PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Techniques Used in Archaeological Field Surveys

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Phil. Trans. R. Soc. Lond. A 1970 **269**, 89-108
doi: 10.1098/rsta.1970.0088

Phil. Trans. Roy. Soc. Lond. A. **269**, 89–108 (1970) [89]
Printed in Great Britain

Techniques used in archaeological field surveys

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As with radiocarbon dating also the subject of archaeological prospecting now has a reasonably long and full development. Even so it is probable that there remain those both on the archaeological and on the scientific side who are not completely clear as to what has and can be done. Thus it was most opportune that the present paper could be included in the symposium in the hope that this may encourage even further use and development of the methods.

While there exist a whole range of possible techniques for archaeological field surveys those of geophysical prospecting enter most closely within the general topic of this symposium and so will mainly be concentrated upon. In all cases the basic aim of any survey will be that of discovering information on buried archaeological sites either before or instead of excavation. The value of such information in part depends on the fact that normally the archaeological deposits will not be disturbed while almost always the surveying can be carried out relatively rapidly; at least compared to the time required for excavation. This gaining of information on the hidden archaeological features is the main reason for the use of prospecting methods. However their value for archaeology has been greatly increased as a result of the difficulties caused by modern developments. So many of these tend to result in damage to or even complete destruction of archaeological sites. Often either the existence of a site or its exact extent will be unknown with the result that there is no chance to undertake an adequate investigation before all is lost. If a sufficiently clear idea could be obtained sufficiently quickly then much more could be done. Such applications represent one of the most important aids offered to archaeology by prospecting techniques. Even so it must not be forgotten that they have much to offer irrespective of these present-day practical problems and it is worth underlining their value in giving information, often in some detail, without any disturbance to the archaeological features.

Non-geophysical methods of prospection

Before turning to the main subject of the paper it is interesting to mention briefly the other methods available. Prospecting techniques can be divided into three main groups; those based on surface traces, those using sampling methods and those of geophysical prospecting.

Surface traces

The first and most obvious, but none the less important, method is that of a simple surface search. A qualified observer can often discover a whole wealth of small indications sufficient to suggest the existence and possibly something about the nature of the buried archaeological features. Such surface checks obviously should form the preliminary to any more complex surveying technique. Despite this in very many situations little or nothing can be learnt from the surface and thus the other methods become essential.

Air photography

Also included in the category of surface traces is the very important method of air photography. This normally always reveals changes that are also visible on the ground whether in the form of slight irregularities, or as colour and other changes in the soil or vegetation cover. The advantage of air photography is then that of giving a more distant and thus clearer view where the individual traces can fit together into more meaningful patterns, while at the same time recording a large area at the one moment. As is well known such air photographs can give very great detail on buried archaeological sites. However, it must not be forgotten that the method also has several very important limitations.

Apart from practical difficulties involved in being able to take the required photographs the surface traces to be recorded are often only visible for very brief periods with much depending on the nature of the vegetation cover. Thus air photography is of necessity a long-term study. In order to obtain results for any one given site many attempts may be necessary, perhaps over many years, without the certainty of gaining any positive information. If something is required quickly for an unknown area then it is unlikely that air photography will be of any immediate value.

Another limitation is that normally the method is applicable where the soil cover is relatively shallow thus excluding many areas. In particular within alluvial plains the build up of flood deposits coupled often with land sinkage can result in the formation of a soil cover of the order of a few metres as has occurred, for example, in part of the south of Italy. Here some of the early sites of the Greek colonization period are found buried under deposits of at least 3 m in thickness.

Sampling methods

In cases such as those just mentioned the second type of prospecting method can often be the only one easily applicable; that of obtaining samples of the deposits normally using a drilling or augering system.

By means of a regular grid of test points every 50 or 100 m the existence and limits of any archaeological zone can be found either in terms of actual fragments of material or by analysing the samples. In this second case useful methods include those of measuring the phosphate content or the magnetic susceptibility which normally are higher in areas where occupation once occurred.

Successful uses of the sampling techniques include the location of the archaic area of Sybaris (Lerici *et al.* 1967) while recently a new search has been started for the missing city of Siris, both in the south of Italy. In such cases the area to be covered can well be several square kilometres in extent making the sampling system the only one feasible at least until the rough limits of the archaeological zone have been discovered.

Geophysical methods

It is within the third group of prospecting methods, those of geophysical surveying, that the main developments are taking place at the present time. In addition in the last 20 years a fair amount has been done even if many types of archaeological problems still remain to be tested. It is thus difficult to know what aspect to select for such a brief summary as the present paper. The choice has fallen on trying to show the general nature of prospecting by means of two main examples one of which was specially produced for the symposium, followed by a brief outline of the methods, stressing recent developments.

General aspects of geophysical prospecting

Any geophysical method that can be applied to archaeology must obey certain fundamental requirements. The basis of every method is that of measuring a physical property along or above the present ground surface and then, from the variations in the chosen property, trying to deduce the presence and nature of buried archaeological features. Thus the first essential is that the archaeological deposits must contain meaningful physical contrasts.

Ideally each archaeological feature sought for should be formed from a homogeneous material and be surrounded by equally uniform deposits. In addition, the feature should be characterized by having a distinctly different value of a suitable physical property so that it causes a clear variation in the geophysical measurements. In practice many archaeological features are far from having this perfect form. The main difficulties can be a lack of homogeneity with any one feature often containing a range of materials of different physical properties, and an overall complexity either due to irregularities in the form of a single feature or to a large number occurring fairly closely spaced one from another. In addition, non-archaeological features or effects can occur which also produce variations in the geophysical measurements. Luckily many relatively simple cases can still be found.

However it cannot be over-stressed that the existence of an archaeological feature does not by itself automatically mean that a geophysical variation will also occur. Thus a pit cut by man into the natural rock and then filled and covered by earth deposits may give a geophysical anomaly not just because it was man-made but because the material within the pit is different physically from the surrounding rock. Perhaps a similar pit cut into earth deposits would not give any anomaly at all despite the fact that it too was a man-made feature. On the other hand, a natural feature, such as a solution hole formed in the rock surface, could also result in the required physical contrast and again give an anomaly even if in this case of no archaeological interest. Here the problem thus becomes one of distinguishing important from unimportant variations; that is the interpretation of the geophysical results.

A second point to remember is that not every type of archaeological difference will produce a physical contrast. An example will be mentioned below, here one can consider the problem of trying to locate inscribed slabs. The physical difference between an inscribed slab and a plain one is likely to be so very small that such a search would be nonsensical unless it was known that only inscribed slab occurred in which case the problem would be that of finding the slabs and not the inscriptions.

