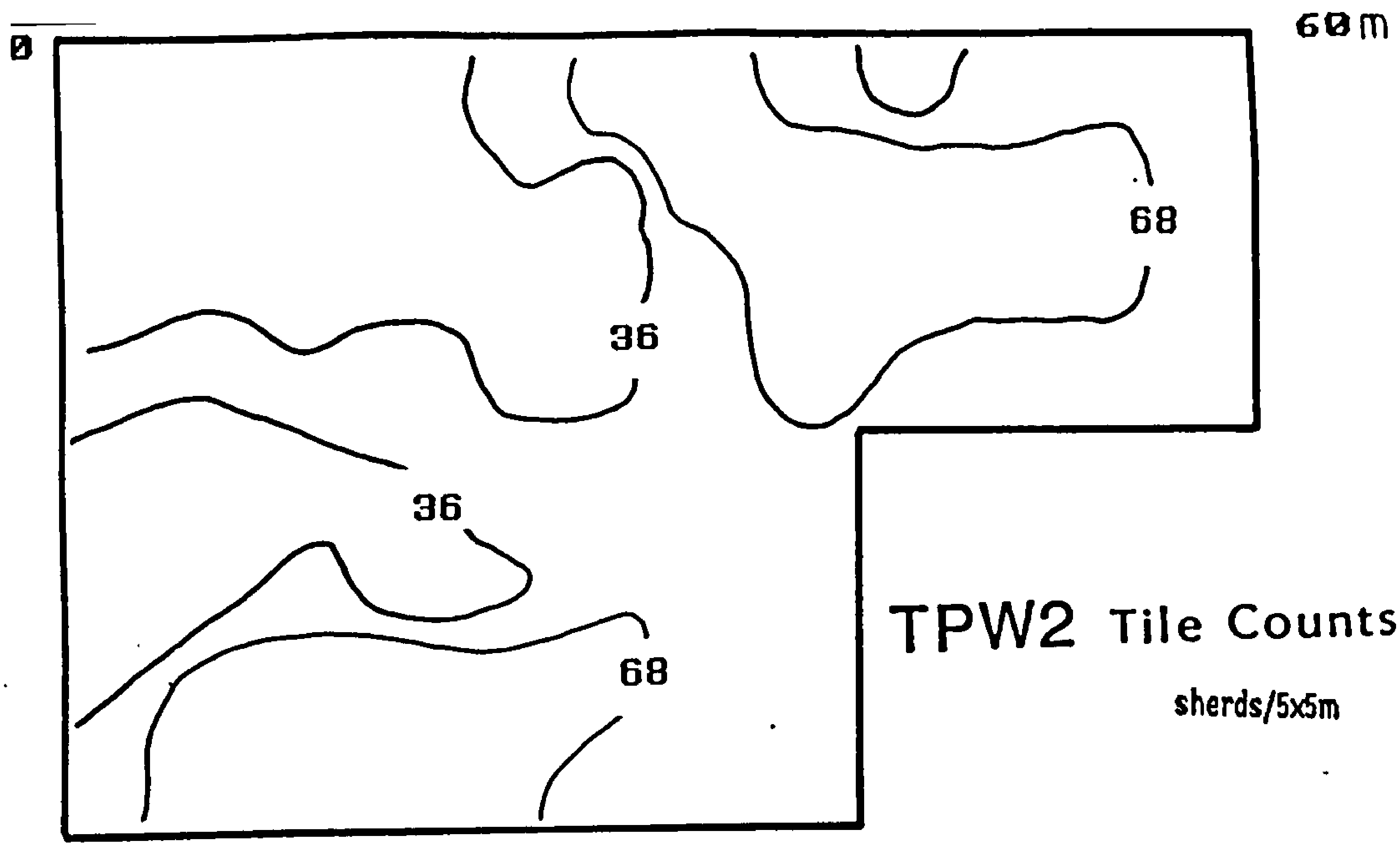
TECHNIQUES: Ceramic count; Tile count; T.E.A.
Schlumberger; Magnetic Susceptibility
Magnetic Viscosity.

This site is a typical, relatively large Late Roman site from the Boeotian data base. Due to the extent of the site only a sample could be investigated in this research. The site is situated on a small platform in the plain of Thespiae, very close to the edge of the ancient city. The 3.4 ha that the site covers, naturally produces a large 'halo' effect which in turn runs into the massive ceramic counts associated with the halo of the city itself (see Fig.8.3). The latter is due to a number of different disposal practices, only some of which would have been related to agricultural use.

As the site at TPW2 was so large, a flexible approach to the intra-site sherding was adopted. The site was analysed using a series of samples across the core of the site. Ostensibly this information was used to identify the significant chronological sequence at the site, rather than the identification of significant intra-site areas. Of the nine samples in Table 8.10., which were all situated in the main area of ceramic concentration, the date range is very clearly Late Roman.

