ELECTRICAL RESISTIVITY DETERMINATION OF SUBSURFACE LAYERS, SUBSOIL COMPETENCE AND SOIL CORROSIVITY AT AN ENGINEERING SITE LOCATION IN AKUNGBA-AKOKO, SOUTHWESTERN NIGERIA

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Abstract

A geophysical investigation involving the electrical resistivity method was carried out at a site located in the eastern part of Akungba-Akoko, Southwestern Nigeria. The aim of the investigation was to characterize the site according to subsurface lithologic layering, subsoil competence and soil corrosivity, which may affect the location and maintenance of engineering constructions that may be built on the site.

A total of 1063 vertical electrical sounding (VES) stations were established within the site along 58 traverse, but only 949 out of the established stations were eventually occupied for sounding as some of the stations fell on bare rocks or in inaccessible areas. Raw apparent resistivity values for three theoretical depth levels (0.5 m, 3 m and 8 m) were plotted for all the VES stations, contoured and then interpreted qualitatively in terms of soil competence. The methods of partial curve matching and 1-D computer iteration were also used to quantitatively interpret the VES curves that were generated. The quantitative interpretation results (layer resistivities and thicknesses) obtained for the topsoil were used to determine the subsurface lithologic layering and to characterize the soil corrosivity.

Three main subsurface layers-the topsoil (0-3.9 m thick and 30-5500 ohm-m in resistivity), the weathered layer (0-44.6 m thick and 9-781 ohm-m in resistivity) and the partially weathered/fractured/fresh bedrock (270 to ∞ ohm-m in resistivity)-make up the subsurface. The distribution of apparent resistivity values at different depth levels and the topsoil resistivity values suggested that competent soils ($\geq$100 ohm-m) with slightly to practically non-corrosive ($\geq$ 60 0hm-m) tendencies underlie the site. The study concluded that the characteristics of the earth materials in the site would be favourable to normal engineering structures/materials that may be located on it.

Keywords: Resistivity, subsurface layering, competence, corrosivity, engineering site

1. Introduction

In the developed World, the characterization of sites earmarked to host developmental projects is carried out as a matter of routine in keeping with relevant legislation (Canter, 1995). This is done either to ascertain the suitability of the characteristics of such sites to host planned structures or to determine the likely impact such structures may have on the environment when eventually implemented. This, until very recently, had not been the case in the developing Third World Countries (including Nigeria); and has led to uninformed decisions about projects resulting in ill-designed and poorly completed projects, which were bound to fail with time and/or adversely affect the environment (Olorunfemi *et al.* 2000a; Olorunfemi *et al.*, 2000b; Olorunfemi *et al.*, 2004).

Nonetheless, the awareness regarding the need to emulate the example of the developed World has steadily increased in recent years. As a case in point, the establishment of the Federal Environmental Protection Agency (FEPA) by the Federal Government of Nigeria by Decree 58 of 1988 was a step taken to fit into the conceptual framework of the global environmental awareness and good planning practice drive. This decree mandated FEPA to establish environmental guidelines and standards for protecting, restoring and preserving the ecosystems of the country (FEPA, 1991). In response to this mandate, FEPA has, among other policies, put in place blueprints for Environmental Impact Assessment (EIA) studies in Nigeria. The overall aim of site testing in EIA studies is to furnish baseline

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information on which the decision(s) geared towards obtaining optimum benefits from intended projects can be based.

Engineering geophysics offers a wide spectrum of methods that can be used in site testing to provide solutions to near-surface problems. The strength of the methods lies in their being fast, cost-effective, multidimensional and non-invasive, when compared to competing non-geophysical techniques (e.g., borehole drilling and sampling). Because of the non-uniqueness in the interpretation of results of geophysical data, complementary methods are routinely used to make for coincident interpretations (Kearey *et al.*, 2002). The electrical resistivity method is most frequently used in environmental studies because the electrical resistivity of Earth materials is determined by environmental parameters such as the amount and concentration of saturating fluids, the conductivity of matrix, porosity, permeability, temperature, degree of fracturing, grain size, degree of grain cementation, rock type and the extent of weathering of the medium (Sharma, 1997; Olorunfemi, 2001). For these reasons, this geophysical method was used to investigate the subsurface stratigraphy, subsoil competence and soil corrosivity characteristics of a site intended for future development located within the basement terrain of southwestern Nigeria. These environmental parameters were investigated as they constitute some of the most crucial near surface/subsurface factors that may affect the location and maintenance of engineering infrastructures.

2. Location, Geology and Geomorphology of the Site

The investigated site is located in the eastern part of Akungba-Akoko town, Nigeria (Fig. 1), and lies between latitudes 7°28'13.29"N and 7°29'19.29"N and longitudes 5°45'10.49"E and 5°46'48.61"E. In the UTM coordinate system these geographic coordinates are respectively equivalent to the Northings 826621.810 mN and 828668.130 mN and the Eastings 803866.740 mE and 806864.970 mE of Zone 31. Geological investigation in the site revealed that it is underlain by two types of migmatite-gneiss, namely the gray gneiss and the granite gneiss/augen gneiss. Foliation, lineation, minor folds and minor faults are the common structural elements in the site. These structures have a strong E-W orientation.

The general slope of the ground surface is $\leq 5°$. East/Southeast and West/Southwest slope aspects dominate the landscape. The physiographic disposition strongly influences the drainage composed of River Alatan, which drains the southern border of the site, and its tributaries.

3. Method of Study

The study involved the use of the electrical resistivity geophysical method. For the data acquisition, a total of 58 N-S traverses with 50 m inter-traverse spacing were planned for the site, but the rugged terrain conditions made the exact implementation difficult for the surveyors who established the traverses. The actual location of VES points as shown in Figure 2 were given by the Garmin's Geographical Positioning System (GPS) Personal Navigator unit. The orientation was chosen to run approximately perpendicular to the general trend of topographic features in this area. The length of the traverses ranged from 350 m to 1500 m. Measurement stations were marked and pegged along the traverses at 50 m interval. A total of 949 of the 1063 stations were eventually occupied, since 71 and 43 of the established points fell on bare rock outcrops or in inaccessible areas (swamps, etc.), respectively. The elevation value of each measuring station was picked from an existing 1:2500 topographic map, thus the accuracy of the determined elevation values depended on the accuracy of this map. The instrument used for the resistivity data collection was the PASI 16GL digital resistivity meter. The technique of investigation was the vertical electrical sounding (VES). The Schlumberger array was utilized for the survey. The electrode spacing (AB/2) was varied from 1 m to 100 m. The method of partial curve matching was used to quantitatively interpret the VES curves. The results of the curve matching were fed into the computer as starting models of the subsurface parameters (layer resistivities and thicknesses). Through the process of iteration, the computed (theoretical) curves were made to agree with the measured curve. The RESIST version 1.0 (Vander Velpen, 1988), proprietary computer software of the ITC, The Netherlands, was used for the computer iteration. Raw apparent resistivity values for three theoretical depth levels (0.5 m, 3 m and 8 m) were also plotted for all the VES stations, contoured and then interpreted qualitatively, so that the distribution of resistivity values at the levels could be assessed in terms of ground competence.

4. Results and Discussions

(a) Subsurface Layers

In order to determine the 2-D geological model of the subsurface in the site, geoelectric sections were prepared for the N-S traverses using the VES interpretation results (examples are shown in Figures 3a and 3b). The sections interpreted with the aid of available auger-hole data from the site (Fig. 4) indicate three main geoelectric layers, namely the topsoil, the weathered layer and the bedrock.

The topsoil is composed of clay, lateritic clay, sandy clay, clayey sand/sand, and sometimes pure laterite (hard pan). The layer resistivity varies between 30 and 5500 ohm-m, and the mean value is 510 ohm-m (Fig. 5a) with a standard deviation of 610. The coefficient of variation in topsoil resistivity is 120%, which corroborates the high degree of dispersion. The topsoil resistivity map (Fig. 6) shows high relief in the western part of the site (with a N/S-E-W trend) and around most of the rock outcrops. The topsoil thickness ranges from 0 (in areas of outcrop) to 4.9 m with a mean of 1.3 m (Fig. 5b). The standard deviation and the coefficient of variation are 1.0 and 77%, respectively. Areas around outcrops that form the prominent hills in the site generally have thin topsoil layer (Fig. 7).

The weathered layer, composed of sandy clay, clayey sand and sand, has resistivity values that vary from 9 ohm-m to 781 ohm-m (Fig. 8a). The average resistivity being 142 ohm-m, with a standard deviation of 124 ohm-m. The coefficient of variance is about 87%. The weathered layer resistivity map (Fig. 9) does not indicate a significant pattern. The thickness of the weathered layer ranges from 0 (for areas of outcrop) to 44.6 m (Fig. 8b). The mean thickness is 7.6 m, whereas the standard deviation and the coefficient of variance are 6.9 and 91%, respectively. Most of the high thickness values are found in the western half of the map, while values are generally ≤ 10 m in the eastern part (Fig. 10).