Another point of fundamental importance is the form of the geophysical variations. In general any given feature will cause an anomaly not just in the area directly above it but also laterally. That is, the width of the anomaly will be greater than that of the feature. This means that if there are many features and especially if they are closely spaced then the geophysical variations will overlap and confusion may well occur. For complex sites the results also will be complicated, possibly to such a degree as to make it almost impossible to deduce the one from the other. Given the very wide range of types of archaeological site it is reasonable to expect a corresponding wide range of application from simple clear cases up to those so difficult as to exclude the use of geophysical methods. It is obviously of great interest to know where the limits of applicability lie and here examples can be of very great value. To give some idea of the situation two selected cases have been included.

MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

Examples of geophysical prospecting

A fairly simple problem: defining a settlement by following its boundary ditch

The first example is for a problem where a geophysical prospection was of prime importance. Figure 1 shows a simplified plan of the results of an emergency excavation carried out in advance of road work at Makotřasy near Prague in Czechoslovakia in 1961 (Pleslova & Knor 1964). This work was done by the Institute of Archaeology of Prague and revealed a dense group of pits of the eneolithic period bounded on the south by two ditches. Although work in the northern part of the road zone was limited it seemed probable that the main archaeological site consisted of a small settlement about 50 to 100 m in diameter surrounded by the larger of the two ditches; possible limits for the settlement are shown by the dashed line. This would

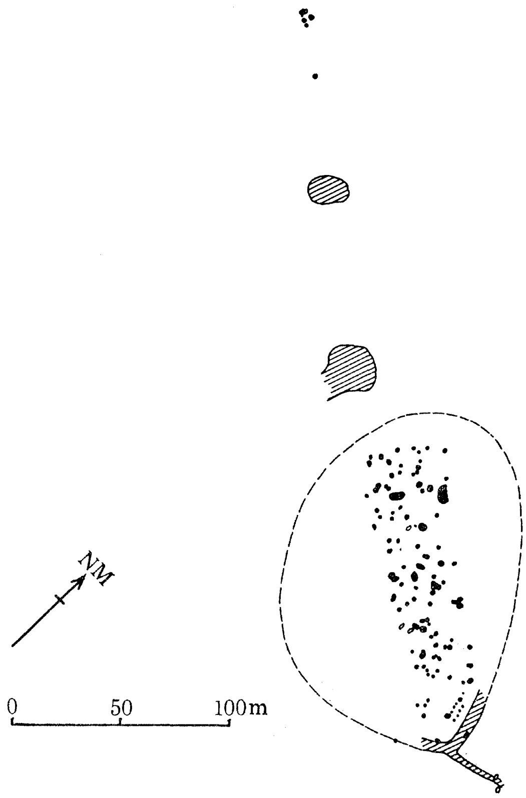

FIGURE 1. Simplified plan of the excavated part of an eneolithic settlement at Makotřasy, Czechoslovakia. The archaeological features consisted of pits (in black), two ditches and some shallow depressions (shaded) together with a few much later graves (in outline). The dashed line shows the expected size of the settlement.

have fitted in fairly well with other sites of this period in the region. Even so several doubts remained and it was of considerable interest to establish the nature of the unexcavated parts of the area not only because of the archaeological importance, Makotřasy being a particularly rich site, but also to allow for planning control and scheduling of the site. In 1968 a short surveying campaign was undertaken by the Lerici Foundation in cooperation with the Institute of Archaeology and one of the main sites selected for test work was that of Makotřasy (Linington 1969*a*). The presence of grain crops limited all work to the part south of the road where, despite dense sugar beet it was possible to survey over 2 hm² (5 acres) in only 1 week's work using a differential proton magnetometer. Figure 2 gives a diagram of the survey results. This was prepared from over 20000 measurements so as to highlight those areas probably corresponding to the main archaeological features which in this case were mainly ditches and pits. These should cause higher than normal values of the Earth's magnetic intensity and it is such areas that are shown dotted in the figure. In order to delimit the site the work mainly took the form of surveying along the line of the larger of the two ditches. The course of this is immediately obvious with the most unexpected result that over 500 m of ditch were revealed giving a site of about 300 m in diameter. That is about 10 to 20 times larger in area than thought possible. This alone is a most important result suggesting that Makotřasy may be of very special interest,

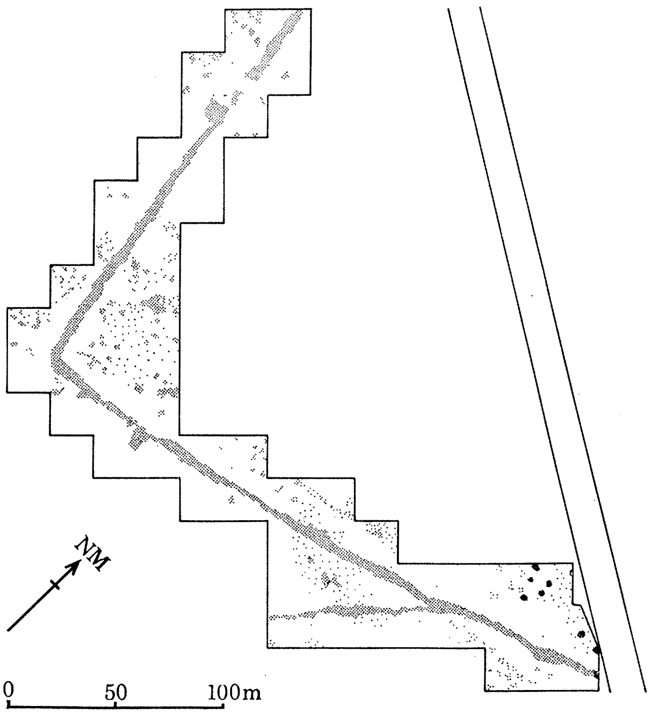

Figure 2. Magnetic survey in the same zone as shown in figure 1. Areas of higher than normal magnetic intensity are shown dotted. These presumably correspond to the main archaeological features (ditches, pits and graves).

possibly even a key site for the whole eneolithic of central Europe. In addition, the magnetic survey shows many other details; thus, for example, two probable entrances in the main ditch as well as part of the course of the smaller ditch. A slight curve in the plan of that part of the main ditch where it runs into the smaller one would suggest that the smaller one could be earlier. In fact this is indeed the case as was proved by the original excavations. Although little of the interior could be surveyed also here the survey seems to offer some useful information and probably could suggest the positions of the main concentrations of pits and thus of the inhabited areas. One final small point concerns a few much stronger spot anomalies in the extreme eastern part of the surveyed area. These probably are due to those graves of a La Tène cemetery which contain objects of iron. A few such graves had been found in the excavation and are shown in outline in figure 1.

Thus this very brief survey of only 1 week in duration sufficed to give a very complete picture of the archaeological zone without necessitating any disturbance to the archaeological deposits. As was estimated by the archaeologist concerned, Pleslova, this work represents a saving in time of at least two years as well as rendering unnecessary much excavation. Such an example shows how geophysical methods can be of very great value on simple archaeological sites.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

A more complex case: a theoretical study for a damaged construction

For the second example it is of interest to turn to what is almost the other extreme of a fairly complex problem. Here rather than taking an actual practical survey a special theoretical calculation was made using a computer system developed by the author (Linington 1969*b*). This calculation was of the magnetic anomaly for a feature taken to be equivalent to a fairly simpl e construction.

