

## Resistivity Imaging of Shallow Sediments within University of Maiduguri Campus, Northeast Nigeria

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**Abstract:** Electrical resistivity imaging within University of Maiduguri campus shows varying resistivity values and thicknesses for shallow sediments from one profile line to another. Sequence stratigraphy of the sediments indicates they were deposited at different times and varying conditions. Structure of the medium of deposition conditioned the lithological structures of the sediments. Basin or bowl-shapes of some resistivity structures are characteristics of some gravelly and clayey sediments. In most cases where such structures are encountered, gravels seem to host sands; while clays are located at the central parts. This situation may suggest that the sediments were deposited at the same time, where heavier ones settled to the bottom of the stratigraphy. Sometimes clayey sediments host sandy sediments; a situation that may be associated with different times of deposition. Some sediments were laid horizontally, some inclined and others nosed into overlying ones. Majority of the resistivity images indicate clayey sediments occupying the basal resistivity units. Lower resistivity values associated with some clayey sediment suggest high degree of saturation. The water might have been derived through infiltration of the overlying porous sediments. The clays may be followed upwardly by sands, while gravels sometimes form the capping sediments. Few resistivity profiles host the three sediments at the bottom of the resistivity structures. Stratigraphic thicknesses for the sediments vary both laterally and vertically. These are associated with the structure of the medium and prevailing conditions at the time of deposition.

**Keywords:** Dipole-dipole, profile, sediments, resistivity, imaging, structures

### I. Introduction

The area is situated in Maiduguri metropolitan area in North Eastern Nigeria between latitudes  $11^{\circ}48'$  -  $11^{\circ}55'$  N and longitudes  $13^{\circ}04'$  E -  $13^{\circ}14'$  E (Fig. 1).

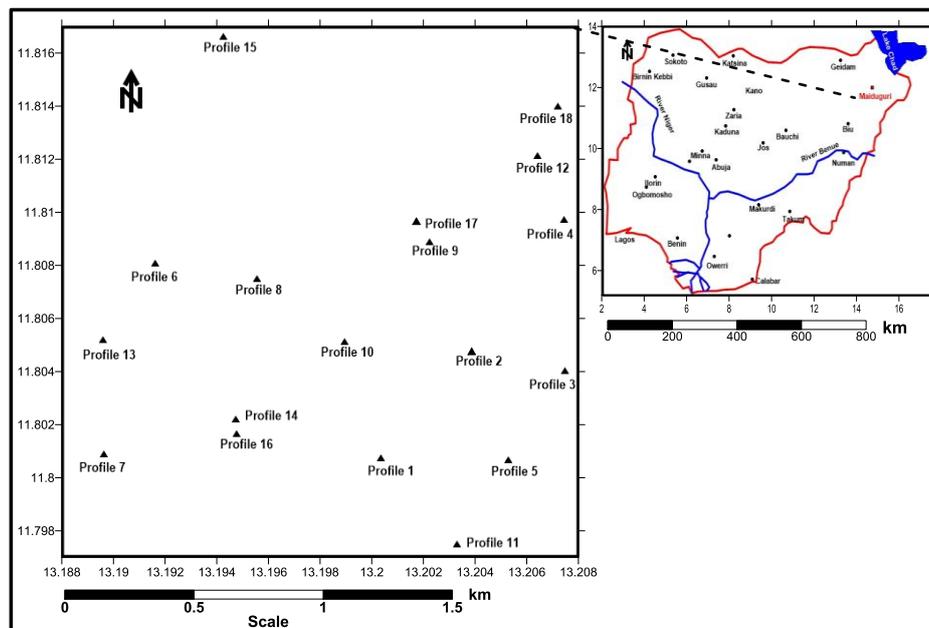


Fig. 1 Location of resistivity profiles

Maiduguri area lies on a semi arid zone of long dry season from October to April and short rainy season that lasts from May to September. Rainfall is generally low, averaging 405 mm. The temperature ranges from  $24^{\circ}$  -  $40^{\circ}$  C and more during the months of April - June. Dry dusty harmattan blows off the desert during

the months of December - February. Evaporation is about 1600 mm. Maximum precipitation is from 650 - 700 mm. Effective precipitation is appreciably preceded by high rate of evaporation.

The University of Maiduguri Campus is situated on the Chad Basin sediments. The campus area is relatively flat, but slopes gently away from the Bama Ridge area in the south towards the north. The soil consists of clays, sands and gravels. Shallow subsurface sediments considered in the survey comprise the superficial sediments and drift deposited by the activities of surface water runoff and winds. These sediments post-date the well known stratigraphy of the Chad Formation which is of plio-pleistocene age. Recent sand dunes accumulated in the Chad Basin and several ancient dune systems may be observed.

The present work is aimed at determining 2D resistivity structures of shallow sediments within the University of Maiduguri Campus using dipole arrangement.

## II. Geology of the study area

The area is underlain by sediments of the Chad Formation (Fig. 2). The Chad Formation overlies the Kerri Kerri Formation of Tertiary period and it is in turn overlain by recent alluvial deposits (Barber, 1965). These sediments were deposited during the end of the Cretaceous period and the beginning of the Tertiary period. The formation covers an area of about 23,000 km<sup>2</sup> in parts of Bauchi, Borno, Jigawa, Kano and Yobe States in Nigeria. The sediments are poorly sorted and vary in grain size and colour; finer grains exhibit fluvial depositional patterns.

