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# Archaeological Prospecting using Electric and Electrostatic Mobile Arrays

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ABSTRACT The latest generation of mobile electric and electrostatic arrays allows the measurement of the apparent resistivity over large areas with a high spatial sampling and for several depths of investigation. This paper presents three experiments undertaken over three archaeological sites of three different historical periods (Iron Age, Roman, medieval) and three different subsoil covers (meadow, ploughed field, asphalt). The archaeological structures (ditches, enclosures or walls) are described with a good accuracy. They are integrated in their environmental and geological context. © 1998 John Wiley & Sons, Ltd.

*Key words:* Apparent resistivity; electric array; electrostatic array; mobile multidepth system; high spatial sampling.

## Introduction

In shallow-depth electrical prospecting for archaeology, two parameters are essential: the spatial sampling and duration (consequently the cost) of the survey. The developments of mobile quadripoles for electrical prospecting aim at optimizing both parameters. Since the first experiment was performed more than 30 years ago by A. Hesse (1986), significant advances have been achieved.

This paper presents the results obtained with the latest generation of mobile electric and electrostatic mobile arrays over 'large areas' (at least 1 ha) on different archaeological sites. The sought-for features are representative of three different historical periods (Iron Age, Roman, medieval) and the nature of the soil cover differs in the three cases (meadow, ploughed field, asphalt).

## Mobile arrays

Archaeological features, are, in general, three dimensional, they result from the building, the use and the destruction of the site. A small measurement mesh must be used in order to detect the short variations of the ground resistivity due to the presence of anthropogenic features. With a classical array, such as Wenner, bipole or twin, the spatial sampling according to the Nyquist criterion corresponds to the distance, *a*, separating two neighbouring electrodes. The electrical prospecting of a 1 ha area with a square mesh of 1 m corresponds to the acquisition of a series of 10,000 measurements. In general, two days are necessary for experimental prospectors to achieve these measurements. With mobile quadripoles, we need between 4 and 6 h for the

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same area, depending on the surface conditions (regular or irregular). These quadripoles respond to a major concern of the modern practice and needs of archaeology. Large areas can be surveyed in a relatively short time and the cost of the measurement is reduced drastically. It is very important in the current archaeological context, where most excavations are undertaken in advance of planning for motorways, railway tracks, etc., to acquire global archaeological information by combining all the information available, e.g. historical literature and ancient maps, with airborne and surface geophysical prospections, to establish an assessment of the archaeological risk and to focus excavations on sensitive areas.

### *Quadripoles with only one depth of investigation*

Different types of mobile quadripoles have been developed over the past 15 years (Panissod *et al*, 1998), for example the square quadripole, which has a good depth of investigation for a very limited size, with a response that is almost isotropic. Moreover, this arrangement is very practical for systems pulled by a vehicle. There is another system with only one depth of investigation, which is a light pole–pole array pulled by the operator manually. The pole–pole array has the best depth of investigation for a given size compared with other classical arrays and it has the most isotropic response. This arrangement is particularly well adapted for small and light devices, because two electrodes only are mobile (the other two electrodes are fixed at great distances apart from the mobile bipole and from each other). This device, however, necessitates the use of long electric cables, which have to be pulled by the operator with the carriage. For multipole arrays, a theoretical study has been carried out in order to optimize the arrangement of electrodes for obtaining the most isotropic response. A new configuration has been proposed that involves conducting two or four pole–pole measurements in two orthogonal directions (Panissod *et al*, 1997b). The first archaeological surveys have confirmed the importance of such a device. A mobile system will be soon realized on the basis of this geometry.

### *Multipole with several depths of investigation*

Another development in electrical prospecting is concerned with the design of mobile multidepth systems towed by a vehicle, which allow a three-dimensional investigation of the ground resistivity. A Danish team (Soerensen, 1996) have developed a system based on the adaptation of the Wenner geometry in hydrogeological investigations for sounding in the decametric range of depth. The systems, presented in this paper, are adapted to investigations of the first 3 m of the ground and are especially for archaeological applications. They are called MUCEP (multipole continuous electrical profiling). A V-shaped geometry has been adopted called ‘Vol-de-canards’, after a theoretical study including forward and inverse three-dimensional modelling (Panissod *et al*, 1997a). This configuration presents three main advantages compared with a rectangular geometry (several dipoles of the same size placed one after the other): (i) it improves the signal acquired; (ii) the superficial geophysical noise is decreased for the larger dipoles; (iii) the depth of investigation is slightly increased and is approximately equivalent to the size of the quadripole. Moreover, several measurements for different depths of investigation are recorded continuously and simultaneously without switching. This type of multipole should play an important role in archaeological prospection, where essentially features are three dimensional and where the depths of features are unknown a priori. It is very interesting also to have the response of a wide dipole in order to present archaeological features in the local geological and pedological context.

With electrostatic multipoles, the field application of electrical methods can be extended to very resistive surfaces, such as asphalt. Indeed, the electrostatic method is a generalization of the electrical method for dielectric media (Tabbagh *et al*, 1993). A capacitive coupling is obtained by means of metallic poles, instead of the galvanic ground contact obtained with electrodes. For the resistivity range commonly observed in the ground and a frequency less than 100 kHz, the electrostatic method follows the same theory as the electrical method: a quadripole is necessary to perform the measurement of the apparent