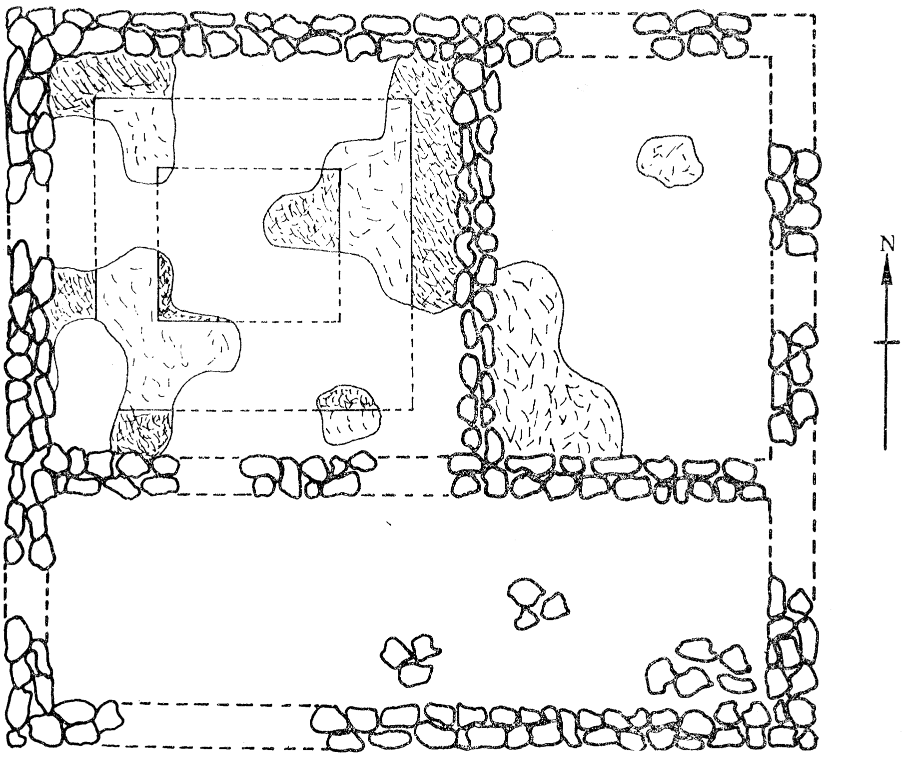

FIGURE 3. An imaginary construction used as the basis for a theoretical study to show the type of result obtainable from surveying on complex sites.

Figure 3 shows a plan of the structure as could have been obtained after an excavation. As it is a theoretical example no scale is given, however outer dimensions of 6.5 m by 6 m would be quite reasonable. The structure consists of a simple three-roomed building of which two contain traces of pavements. The walls are partly destroyed in a few points while the lower long narrow room has three groups of stones (either another pavement or rubble). The first point of importance is that this plan includes both elements which physically exist together with those which presumably once occurred but now are missing. Thus the lines of the walls are restored by the dashed lines even although these parts are no longer physically there. Such a reconstruction is obviously justified, however it must not be forgotten that any geophysical survey will see the variations as produced by what is actually present, that is, not from the complete building as originally built and as envisaged in the archaeological reconstruction, but rather from the incomplete remains as can be recovered by excavation. The main room shows a second type of reconstruction; that of the very simple decoration on the pavement. Here on excavation the fact that the pavement originally had three zones of decoration may be archaeologically perfectly clear. From a geophysical point of view it is probable the decoration will not give any difference, while in any case the pavement will appear as a series of fragments rather than as a continuous feature. The decoration thus forms another good example of a part of the archaeological evidence which may be important but which cannot be found from any geophysical survey.

Finally the general form of the geophysical variations will also depend on the overlapping effects as mentioned previously. These are likely to be fairly extensive for a complex structure such as the given example. For the structure shown in figure 3 the magnetic anomaly is given in figure 4 in the form of a computer-produced symbol diagram. This was calculated assuming

FIGURE 4. The theoretical magnetic anomaly for the construction shown in figure 3.

an angle of dip of 60°. It can be seen that it would not be at all easy to deduce the original plan of the building from the geophysical results. Certainly it could still be possible to decide that a structure existed, but any interpretation in more detail would be somewhat risky. To show how the various elements involved change the final anomaly it is of interest to consider the development given in figure 5. Here the left-hand column of diagrams shows in more diagrammatic form the feature considered, while the right-hand column gives the corresponding symbol diagrams of the magnetic anomaly. In these diagrams the choice of symbols is somewhat different from that of figure 4. If it is assumed that the constructional features are made of material of lower magnetic susceptibility than their surroundings, as would probably be the case, then the main symbols in figure 4 are for values of lower than normal magnetic intensity (these are +, 0, X and the double symbols). Higher than normal values are also shown in figure 4 but not in figure 5, while a fair range of intermediate values are left blank. Thus the symbol diagrams represent those magnetic anomalies which could correspond to the main constructional features. Starting at the top the first two diagrams of figure 5 show respectively,

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

on the left a plan of the undamaged walls, and on the right the corresponding magnetic anomaly. It can be seen that the anomaly follows the plan of the feature fairly closely. The second pair of diagrams shows the results of damage to the walls where the interruptions are not complete gaps but rather areas where the magnetic susceptibility contrast is reduced to a quarter of its normal value. This takes into account the probable presence of mixed rubbish deposits, etc. The anomaly already begins to be less clear.