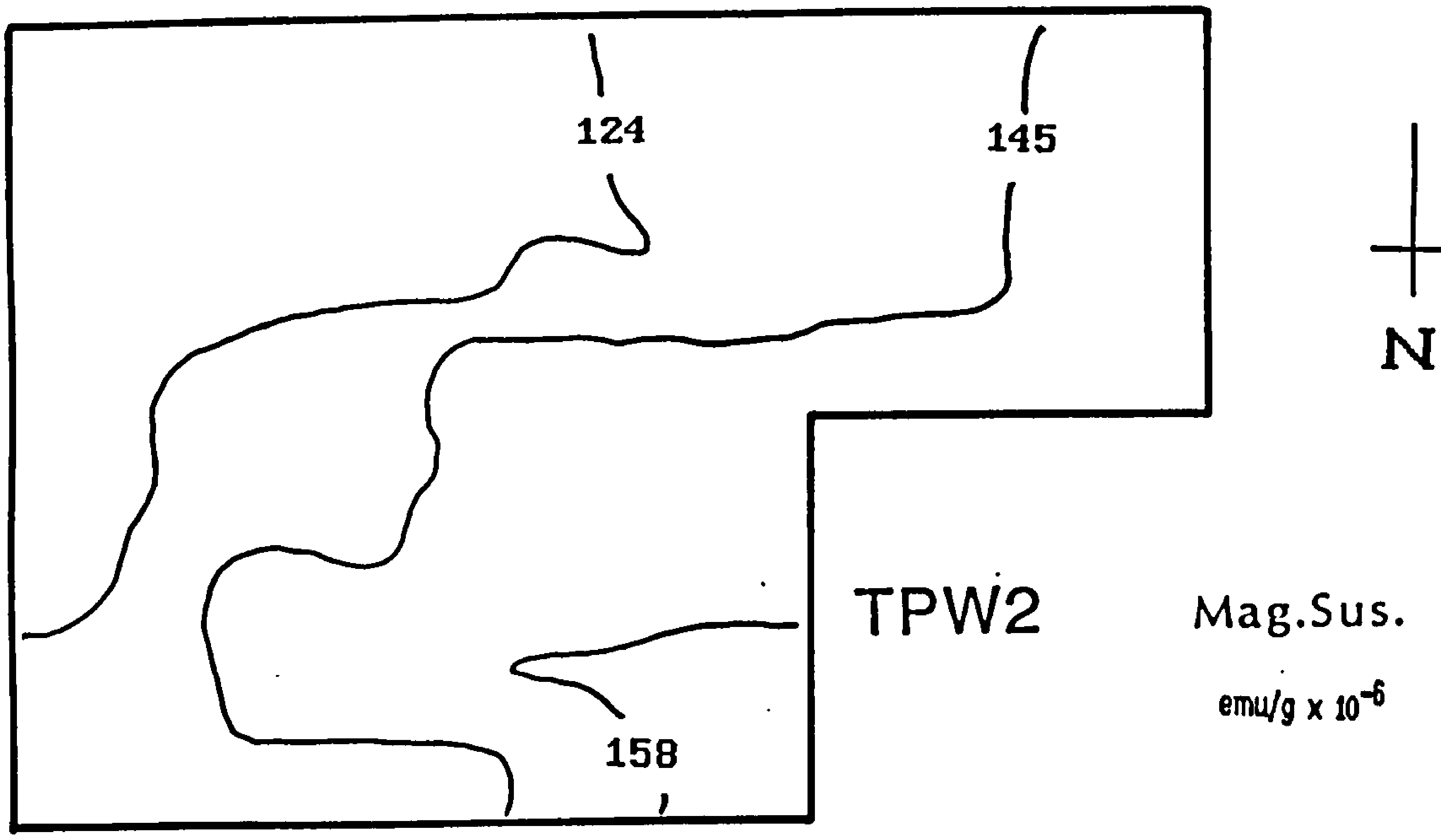
The first measurements to be taken in the secondary investigation was a tile count over 2000m^2 (Fig 8.42). This information defined two areas of tile concentration. Contrasting with this was the magnetic susceptibility distribution that showed a trend of decreasing susceptibility toward the S-E corner of the grid (Fig.8.42). At first sight this is a confusing picture, one that might be thought to have been produced by post-depositional factors. However, if this were true, then it may be expected that the distribution of the magnetic viscosity may also follow this pattern. As this is not so, we may therefore conclude that the susceptibility pattern is not an artefact of modern plough action. The viscous element in fact shows two series of low values between the major tile peaks. The question that therefore arises, is does this give some credence to the suggestion that there may be two separate use areas on the platform?

On this site ground conditions were particularly hard and contact resistance was very high. To achieve readings using the Schlumberger array not only were the current probes watered in, but at every position the potential probes were also similarly treated. Although this is a laborious, time-consuming and energy-sapping exercise, it was felt that this important site warranted this, especially as a plentiful