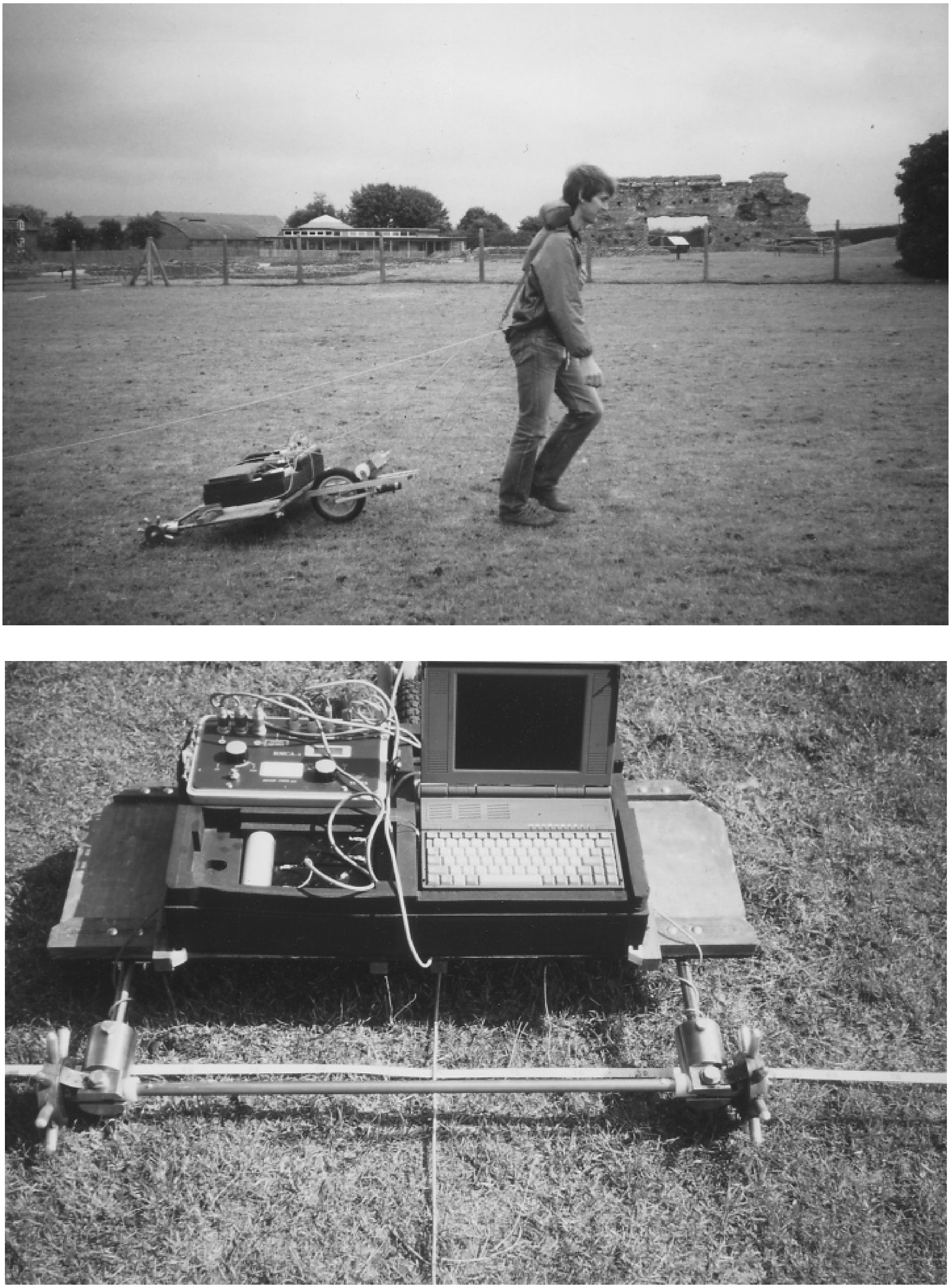


Figure 1. Photograph of the mobile pole–pole array: (a) operating system, (b) view of the carriage.

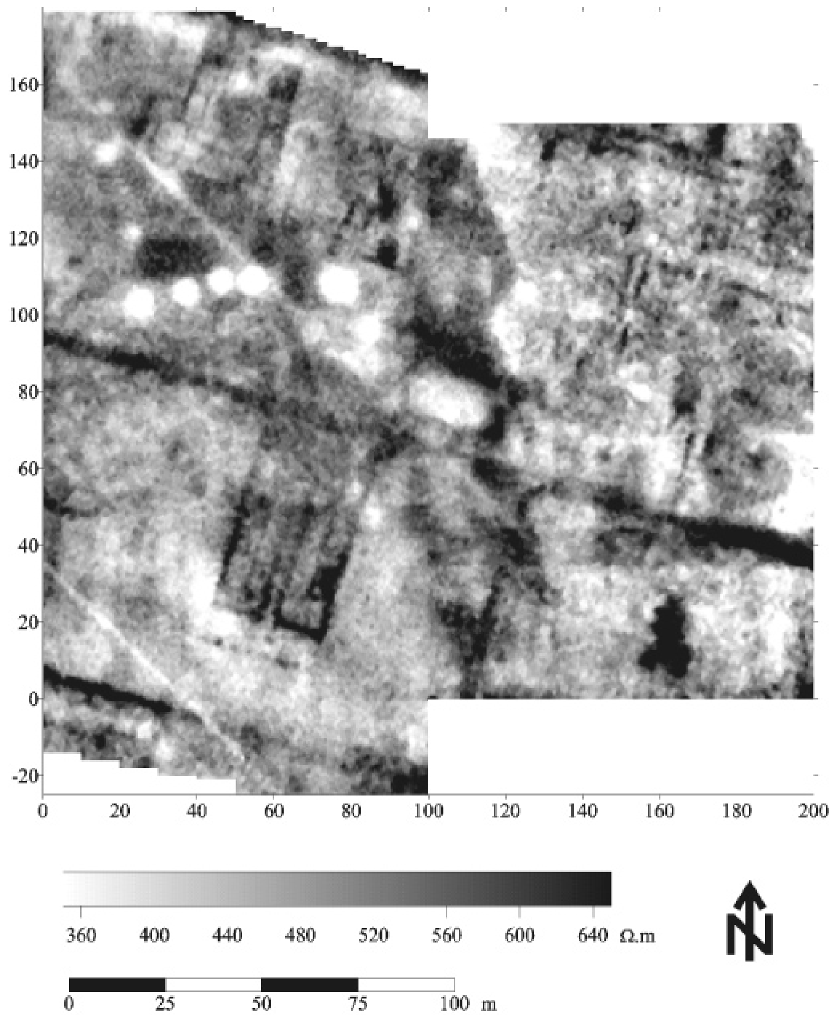



Figure 2. Map of the apparent resistivity obtained with the mobile pole–pole array at Wroxeter (England).

resistivity — the developments of the method are exactly those of the electrical method.