The resistivity of the fractured basement is from 26 ohm-m to 957 ohm-m (Fig. 11a) with a mean of 347 ohm-m, whereas its thickness values range from 0.9 m to 42.8 m (Fig. 11b) with an average of 12.9 m. The resistivity values of the basement range from 270 ohm-m to ∞(infinity).

(b) Subsoil Competence Evaluation

On the one hand, the competence (or strength) of any geological material is influenced by several factors such as the mineralogy of its particles, the character of the particle contact and the agents of weathering (Blyth and de Freitas, 1984). On the other hand, the electrical resistivity of materials can be influenced by many factors including saturating fluids, porosity, temperature, rock texture, rock type and geological processes. As a consequence of this, the electrical resistivity is poor index of lithology since there is significant overlap in the range of values for different lithologic types. However, in a given locality resistivity values can give a reliable indication of lithology. For instance, on the basis of this study (Fig. 4) and from experience gained elsewhere (e.g., Olorunfemi *et al.*, 2004) certain ranges of apparent resistivity values can be correlated with lithologic competence as shown in Table 1.

In engineering geophysics, clays characterized by low resistivity (usually < 100 ohm-m) are regarded as incompetent materials as they tend to flow under stress (Sheriff, 1991). Sands and crystalline rocks (bedrock), on the contrary are regarded as competent materials as they can withstand stress. Because of this, it is normally required during the testing of sites earmarked for hosting civil engineering structures that the amount of clays in the surface and in the near surface horizons be adequately estimated. Failure to do this has always resulted in the location of structures on incompetent materials, which in turn invariably led to the failure (manifesting as cracks on walls, floor subsidence in buildings, collapse of dams, potholes on roads, etc.) of such structures with time, as differential settling set in (Olorunfemi and Meshida, 1987; Olorunfemi *et al.*, 2000a; Olorunfemi *et al.*, 2004). In order to derive information to help guide against this in the present site, raw apparent resistivity values for three theoretical depth levels (0.5 m, 3 m and 8 m) were plotted for all the VES stations occupied and then contoured, so that the competence of materials at these levels could be assessed through their resistivity response. These depth levels were derived supposing that the effective depth of investigation during electrical surveys involving the Schlumberger array is given by 0.125L, where L (or AB) is the current electrodes separation (Roy and Apparao, 1971). Hence, the investigated theoretical depth levels correspond to the AB/2 of 2 m, 12 m and 32 m (Figs 12-14). To aid interpretation of the maps, the lithologic competence ratings shown in Table 1 were used.

At the depth of 0.5 m (Fig. 12), the predominant material is sandy clay. Clayey sand and laterite are found mainly in the western part of the site and around areas of outcrops. At the depth level of 3 m (Fig. 13) the materials are mainly composed of sandy clay. Here clayey sand and sand/lateritic are found around the outcrops. Even rock bodies without surface expression are mapped at this depth level. This is exemplified by the relatively lower resistivity values (100-400 ohm-m) in the northeastern extreme of Figure 12 compared with high values (100-1200 ohm-m) in the same area in Figure 13. Figure 14 indicates that the clayey sand and sand/laterite/ bedrock materials predominate at the depth level of 8 m. Thus, on the basis of the electrical behaviour of the materials in the site, they may be regarded as of adequate bearing capacity. At the depth of normal foundation level (about 2 m) and deeper, the materials may be expected to be able to host normal civil engineering structures that may be erected on them.

(c) Soil Corrosivity Evaluation

A corrosive material is that which has the quality of eating away or consuming another material. For soils, corrosivity may be defined in terms of a soil's ability to corrode a material that may be buried in it. As soils at building sites would normally host building foundations, pipes, etc., it becomes mandatory in a well-organized site testing exercise to evaluate soil aggressivity (corrosivity) taking into consideration the type of materials to be buried in it. A soil may be corrosive depending upon its mineralogical

Table 1: Lithologic competence rating in terms of apparent resistivity values.

Apparent resistivity range (ohm-m)	Lithology	Competence rating
<100	Clay	Incompetent
100 – 350	Sandy clay	Moderately competent
350 -750	Clayey sand	Competent
>750	Sand/laterite/bedrock	Highly competent

composition and its structure (Agunloye, 1984). Thus, clay soils tend to be corrosive because they usually retain water, which can favour oxidation of metals embedded in them. Other factors that may make a soil corrosive include reduced aeration and high level of electrolyte saturation or high concentration of salts dissolved in the water contained in pore spaces. All these factors generate low electrical resistivities.

Thus corrosivity of soils may be related to the electrical resistivity response of such soils. Accordingly, a four-fold classification of soil resistivity in terms of corrosivity is given in Table 2. According to this table, soils with resistivity values of 180 ohm-m may be regarded as corrosive, while those with higher resistivity values may be considered non-corrosive.

To assess the corrosivity level of the soils in the site, the topsoil resistivity values (Fig. 6) have been used, as the mean thickness of the topsoil (1.3 m) falls within the average limiting depth of burial of pipes usually taken to be 2 m. Based on these data, very strongly corrosive soils with resistivity value of 10 ohm-m are practically absent from the site. Moderately corrosive soils (10-60 ohm-m) are found in pockets within the site with the bigger pockets located in the western part of the site. Soils with slightly to practically non-corrosive tendencies underlie the greater percentage of the surface area of the site.

5. Conclusions

A site located to the eastern part of Akungba-Akoko, southwestern Nigeria, has been investigated using the electrical resistivity method of geophysical survey. The basic aim of the investigation was to determine the near surface/subsurface factors (such as stratigraphy, subsoil competence and soil corrosivity) that may affect the location and maintenance of engineering constructions in the site. For the data acquisition, a total of 58 traverses with 50 m inter-traverse spacing were laid out within the site. A total of 949 VES stations were thus occupied. The instrument used for the resistivity data collection was the PASI 16GL digital resistivity meter. The technique of investigation was the vertical electrical sounding (VES). The method of partial curve matching was used to quantitatively interpret the VES curves. Raw apparent resistivity values for three theoretical depth levels were also plotted for all the VES stations, contoured and then interpreted qualitatively, so that the distribution of resistivity values at the levels could be assessed in terms of material competence.

Geoelectric cross-sections taken across the site indicate that three main layers – the topsoil (clay, lateritic clay, sandy clay, clayey sand/sand, and sometimes pure lateritic hard pan), the weathered layer (clays, sandy clay, clayey sand and sand) and the fresh bedrock – make up the subsurface. The partially weathered/fractured basement layer is poorly developed in the site. The topsoil varies in thickness from 0 (for areas where the basement outcrops) to 3.9 m, and the resistivity values range between 30 and 5500 ohm-m. The weathered layer thickness spans the 0 (for areas where the bedrock outcrops) to 44.6 m range, and the layer resistivity varies from as low as 9 ohm-m to 781 ohm-m. The resistivity of the basement varies from 270 to (infinity) ohm-m. ∞

The distribution of apparent resistivity values at three theoretical depth levels (0.5 m, 3 m and 8 m) suggests that clay materials with characteristic resistivity values of < 100 ohm-m are found at isolated locations, which locations become fewer with depth and practically absent at the 8 m depth level. Thus, at the depth of normal foundation level and deeper, the subsurface materials in the site may be expected to be able to host normal civil engineering structures that may be erected on them.

Very strongly corrosive soils with resistivity values of 10 ohm-m are practically absent from the site. Moderately corrosive soils (10-60 ohm-m) are found in pockets within the site with the bigger ones located in the western part of the site. Soils with slightly to practically non-corrosive tendencies underlie the greater part of the surface area of the site. Therefore, the soils in the site are not aggressive and may host metallic materials without serious danger of corrosion.

Acknowledgements

Table 2: Classification of soil resistivity in terms of corrosivity (based on Baeckmann and Schwenk, 1975; Agunloye, 1984).

