THE USE OF AZIMUTHAL INHOMOGENEITY RATIO (AIR) IN THE INTERPRETATION OF ARCHAEOLOGICAL RESISTIVITY PROSPECTING USING THE "SQUARE ARRAY" TECHNIQUE

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ABSTRACT

By sampling apparent resistivity at two mutually perpendicular orientations, the "square array" technique (Habberjam and Watkins, 1967) attempts to provide a more orientatationally stable measure of apparent resistivity (the mean value p) and, at the same time, provide some check through the Azimuthal Inhomogeneity Ratio (A.I.R.) on the existence of lateral effects.

An archaeological resistivity survey was carried out in Dalton Parlours Villa (W. Yorkshire) and the results obtained were interpreted using contour maps of the mean apparent resistivity, and the A.I.R. with very good results.

Since the resistivity was affected by the soil moisture variation, all the earth resistance measurements were normalised to overcome this problem.

1. OBJECTS OF THE SURVEY

Since archaeological features express themselves in the soil, the resistivity method has long been established as a useful technique for detecting and describing archaeological phenomena. However, in the archaeological resistivity surveys, little use has been made of the square array electrode design and the resulting special data manipulations this design allows, such as the azimuthal inhomogeneity ratio.

The response of an archaeological target to the resistivity method can be influenced by a number of factors. These factors are: the size of the array used, the nature of the site investigated and the nature of soil cover.

Two arrays are to be used, the 1.00 and 4.00 metre square sides. The site investigated is the South margin of Dalton Parlours villa. The Iron Age ditches, which were filled in by Romans, and the stone buildings suggest the resistivity targets. The ditches, cut in the weathered limestone, filled in and concealed by a thin layer of soil, will be a good target, because they are a good example of a body of relatively good conductivity within a poorly conducting medium (limestone). There is a concentration of current flow through the refilled ditches in preference to limestone, and a corresponding disturbance in the potential distribution in and around the ditches, which can be measured at the surface if the ditch is large enough and not too deeply buried.

On the other hand, stone buildings suggest a higher resistivity target within a relatively poor resistivity medium.

During the first part of the survey a stripped area was investigated, where the targets are known. In the second part an "unknown" area was investigated, and the results obtained from the stripped area were used to interpret the results obtained from the "unknown" are in order to locate ditches, buildings, etc.

The soil cover in the "unknown" area should be fairly homogeneous, but it is its moisture content that perhaps has a major influence on the soil resistivity. Since large variations in the water content from one day to the next will correspondingly produce a variation in soil resistivity, the soil moisture variations were monitored, and all the measurements were normalised to overcome this problem.

2. THEORY OF RESISTIVITY METHOD

Earth resistance measurements made at the surface of the ground are commonly conducted by passing current beteween two points A and B and measuring the potential difference between two other points M and N.

The ground resistivity is

$$p = 2\pi RG \tag{1}$$

where

$$G = \left(\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}} \right)^{-1} = \text{configuration factor} \tag{2}$$

The resistivity in equation (1) is the true ground resistivity only if the ground is homogeneous and isotropic. However this value represents the "apparent resistivity" in the practical case of making a measurement at the earth's surface where the ground is not homogeneous.

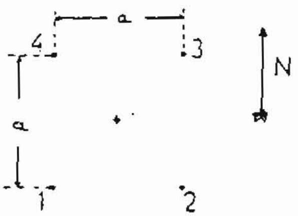
By sampling apparent resistivity at two mutually perpendicular orientations, the "square array" technique (Habberjam and Watkins,1967) attempts to provide a more orientationally stable measure of apparent resistivity (the mean value p) and, at the same time, provide some check, through the Azimuthal Inhomogeneity Ratio (A.I.R.) on the existence of lateral effects.

Considering the configuration of Fig. 1, let the electrodes be numbered 1,2,3 and 4 in anti-clockwise direction, then there are 24 ways in which A,B,M and N can be arranged amongst them.

For any particular arrangement interchanging the subscript of either the potential (A,B) or current (M,N) electrodes separately alters the sign but not the magnitude of both the resistance R and the configuration factor G (see Equn. 1).

By a generalised form of Helmholtz's Reciprocal Theorem, interchange of current and potential electrodes does not affect the value of the measured resistance, and therefore there can only be three basically different resistances for any four electrode configuration. Also, from equation (2), and interchange of current and potential electrodes does not affect either the sign or magnitude of G, and therefore there are only three apparent resistivities for any four electrode configuration.