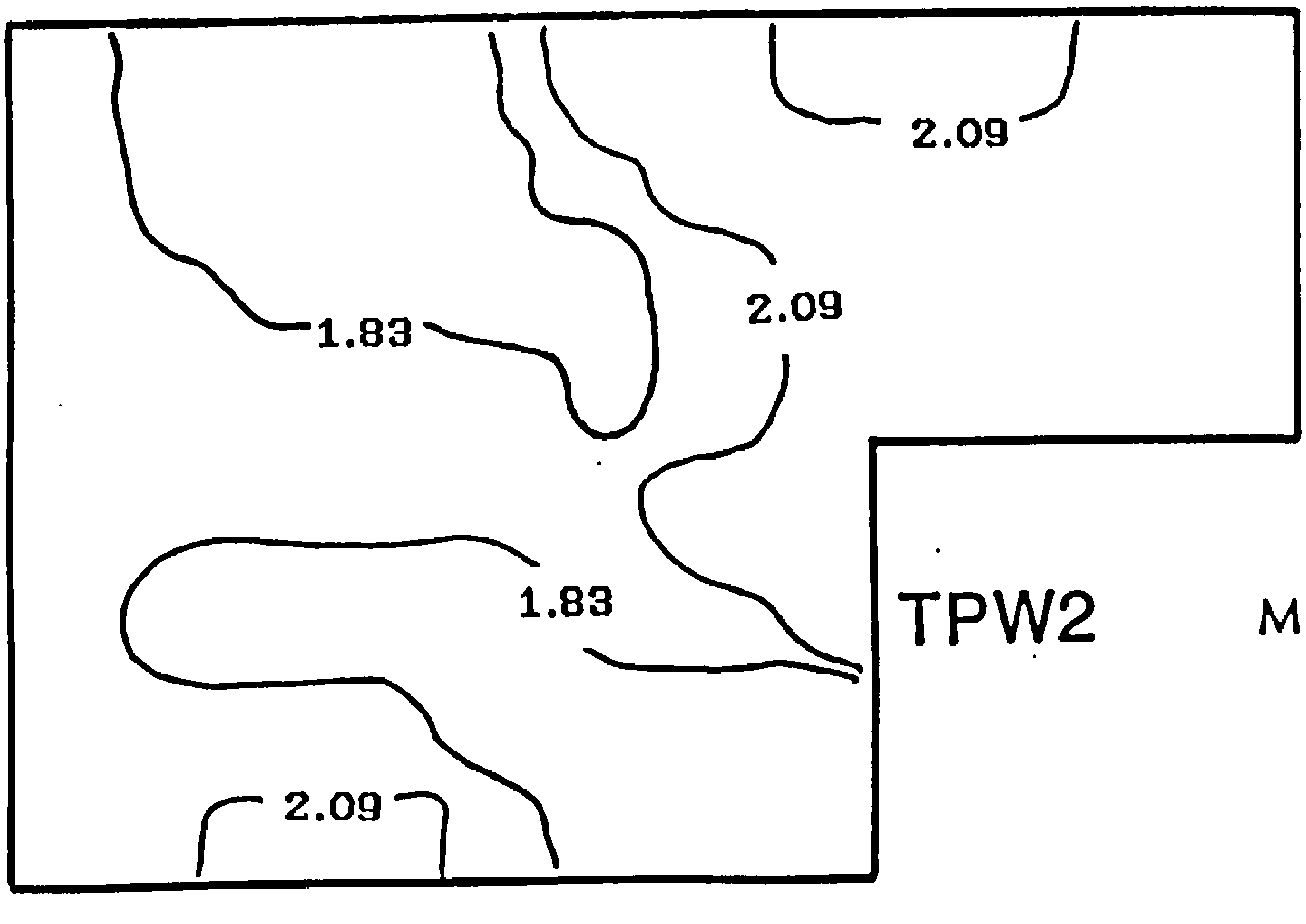
TPW2 Tile Counts

sherds/5x5m



TPW2 Mag.Sus.

emu/g x 10^{-6}



TPW2 Mag.Vis

%

supply of water was available locally. However, only a small 40x20m area could be surveyed using this technique, and no results were collected using the Twin-Probe configuration. The Schlumberger survey was centred upon the two northern grids. With the current probes positioned N-S a very large, high resistance feature may be seen running at right angles to the straight through line (Fig.8.43). Although this feature is broken up in many places it is still coherent, as is the high resistance block in the S-W corner of the survey.

As expected, the complementary survey (with the current probes positioned E-W) did not reveal any trace of the major linear feature seen above, but did locate the high resistance block in the S-W corner (Fig.8.44). Otherwise, the survey may have identified some small features running at right angles to the C-C line and within a confused background. The approximate orientation of the feature has been indicated on the diagrams.

The merged data (Fig.8.45) shows a much clearer, much more coherent set of results. The concentration of tile noted above may be delimited in the resistivity by the apparently large scale feature, as shown in the interpretation of the combined values. Although the precise definition of the anomaly in the E-W direction is problematical, it seems likely that remains with that orientation exist from the interpretation of Fig. 8.44. It is likely, therefore, that the small area surveyed contains one massive wall with a smaller wall at right angles to this. A low concentration of ceramic tile suggests that a shed or a similar flimsy

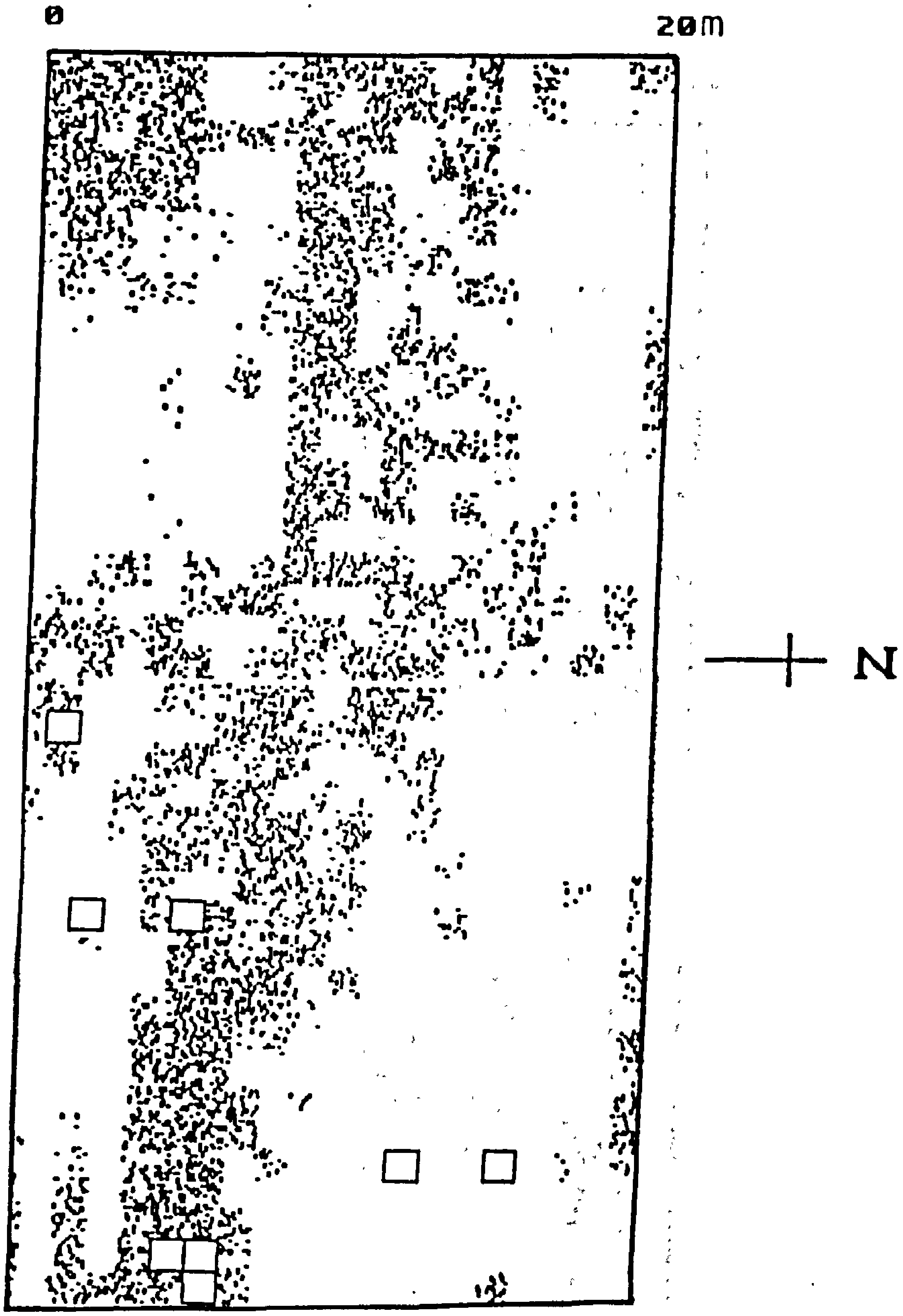


Figure 8.43. TPW2. Schlumberger, current probes N-S.