Soil resistivity (ohm-m)	Soil Corrosivity
Up to 10	Very strongly corrosive (VSC)
10 – 60	Moderately corrosive (MC)
60 – 180	Slightly corrosive (SC)
180 and above	Practically non-corrosive (PNC)

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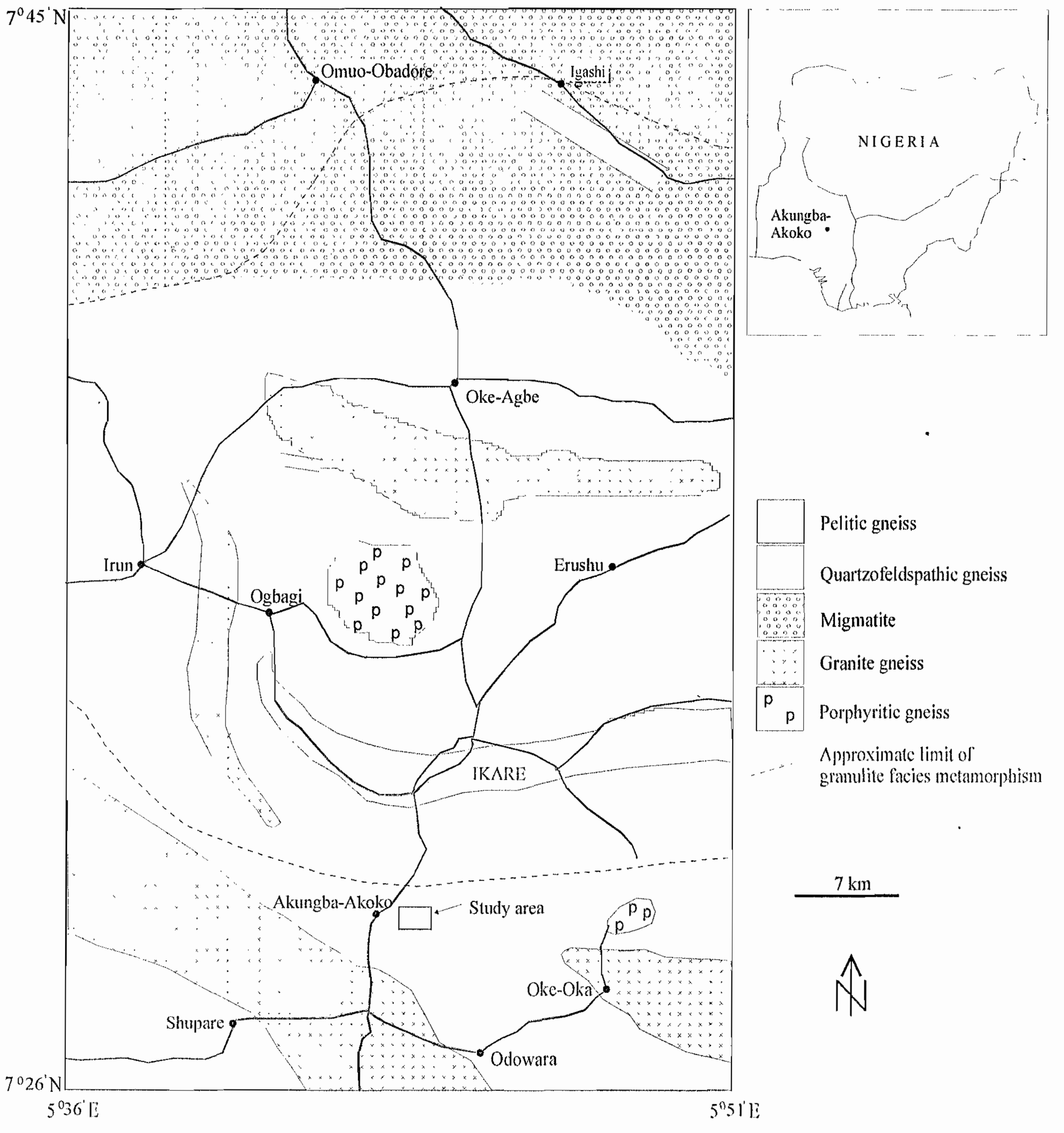


Fig. 1: Geological sketch map of Ikare area (modified after Rahaman and Ocan, 1988) showing the study area.

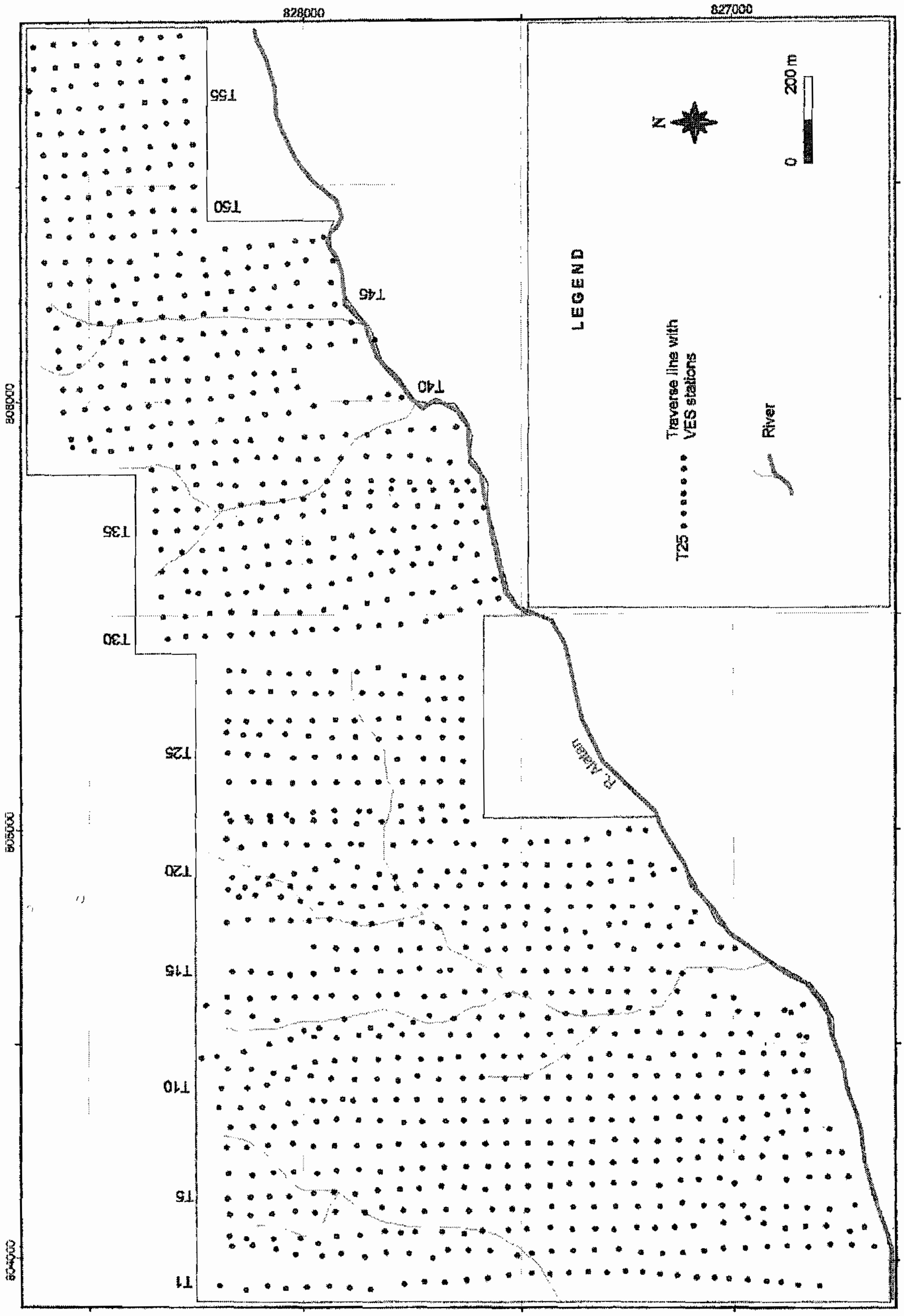


Fig. 2: Geophysical data acquisition map of the site.