These three basic arrangements are shown in Fig. 1, where A is the unit current source, B the sink and M and N the potential electrodes.



	1	2	3	4
α	A	M	N	B
β	A	B	N	M
γ	A	M	B	N

Fig. 1 : The square configuration and the possible modes of connection for resistance measurement.

The tripotential condition that

$$R\alpha(a) = R\beta(a) + R\gamma(a) \qquad (3)$$

holds and can be used to check resistance measurements.

Using equation (1) the apparent resistivity for the configurations α and β can be calculated :

$$\rho\alpha(a) = \frac{2\pi a}{2-\sqrt{2}} R\alpha(\alpha) \quad \text{(Ohm.metre)} \qquad (4)$$

Similarly,

$$\rho\ \beta\ (a) = \frac{2\pi a}{2-\ 2}\ R\beta\ (a)\quad \text{Ohm.metre)} \qquad (5)$$

Whilst these two resistivities could be used separately, ρα (a) is more heavily weighted to easterly potential variations and ρβ (a) to northerly components. This lack of symmetry is removed when the mean resistivity ρ (a) is formed as :

$$\rho\ (a) = \frac{2\pi a}{2-\ 2}\ \frac{(R\alpha\ (a)\ +\ R\beta\ (a)}{(\qquad 2\qquad)} \qquad (6)$$

On the square configuration the resistance Rγ (a) has the special significance that its magnitude is dependent on the existence of lateral resistivity variation.

The lateral inhomogeneities which exist in the ground can be expressed by the Azimuthal Inhomogeneity Ratio :

$$A.I.R. = \frac{2R\gamma\ (a)}{R\alpha\ (a)\ +\ R\beta\ (a)} \qquad (7)$$

The AIR is a measure of the lateral inhomogeneity of resistance in the ground expressed as a function of Rγ. If the AIR is negative then Rβ is the dominant resistance, if positive then the Rα dominates. It is, in fact, a measure of an apparent direction of resistance. Obtaining this however does not require the Rγ. Value a ration of Rα to Rβ or vice verca will do the same job.

5. FIELD PROCEDURE

The survey was carried out in two parts. During the first part an excavated area was investigated using the 1.00 m and 4.00 m square arrays. Eleven traverses 2 m apart using the 1.00 m square and taking a reading at every 1 m, were carried out. Six more traverses 4 m apart using the 4.00 m square and taking a reading at every 4 m, were carried out (Fig. 2). All the traverses had an E-W direction.

The AB side of each array for the configuration was orientated to a S-N direction, orientation which kept the same during the whole survey.

The station N482-E306 (i.e. the 1m square, the centre of which was at that point) was the control station for the 4 m square (it is shown in Fig. 2 as control A). At the start of each day of field work the frame was returned to this position and a measurement was taken.

The station N490-E300 was the control station for that area for the 1 m square (it is shown in Fig. 2 as control B).

On completion of the investigation of that area a tie-line was carried out at right angles to the traverses direction (first station : N470-E286.5, last station N490-E286.5).

During the second part of the survey an "unknown" grass area was investigated (Fig. 3). Sixteen traverses 2 m apart using the 1.00 m square and taking a reading at every 1 m were carried out. Eight more traverses 4 m apart using the 4.00 m square and taking a reading at every 4 m were carried out as well.

The station N445.30-E320 was the control station for the 4 m square (it is shown in Fig. 3 as control C), and the station N445.30-E319.50 was the control station for the 1 m square (it is shown in Fig. 3 as control D).

On completion of the investigation of the area a tie-line was carried out at right angles to the traverses direction (first station N425.30-E320.60, last station N455.30-E320.60).

At the beginning of each day of field work the stake resistance was measured between each pair of electrodes. Measurements were also taken when the tripotential rule was not met or when the "Megger" could not be balanced. In such situations the electrodes were penetrated deeper into the soil. On completion of the survey the "Megger Earth Tester" was calibrated in the laboratory.

DATA PROCESSING

The method, which was chosen as the normalising technique to be employed in this investigation, is expressed as follows

$$Ra,nor = \frac{Rai}{Raci} \times Rac$$

where Ra, nor = the normalised Ra at a position i

Rai = the Ra measured at a position i

Raci = the Ra measured at the control station related to Rai

Rac = the Ra measured at the control station on a specific day.