## The case of a mobile electrical pole–pole array

### *The site of Wroxeter: a large Roman city (England)*

Wroxeter is the site of a large Roman city, in the care of English Heritage, that has been the subject of a recent programme of multidisciplinary research (Wroxeter Hinterland Project, Vince Gaffney of the University of Birmingham). The results of continuous measurements with GPR (ground-penetrating radar), magnetic and electrical methods have been compared. We present here detailed resistivity maps of buildings extracted from a 3.5 ha map. This site is covered by a meadow, which implies that the surface is very regular, and the galvanic contact thus quite good.

This survey was completed in five days with a small and light pole–pole array. The array is composed of two small moving spiked wheels separated by 1 m (the separating distance is adjustable from 0.5 to 1 m) and two other remote electrodes separated by great distances (Figure 1a). The acquisition system (resistivity

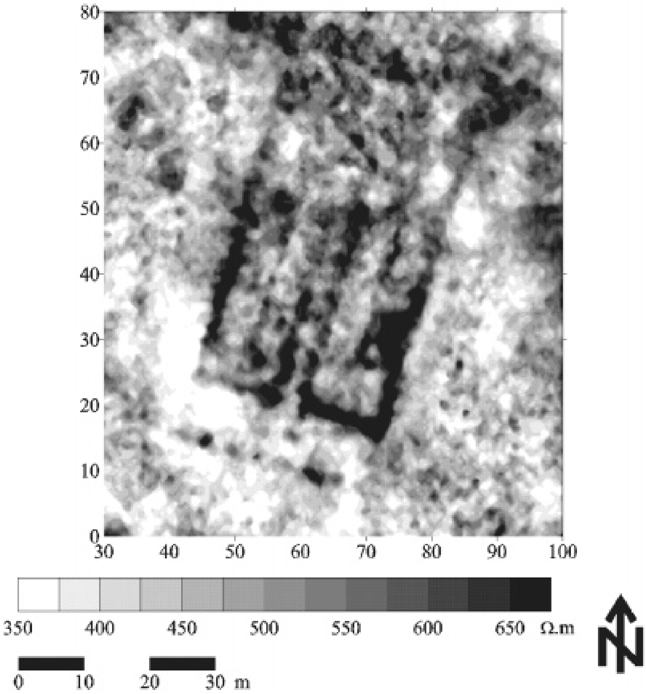



Figure 3. Detailed map over an important building at Wroxeter (England).

meter, acquisition unit, PC, batteries) is fixed on the array and pulled by the operator (Figure 1b). The measurement is performed continuously along the profile with a step of 10 cm (distance taken by a wheel encoder) and the profiles are also 1 m apart. Each profile is filtered by means of a median filter with a one-dimensional moving window 1 m wide; after that the measurements can be interpolated to a square mesh of 0.5 or 1 m, according to the level of geophysical noise.

The map of apparent resistivity shows many features, such as major streets and large buildings (Figure 2), with a good accuracy. The rectangular layout of the Roman city is clearly in evidence. Some other anomalies are superposed on those that have a Roman origin. We note the presence of two pipelines crossing the fields from northwest to southeast, and features linked to sheep farming. We will focus our attention on a large building that can be seen in the southwest part of the map. We can see on the detailed map (Figure 3) most of the inner walls and a series of small resistive anomalies with regular spacing in front of the main entrance to the building. These anomalies are assumed to correspond to a colonnade. A detailed three-dimensional survey was conducted over these anomalies by an English team, whose prospection confirmed the presence of these features.

## The case of a mobile electrical multipole array

### *The survey of an agricultural area in the Nièvre department (France)*

Aerial surveys were carried out by A. Bouthier, during the spring and winter of 1997 over the northern part of the Nièvre (France). The photographs enabled an inventory to be made of a large number of new archaeological sites of different historical periods. Indeed, many archaeological features became apparent in the cereal growth (crop marks) and in the colour of the ground after ploughing (soil marks). Essentially, these features are ditches and enclosures. A ground control survey was undertaken by electrical prospection of an agricultural area