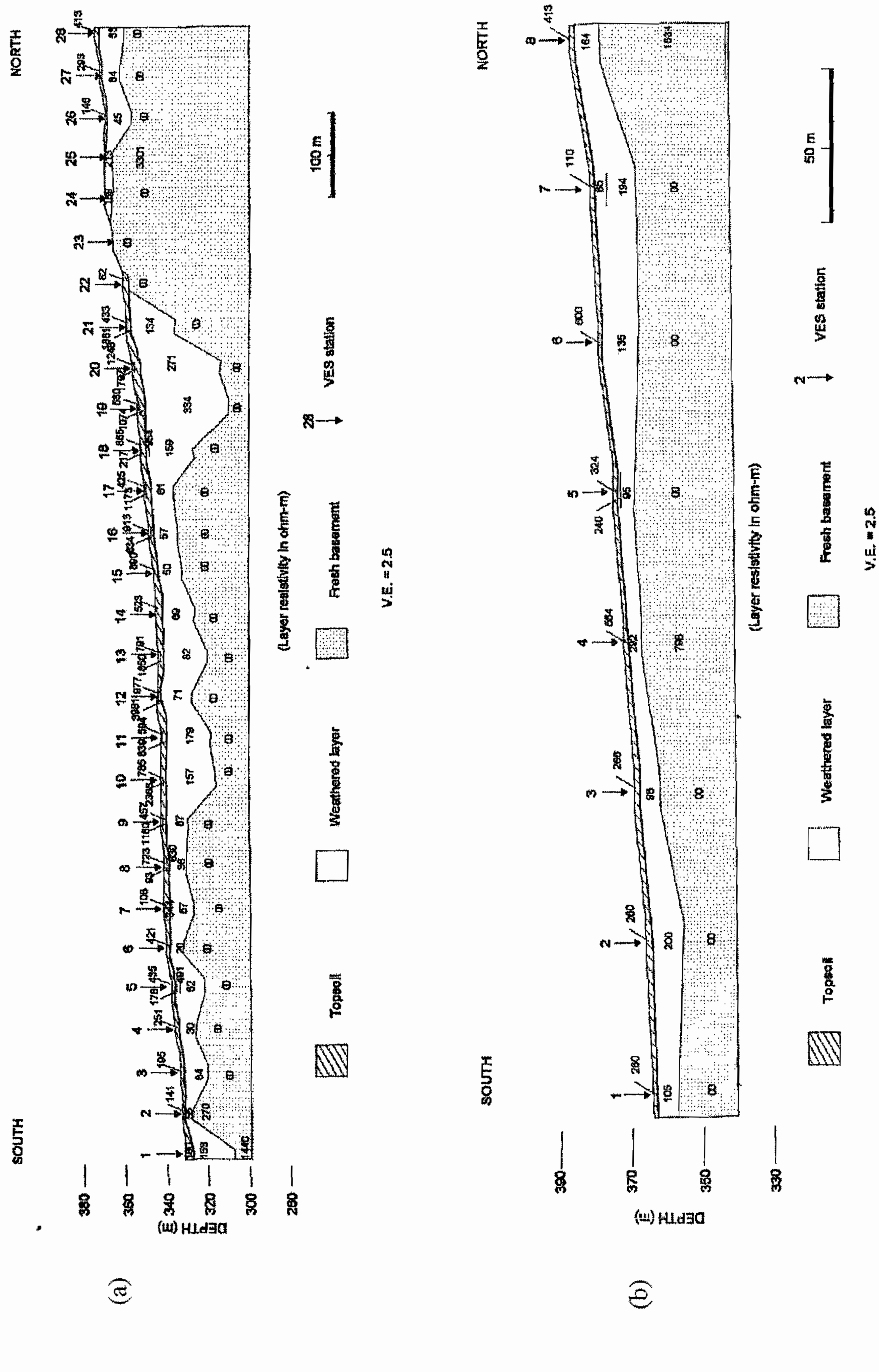


Fig. 3: Geoelctric section along (a) Traverse 10 and (b) Traverse 58.

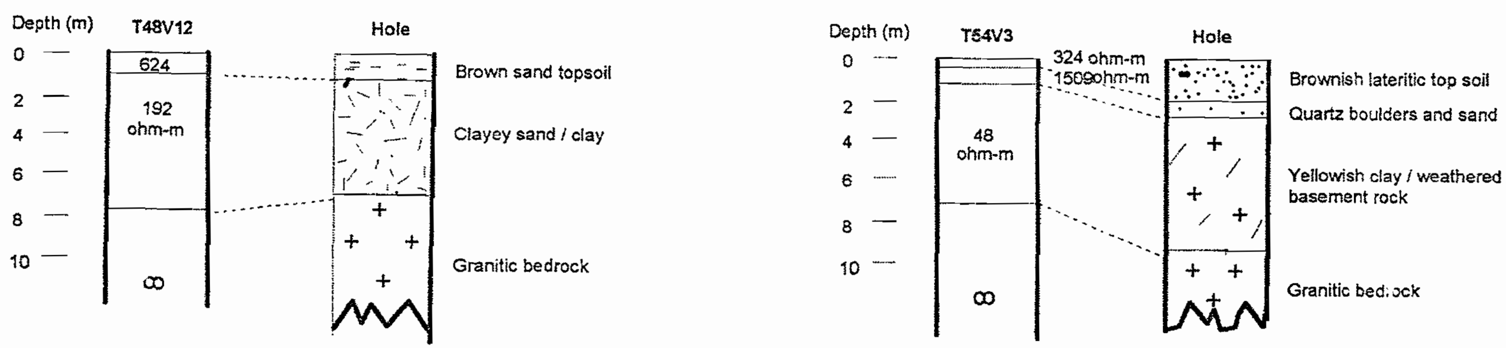


Fig. 4: Typical correlation of VES interpretation results with auger-hole data in the site.

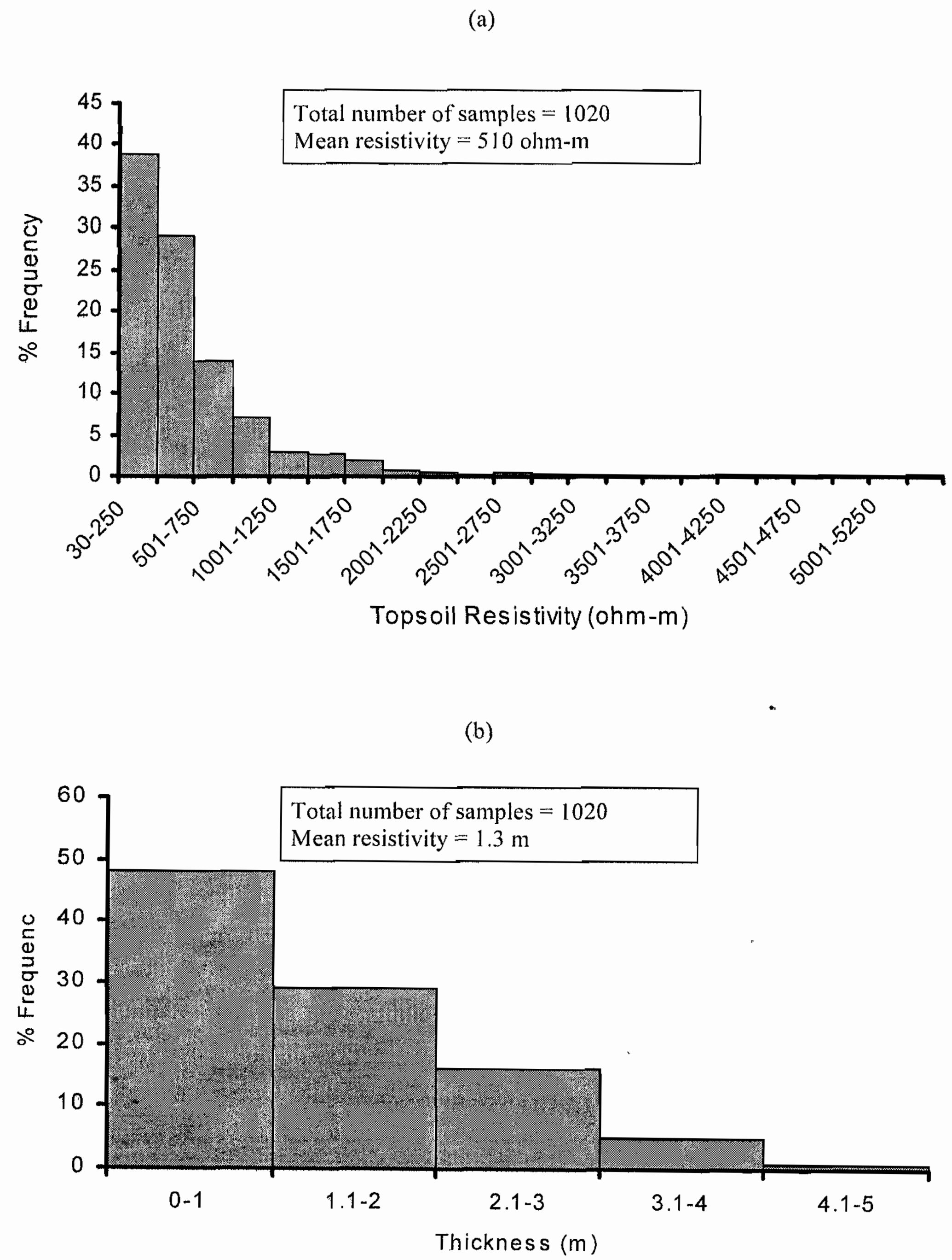


Fig. 5: Histograms of (a) top soil resistivity, and (b) top soil thickness.