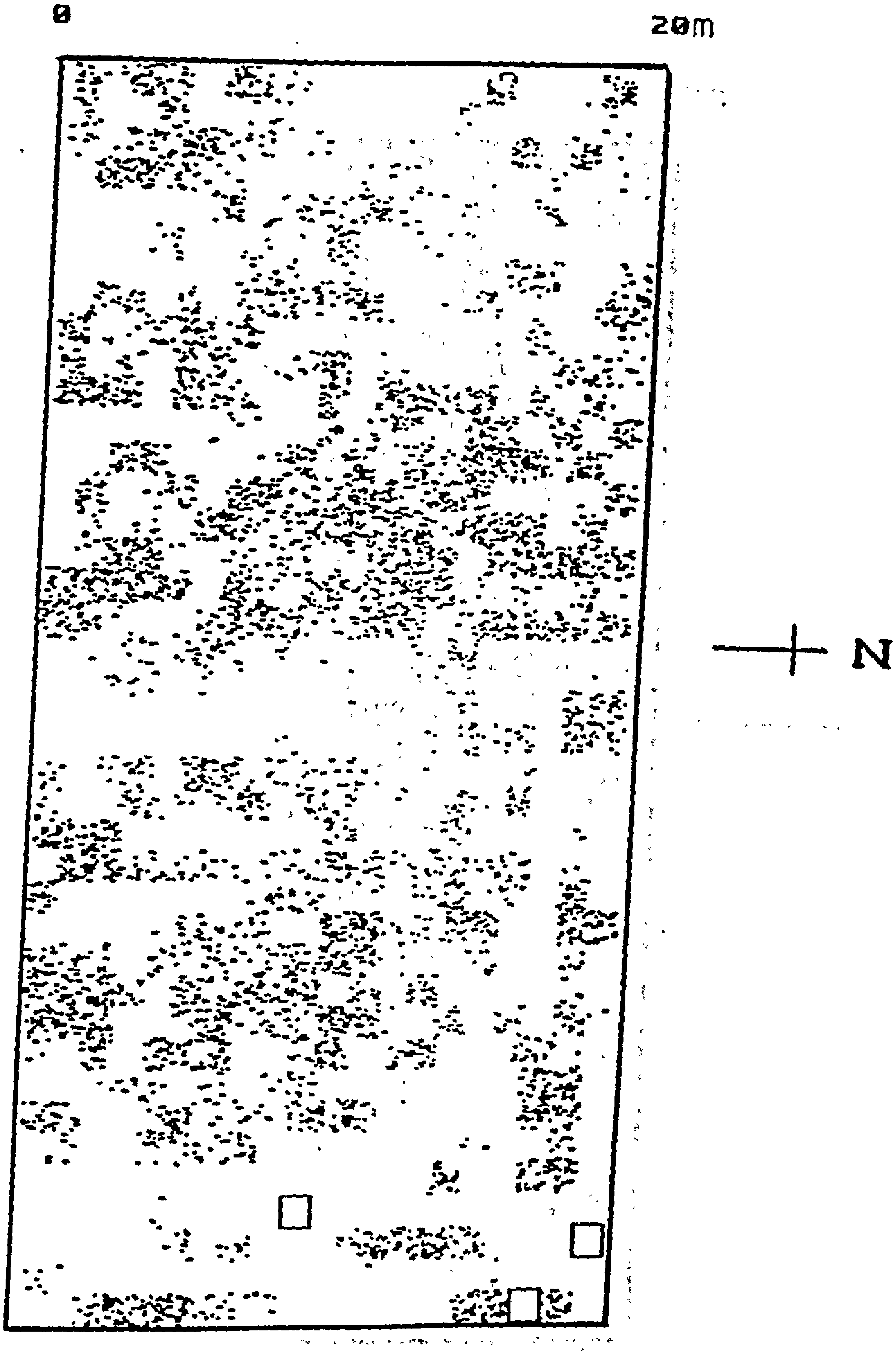


Figure 8.44. TPW2. Schlumberger, current probes E-W.