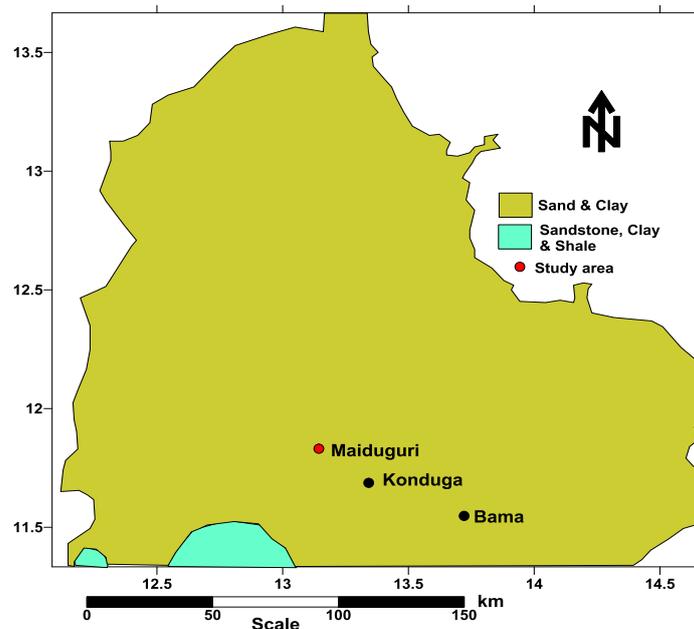


Fig. 2 Geological map of part of Borno State showing the study area

Deposition of the Chad Formation commenced after the regression of the sea southwards at the end of Cretaceous time (Barber and Jones, 1960). Boreholes' drilling in Maiduguri has revealed three distinct zones of sandy sediments separated by clay deposits. The sediments show both lateral and vertical heterogeneities.

## III. Materials and methods

The survey was designed to image/map subsurface sediments from only a few metres in depth. ABEM Terrameter was used to acquire the data. The survey was conducted in the month of July when the rainy season has fully set in, which minimized the fatigue of wetting the electrodes. Eighteen profile lines spanning from 100 - 110 m, and covering almost the entire University Campus area were established. The lines were coordinated with Global Positioning System at the beginning of the traverses.

The spacing between the current electrodes pair, C2-C1 given as "a" was the same as the distance between the potential electrodes pair P1-P2 (Fig. 3). The factor marked as "n" is the ratio of the distance between the C1 and P1 electrodes to the C2-C1 (or P1-P2) dipole length "a". For this array, the "a" spacing was initially kept fixed at the smallest unit electrode spacing and the "n" factor was increased from 1 to 2 to 3 until up to about 6 in order to increase the depth of investigation (Loke, 2000).

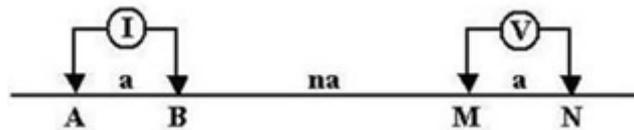


Fig. 3 Arrangement of the electrodes

To plot the data from a 2D imaging survey, the data was inverted using the pseudosection contouring method in a DIPPRO software environment. In this case, the horizontal location of the point was placed at the mid-point of the set of electrodes used to make the measurement. Vertical location of the plotting point was placed at a distance that was proportional to the separation between the electrodes. Results of inverted model resistivity distribution of pseudosection for Profile 2 is shown in Fig. 4

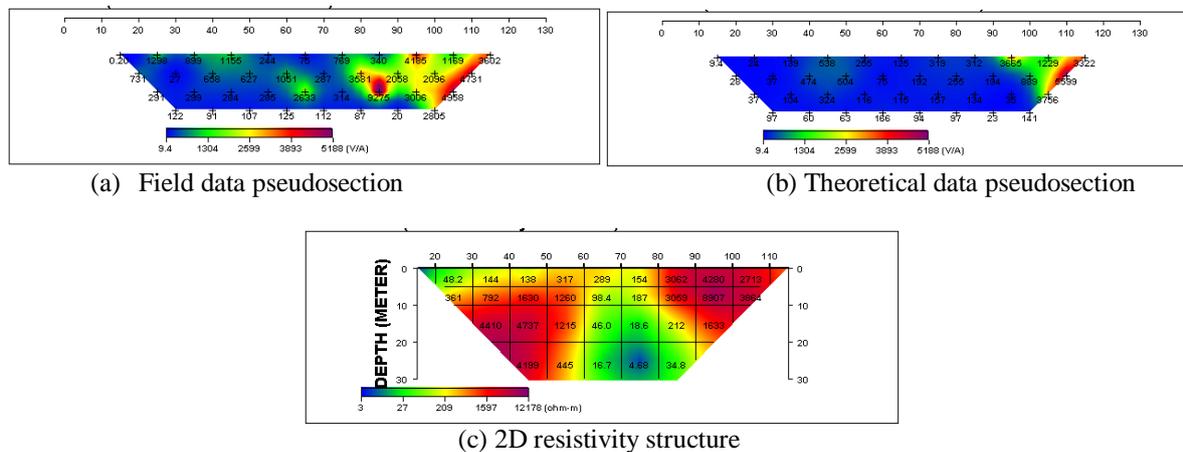


Fig. 4: Field data pseudosection, theoretical data pseudosection and 2D resistivity structure for Profile 2

#### IV. Electrical resistivity tomography

Resistivity surveys measure variations in the electrical resistivity of the ground, by applying small electric currents across arrays of ground electrodes. The measured resistivity is a bulk physical property of materials that describes how difficult it is to pass an electrical current through the material.

During the resistivity survey, current was injected into the earth through current electrodes and the potential difference, or “apparent resistivity” was measured between potential electrodes. Apparent resistivity is the bulk average resistivity of all soils and rock influencing the flow of current (Powers et al, 1999). It is calculated by dividing the measured potential difference with the input current, and multiplying by a geometric factor related to the array used and electrode spacing.

Resistivity imaging or electrical tomography technique combines resistivity sounding and profiling, incorporates the effects of lateral variations in resistivity on sounding, and produces a two-dimensional subsurface resistivity image.