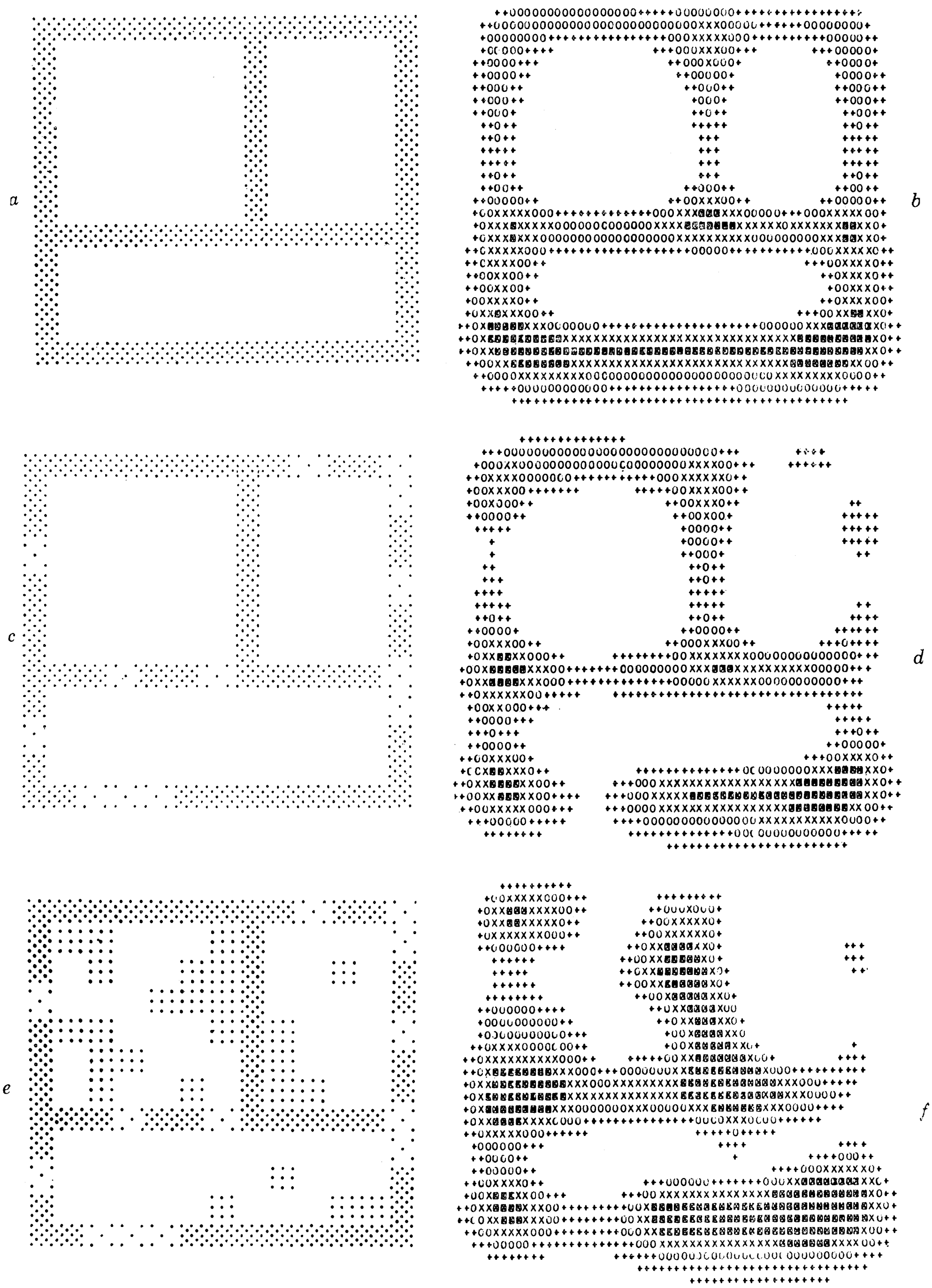

FIGURE 5. A series of theoretical diagrams showing how the geophysical variations change with increasing complexity of the feature. These are for the same study as figures 3 and 4.

Finally the lowest pair of diagrams show the results of adding the effects of the pavements and their foundations where these are taken as areas of susceptibility contrast equal to three-quarters the value for the walling; this gives the final anomaly.

In order to show that this theoretical example is not too far removed from reality it is of interest to compare the anomaly of figure 4 with the results shown in figure 6. These last are from a magnetic survey undertaken recently at Metapontum in the south of Italy. This was an extensive city with a fairly long history from its foundation as a Greek colony to its abandonment in the Roman period. Thus it was likely that a large number of constructions would be found many of which should be in stone. Such structures should give magnetic anomalies

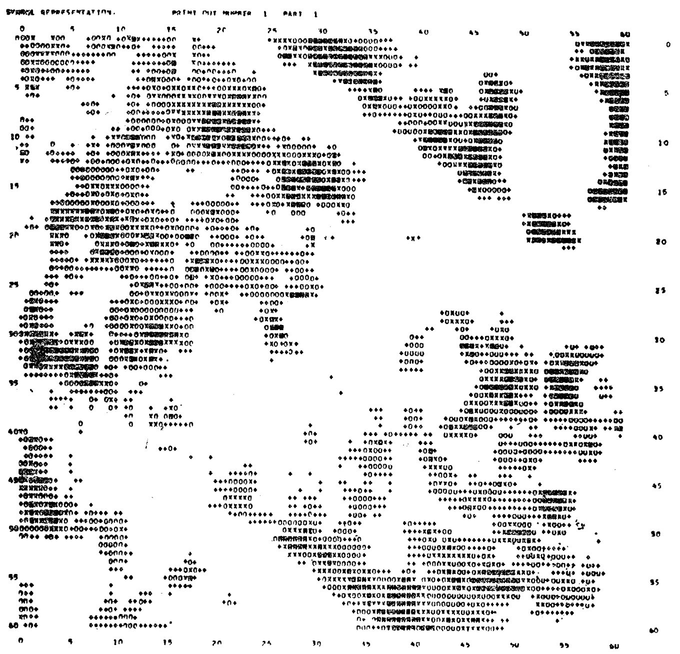

FIGURE 6. A computer produced symbol diagram of magnetic results from a survey within the area of the ancient city of Metapontum. Comparison with figure 4 suggests that the anomalies may well be due to structures.

associated with lower than normal magnetic field intensities due to the contrast between the stone and the earth deposits. It is this part of the magnetic variations which is shown by the symbols in the computer-produced diagram of figure 6. It can be seen that the general form of the anomalies is quite similar to those of the theoretical example of figure 4. In particular what appears to be a rectangular or even possibly an L-shaped structure occurs in the left-hand part of the diagram. These results thus show that the theoretical study is quite reasonable, while they also show how such theoretical studies can often be of very great value in helping interpret practical results.

Before leaving the theoretical example it is of interest to consider the results in the form of another type of representation; that of isometric drawings. Figures 7 and 8 shows respectively the magnetic anomaly for the simple walling alone (uppermost set of figure 5) and that for the complete case (figures 3, 4 and the lowest set of figure 5). Such drawings give a very good idea of the overall anomaly form; in this example they show how the feature as a whole gives an area of general anomaly as compared to its surroundings (figure 8).