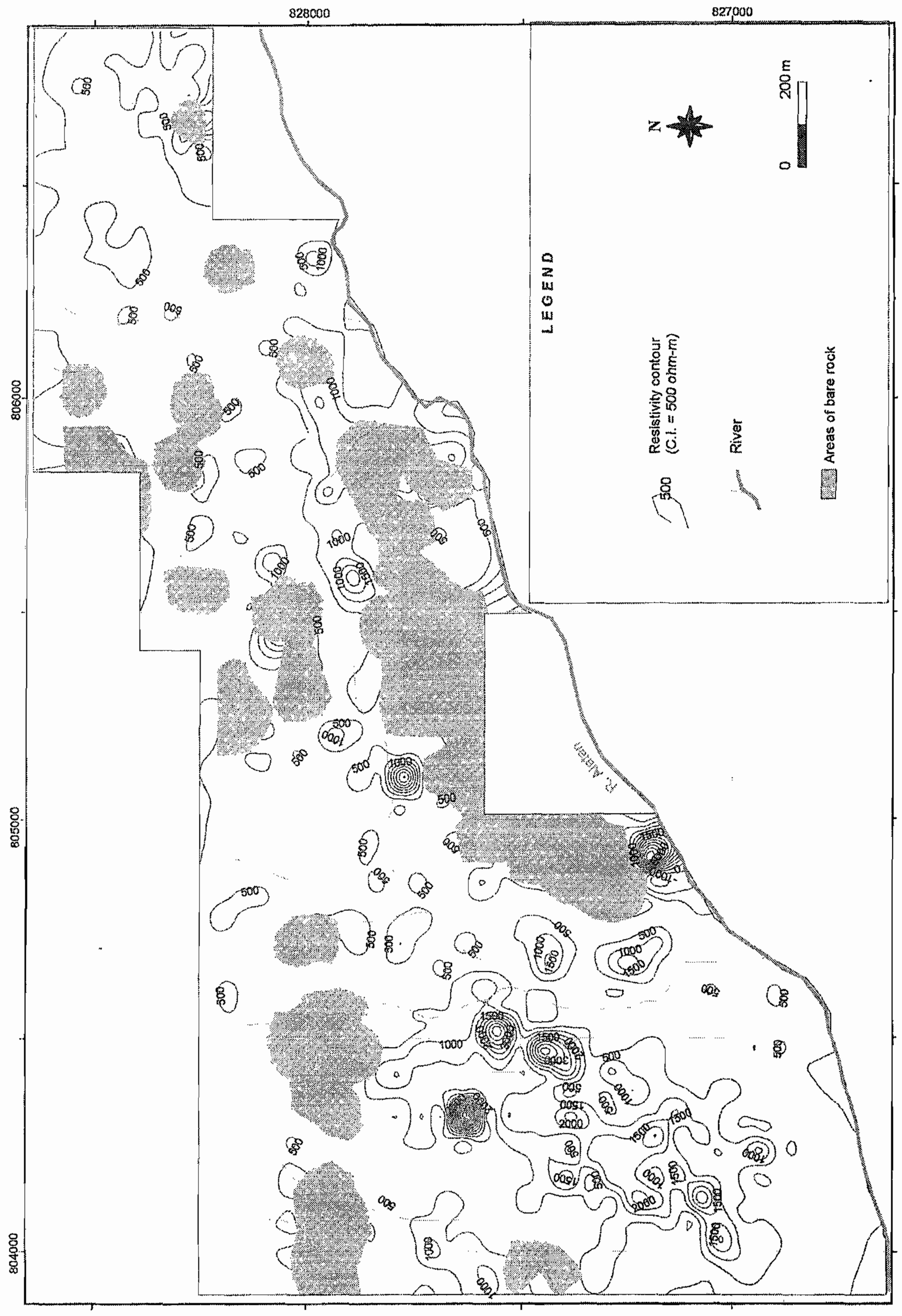


Fig. 6: Topsoil resistivity map of the site.

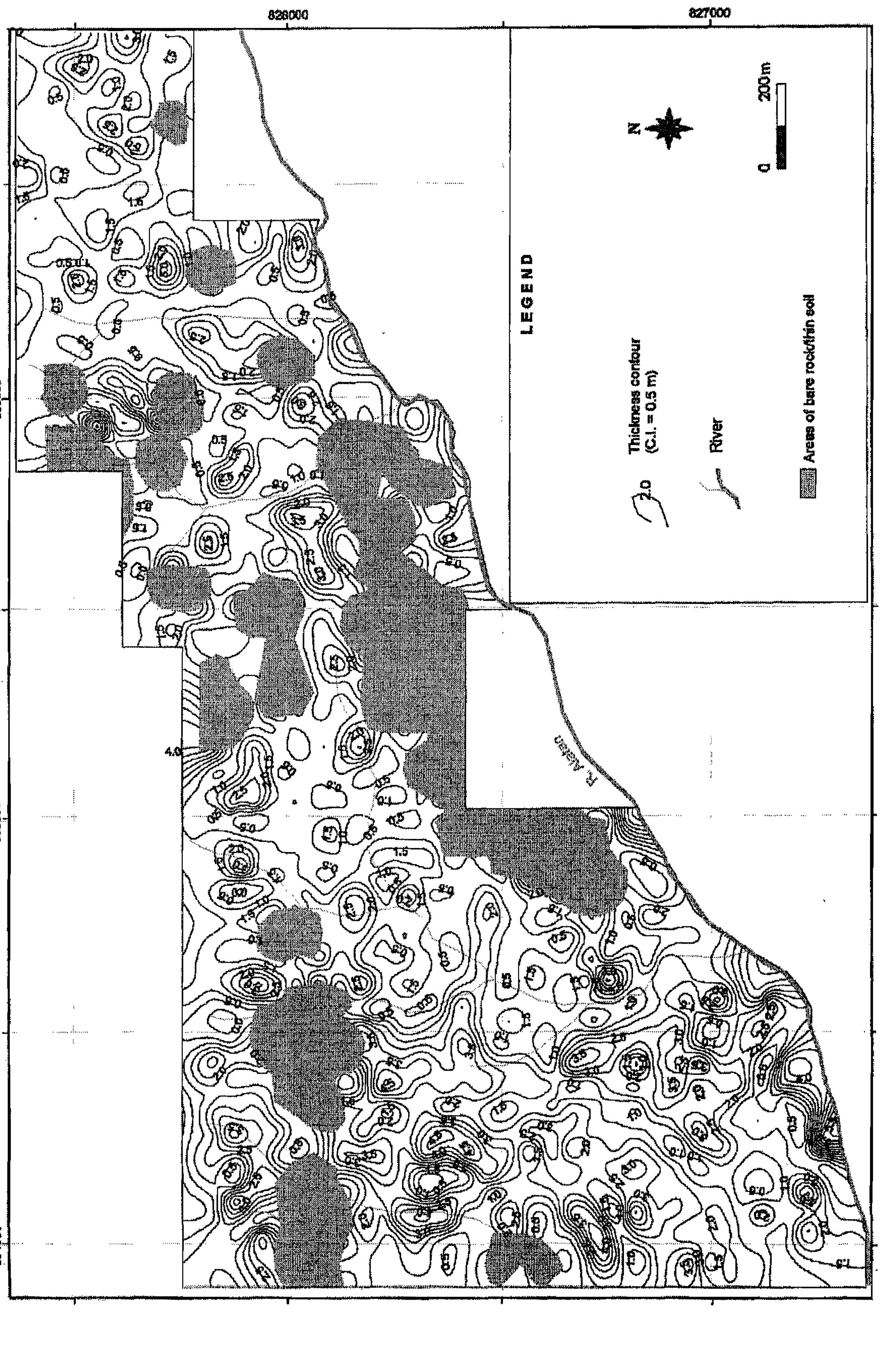
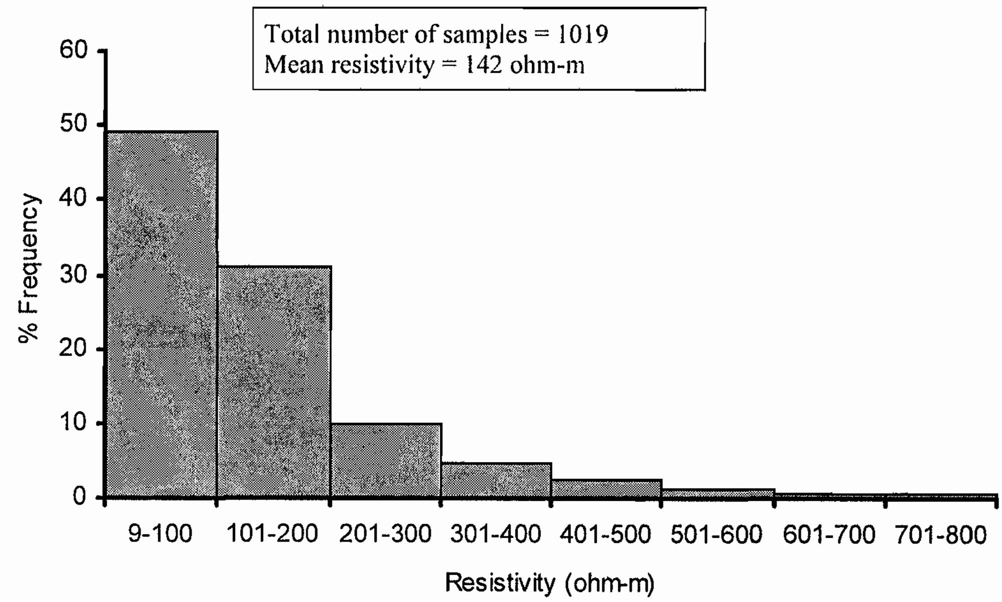


Fig. 7: Topsoil thickness map of the site.