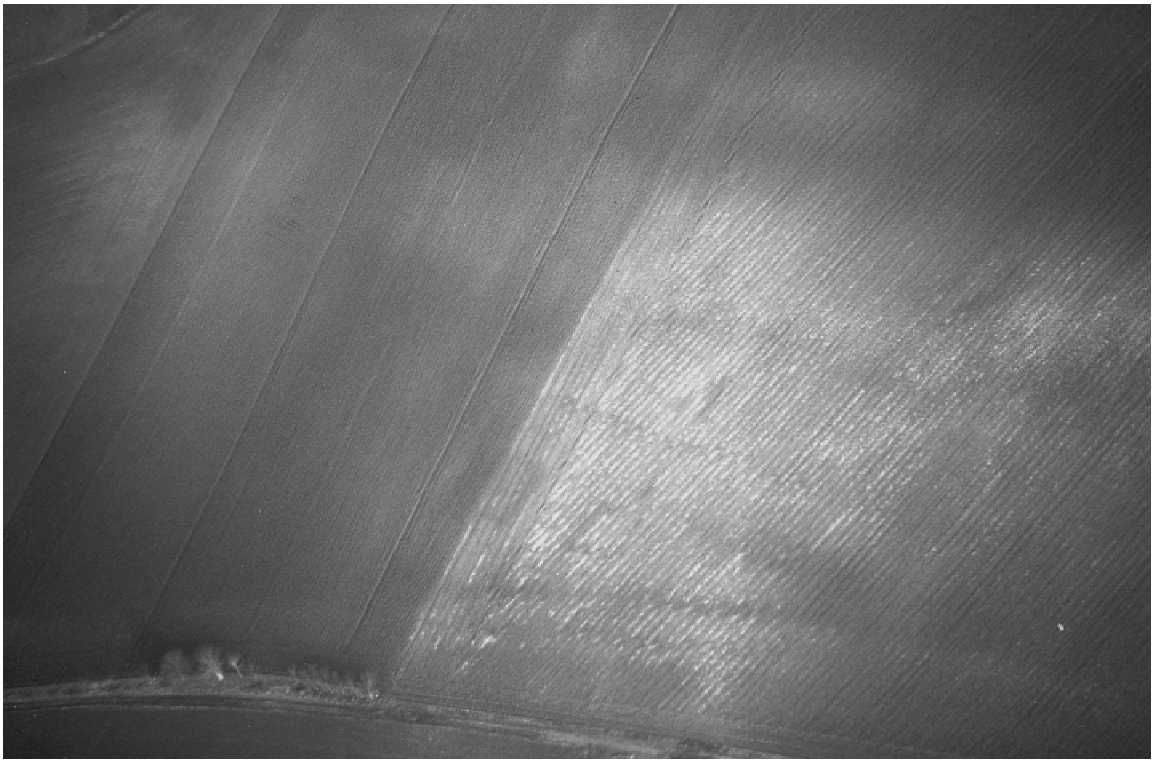


Figure 4. Aerial photograph over the hamlet of Meung (France, 58).

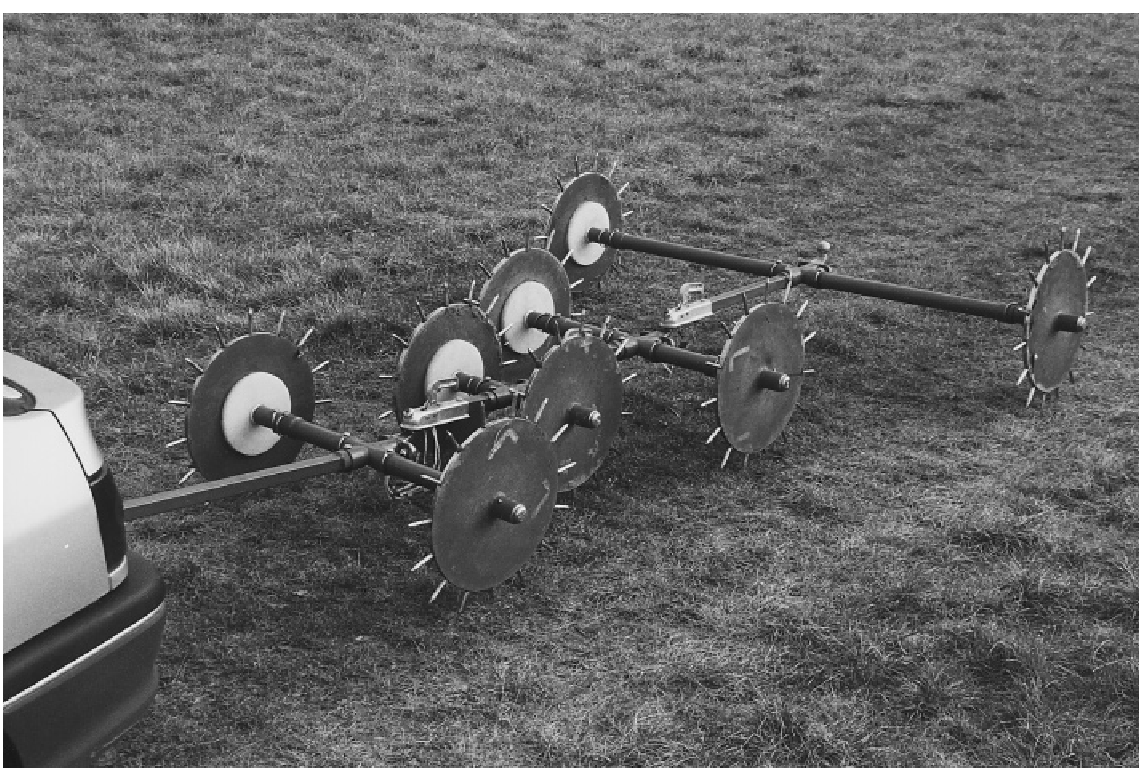


Figure 5. Photograph of the V-MUCEP system.

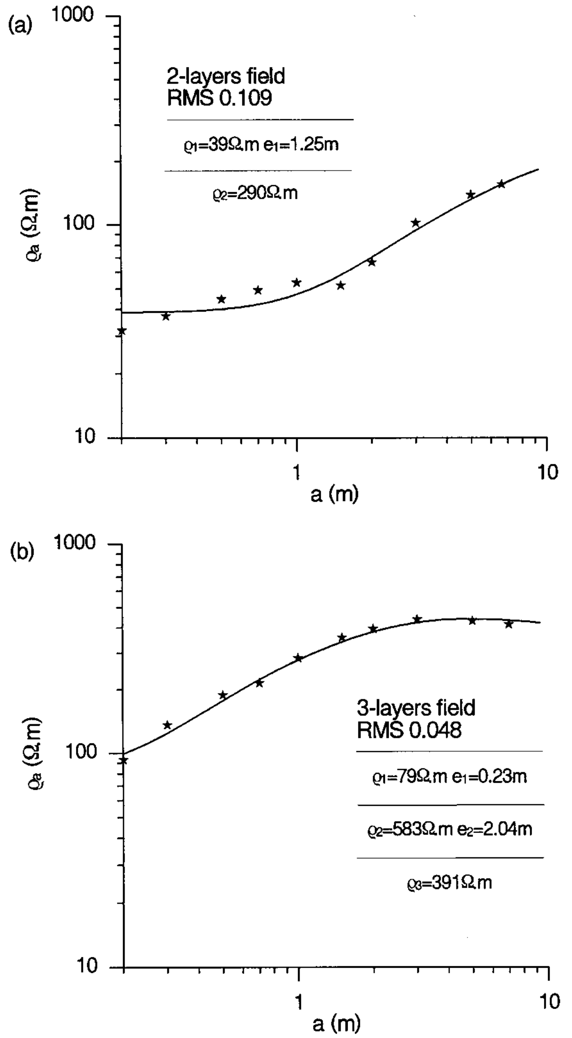



Figure 6. Electrical soundings obtained at Meung (France, 58): (a) sounding S1 (P0,20 E–W); (b) sounding S2 (P30,98 N–S).