This expression reletes all values to a specific value taken as reference-value. Similar expressions can be used for Rβ and Rγ.

All the measured resistances of the stripped area were normalised with respect to the last day's field work in that area, while all the measured resistances of the "unknown" area were normalised with respect to the first day's field work in that area.

7. INTERPRETATION

7.1 Presentation of results

The following eight maps, illustrating the relults obtained from both areas, have been drawn:

- Two contour maps of the 4.00 m spacing mean apparent resistivities, one for each are (Fig. 4, Fig. 7).

- Two contour maps of the 1.00 m spacing mean apparent resistivities, one for each area (Fig. 5, Fig. 8)

- Two contour maps of the 1.00 m spacing AIR (Fig.6, Fig.9).

All eight maps are drawn at a scale of 1:200.

The normalised apparent resistivity maps are contoured on a lorarithmic scale. The logarithmic contour interval was chosen because the apparent resistivities showed a variation from low to high values that would be best described by a logarithmic scale than by a linear one. The scale chosen for contouring is based on the number 2 1/4 and the log to the base 10, thus the contour intervals used are : 10, 11.89, 14.14, 16.82, 20, 23.78 etc.

The A.I.R. maps are contoured on a linear scale.

The contour intervals used in both areas are selected in such a way that they could be comparable.

7.2 Interpretation of contour maps

Correlating the 1.00 m apparent resistivity map of the stripped area (Fig. 5) and the site plan, (Fig. 2) the low apparent resistivity region corresponds exactly to the excavated ditch. The high resistivity region shown in the map cannot be considered as a stone building, purely because no building have been found in that particular region. Therefore it can be interpreted as the effect of the outcropping bedrock.

The 4.00 m apparent resistivity map of the same area is illustrated in Fig. 4. There is a general trend from low to high résistivities corresponding to the excavated soil cover (the resistivities are higher where the bedrock outcrops).

Having in mind that the major archaeological features express themselves on the 1.00 m apparent resistivity map, while the 4.00 m map describes better the geology, and correlating these maps one could propose that the low resistivity regions are due to refilled ditches of the Iron Age. This is clear enough at the top left corner of the 1.00 map, where the low resistivity region can be related only to archaeological features (such as ditches) and not to geology features, because in the 4.00 m map this region is a high resistivity one.

The changes from low to high resistivity values are shown in the A.I.R. (Fig. 6) as well, although the correlation is less distinctive. However this map can give a picture of the lateral inhomogeneities of the ground.

The 1.00 m apparent resistivity map of the unknown are (Fig. 8) shows a low resistivity region surrounding a high resistivity region. Another one high resistivity region is shown at the top left corner of the same map.

The 4.00 m apparent resistivity map (Fig. 7) shows again two high resistivity regions, but in general terms there is no large variation from high to low resistivity values.

The A.I.R. map of the 1.00 m spacing (Fig. 9) shows the existence of lateral inhomogeneities and some changes in the resistivity, but once more the correlation is less distinctive.

When relating the above information to the information obtained from the interpretation of the stripped area, one can propose that the low resistivity regions shown in Fig. 8 are due to the existence of buried ditches. Unfortunately the high resistivity region in the middle of Fig. 8 can be considered as a deflection of the surrounding low resistivity zone or even as it is due to the local geology (see also 4.00 m resistivity map, Fig. 7). However the possibility of the existence of a buried stone building is not negligible. Another promising region seems to be the high resistivity region at the top left corner of Fig. 8.

CONCLUSIONS

The resistivity method using the square array electrode design has proved succesful in defining archaelogical features, which express themselves in the soil.

The technique used provided a more orientationally stable measure of apparent resistivity (the mean value ρ) and, at the same time, provided some check through the Azimuthal Inhomogeneity Ratio (A.I.R.) on the existence of lateral effects. The use of AIR maps during the interpretation gave a good picture of lateral inhomogeneities of the ground, special in regious where there are changes from low to high resistivity values.

According to the interpretation of AIR maps there are promising regious where there are resistivity lows, probably due to the existence of buried ditches.