(a)



(b)

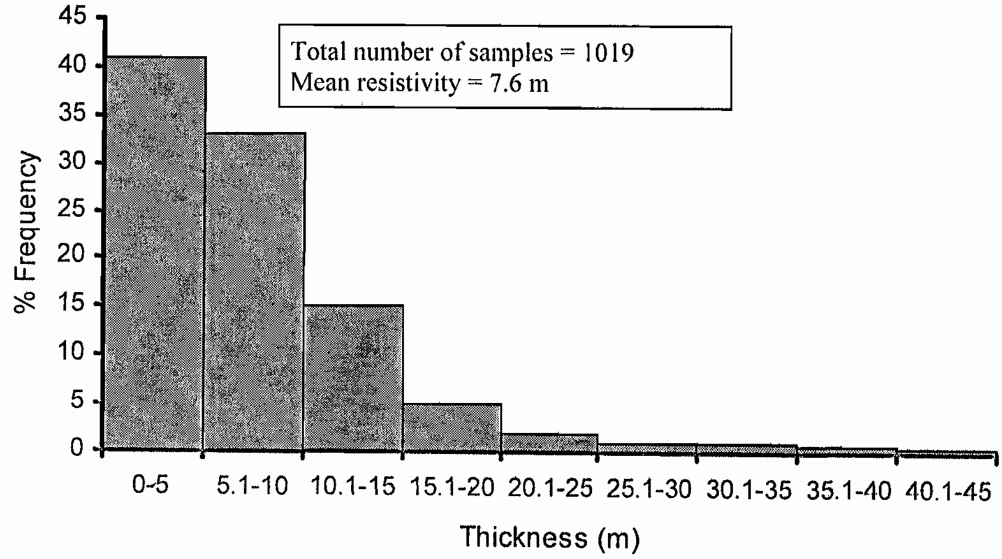


Fig. 8: Histograms of (a) weathered layer resistivity, and (b) weathered layer thickness.

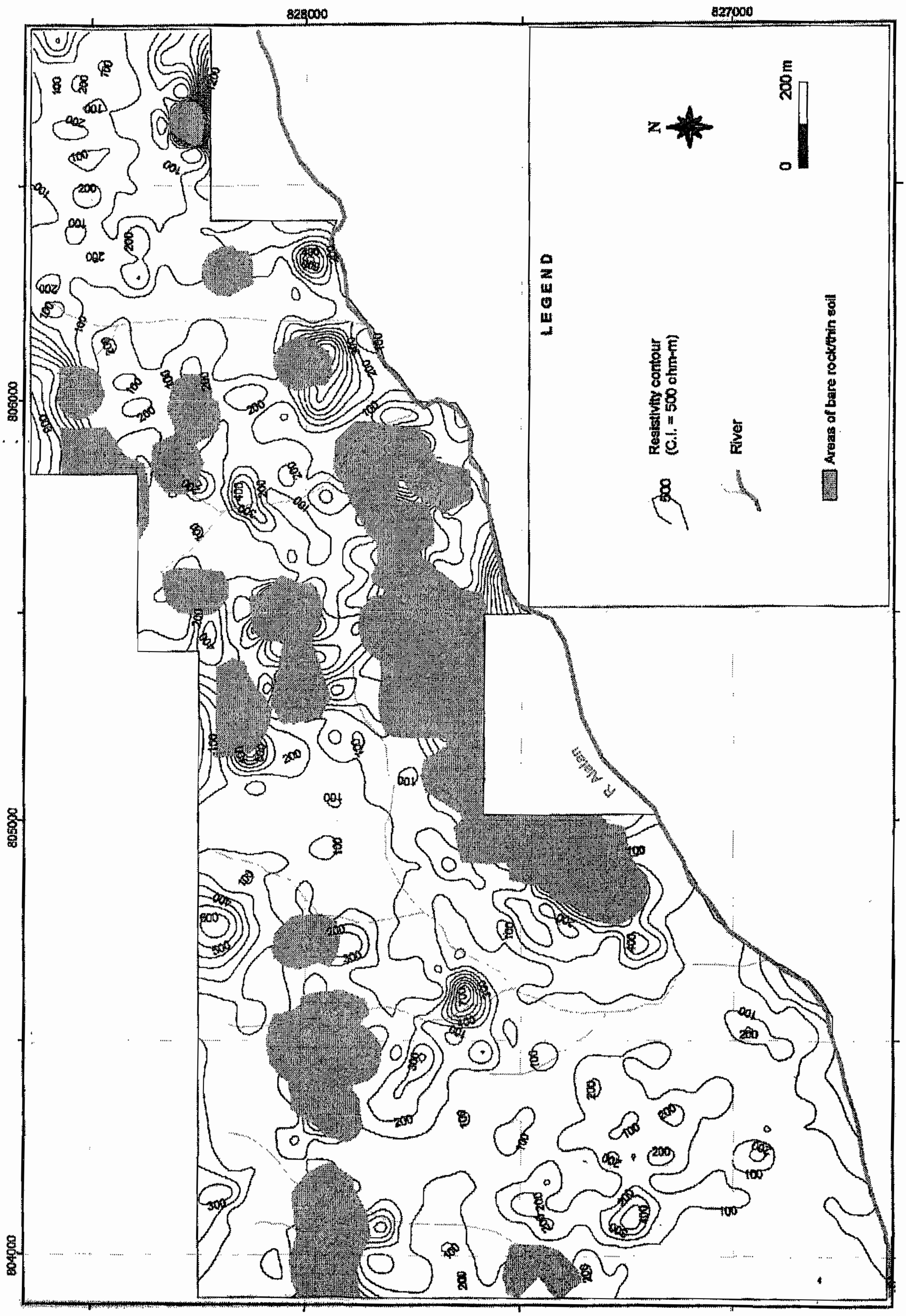


Fig. 9: Weathered layer resistivity map of the site.