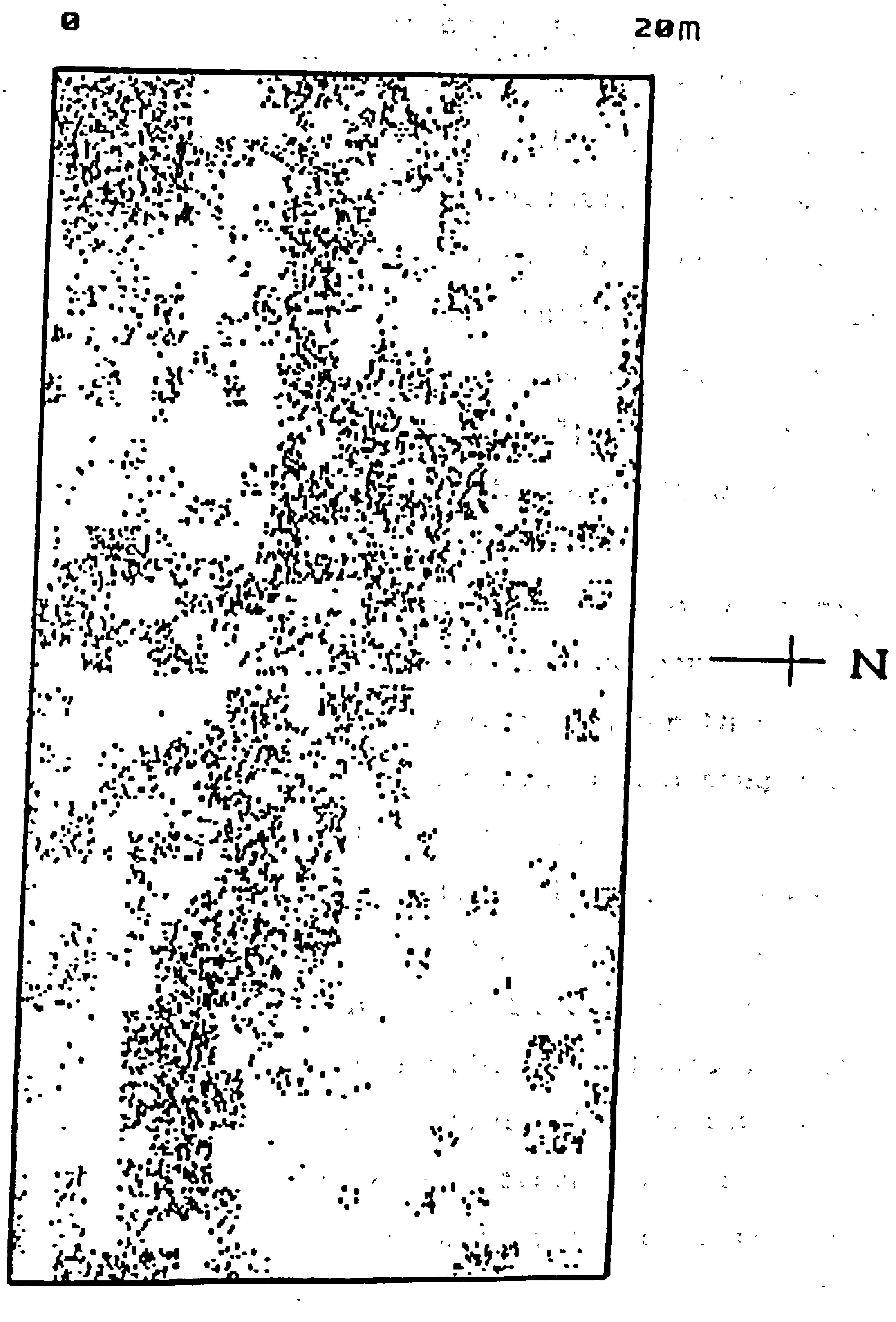


Figure 8.45. TPW2. Schlumberger, combined.

structure might have seen built against this wall. It is also noticeable that the magnetic viscosity produces a low area of readings to complement the tile data.

It is interesting to discuss the archaeological interpretation of the high resistance feature that is visible in both of the resistivity sets. Whilst this anomaly could be the corner of a structure, the tank simulation work would suggest that the anomaly might be a small, square feature i.e. a feature without significant length to breadth differences. This could be interpreted as either a rubble spread, or a small structure (a tower base ?). Evidently, it would be of great interest to know if this anomaly continues beyond the surveyed area.

In the trace element analysis, the usual two elements have been highlighted (Fig.8.46). For both copper and lead the site mean levels are statistically much greater than the regional backgrounds. The copper, although exhibiting some peaks that might be associated with the geophysical structures, clearly shows accumulations in other areas. Whereas it may be possible to say that the copper is associated with the roofed structures, as in the case at PP17 and VM64, the lead again has a contrasting distribution. The lead, although partially peaking over the resistivity anomalies, clearly has a more dispersed pattern. As in the previous sites the lead is peaking across the site rather than indicating the structural area.