located to the north of the hamlet of Meung (Figure 4. The aim of this control by geophysical methods was to define the extent of the features that were indicated by soil marks in the neighbouring area. The field was ploughed at the time of prospection. The prospection combined an electromagnetic survey with EM38 over wide mesh in order to detect the presence of archaeological soil layers and a detailed electrical survey (sounding and profiling) with a multipole. Here we will restrict our presentation to the result of the resistivity measurements.

The soundings were carried out using Wenner arrays from $a = 10$ cm to $a = 7$ m. The device used for the profiling was a V-MUCEP multipole (Figure 5), composed of three potential dipoles, corresponding to three different depths of investigation (approximately 0.5 m, 1 m and 2 m). The array was towed by an agricultural tractor over a 1.5 ha area. The spatial sampling was fixed at 10 cm along the profiles and 1 m between each profile (east–west). After applying a median filtering along each profile, they were put together and interpolated on a 50 cm square mesh of measurement. As is often observed when ploughed fields are surveyed in continuous electrical prospecting, profiles are affected by changes in the microtopography caused by the ploughing. This effect, which we can consider as noise, is reduced by the use of destripping and two-dimensional median filtering. Nevertheless, for some cases, when the effect of ploughing is very marked, a new treatment has been developed in order to eliminate this type of noise (Tabbagh, 1998).

The interpretation of electrical soundings shows the variation of the thickness of the cultivated layer above a resistive limestone plateau (Figure 6). The thickness of the soil reaches a maximum in the southwest part (1.2 m on S1), probably due to the presence of colluvium. The three-dimensional mapping of the apparent resistivity allows us to follow these variations over the whole area (Figure 7). We can see that the structure of the limestone plateau is relatively complex, with two main resistive anomalies located in the eastern part of the survey. A square conductive enclosure, with 15 cm sides is clearly revealed on top of one of these resistive anomalies. Three linear anomalies resulting from the presence of small drainage trenches on the surface go through the field from north to south. We can identify other linear features and edges that go through the area of the survey from west to east. The first one is composed of two staggered branches, with a right angle between the positions 64 m and 72 m along the profiles. The second one is a large conductive edge at the south of the larger resistive anomaly on the maps. We can assume that the important conductive anomaly located at the north of the map is of anthropogenic origin

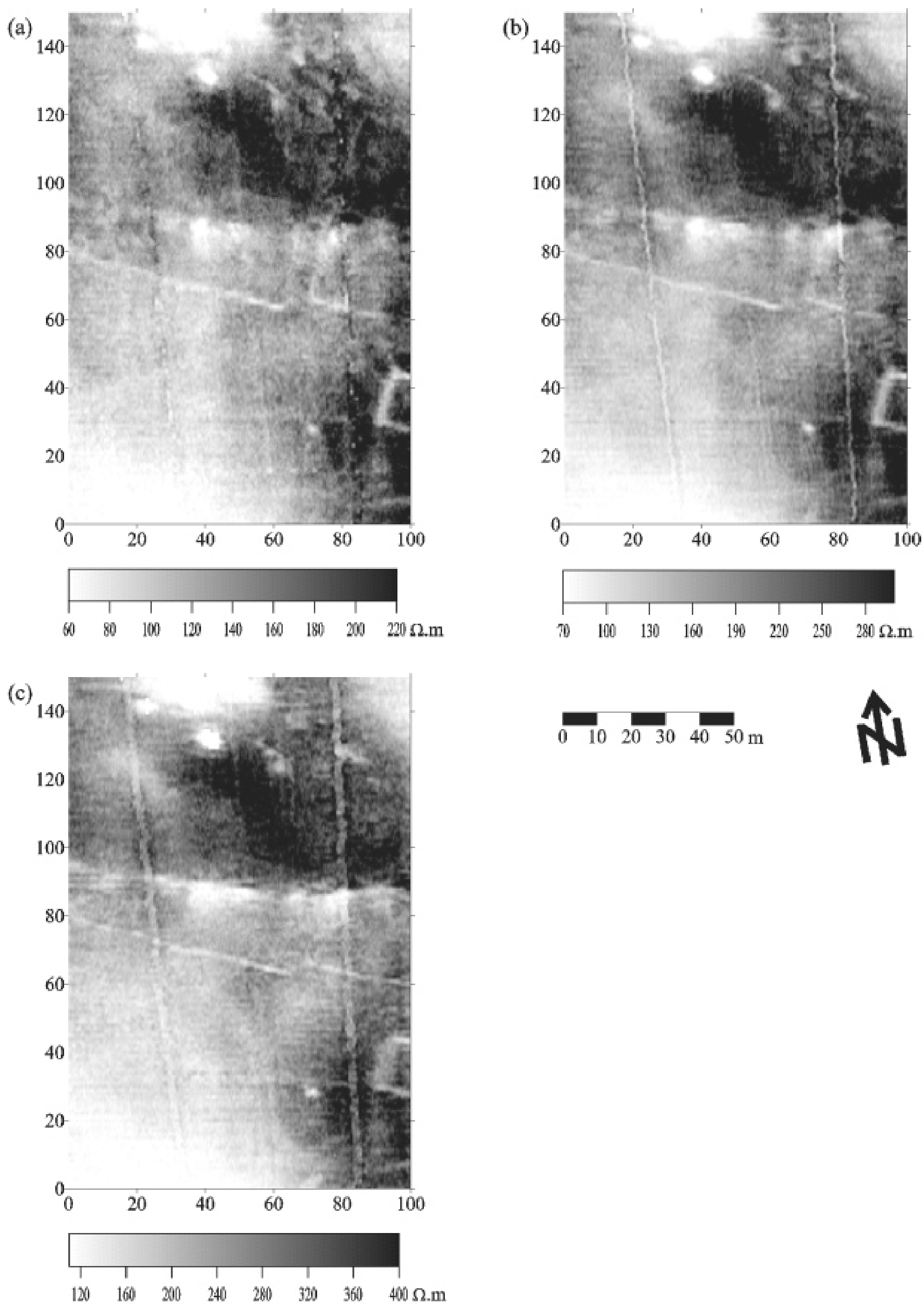
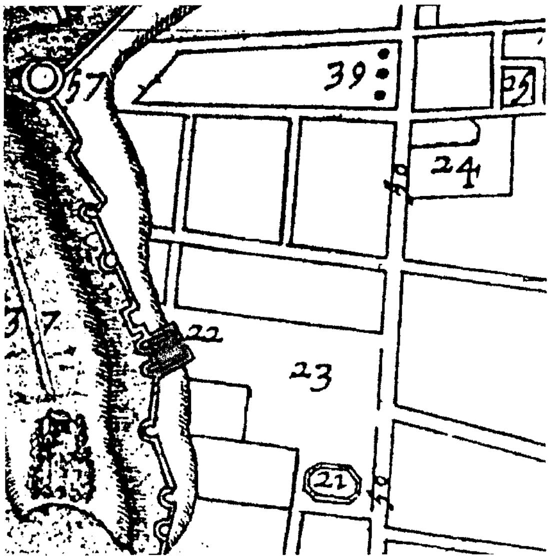
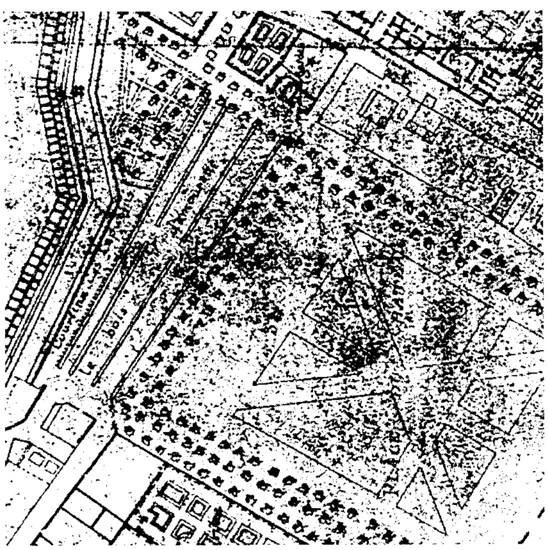