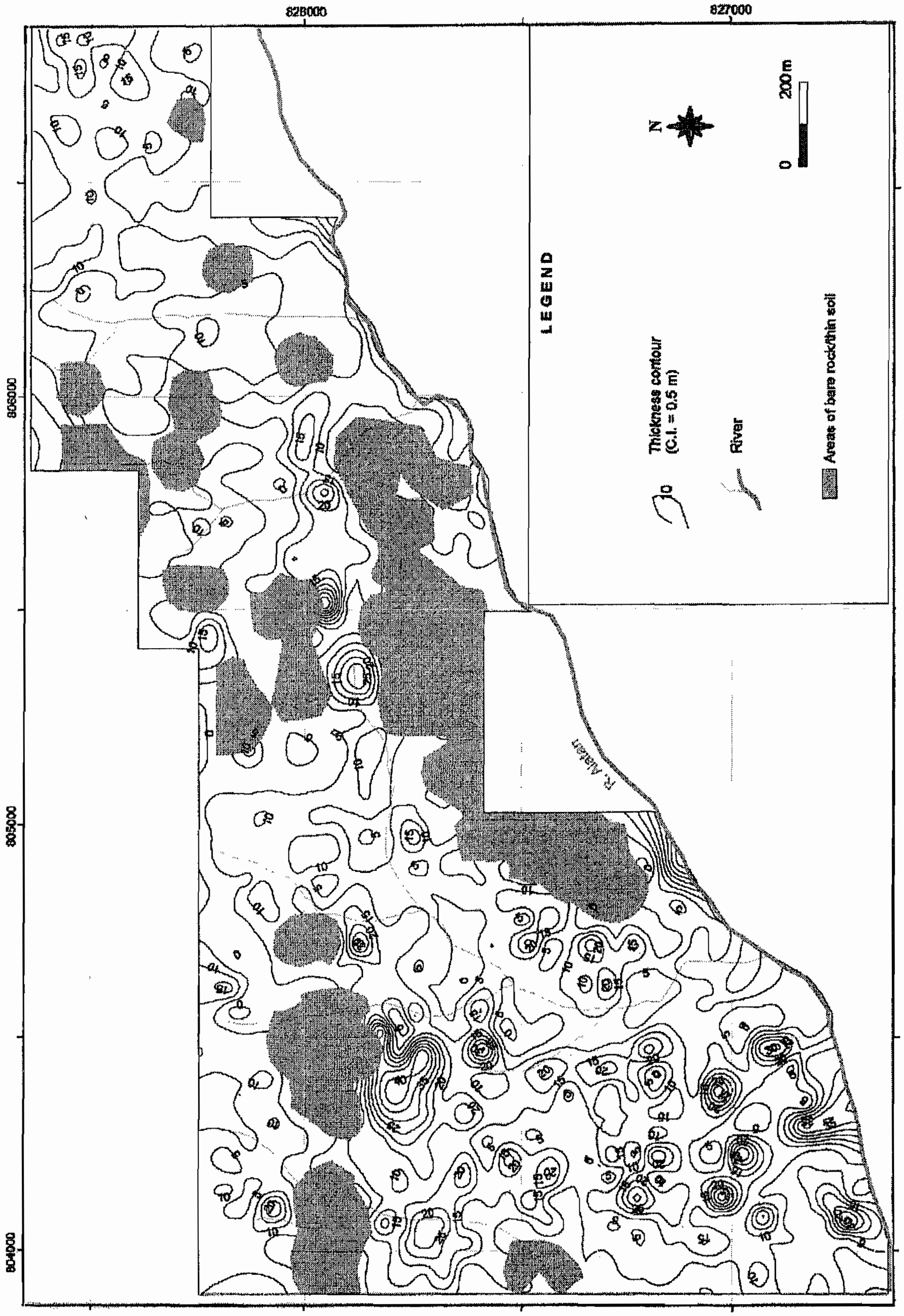
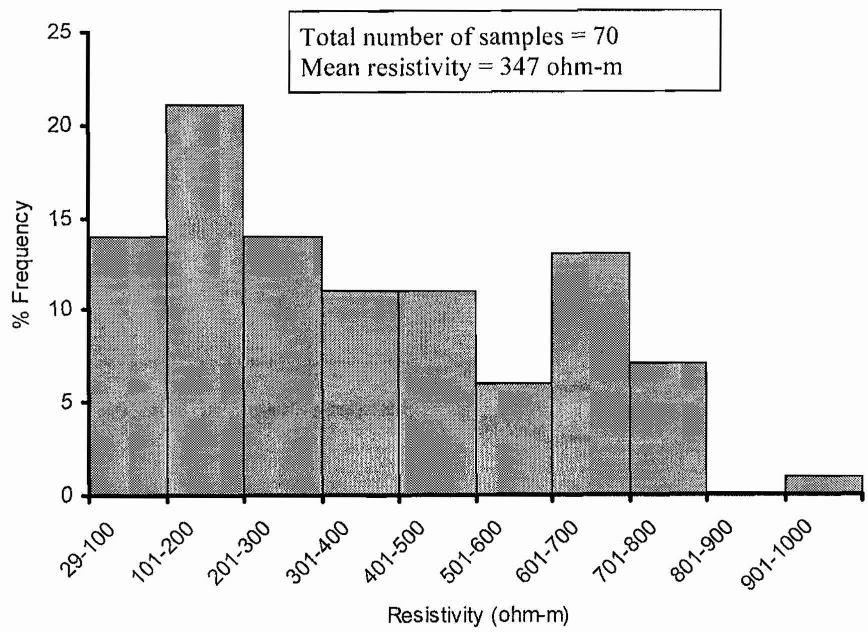


Fig. 10: Weathered layer thickness map of the site.

(a)



(b)

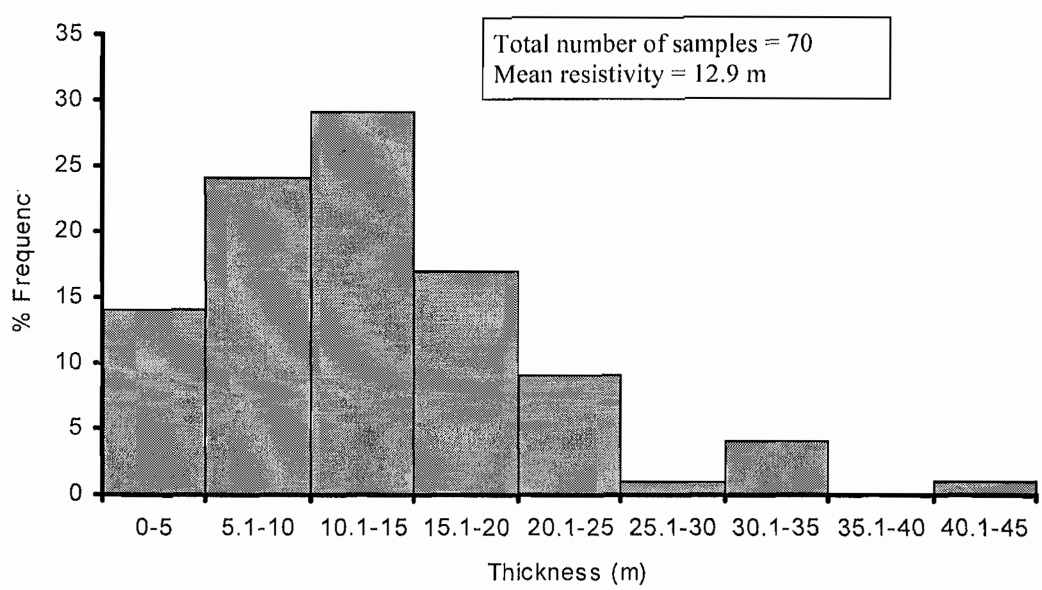


Fig. 11: Histograms of (a) fractured basement resistivity, and (b) fractured basement thickness.

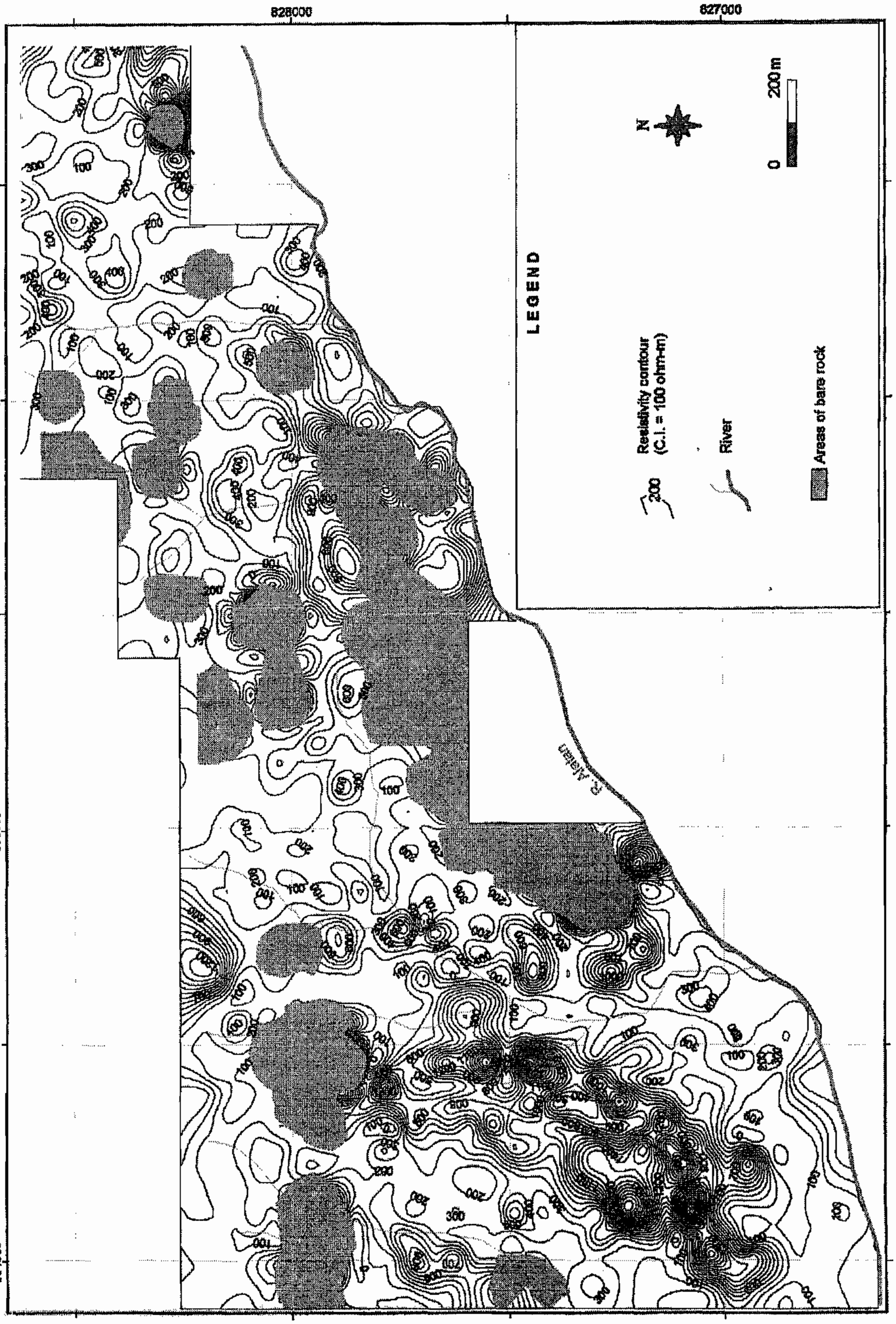


Fig. 12: Apparent resistivity distribution map at depth level of 0.5 m in the site.