All geophysical inversion methods try to determine a model for the subsurface whose response agrees with the measured data subject to certain restrictions. The model parameters are the resistivity values, while the data is the measured apparent resistivity values. The mathematical link between the model parameters and the model response for the 2D resistivity models is provided by the finite-difference (Dey and Morrison, 1979) or finite-element methods (Silvester and Ferrari, 1996). In all optimization methods, an initial model is modified in an iterative manner so that the difference between the model response and the observed data values agree reasonably well.

Unconsolidated sediments generally have lower resistivity values than sedimentary rocks. Clay materials, metallic oxides, and sulphide minerals are common sedimentary materials that carry significant electrical current through them. As such, the resistivity of most near surface sedimentary materials is primarily controlled by the quantity and chemistry of the pore fluids within the material (Kumar, 2012). Any particular material can have a broad range of resistivity responses that is dependent on the level of saturation, the concentration of ions, the presence of organic fluids, faulting, jointing, weathering, etc (Loke, 2004).

Eighteen traverses of lengths between 100 and 110 m were used for the purpose of the research. Resistivity structures along the profiles are presented, described and discussed.

Resistivity image of Fig. 5 consists of clay sediments at its base from position 60 – 90 m of the profile distance. The clay deposit occurs in crescent form where its upper boundary terminates at a depth of 5 m around profile position of 70 – 80 m. Some clay sediments of a similar shape are also observed between 20 – 40 m at a

depth of 5 m. The basal interval of 40 – 60 m that separates the clays contains sands which may be traced upwards to 20 m below the surface. The sands are overlain by gravels at this depth to the surface. Thickness for the gravel deposits is around 20 m. Surface deposits of the profile length consists basically of gravels; except along positions 20 – 30 m and 60 – 70 m where 5 m thick of sandy sediments occur.

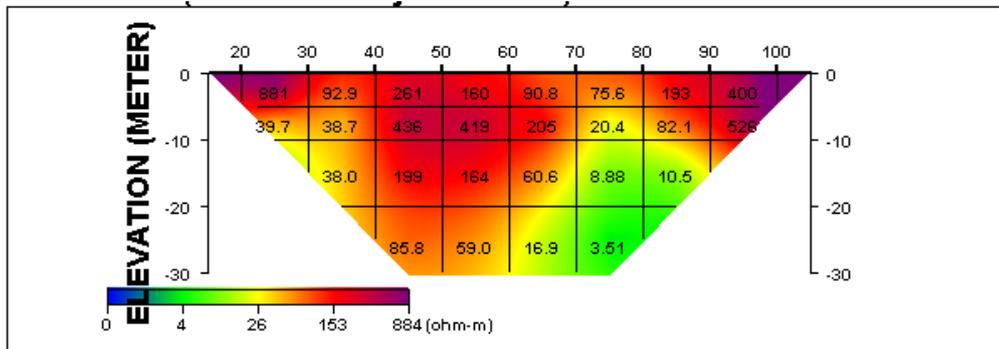


Fig. 5 Resistivity Structure of Profile 1

Fig. 6 shows clay sediments at the bottom of the resistivity structure around profile position of 60 - 80 m. The clays terminate at 10 m below the surface. Sandy sediments are disseminated around 0 - 30 m on the surface and around 60 – 70 m at 5 m below the surface. Each sandy unit has an estimated thickness of 5 m. The main composition of the resistivity structure consists of unconsolidated and consolidated gravels of relatively higher resistivity values. The gravels that are separated at depth by clays and sands are linked on the surface.

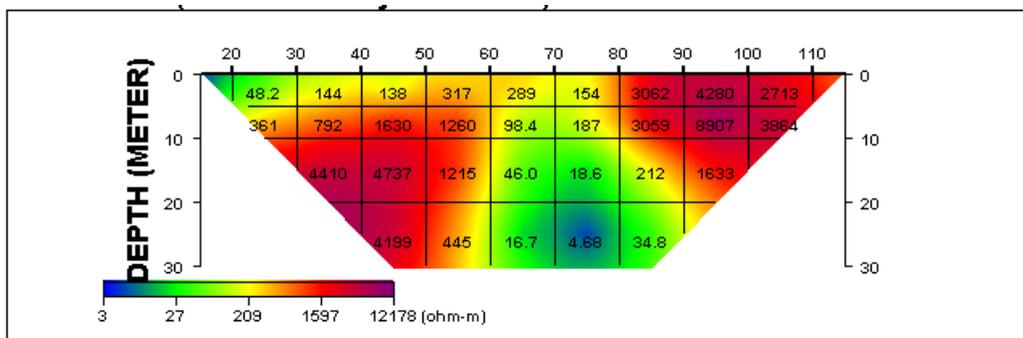


Fig. 6 Resistivity Structure of Profile 2

The basal unit of Fig. 7 is partitioned into sands (0 - 50 m), gravels (50 – 80 m), clays (80 – 90 m) and sands (90 – 110 m) of the profile length. The upper boundaries of the sands and clays terminate at depths of 10 m and 5 m respectively. Surface expression of the profile consists almost entirely of gravels, except along the lateral distance of 100 – 110 m, where a deposit of sand is observed.

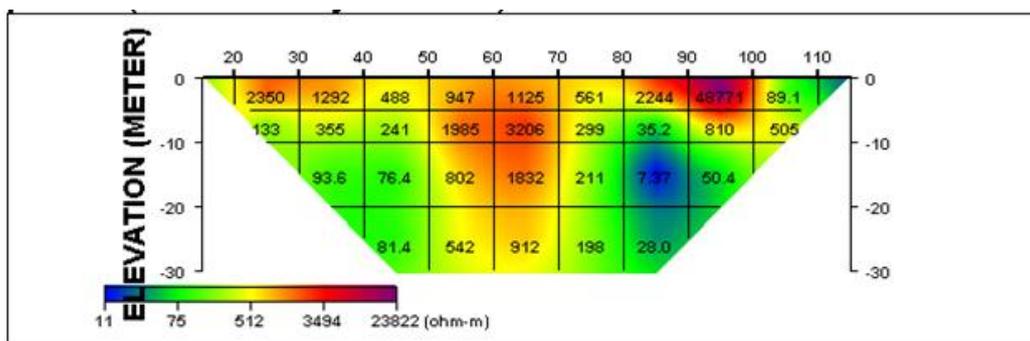


Fig. 7 Resistivity Structure of Profile 3

Along lateral distance of 60 – 90 m in Fig. 8, the basal unit is composed of a clay lens whose upper part is observed at a depth of 10 m along lateral distance of 70 – 90 m. Also at the base of the geoelectric section are deposits of gravels and sands. The lateral distance from 0 – 50 m contains gravels which extend through the