The above theoretical study enables several general conclusions to be drawn. First, one can see that for complex archaeological features the geophysical variations will not only reflect this complexity but that it may prove impossible to deduce with any certainty all of the details of the archaeological plan. This is mainly because the observed variations depend on what is actually present while the archaeologist obviously tends to be more interested in what was originally constructed. It may be difficult to arrive at the second from the first even after careful excavation, certainly not via a geophysical survey. The next conclusion is that while it may be impossible to obtain a full plan much useful information can still be gained. Thus in the

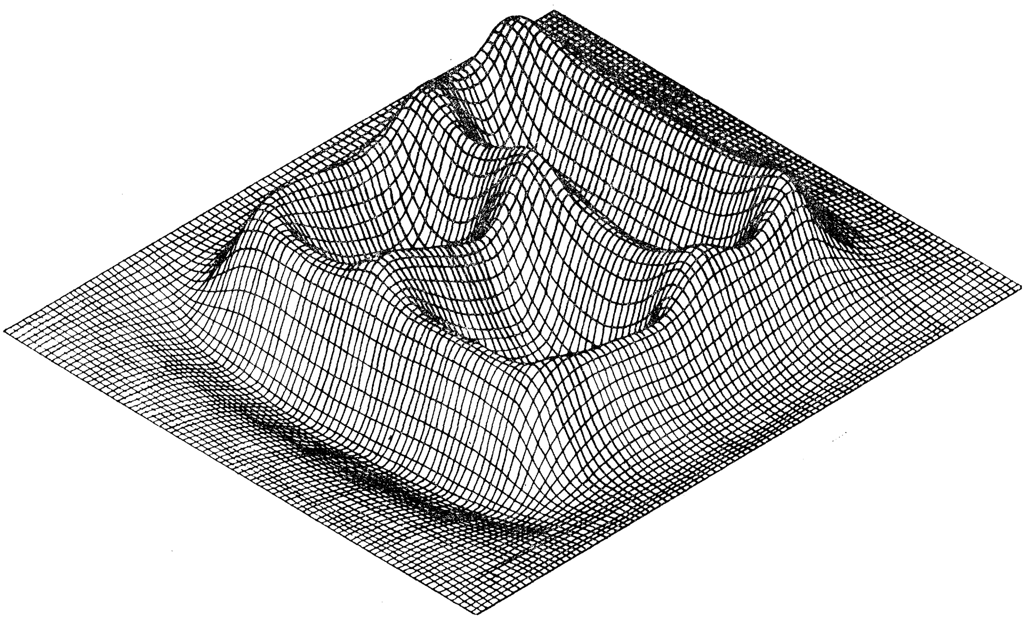

Figure 7. An isometric view of the anomaly corresponding to the undamaged structure of the theoretical study.

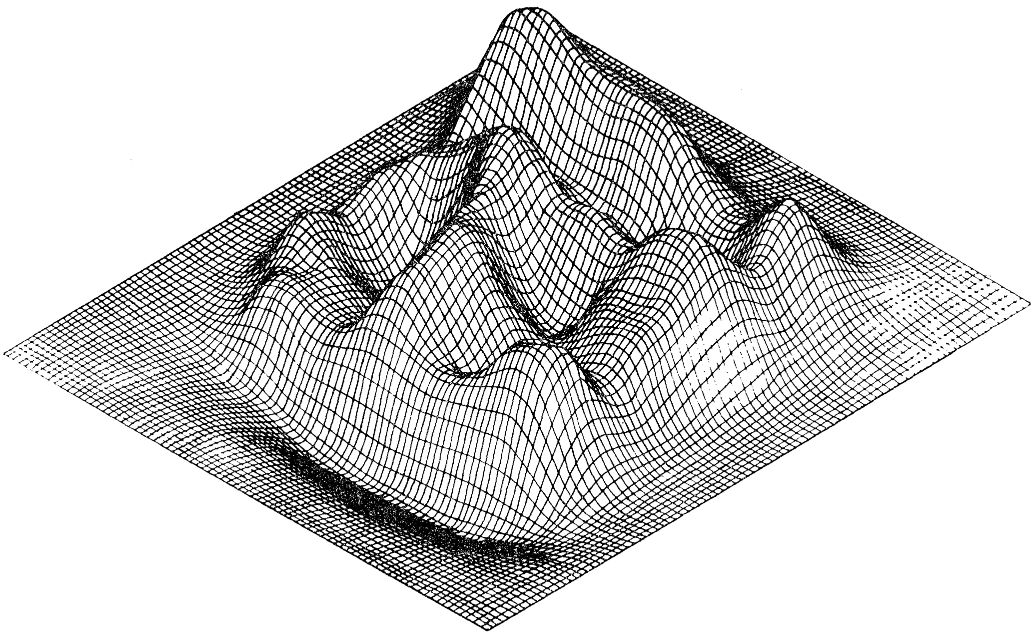

Figure 8. An isometric view of the anomaly from the damaged structure of figure 3.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

example it could still be possible to deduce the presence of a construction approximately square in form. Such conclusions can be useful in delimiting isolated buildings or giving an idea of the character of different parts of a more extensive site such as a city.

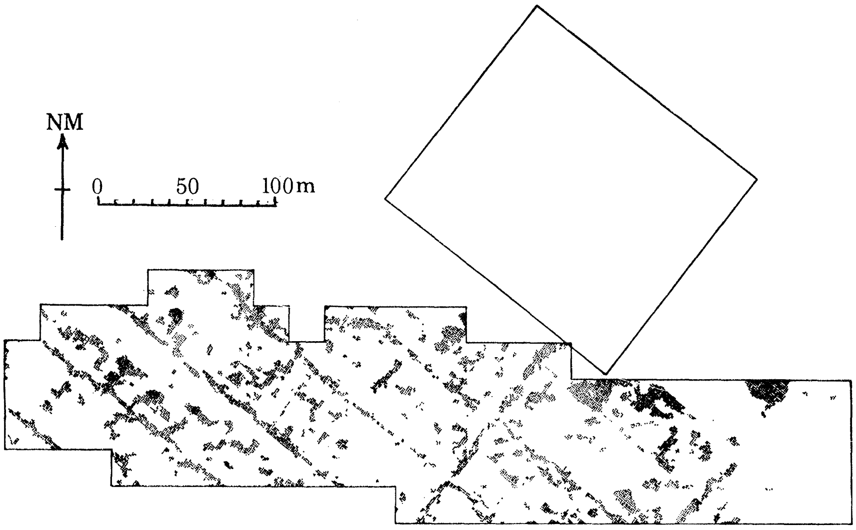

FIGURE 9. A much larger part of the survey from Metapontum. This gives a very clear idea of the main roadways and thus of the general plan of the city.

A practical example of surveying on a complex site

In order not to risk giving too pessimistic an idea it is interesting to show a larger portion of the survey already mentioned in connexion with figure 6. This showed a small part of the magnetic results from Metapontum. Figure 9 shows a much more extensive area from the same survey, however this time stressing those parts of the results which correspond to higher than normal magnetic field intensities. Thus the dotted areas in figure 9 correspond to the blank parts of figure 6. As was mentioned above these are probably the areas containing a higher proportion of earthy deposits and less building material, that is, probably spaces between constructions and, what is more important in the present case, the main roadways of the city. A series of very clear anomalies obviously corresponding to these roadways can be seen to cross almost all of the surveyed area. These run diagonally in a roughly NW to SE direction and occur at regular intervals one from another determining long thin city blocks of the form typical in the Greek colonies of Italy. Traces of two cross roads also occur. This result is in fact of some considerable archaeological importance in that previously this part of the ancient city was thought to consist only of a very large open square (the Agora of the city). The geophysical survey has shown that this is not the case and has made a very important contribution to the general knowledge of the site. Again it is perhaps worth stressing that this was achieved in a short period (just over a month's work involving nearly 50000 measurements) and without the need for any excavation or other disturbance to the deposits. From the point of view of the present article the survey shows how even on a very complex site information can still be gained. However, it would not be correct to leave the Metapontum results without mentioning that figure 9 represents only a first hurried study and that it is probable that even more can be gained from the results than just the plan of the main roadways of the city.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

General deductions

From these two main examples it is clear that geophysical methods are applicable to a very wide range of archaeological problems as long as the inevitable limitations caused by the physical nature of the sites and by the nature of the methods themselves are taken into account. That is, the questions asked by the archaeologist should be ones that make sense from a geophysical point of view.