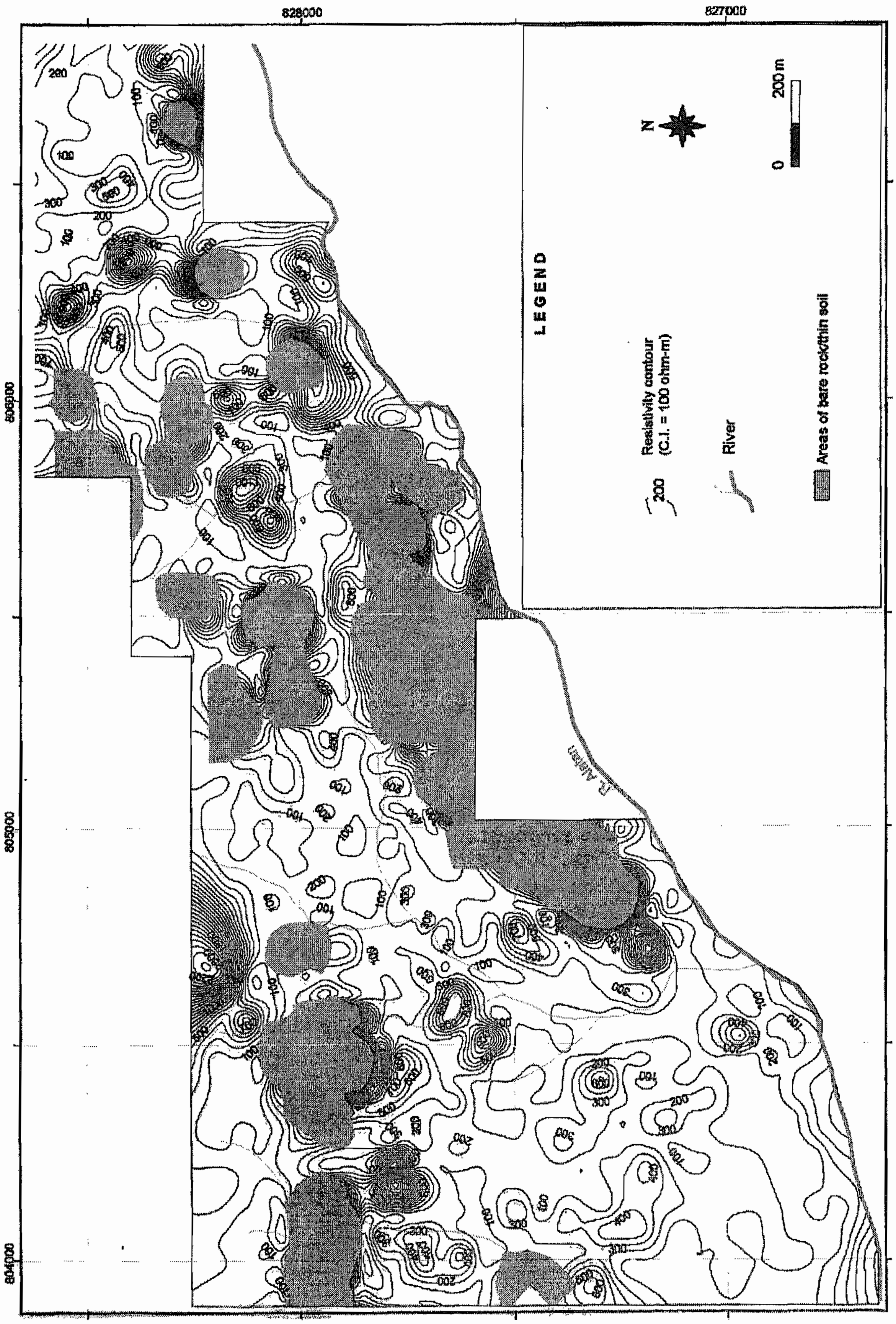


Fig. 13: Apparent resistivity distribution map at depth level of 3 m in the site.

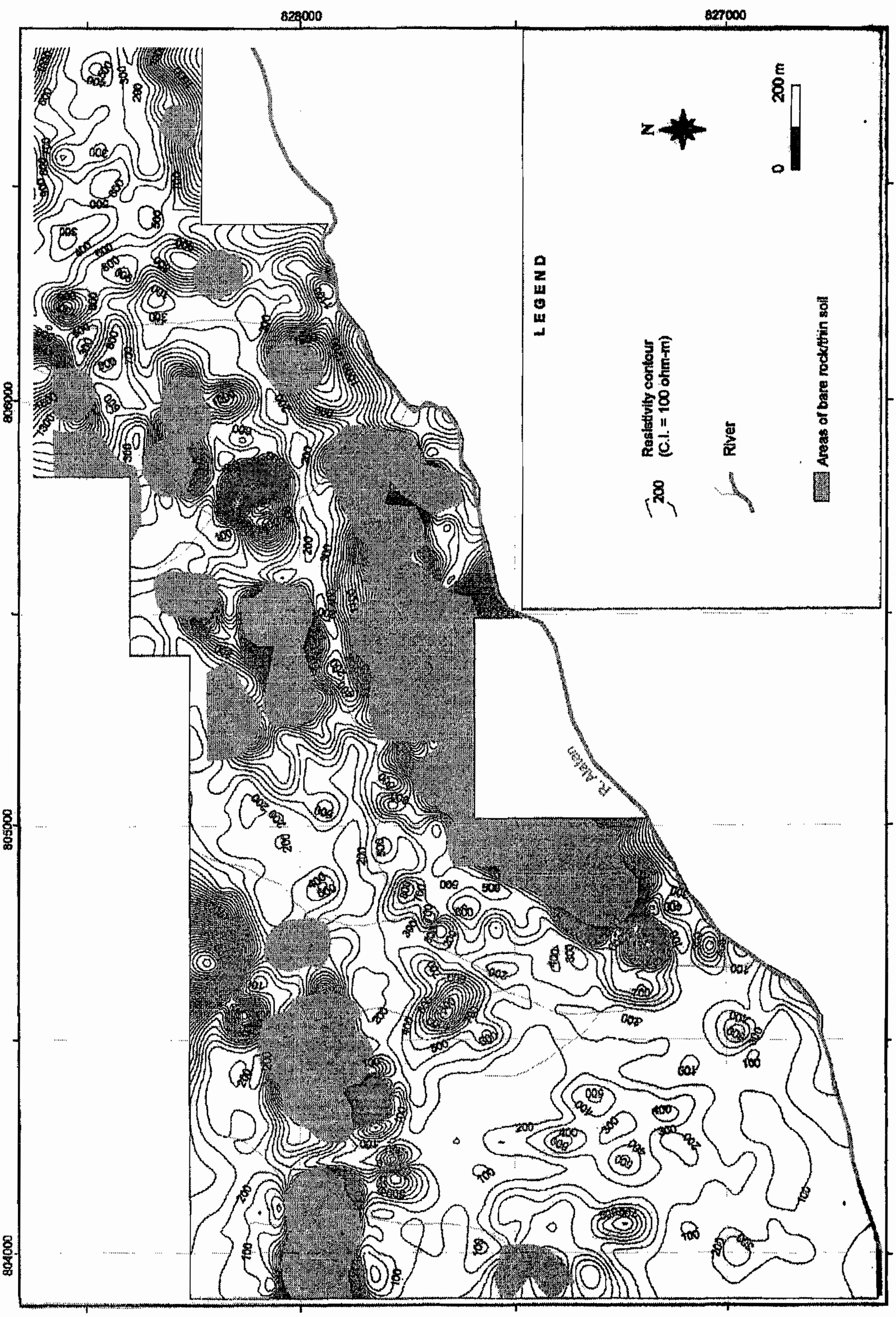


Fig. 14: Apparent resistivity distribution map at depth level of 8 m in the site.