profile thickness to the surface. The lateral distance from 50 – 60 m has sands whose upper boundary can be reached at a depth of 20 m. The top of a sandy deposit is also observed at a depth of 10 m along profile distance of 80 – 90 m. Gravels form the surface cover of the subsurface materials.

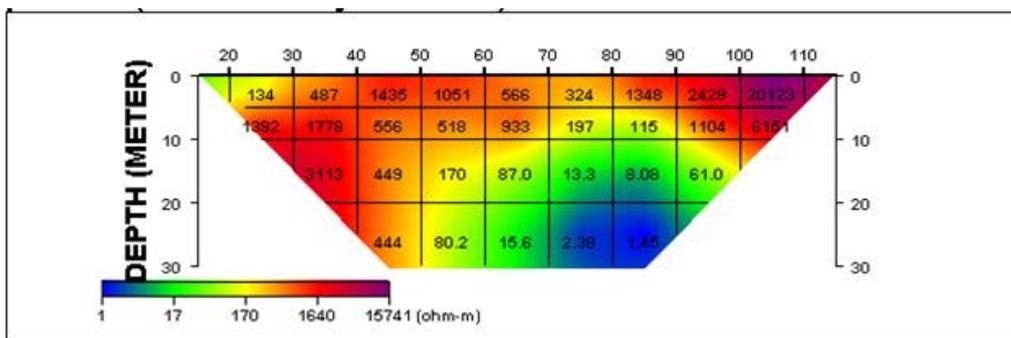


Fig. 8 Resistivity Structure of Profile 4

In Fig. 9 the basal topography is constituted essentially of clayey sediments that extended to a depth of 5 m around 70 – 80 m profile distance. The general thickness for the clay deposit is 20 m. The clays are followed upwardly by sandy sediments whose lower boundary is observed at 10 m below the surface. Surface expression of the sands is seen around 50 - 90 m distance of the profile. The sands measure about 5 m thick. A greater proportion of gravelly materials occur on the surface. These are observed around lateral positions of 0 - 50 m and 80 – 110 m. Thickness of the gravels may exceed 10 m as indicated along the interval of 100 – 110 m.

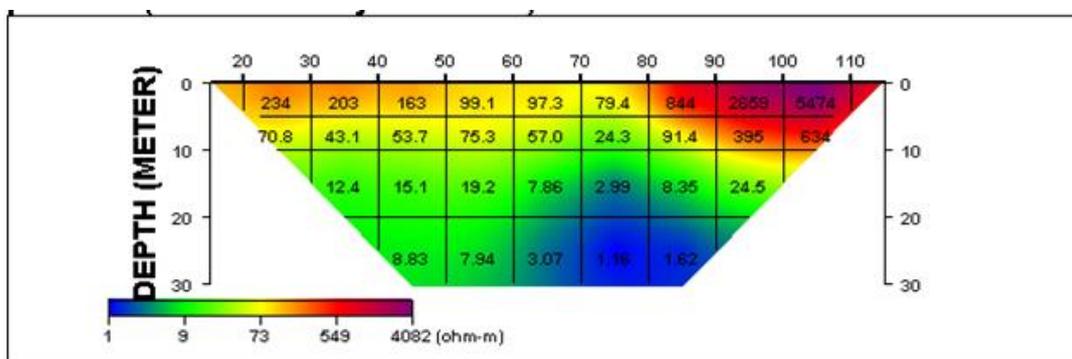


Fig. 9 Resistivity Structure of Profile 5

Along Fig. 10 clayey sediments form the basal stratigraphy of the profile. The upper part of the clays can be reached at 5 m below ground level. Sandy sediments rest upon clayey sediments around lateral distances of 20 – 30 m and 50 – 70 m. Gravelly sediments are observed around 0 – 50 m and 70 – 110 m where their surface expressions are interrupted by a sandy deposit. The 70 – 110 m section of the profile probably served as a basin where about 10 m thick of gravelly materials were deposited.

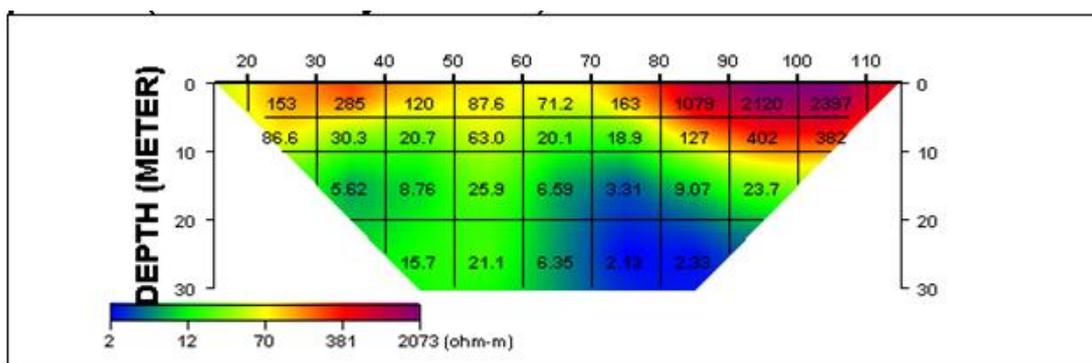


Fig. 10 Resistivity Structure of Profile 6

Clayey sediments dominate the profile length of Fig. 11. They occupy the basal unit and extend to the surface around 40 – 80 m. Most of the clays are saturated with water as indicated by their low resistivity values.