Before leaving this part of the paper the above two examples also offer the chance to mention two other aspects of geophysical surveying in archaeology. First, the form of the variations is such that a large number of measurements have to be made. Normally a spacing between values of about 1 m will be necessary. Otherwise there is a risk of falsifying the anomaly shapes. This means that any reasonably sized survey will contain a very large number of readings; tens of thousands of values will not be uncommon. The second aspect is that much depends on how the geophysical results are represented; two systems are illustrated above, those of symbols diagrams and isometric drawings, and other types also exist. In order to gain a full idea of the nature of the variations and thus to take full advantage of the geophysical work it may well be necessary to try a whole series of representations. This can be particularly important for more complex cases where the main difficulty lies in the interpretation of the results and this, in turn, will depend on their being represented in the most suitable form.

From these two basic aspects of prospecting it is clear that the methods and their study must be such that large numbers of measurements can be obtained and handled easily and quickly. As far as the problem of field work is concerned this aim has in part been achieved by the development of suitable instruments and surveying methods. More difficulty has been experienced over the treatment of the results; however, the recent application of computer techniques is proving of great value (Linington 1968, 1969*a*, *b*; Scollar & Krückeberg 1966; Scollar 1968*a*, *b*). Of course much depends on the type of archaeological problem and the way any surveying is to be organized. For very simple sites and small-scale work obviously the above factors are less important than for large surveys on complex sites. Even so, as it is just this large-scale work which is likely to be of most value for archaeology, these practical points are and will be of increasing importance.

The methods used for geophysical prospecting in archaeology

So far the discussion of geophysical prospecting methods has been kept to general terms even if the two examples are both from magnetic surveying. Obviously much will depend on the nature of the different methods and so it is impossible to cover the subject of the present paper without listing the main methods available. Here a difference must inevitably occur between the written and the spoken versions for it is not possible to produce the wide range of illustrations used at the Symposium. In any case other general accounts exist which give useful summaries (Aitken 1961, 1963; Atkinson 1963; Clark 1963; Hesse 1966*a*, *b*; Lerici 1961, 1963; Lerici & Linington 1968, 1969; Linington 1961, 1963; Scollar 1965). Thus below the methods will only be briefly set out, commenting on their relative merits and mentioning recent progress without giving details of any field applications.

In the use of geophysical prospecting in archaeology it is possible to distinguish three periods, although not in any rigorously exclusive way.

First, there was the application of existing geophysical methods and equipment to archaeological problems. These first tests were all on a limited scale and took the techniques from petroleum and mineral prospecting, and indeed were often carried out directly by specialists from these fields. The next phase was the development and selection of improved instruments and field survey procedures to allow for the special conditions encountered. In particular these were the necessity for making a much larger number of measurements at much closer intervals than for other geophysical surveying problems. These improvements in the field work were not however always associated with improvements in the handling and interpretation of the results which have tended to remain at a fairly simple level.

A great disadvantage of almost all the work undertaken has been the fact that it has been almost entirely organized on a casual or spare time basis without the establishment of permanent research positions and survey teams. For any large-scale applications of the methods of the type illustrated above a permanent organization is essential.

Recently prospecting seems to have entered more fully into a third phase; that of attempts to involve new methods and, even more importantly, further research into the nature and use of the existing ones. In addition a little has been done towards trying to give the subject a more permanent basis as regards personnel and facilities.

Electrical resistivity surveying

The first geophysical method to be adapted to archaeology was that of resistivity surveying. Variations in the electrical resistance of the ground are found by applying a known voltage across the region of interest and measuring the current flow produced. A direct measurement between two points is, however, not possible as both contact effects at the points of current entry and the interference of natural earth currents can cause large errors. To overcome these difficulties the normal system used is that of having four different contacts, passing the current between two of these and measuring the resultant voltage formed between the other two. While some of the original instruments used direct current and measured the values of the voltage and current separately, nowadays low-frequency alternating current is used together with a direct reading of the ratio of voltage divided by current; that is, the instrument gives directly a resistivity value. This value depends both on the nature of the deposits and on the arrangement of the four contacts. It is this second factor which tends to cause the most practical difficulty.

The earliest work used the simplest system of the four contacts placed at equal intervals along a straight line with the current being applied to the outer pair and the voltage measured across the inner pair (Wenner arrangement). This system often tends to give complex variations from near surface features and so other contact arrangements have been suggested such as the Schlumberger where although all four contacts are still placed in a straight line the inner pair are closer together than in the Wenner case. This seems to be more useful than the other possibility of increasing the separation. Even non-linear systems can also be used such as a square array arrangement (Clark 1968). In addition, the pair of contacts used for the current (or voltage) can be altered thus giving, for example, the so called double-dipole system instead of the normal Wenner (Carabelli 1967), in this case adjacent pairs of contacts are used for the current and voltage respectively.

Normally almost all the applications of resistivity surveying consist of making lines of readings, keeping the same contact arrangement and separations, in order to locate horizontal changes in the measured resistivity values and thus the archaeological features producing these changes. Often these lines will be combined to give an overall rectangular grid of values. A much less usual application is that of vertical soundings where a series of readings are taken at a single point using the same contact arrangement but with increasing values of the contact separations. From the changes in the measured resistivity it is sometimes possible to deduce vertical changes in the underlying deposits. A combined approach of horizontal lines and vertical soundings has also been suggested, although this is normally very time-consuming (Peschel 1967*a*). Often it is useful just to repeat each line at two different separations as this can help distinguish archaeological from geological effects.

As mentioned above the physical property of importance in resistivity surveying is that of the electrical resistance of the materials. Here a very important factor is that of moisture content, differences in which can alter the resistivity of a deposit by considerable amounts. In general unconsolidated deposits such as soil, sand and clay will give much lower values than rocks, while differences in homogeneity and compactness can also be important in that these also can alter the amount of moisture present. This last effect can be of value in giving the possibility of discovering a disturbance in what is otherwise a uniform deposit. It is unlikely that the fill of the disturbance will be as compact as the surrounding deposits even if otherwise they are identical. These effects have been shown to be important for both resistivity surveying and air photography for the case of ditches (Strunk-Lichtenberg 1965). Other applications of resistivity surveying will include features where a contrast occurs between rock and soil deposits such as stone built structures buried in soil and soil filled features cut into rock, These cover quite a large range of archaeological problems.