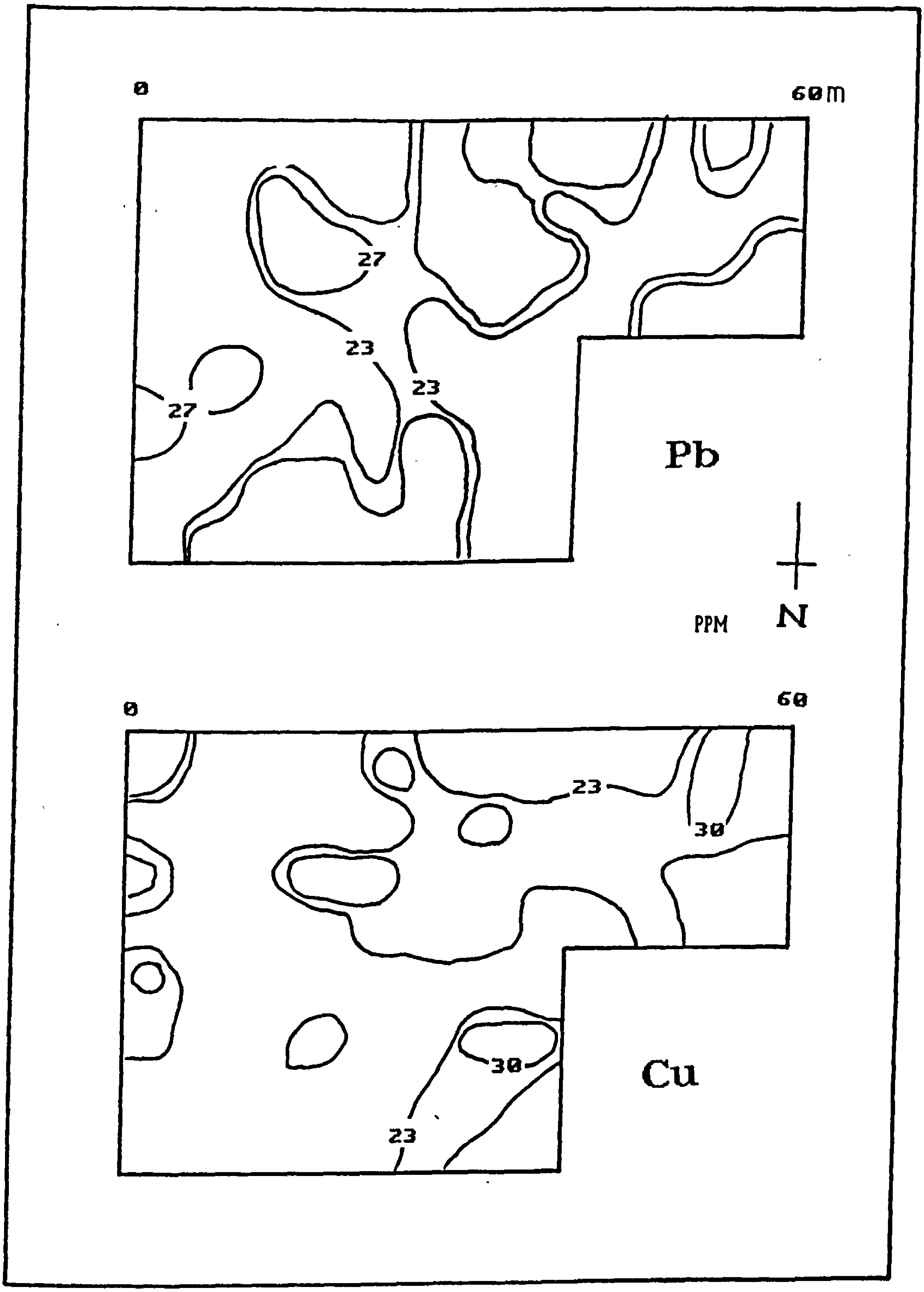


Figure 8.46. TPW2. Trace element distribution.

Conclusion

The Schlumberger survey has added quite significantly to our knowledge and understanding of this site. The site has proved to contain a massive structure that may be associated with a surface tile scatter. Whilst the trace elements and tile information show clear differentiation within the site, it is still difficult to argue for a complete interpretation of the surveyed area. The patterns that have been defined, especially in the trace element and the viscosity data, may well be significant, but no definite archaeological explanation can be offered.

The intra-site analysis of TPW2 is difficult to assess, due to the overall site size. It is felt that this investigation has indicated that substantial archaeological remains are buried at this site, and that the topsoil information is relevant to the site's interpretation. The results from the site suggest that a larger investigation could be warranted.

Table 8.10 Diagnostic material from TPW2

		DATE				
	CERAMIC	C-H	ER	R-LR	LR	TOTAL
SAMPLE						
1	249				1	1
2	442				3	3
3	338				5	5
4	308				6	6
5	116	1				1
6	54					0
7	107				4	4
8	216				3	3
9	1671		1	5		6
	----	---	---	---	--	--
TOTAL	3501	1	1	5	22	29
	----	---	---	---	--	--

SITE: TPW11
DATE RANGE: (Roman-) Late Roman
TECHNIQUES: Ceramic counts; Tile counts;
Magnetic Susceptibility; Mag.Viscosity

This again was a potentially interesting small site, situated in the same plain as TPW2. The site had a limited chronological span, as well as covering a very small area. Again, the resistivity technique was foiled by very dry field conditions.

The tile measurements suggested a major increase downslope to the west. The susceptibility showed no increase in this area. Infact, the topsoil values at this site were not particularly enhanced. The viscosity measurements show a slight increase in the area of the highest tile counts. However, the number of measurements are too small to make an argument for any particular activity at the site.

In the light of the previous studies, it is possible that the only way to investigate a site such as TPW11 is to broaden the area investigated. This would show the relationship of the site to the activity around it.

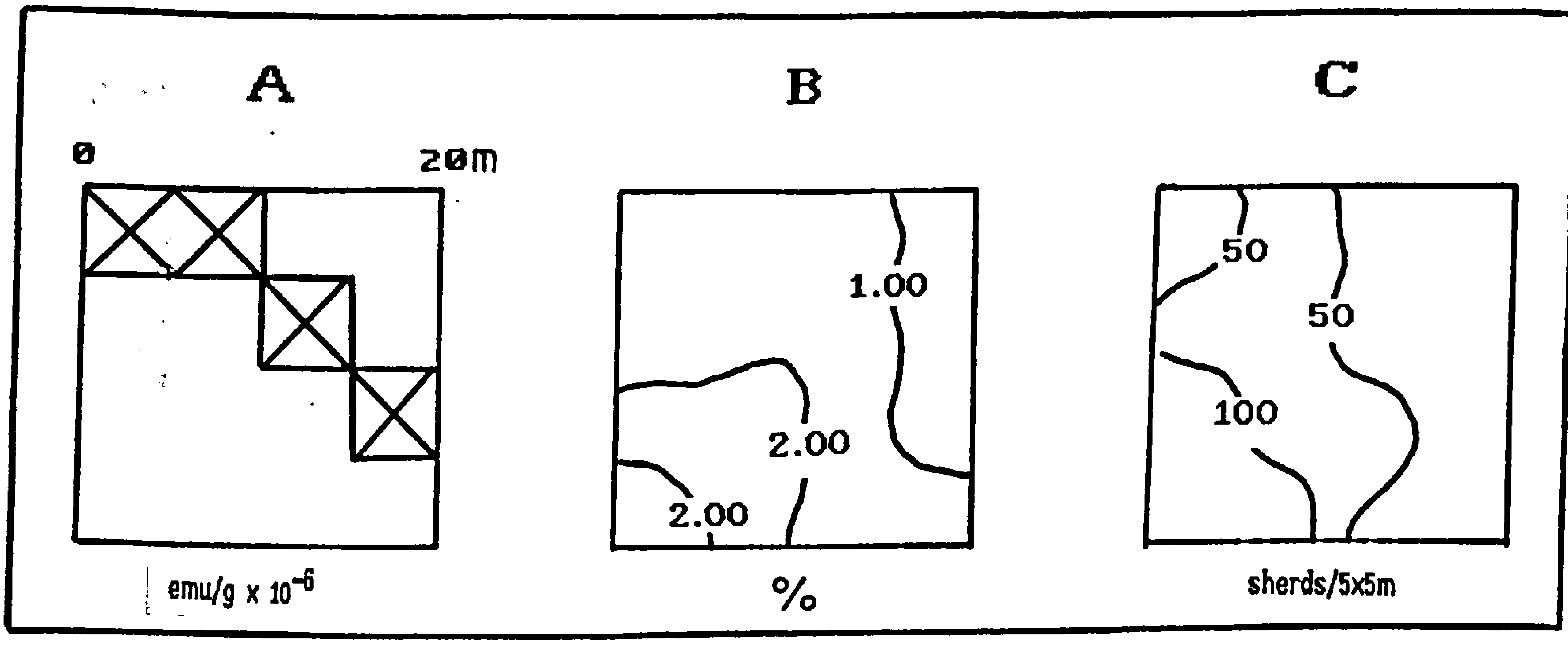


Figure 8.47. TPW11. A - Magnetic susceptibility (values higher than the mean hatched)