Sandy sediments are exposed on the surface and are limited to 0 – 40 m of the profile distance. They attain maximum thickness of 10 m. Surface position from 90 – 110 m of the profile is constituted by gravelly sediments of about 10 m thick.

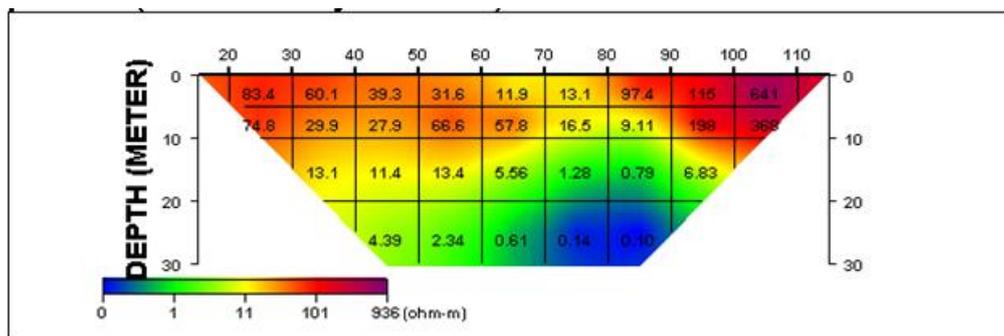


Fig. 11 Resistivity Structure of Profile 7

The bottom of the resistivity structure of Fig. 12 consists of clayey and sandy sediments. The upper part of the clays appears at 5 m below the surface around 70 – 80 m distance. A bowl shape medium consisting of clayey deposits occurs on the surface to a depth of 20 m around 20 – 50 m separation. Sandy sediments are the main host of the clays. Apart from the 50 – 60 m distance at a depth of 10 m where gravels are observed, the major proportion of gravelly sediments are confined to the 90 – 110 end of the profile where they are exposed on the surface. The gravels have vertical thickness of 10 m.

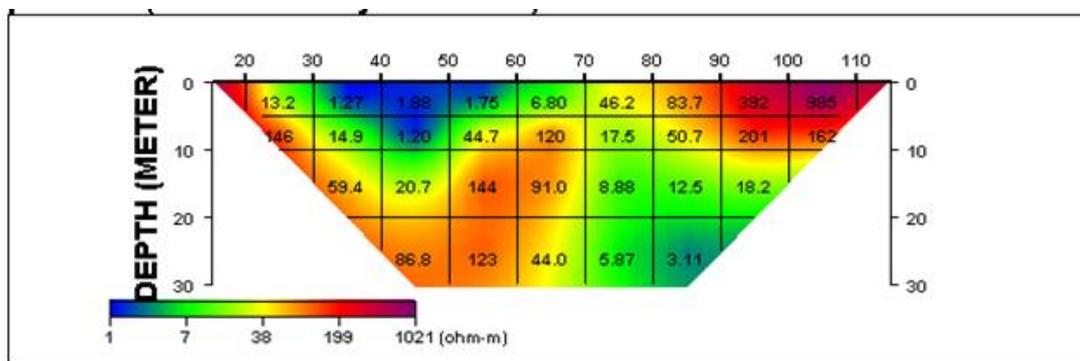


Fig. 12 Resistivity Structure of Profile 8

The profile of Fig. 13 portrays an image of a basin, where gravelly sediments occupy the bottom (not completely revealed) of the basin. The gravels outcropped on the surface at the edges of the basin. Sandy sediments are laid on the gravels and clayey sediments occupy the central part of the basin. Both sandy and clayey deposits outcropped on the surface. Wider electrode separation may give a clearer picture of the structure of the basin.

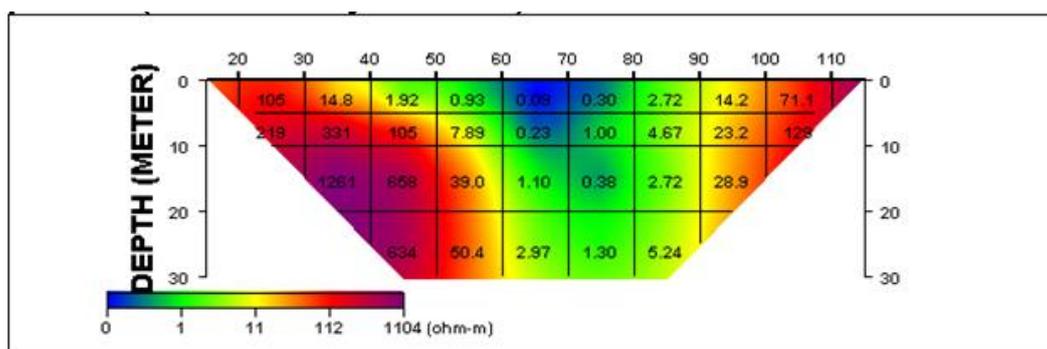


Fig. 13 Resistivity Structure of Profile 9

Clayey sediments are the main constituents at the base of the electrical resistivity image of Fig. 14. The upper surface of the clays approaches the surface at depths of 5 m around 40 - 60 m and 70 – 80 m of the profile

distances. Sandy sediments assumed the wavy structure developed by the upper margin of the clays. The sandy materials outcropped on the surface around 0 – 50 m and 70 – 80 m. At some locations the sands attained thickness of 20 m. Gravelly sediments occur on the surface along lateral distances of 50 – 70 m and 80 – 110. Estimated thickness of about 10 m of the deposit occurs around 100 - 110 m distance of the profile.