REFERENCES

1. HABBERJAM, G.M., CARPENTER, E.W. A tripotential method of resistivity prospecting, Geophysics, Vol.21, pp.455-469.
2. HABBERJAM, G.M., JACKSON, A.A., Approximate rules for the composition of apparent resistivity sections. Geophysical Prosp. 15, 221-235.
3. HABBERJAM, G.M., WATKINS, G.E. The use of square configuration in resistivity prospecting, Geophysical Prospecting, Vol. 15, pp. 445-467.
4. HABBERJAM, G.M. Apparent resistivity variations and the use of square array techniques, Geoexploration Monographs, 1979.
5. KARVATOWSKI, J., HABBERJAM, G.M. A tunnel resolution investigation using an automated resistivity tank analog. Geophysical Prosp. 23, 611-621.
6. KOEFOED, O., Geosounding Principles, 1. Elsevier, Amsterdam, 2.76 pp.
7. LODGE, Thesis submitted for MSc. in Geophysics, University of Leeds, 1978.

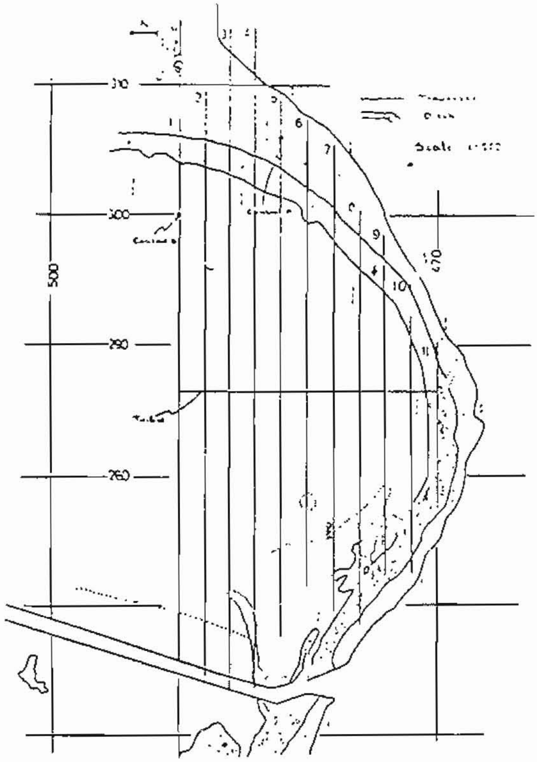
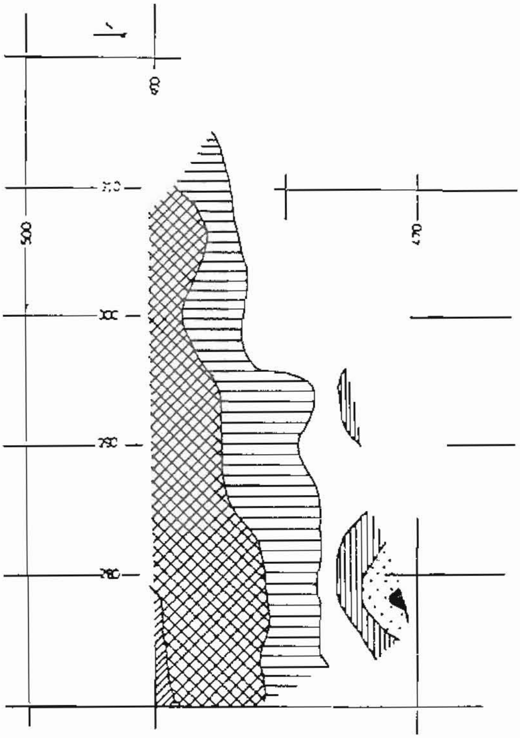


Fig.2 : Site plan
(Area 1)
Scale 1:200

Fig. 4 : Mean app. resistivity map
(4.00 m. square
Area 1)
Scale 1:200

▓	<269.09-320.00
⋯	269.09-320.00
‖‖	320.00-380.55
☐	380.55-452.55
☰	452.55-538.17
⊠	>538.17