B - Viscosity

C - Tile count

Table 9.10 Diagnostic material from TPW11

		DATE			
	CERAMIC	H-R	R-LR	LR	TOTAL
SAMPLE					
1	482		1	2	3
2	414	1	4	3	8
3	97	1		1	2
4	46			1	1
5	184			2	2
6	486			1	1
TOTAL	1309	2	5	10	17

8.7. Conclusions to the Intra-Site studies

The studies related in the previous section are part of a wider investigation into the ancient Boeotian landscape. The overall project is long-term, and its research goals will continue to change as new avenues are made available from the data set. However, the problem of rural sites will continue as ever present, literally covering our maps of the ancient landscape.

The limited objective of this study was to study a number of the sites that contribute to this landscape, and to assess their nature. The availability of techniques and the limited time of fieldwork each year has produced something of an 'organic' research design. Some elements have provided clear information that is of considerable archaeological interest. What is important to the project is that none of the sites have provided us with no information. For example, the trace element information has indicated that a site such as VM95, which is considered poor in many archaeological attributes, still exhibits levels of copper and lead that are considerably higher than the regional means. Therefore, we are still probably considering this site as a previous habitation.

The main objective of the resistivity surveys was to locate and map the structures associated with the ceramic scatters. Due, partially to the very dry conditions, the results have given us only partial success. There are six sites where the technique has been of some considerable value; MPA2, PP17, PP27, VM64, VM70 and TPW2. Only one of these has provided positive Schlumberger responses for high resistance structural evidence i.e. TPW2. However, the response from that site is typical of the results obtained previously in field and tank simulations. The archaeological interpretation of all six sites must be regarded as significantly superior to those without subsurface indications.

The results from the resistivity surveys are, however, unable to give anything other than general information about what lies under the field scatters. The overall view of the sites, including the other parameters, indicate gross differences between the sites. For example, the patterning of magnetic susceptibilty at VM70 is very striking, peaking over the highest tile counts. At VM95, the susceptibility has no patterning, and could hardly be described as enhanced. It is likely that by our definition of these sites, that we could be indicating function, without being able to suggest what the functional differences could be. The fact that none of the sites indicated any major industrial activity (that is there was no relevant surface material and no suggestion from the magnetic viscosity), probably indicates that the differences between sites are very subtle.

None of the sites indicated that they were particularly different in any way, except for TPW2, which showed considerable varition in all of the parameters measured.

However, it was known prior to the intra-site work that this site was different due to its size. The resistivity results suggested that this site exhibited a possible tower, perhaps emphasising the massive nature of the site. What was not unusual at this site was the complex variation in the trace elements. Future work on selected sites and 'fossilised' environments will be most informative in the interpretation of these sites. What is not necessarily clear is whether the sample interval is correct for this work. To analyse at a smaller sample interval would be very costly, and difficult to justify. What would be most interesting would be more information outside the core of the site. Whilst the project already has a good recognition of what background levels are for the trace elements, what is not known is the spatial variation off-site. A knowledge of this information could help identify non-natural distributions on site.

The conclusions from this study are not classically defined in terms of the results and an interpretation. They are more directed toward the future use of scientific means of analysis on site. This controlled investigation has revealed substantial information on the status of farm buildings at sites MPA2, PP17, PP27, VM64 and VM70. The results from these sites, coupled with the analysis of the larger, 'estate' at TPW2, have justified the belief in the battery method of analysis.

However, to retrieve the maximum archaeological information may require a re-orientation of aims. The ability to gather detailed plans of buried farmsteads has been complicated by one of three possibilities. Firstly, damage by the plough could be greater than that normally imagined. Secondly, if the problem is simply one of resistivity contrasts, then a change in the season for the fieldwork should be of importance. The third possibility concerns the original assumption that the 'target' features would be constructed out of high resistance material. If the first possibility is true, then future work should be focussed on the parameters associated with the topsoil. However, if this is the case, then the long term success of such analysis cannot be envisaged.

Chapter 9

A Summary of the Potential of the Schlumberger Array in Archaeological Prospecting.

9.1 Introduction

The scope of this thesis has developed beyond the operationalisation of the Schlumberger array in archaeological prospecting. Whilst it is clear that the technique of resistance survey has not proved totally successful on the sites of Boeotia, it is felt that use of the array in the context of field survey interpretation has benefited the understanding of the archaeology. Conversely, the experience has has also indicated the limitations of the use of the array, if not the the technique of resistivity surveying, during the summer months in parts of the Mediterranean.

The early field studies presented in Chapter 4 suggested that the array would indeed be most beneficial to archaeological interpretation. However, none of the British case studies, excepting perhaps the Chesters villa, were conducted over sites that were badly plough damaged. This recent destruction is surely the major factor in the poor response of the Schlumberger array on the Greek sites. It is likely that most of the sites in the Boeotian data base are too badly plough damaged to use any resistivity techniques to identify buried archaeological remains. The only way to prove this would be to conduct surveys during another part of the year, and preferably also using a comparative method, such as contact-less E.M. system to measure the conductivity. The ravages of modern agricultural practices have probably radically altered the archaeological 'equilibrium' between the sealed deposits and the topsoil. In terms of prospecting on the smaller sites using any resistivity arrangement, the chances of success are minimal. However, exciting possibilities have been uncovered showing the variation in other soil components available in the topsoil. Ironically, the same destructive forces that have contributed to the failure of the Schlumberger array, has aided the availability of magnetic susceptibity, trace elements, etc. Some conclusions concerning the future of intra-site analysis for the Boeotian project have been suggested in section 8.7.