Figure 7. Maps of the apparent resistivity obtained with the V-MUCEP at 'Les Poiriers' (France, 58): (a) shallowest quadripole, (b) median quadripole, (c) deepest quadripole.




(a)



(b)

Figure 8. Map extracts of La Rochelle (France) for the seventeenth and eighteenth centuries.

(high susceptibility). Indeed, it is associated with two other small anomalies at the edge of the resistive limestone massif. This anomaly is more conductive than the conductive soil located in the south part of the map and may be an Iron Age ditch. It would be interesting to improve this study by a detailed survey over the linear ditches, which appear as very superficial features. A multipole that gives an isotropic response would be most appropriate for this type of survey.

## The case of a mobile electrostatic multipole array

### *The prospection of the town square of Verdun at La Rochelle (France)*

The survey of the town square of Verdun at La Rochelle constituted a preliminary study before the building of an underground car park. This town square is located in the old city centre, which was fortified. Maps of the seventeenth and eighteenth centuries (Figure 8a and b) show that this place, located inside the city walls, should correspond to the site of a medieval castle (thirteenth century, labelled 22 in Figure 8a, and 'Place of the Castle' in Figure 8b). The aim of this survey was to detect resistive features that correspond to the presence of walls or foundations of these fortifications. Archaeological soundings, made in the eastern part of the area, had shown building remains at a depth around 60 cm. Two geophysical methods were used for this prospection owing to the inherent limitations of the asphalt surface. They were GPR and an electrostatic multipole. Ground-penetrating radar is commonly used in civil engineering for the detection of pipes and cables in urban areas; direct archaeological applications remain rare (as does in general, archaeological prospection in urban areas). This was the first experiment carried out using an electrostatic multipole. The site was an excellent opportunity in view of the large surface that could be covered, but also considering the constraints due to the urban context (road traffic, trees, park benches, pavements, etc.). The survey was carried out during the night (over 6 h) in order to avoid any disturbance to the traffic.

The electrostatic multipole used was a prototype of the MPU system presented in Figure 9. It was composed of one dipole for injection and two dipoles for measurement corresponding to two different depths of investigation, around 0.7 m and 1.4 m. The choice of these sizes of quadripoles is in accordance with the depth of