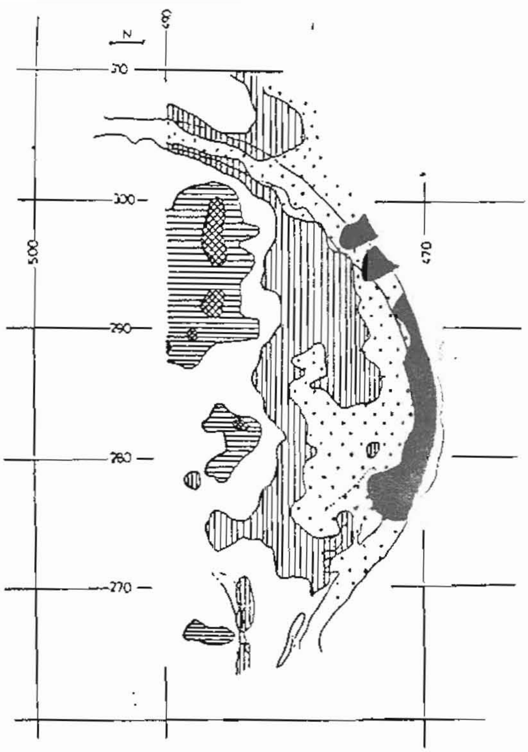
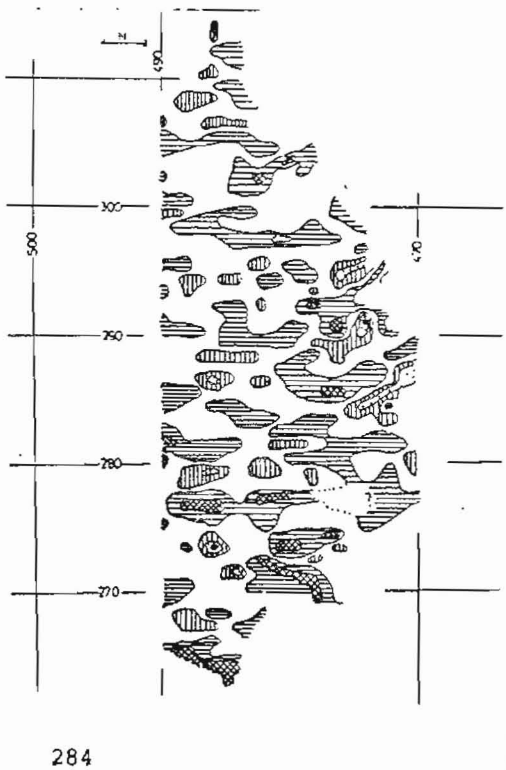


Fig.5 : Mean app. resistivity map
(1.00 m square
Area 1)
Scale 1:200

< 380.55 Ohm.m
380.55-538.17
761.09-1076.35
1076.35-1522.19
> 1522.19

Fig. 6 : A.I.R. map
(1.00 m.square
Area 1)
Scale 1:200

<-0.50
-0.50- -0.30
-0.30- -0.10
-0.10- +0.10
0.10- 0.30
0.30- 0.50
>0.50



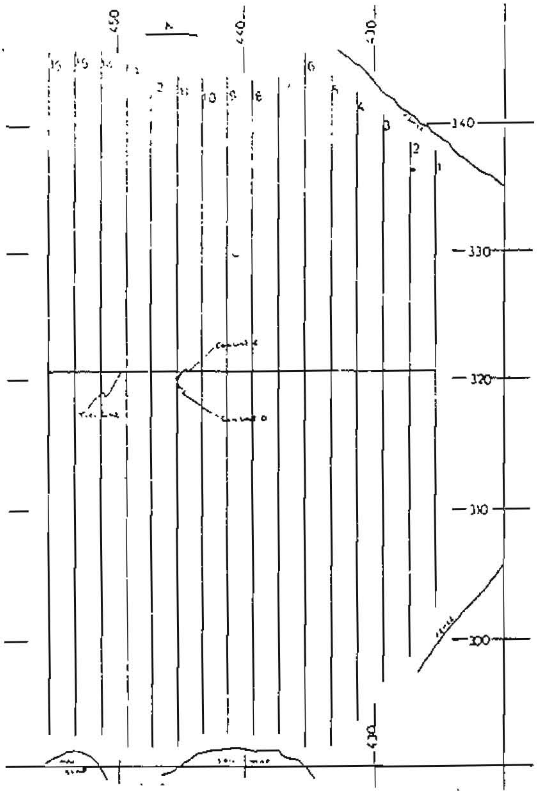


Fig. 3 : Area 3 (plan)