9.2 Practical considerations of the Schlumberger array

The ultimate aim of this thesis was to use the Schlumberger array in such a way as to achieve the best performance from the array, whilst speeding up the data capture. Tailoring the array to be used within the 20x20m grid squares used in the School's work speeded the data collection. However, the directional properties first encountered at All Hallows (section 4.3) proved to be the major practical consideration in the use of the array. However, by extending the C-C distance to such an extreme it is clear that many of the positive aspects of the Schlumberger had been maintained i.e. the resolution of the array and its depth penetration. Due to the retention of the array using such parameters, the fact that it is suggested that each grid should be surveyed twice is not too extreme. The possibility remains that a four probe potential device could be used in such circumstances i.e. both sets of current probes could be set out and the two resistance measurements taken at the same time. A dedicated logger could be built to identify each reading, and the data stored in its three forms - N-S direction, E-W direction and combined. The combination of the data sets should be researched more fully.The value in this context for the array can only be judged by further use. The small field tests detailed in this thesis merely suggest the level of detail that may be obtained.

9.3 The Schlumberger Array and Further Simulation Work

The major properties of the Schlumberger array have been defined in this thesis. It would be beneficial to understand more about the resolution of the array when two or more small features are buried together. Preliminary work by the author, using high resistance objects at right angles to the C-C line, indicates that the resolution is very good when two objects of similar resistivity are close together. Whether the this is true for dissimilar objects is not known. The grid system used in this thesis would require only minor changes to the feature holder to assess this problem.

An ancilliary problem that has not been discussed is that of sample interval. To investigate particularly complex sites with the Schlumberger may involve the use of finer sample intervals than those used in this thesis. The 1m sample interval used in this work is the standard field practice. However, a logistical problem is caused by the smallness of the tank. The construction of a tank with a larger surface area could be justified, to allow the errors due to probe size to be minimised.

The problem of the identification of low resistance features remains difficult to solve in the tank. It is likely that individual archaeological ditches will have to be found, probably on simple geology such as chalk, and extensive field tests undertaken. The timing of such survey work will have to be dependant upon optimum conditions for resistivity survey. The depth penetration of the Schlumberger should be relevant in the field tests for low resistance anomalies. As the non-location of such features is often said to be due to drying out in the top part of the negative feature (Clark 1980), it would be relevant to observe whether the Schlumberger could detect the deeper, moister parts of large ditches. A long term series of experiments to investigate this hypothesis would be beneficial.

The accumulated evidence suggests that there would be few problems in matching grids, or interpreting small archaeological features, due to massive geological changes under the current probes. The possibility now arises that certain computer simulations may be undertaken that would be beneficial. In particular, further simulations of objects off-set from the C-C line may be relevant. However,extensive individual feature assessment is not envisaged. Any further work could be further computerised, thereby making the investigations more efficient.

It is with some regret that this thesis has been written at a time when computer graphics have improved so dramatically. Without doubt, one of the major interpretational problems has arisen from the display of the Schlumberger information. This is on two accounts . Firstly, dot-densities are a very poor way of representing complex information. Secondly, rapidly changing information, where the anomalies are represented by only a single reading width, result in a blocked appearance - a form of aliasing. The latter may be difficult to distinguish from noise. This thesis has used a number of different formats for displaying data, some computerised. It is likely that a format that shows the full range of readings is essential for Schlumberger data. Whilst none of the formats used in this thesis have proved ideal, they have been used to show the full complexity of the data.

9.4 Some Concluding Remarks About The Schlumberger Array

This thesis has investigated an array that had shown considerable potential in the discrimination of small, near surface anomalies. Inevitably, in operationalising the array we have discovered some situations when the results have been influenced by the positioning of the probes. In general, the array still has much potential in the archaeological sphere. However, the practical problems due to the directional aspect of the off-set methodology would have to be overcome, if the array is to be used in standard archaeological prospecting.

Appendix 1

Pre-measurement preparation and storage conditions for low resistance anomalies.

To investigate possible anomaly treatment and storage conditions that may irradicate the instability of would be low resistance anomalies, the following tests were made upon three identical steel rods.

Firstly, the rods were immersed in concentrated HNO_3 for ten minutes. The rods were then washed in copious amounts of distilled H_2O and immediately placed into the KCl medium of the tank. Three different storage and pre-measurement techniques were then followed.

(1) One rod was kept immersed in the KCl medium of the tank throughout the trials.

(2) The second rod was measured, dried and stored in air at laboratory temperature before re-measurement after a set time.

(3) The third rod was measured, dried, stored in air at laboratory temperature and the surface scoured with abrasive paper before re-measurement after a set time.

The low resistance rods were placed perpendicular to the main C-C line. A measurement was taken with the feature in position, and a second without the feature to establish the background. The following results were obtained, with the figure in brackets representing the reading as a percentage of the background.

STORAGE TIME(min)	1 ohm	2 ohm	3 ohm	Bg ohm
0	1.04(82.5)	1.04(82.5)	1.05(83.3)	1.26
10	1.01(81.5)	1.02(82.3)	1.27(102)	1.24
25	1.03(82.4)	1.07(85.6)	1.35(109)	1.25
65	1.03(82.4)	1.16(92.8)	1.13(90.4)	1.25
130	1.03(82.4)	1.35(108)	1.49(119)	1.25

The major conclusion to be drawn from this experiment is that a steel rod that has been cleaned by HNO_3 (conc.) may be kept conductive by storing the anomaly in KCl solution. It is apparent that storing the object in air results in a situation where the object gradually exhibits insulating tendancies. It is also apparent that the worst method of 'cleaning' the object involves the use of abrasive paper, which gives a random cleaning effect. The latter was the preferred method before these tests.

It was found that the use of HNO_3 to clean low resistance objects, coupled with the storage of such objects within a stable solution of KCl kept the object at a constant conductivity, even when the object appeared tarnished.

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