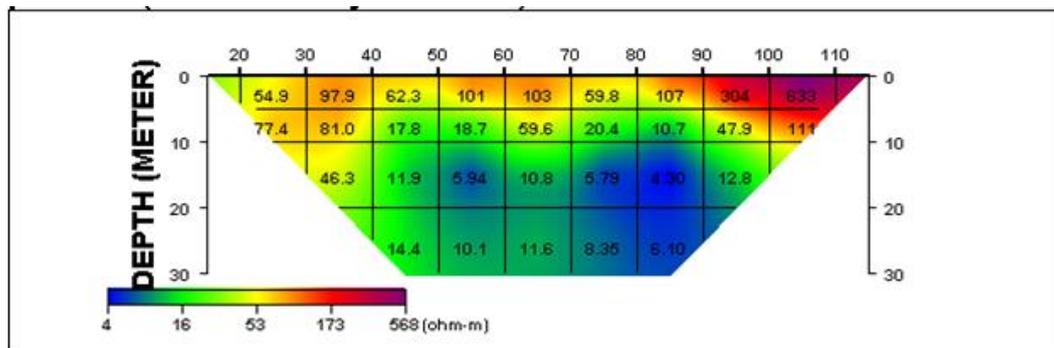


Fig. 14 Resistivity Structure of Profile 10

Resistivity tomography of Fig. 15 indicates the resistivity basement to consisting of sand, gravel and clayey sediments. Basal sandy sediments are located at lateral intervals of 40 – 50 m and 70 – 80 m. Their upper margins occur at depths of 20 m. Gravelly materials occur from 50 – 70 m and are inclined upwardly to the surface around 80 – 90 m. Clayey sediments are observed around 80 – 90 m and are inclined to a depth of 10 m. Clayey sediments also occupy the electrodes’ range of 20 - 50 m at a depth of 5 – 20 m. The clays also appear on the surface along 50 – 80 m and have thickness of 5 m. Sandy sediments are exposed on the surface along 0 – 50 m and 90 – 110 m of the profile distances. Thicknesses for the sand deposits are 5 m and 10 m respectively.

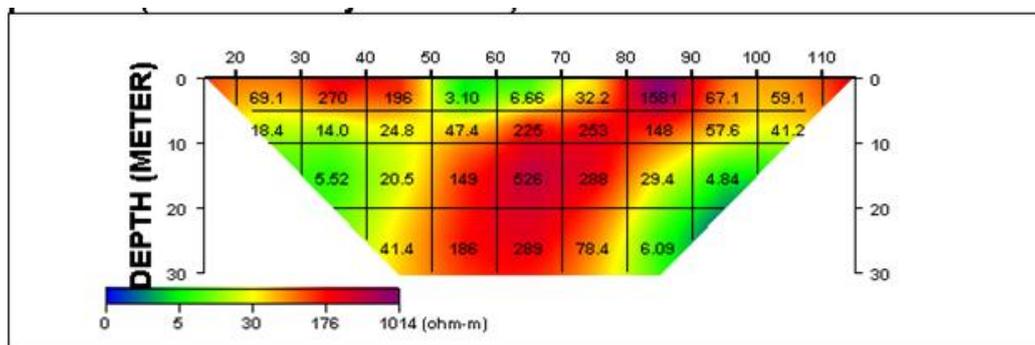


Fig. 15 Resistivity Structure of Profile 11

Electrical resistivity image of Fig. 16 shows clayey sediments occupying the base of the profile. Low resistivity values of the deposit are indications that the zone consists of saturated clays with attainable thickness of about 20 m at some locations. Sandy sediments are exposed on the surface along lateral position of 30 – 80 m. The general thickness for the sand deposits is 10 m. The sands are flanked to the start (0 – 30 m) and to the end (80 – 110 m) of the profile by gravelly sediments. The thickness of the gravel deposit may exceed 20 m.

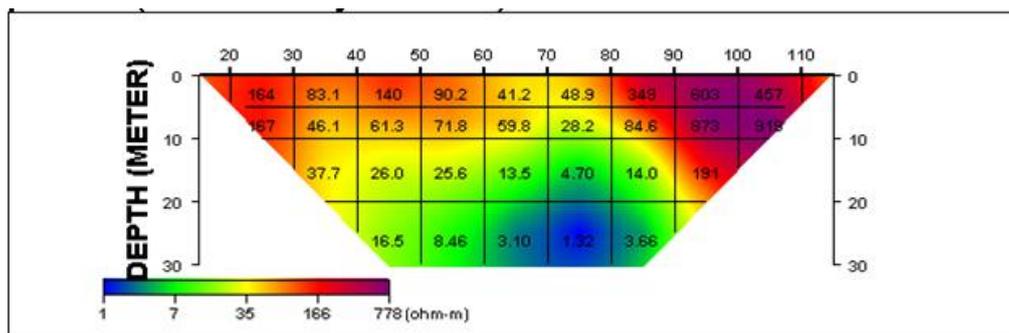


Fig. 16 Resistivity Structure of Profile 12

Clayey sediments form a substantial proportion of the base of the resistivity structure of Fig. 17. The clays extend upwards from the base to 10 m below the surface. A minor deposit of sandy sediments grades into gravels in place. The sandy deposit is located at 30 – 40 m distance at varying depths. Along lateral distance of 50 – 60 m the sands outcropped on the surface. Vertical thicknesses for the sands at the two locations are 10 m each. A significant quantity of gravels is present in the profile structure. The deposits occur at the start and end of the profile. The 80 – 110 m side of the gravels has thickness of 20 m.