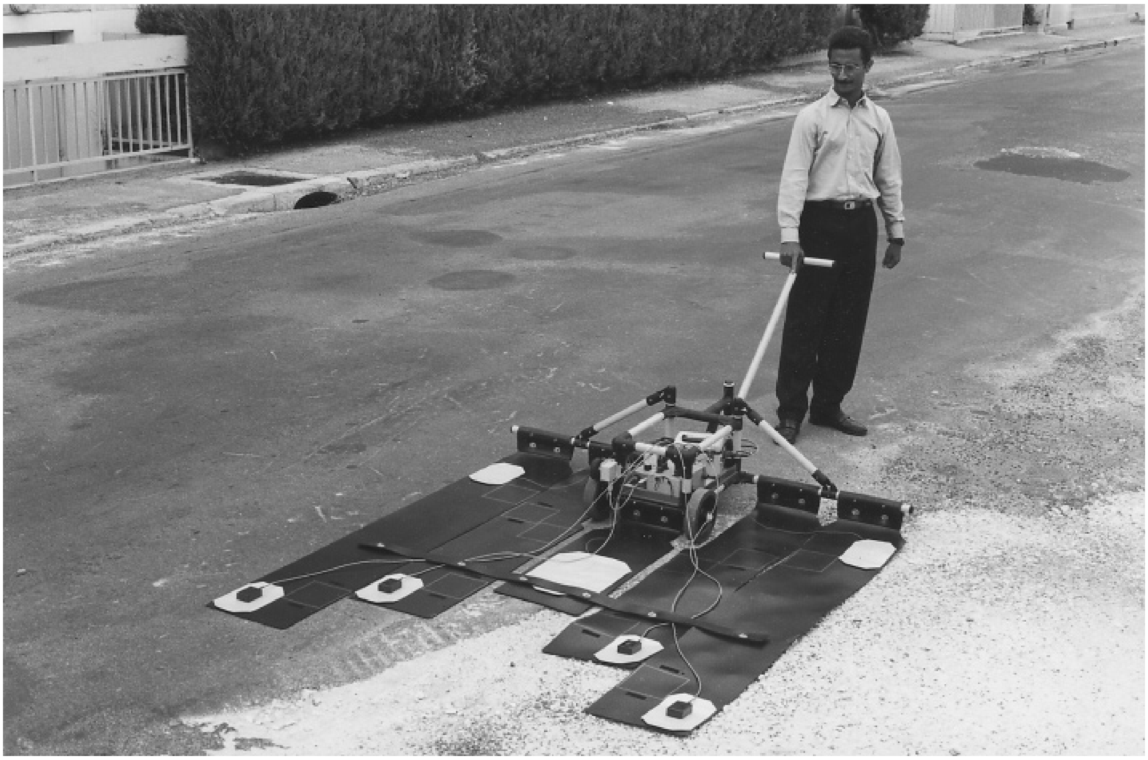


Figure 9. Photograph of the urban electrostatic multipole MPU.

the remains excavated during the archaeological soundings (top at a depth of 60 cm). The spatial sampling was fixed at 10 cm along the profiles and 1 m between each profile. With these parameters, the apparent resistivity map is around 0.75 ha.

The results of the survey (Figure 10) are superimposed on the city map in order to identify the correlation of the anomalies with well-known objects of the different public utility networks, and to compare the directions of the anomalies in the different areas of the survey. We can see several linear resistive features (N–S) in the western part of the area. These resistive lines could correspond to the presence of the walls that can be clearly identified on the eighteenth century map ('Courtine des Capucins', 'Le bois d'amourette'). In the eastern part of the prospection area, we can note an important system of resistive anomalies, which are not in the same direction as the previous one. We can see anomalies with right angles, successive east–west lines with a regular 6 m spacing, which could be the foundations of one or several medieval buildings. The dimensions of this zone are 30 m by 30 m. We have to pay careful attention to these anomalies, because of the expected location of the 'Château de Vauclerc' in this part of the area. Moreover, the origin of these features is probably medieval, because the area has not been modified since the seventeenth century. A resistive circular anomaly appears clearly with both quadripoles. It is difficult to include this feature in the previous sequence of anomalies. It is probably more recent, and could be the remains of a bandstand (nineteenth to twentieth century).

## Conclusion

The results presented in this paper emphasize the importance of mobile systems for the continuous recording of apparent resistivity in archaeological prospection. They allow us to gather an important amount of information in a very short time, and to give rapid answers to specific archaeological problems. They can be applied in both