As the moisture content is so important it is clear that seasonal effects can cause changes and it may even occur that variations will exist at one period but not at another. While it is difficult to forecast the most suitable period for resistivity surveying it is better to avoid extremes of wetness and dryness, while frozen ground can give unexpected effects (Hesse 1966*a*, *b*). On the other hand, shorter term climatic changes such as heavy rain storms seem to be less important than were at first suspected (Al Chalabi & Rees 1962; Rees & Wright 1969).

The common difficulties in resistivity surveying are geological effects and a tendency to fairly wide ranges in the value of any given reading. This second effect is often due to minor errors in the position of the contacts or to irregularities in the way the contacts touch the earth. Normally metal probes will be used, steel rods being common, these being pushed down a short distance into the topsoil. Except in very uniform damp soil it is likely that the amount of the rod actually in contact with the ground will vary considerably and thus also the measurements will vary. In stony deposits these effects can be even more noticeable.

Another defect of the method is that the necessity of inserting contacts into the ground limits the rate at which surveying can be carried out. Some improvement can be gained from the use of five or more contacts coupled with appropriate switching systems so that measurement and contact moving can be carried out simultaneously (Atkinson 1963).

Although the first method applied to archaeology (Atkinson 1953), resistivity surveying has now been somewhat replaced by magnetic prospecting. This mainly is due to the disadvantages mentioned above, especially the slow survey speed and dependence on long-term climatic effects coupled with the fact that the interpretation of the results tends to be difficult except in the simplest cases. Thus recently less interest has been shown in the method. This is unfortunate in that many cases may occur where it can be more suitable or even the only method applicable.

In certain soil conditions electrical resistivity contrasts can occur but not magnetic ones, while often modern disturbances can make it impossible to undertake a magnetic survey although resistivity measurements can still be made. Such cases include work in or near built up areas, and the special but wide-spread case of areas where crops such as vines are grown using iron wire supports.

In the future it is to be hoped that a renewed interest may be taken in the method. It would obviously be very convenient if a system could be found avoiding the necessity of contact insertion or at least of minimizing this as much as possible. Here it could be of interest to study new contact arrangements while more research should be done to decide on the optimum configuration for different problems. Both model and theoretical studies could be of value even if both tend to present several difficulties. It would also be interesting to check further on how far changes in the frequency of the current used effect the results.

Other electrical methods such as that of the equipotential system seem to be of much less value for archaeology. A possible exception is that of induced polarization where recent experimental work appears promising (Aspinall & Lynam 1968; Peschel 1967). For some special problems self potential methods might also be used; however, their application would seem to be very limited.

Electromagnetic surveying

A second important method is that of electromagnetic surveying. Here two different types of prospecting are involved, although the same basic instruments are mainly used; these are the search for metal objects and that for larger scale non-metallic differences in the deposits. The first depends on the induction of eddy currents in the metal object as a result of an electromagnetic field produced by the measuring instrument. These induced currents will in turn produce secondary electromagnetic fields which can be sensed at or above the ground surface. Two serious difficulties limit the use of this system; the fact that the strength of the secondary field decreases very rapidly with depth of the metal object, and the problem of avoiding interaction between the relatively strong primary field and the very weak secondary one. In practice it was found that the first difficulty was greatly increased as a result of secondary fields produced by the deposits as a whole. These could very well completely conceal the effect of anything but very large or very shallow metal objects. Recently a great improvement has been achieved by utilizing the fact that the eddy currents produced by a transient electromagnetic field take longer to decay to zero in good conductors than in bad ones. By making the measurement at a short interval after the primary field has been removed it is possible to avoid much of the difficulty. This has allowed an instrument to be developed which can find metal objects at depths sufficiently large to be of use in archaeology (Colani 1966*a*, *b*; Foster 1968).

Turning to the second aspect, that of discovering differences caused by non-metallic features, in practice both the continuous wave and pulsed instruments have been used with success (Musson 1968; Tite & Mullins 1969). At first it was thought that as for metal detection, the main factor of importance would be the electrical conductivity of the deposits. Indeed the electromagnetic method was looked upon as a hopeful way of undertaking electrical resistivity surveys avoiding the necessity of probe insertion. However, theoretical treatment showed the results based on conductivity effects would tend to be very difficult to interpret (Scollar 1962), while further research on the successful application of the instruments has shown that for these it is the magnetic properties of the deposits which are important (Colani & Aitken 1966; Tite & Mullins 1969).

As mentioned above, useful results have been obtained on locating archaeological features similar to those that can be found by means of magnetic surveying. However, the application of the electromagnetic method seems to be more limited in that the depth restrictions are much more severe while irregularities in the top soil are more important. It is thus likely that the range of applications of the method will be fairly small. This does not exclude its value for special areas while the fact that continuous readings are produced can enable high surveying speeds on very simple sites. For more complex problems the velocity of surveying is likely to be lower than magnetic but higher than electrical resistivity surveying.

Finally the continuous wave instrument has been used in conjunction with registration of the received signal on a portably magnetic tape recorder to give a fairly simple system of automatic recording (Howell 1968). Much of the work done with electromagnetic surveying is of recent date and certainly interest is likely to continue in the method. Some further improvement in instrument design is possible while consideration of the fairly wide number of variables involved (such as frequency, coil sizes, etc.) would be worth while. Even so the depth limitations are likely to mean that the method will be of less general use than the others.

Magnetic surveying

The last main method is that of magnetic surveying which, after first tests had showed its value for archaeological work (Aitken 1958), fairly rapidly took the place of resistivity surveying as the most useful method for archaeology.

In a magnetic survey the intensity of the Earth's magnetic field is measured at points above the present ground surface. The variations in these measurements can reveal the presence of archaeological features. Two magnetic effects are important; those of permanent and induced magnetism. Apart from the often very large variations caused by metallic iron the main cases corresponding to the above effects are those arising from intense heating such as in kilns and furnaces, and a wide range of features where contrasts occur in the magnetic susceptibility of the deposits. Normally most natural sedimentary rocks have very low susceptibilities, while, due to changes in the magnetic iron oxides most soil deposits give higher values. Thus soil-filled features cut into rock or structures formed from rock and buried in soil deposits can both be found. This is similar to the range of features suggested for resistivity surveying. However, the magnetic method has several advantages. First, the problems of geological changes are less as both consolidated and unconsolidated rocks tend both to have very low susceptibilities while they may have quite different electrical resistivities. The magnetic method is also a little less dependent on the uniformity of the deposits.

The main advantage however lies in the fact that the magnetic readings are taken at a single point thus removing all the complications due to the geometry of the contact arrangements. Although this advantage is somewhat offset by the asymmetry of the Earth's magnetic field, on the whole magnetic results are easier to interpret than electrical resistivity ones. There is also inherently a notable difference in speed of surveying with the magnetic method being several times faster, thus enabling complete coverage of closely spaced readings over large areas.