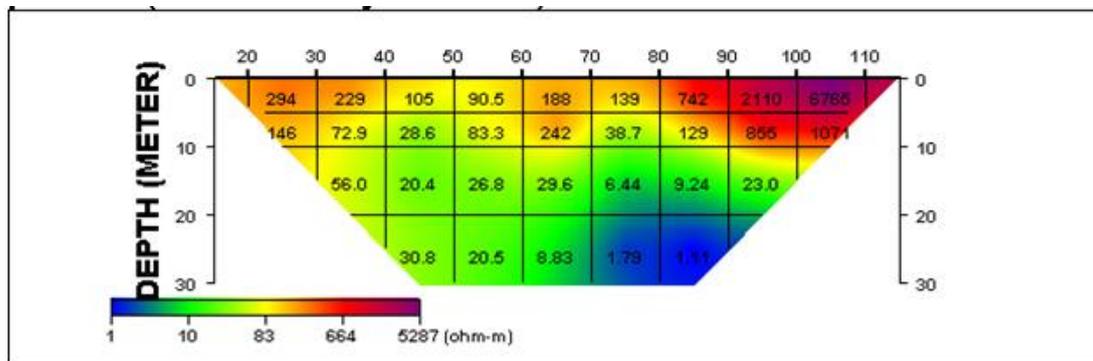


Fig. 17 Resistivity Structure of Profile 13

Clayey sediments occupy a part of the base of Fig. 18. The upper surface of the sediments can be traced to 5 m below the surface along 0 – 80 m profile length. Vertical contact of clays to the start of the profile is defined by gravelly sediments which extend to the surface from 80 – 110 m of the profile length. Thickness of the deposit may exceed 10 m. Sandy sediments are disseminated within the resistivity structure. A five metres thick of a sandy deposit occurs around 20 – 30 m distance at a depth of 5 m. Similar deposits occur along 50 – 60 m and 90 – 100 m distances. The earlier sand deposit outcropped on the surface and the later is 10 below the surface. Each sandy deposit has thickness of 10 m.

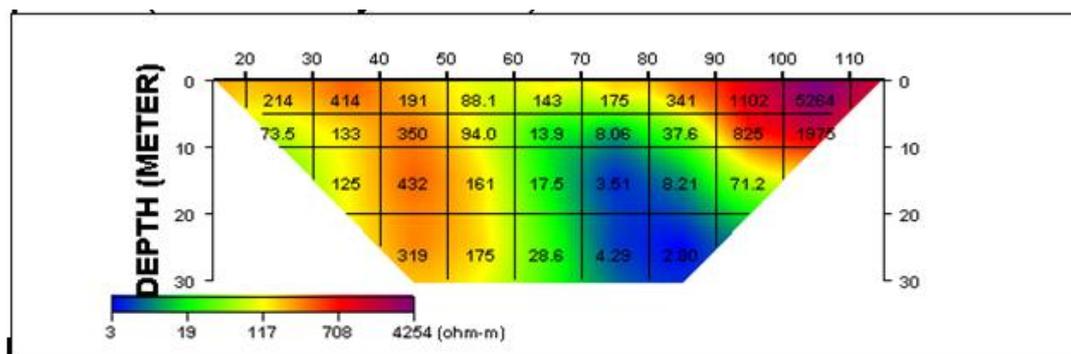


Fig. 18 Resistivity Structure of Profile 14

The basal unit of Fig. 19 is dominated by thick clayey sediments. The clays extend to the surface around lateral distance of 70 – 80 m. A basin structure consisting of relative higher resistivity values that outcropped on the surface around 20 – 60 m, represents that of clayey sand - an interface between the top clayey layer and the bottom sand horizon (Keller and Frischknecht, 1966; Ayolabi, 2013). Main thickness for the sediments is 5 m, although thickness of 10 m may be obtained along 40 – 50 m lateral distance where complete transition to sandy sediments occurs. Gravelly sediments are the chief constituents around 80 – 110 m of the profile distance. Thickness of each sediment may exceed 20 m.

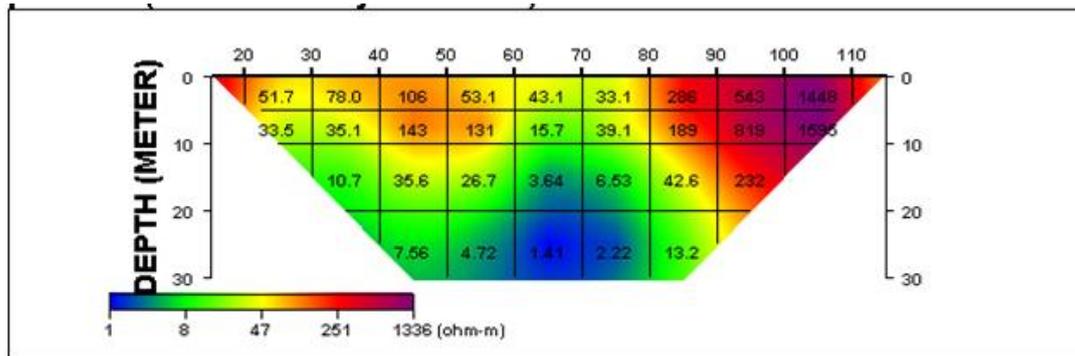


Fig. 19 Resistivity Structure of Profile 15

Fig. 20 has a crescent shaped deposit of clayey sediments at its bottom that nosed upwards to 5 m below the surface around 60 – 90 m of the profile length. Isolated pockets of sandy sediments are observed around lateral distances of 30 – 40 m, 50 - 70 m and 90 – 100 m of the profile length. While the sandy deposits at the two ends occur at 10 m below the surface, the central deposit is exposed on the surface. Gravelly sediments occur along 0 – 50 m and 70 – 110 m distances. The two deposits are exposed on the surface and vertical thickness for each deposit may exceed 10 m.