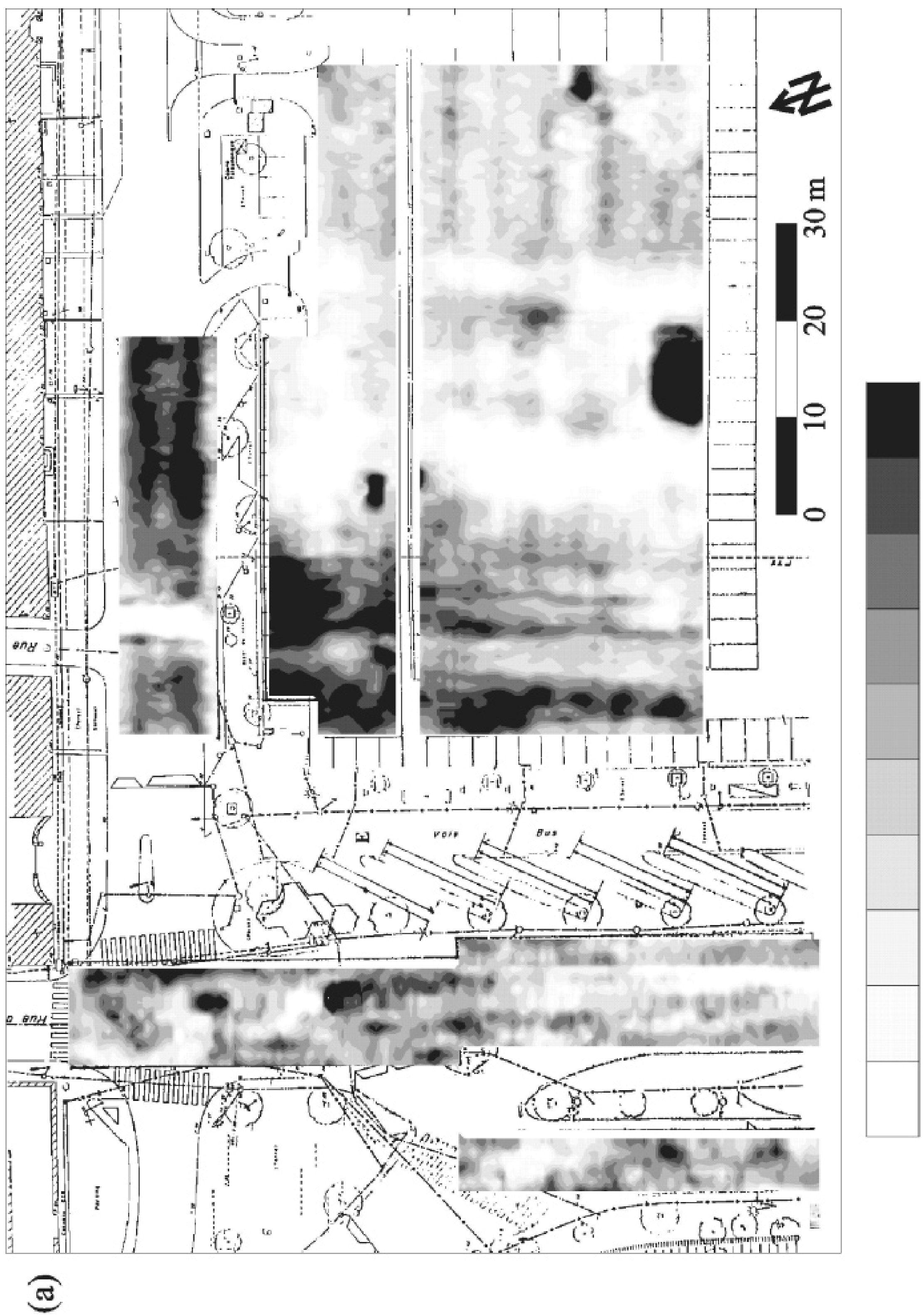



Figure 10(a). Maps of the apparent resistivity obtained with the MPU at La Rochelle (France): shallowest quadripole.

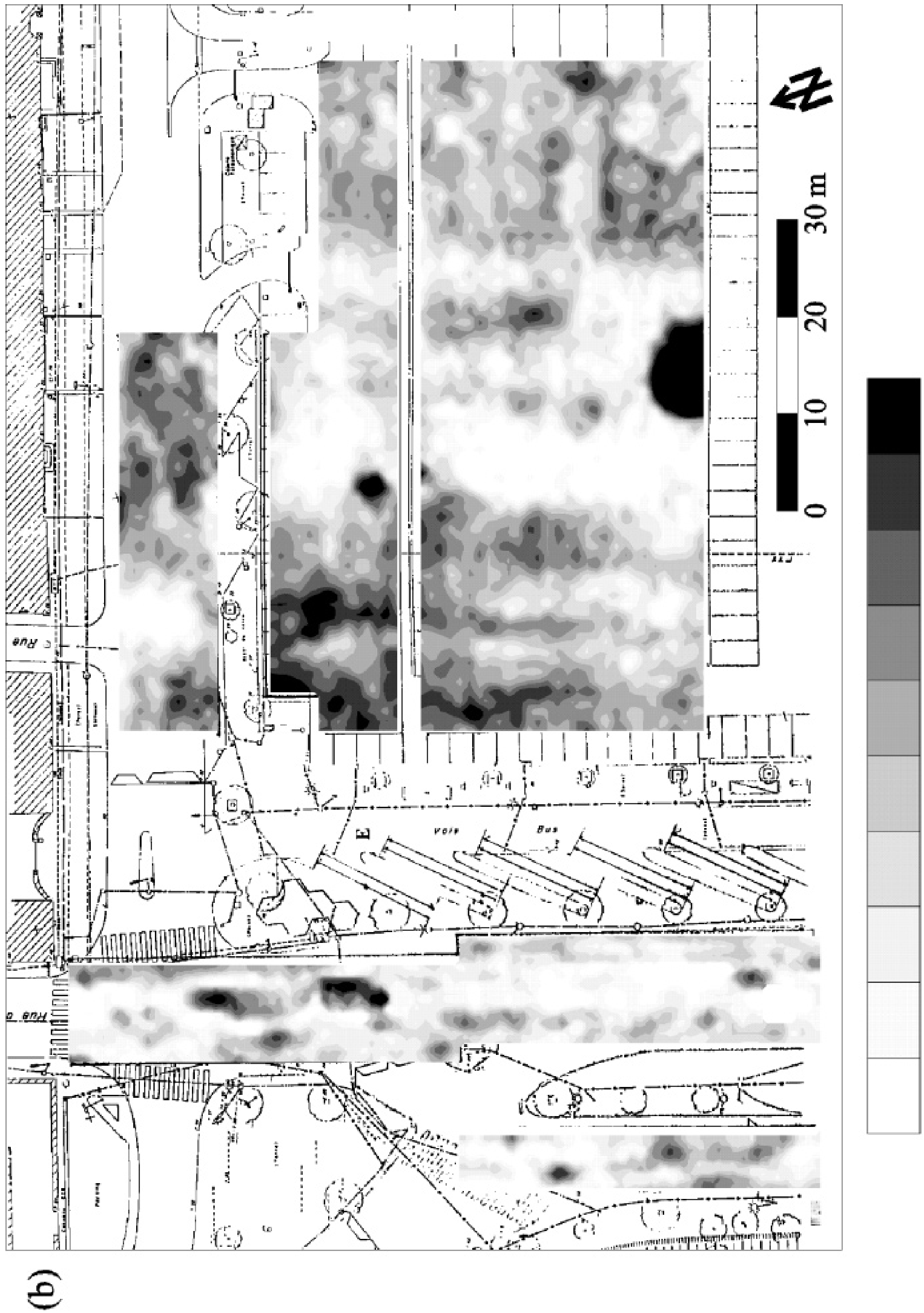



Figure 10(b). Maps of the apparent resistivity obtained with the MPU at La Rochelle (France): deepest quadripole.

urban or agricultural land contexts. Combined with the last forward and inverse modelling algorithms, we can provide a good quantitative interpretation of the electrical data.

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