Magnetic surveying only started to be of value in archaeology with the development of sufficiently rapid methods of measurement; in particular the proton magnetometer. Later other forms of nuclear resonance have also been used as has a fluxgate system. Even so the most useful form of instrument is still the differential proton magnetometer. As this subject is treated in more detail in the paper by Dr Scollar no further details need by given here.

As mentioned above magnetic surveying covers a wide range of archaeological problems being specially suitable for simple fairly shallow sites but also giving useful results in many much more complicated situations; two typical examples were shown in the first part of this paper. The main disadvantages of the method, apart from the fact that the instruments tend to be fairly expensive, are the impossibility of working in most built-up areas and anywhere else where magnetic disturbances occur. Objects of metallic iron can be especially difficult with the widespread use of iron wire for fencing and even for supporting certain crops often causing trouble as in some areas also can irrigation or other tubing. Interference from power lines may be important although this depends on the type of instrument used. Thus while of wide application a fair number of cases will occur where magnetic surveying can not be used and here other methods, mainly that of electrical resistivity, become important.

At present quite a lot of research has been undertaken into instrument design and it is probable that after improvements already in course have been achieved there will be less need for work in this field. In view of the very large number of values that have to be taken, automatic recording would appear to offer advantages, however in practice its use can bring added problems (Scollar 1968*b*). On the question of interpretation of the results recently quite a lot has been achieved especially in connexion with use of computer methods (Linington 1964, 1966*a*, *b*; Scollar 1969) and it is certain that more will be done. Studies using models have also been tried (Aitken & Alldred 1964, 1966). So far most of these studies have been confined to European conditions and with the eventual spread of surveying to areas when the magnetic angle of dip is different some new work will be required.

What is probably the field where most remains to be done is on the question of soil magnetism itself especially the problem of magnetic viscosity. Here valuable work has been achieved on studying how changes in susceptibility occur (Le Borgne 1955, 1960, 1965; Scollar 1965).

Other geophysical methods

The above three methods cover those of normal routine use in archaeological prospecting. In order to complete the description other possible methods can also be mentioned even if so far all of these have proved either to be of very limited application or too full of difficulties for any normal use. Of the methods used in other geophysical fields both gravity and seismic surveying have been tried. The first might seem to offer hopes of discovering cavities; however, apart from the case of large caverns, the type of problem likely in archaeology involves changes at the extreme limits of sensitivity of the instruments without giving any real chance of practical applications (Linington 1966*b*). Seismic surveying as such also has had little practical application although test work has shown that archaeological features can be located (Carson 1962; Lineham 1956; Linington 1962). This is mainly due to the great complexity of the problem of near-surface work coupled with various almost insoluble technical problems. Of more interest are vibration or sonic methods where some hope exists for the location of cavities although again the results are likely to be fairly complex (Carabelli 1968).

Radioactive methods involving active sources seem unlikely to be of great value due to the great limitation on penetration (Alldred & Sheperd 1963), while measurements on natural radioactivity are likely to be very limited in scope even if successful tests have been reported (Peschel 1967*b*).

The recent investigation of Egyptian pyramids by cosmic ray intensities seems to be limited to such very special cases.

Finally the observed thermal effects on some air photographs such as the differential melting of very slight snow cover might seem to offer some hopes of using thermal conductivity or radiation effects. One such method recently suggested has been infrared scanning, however tests do not seem to be very encouraging and it is likely that surface and near surface effects will predominate to such an extent as to conceal any archaeological features (A. J. Clark, personal communication).

Thus at present these minor methods are not very encouraging, however this does not mean that further research should not be attempted. Indeed it is just in these fields that unexpected surprises might occur.

New uses for geophysical surveying

The above concludes the main discussion of surveying methods. This has been confined to field work on buried archaeological sites. Before finishing it is interesting to mention a new field where prospecting may well prove to be equally of value; this is the problem of investigating standing monuments and buildings.

Although little has been done some very interesting results from Czechoslovakia (Hrdlička & Lukášová 1969) and research work in Italy on sonic methods (Carabelli 1966) suggest that the application of prospecting could well be of great importance. The checking of structures for hidden cavities or defects can be fundamental during restoration work while surveying could help historical investigations by revealing traces of earlier constructions below pavements or behind wall paintings, etc. There is also the possibility in some cases of discovering hidden objects while the recent solution to the long-standing problem of the burial of Bartolomeo Colleoni at Bergamo by means of an electromagnetic survey has offered a good example of what could be done.

Conclusions

It is hoped that the above brief account has given some idea of the methods and possibilities of archaeological prospecting. In particular an attempt has been made to suggest that despite the difficulties and the need for a specialist approach the range of applications and thus the value of the methods is larger than perhaps has been realized. Often there has seemed to be a tendency on the part of some archaeologists to feel that a survey was only to be used in very special conditions, especially when all other means have failed, while others may have felt that in any case an excavation could give even more information, or that even if a survey would be worth while, its complexity and expense are not warranted. Perhaps this paper may help to correct these misunderstandings. The whole idea of prospecting is not to replace excavation for obviously no geophysical measurements are likely to give anything like the detailed information that can be gained from a properly conducted excavation. The advantages, as has been stressed several times above, are those of covering much larger areas in much shorter periods of time than any excavation. The value of having information without destruction should also not be forgotten. How much information can actually be gained will of course depend on the nature of the archaeological sites, with the simpler areas normally being most suitable, however even complex sites are not to be excluded. Here the fundamental aspect is to keep the nature of the surveying in mind; that is ask those archaeological questions for which geophysical answers can be given. Within these limits there is surely almost unending possibilities and even necessity for the use of surveying methods. What is required first of all is the collaboration of the archaeologists who in any case are those who have most to gain.

At this point perhaps many archaeologists may quite rightly reply that the main difficulty is not in the desire to use the methods but rather in a very grave lack of practical possibilities. The subject has progressed beyond the stage where the archaeologist himself can do the surveying and nowdays the need is for qualified personnel on a full time basis or at least as close to this as is possible. This is not the place to discuss any further these problems except to recall that the methods can be of real use only if they can be applied on an adequate scale and this means adequate organization and finances.

On the scientific side certainly more could be done on the research aspects and here a closer contact with other forms of geophysical activity, university laboratories, etc. could well be of great value. Probably more advantage could be taken of studies in these allied fields. Here the difficulty is often one of lack of contact and lack of knowledge of the requirements and the problems. Again the collaboration of people in these related subjects could also be of value.

As one of the basic limitations to the appliction of prospecting methods in archaeology is that of lack of means and organization perhaps it is worth concluding on a more optimistic note. Recently, as far as work in Italy is concerned, an important new development has been made; that of the decision to form a research centre of the National Research Council for archaeological prospecting. This is to be set up in collaboration with the Lerici Foundation and thus gives hopes that even more will be achieved for archaeology in this area as well as possibly giving more scope for international collaboration as can be so important in all fields of study.

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