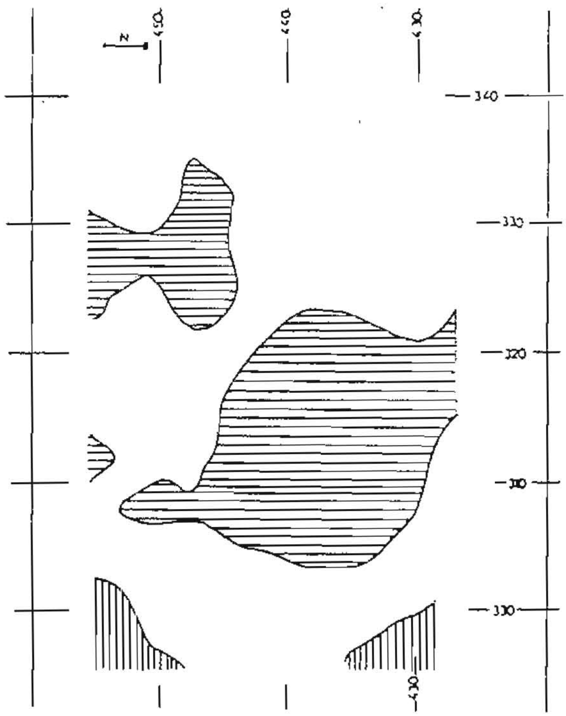


Fig. 7 : Mean app. resistivity
(4.00 m.square
Area 3)
Scale 1:200
<226.27 Ohm.m
226.27-269.09
>269.09

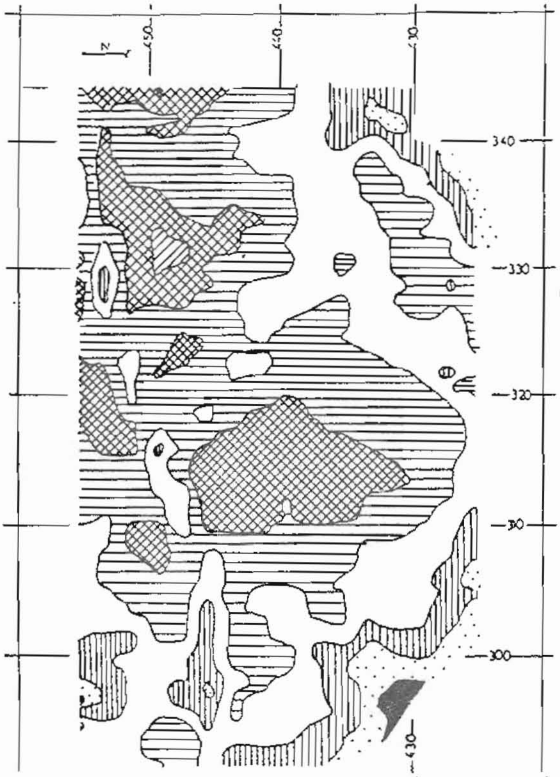


Fig. 8 : Mean app. resistivity map
(1.00 m. square
Area 3)
Scale 1:200

- <134.54 Ohm.m
- 134.54-160.00
- 160.00-190.27
- 190.27-226.27
- 226.27-269.09
- 269.09-320.00
- >320.00

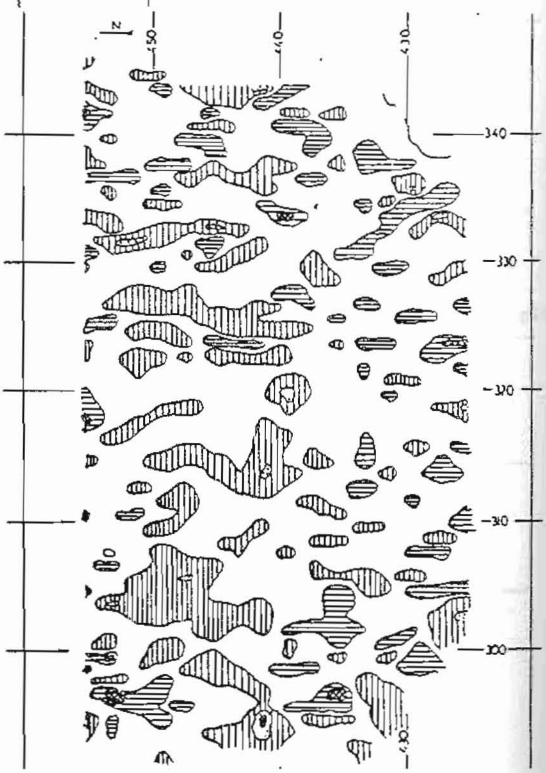


Fig.9 : A.I.R. map
(1.00 m.square
Area 3)
Scale 1:200

- <-0.50
- -0.50- -0.30
- -0.30- -0.10
- -0.10- +0.10
- 0.10- 0.30
- 0.30- 0.50
- >0.50