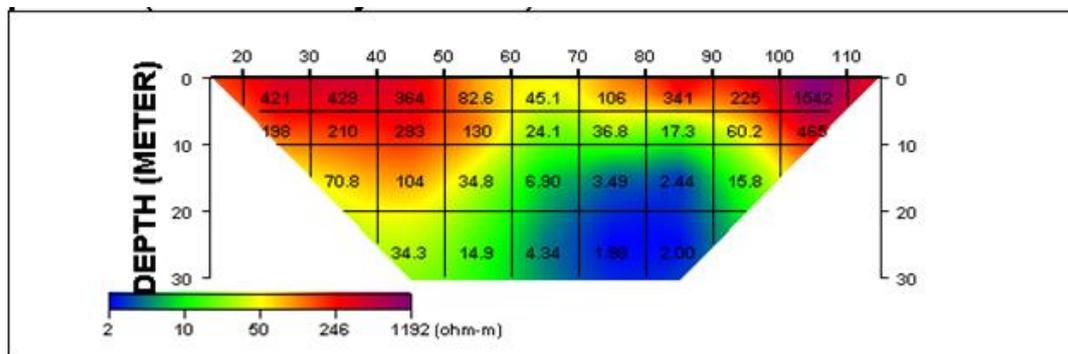


Fig. 20 Resistivity Structure of Profile 16

Fig. 21 consists basically of clayey materials at the bottom. The thickest part of the clays at lateral interval of 40 - 50 m may reach 25 m. The clayey sediments are followed upwardly by sandy sequence at a depth of 10 m around 50 – 90 m. Similar sediments with thickness of 5 m outcropped on the surface around 30 – 40 m. They are observed on the surface along the entire profile length and possess maximum thickness of 20 m along 90 – 100 m.

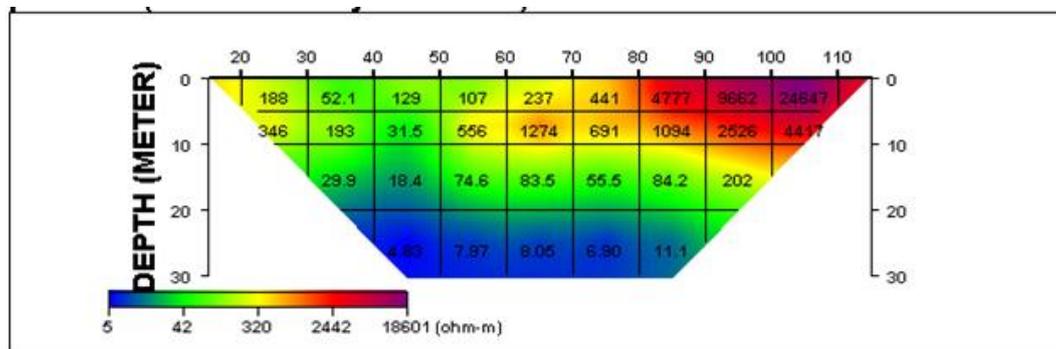


Fig. 21 Resistivity Structure of Profile 17

The entire basal unit of Fig. 22 is composed of clayey sediments that arched upwards and terminated at 5 m below the surface around 50 – 80 m lateral distance. Sandy sediments are exposed on the surface from the beginning of the profile to 80 m lateral distance. The sands show varying thicknesses from 5 – 30 m. The proportion of gravelly materials in the resistivity structure is low. The disseminated gravel pockets occur on the surface at distances of 30 – 40 m and 80 - 110 m. Observed thicknesses for the gravel deposits are 5 m each, although towards the end of the profile, it may exceed 15 m.

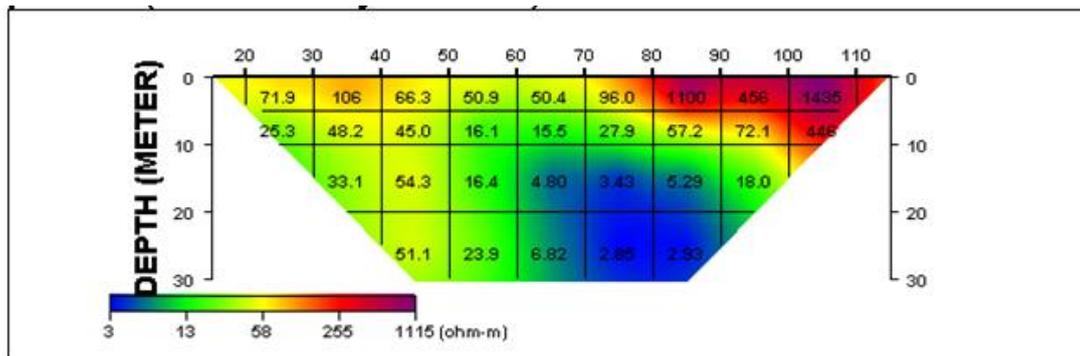


Fig. 22 Resistivity Structure of Profile 18

## V. Discussion and conclusion

The basal units of most survey lines are characterized by clay sediments deposited under low current velocity. Some of the clays at the bottom of the resistivity structures are saturated as indicated by their low resistivity values. The porous overlying sediments might have aided infiltration of rainwater into the underlying clays. Basin structures are common among some profile lines. Some basins are hosts to gravelly sediments at the bottom, which is overlain by sandy sediments and clayey sediments at the central part. The sediments of such basin types were probably deposited by the same transporting agent. Clays, sands and gravels are common sediments occurring at the base of some profile lines. Basin structures of sandy sediments harbour clayey sediments and vice-versa within their depressed regions. The crescent structure of clay sediments at the bottom of a resistivity structure arched upwards into overlying sediments. Pockets of sandy sediments are common within some profiles. Deposition of sandy sediments inherited the sinusoidal structures developed by the upper margins of the clays in some areas. Interfaces between the top sandy layer and the bottom gravelly horizon graded into gravels in places. Some resistivity structures accommodated unconsolidated and consolidated gravels. Gravelly materials form the main surface cover of most subsurface sediments. In places gravelly and clayey sediments are inclined upwardly towards the surface, which is attributed to the nature of the medium to which the sediments settled. The general composition for the sediments shows varying depositional patterns.

The erratic grading of the sediments in the area may suggest that surface water runoff and winds were probably the main transporting agents.

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