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RESISTIVITY INVESTIGATION OF SUBSURFACE STRUCTURES ALONG SARKIN PAWA-MANGORO ROAD PAVEMENT, NIGER STATE, NIGERIA

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ABSTRACT

Geophysical investigations involving the Schlumberger vertical electrical sounding (VES) and Wenner horizontal electrical profiling have been carried out along some stable and unstable sections of the Sarkin-Pawa-Mangoro road in Niger State. This is to investigate the geological factors responsible for the incessant pavement failure within the area. The vertical electrical soundings have been carried out along two traverses P_A and P_B measuring 1350 metres long respectively, one on each side of the road. 28 VES stations at a station separation of 50 metres are on each traverse. The horizontal electrical profiling was carried out with an electrode separation of 10 metres on traverse P_A over a distance of 1150 metres. The geoelectric/geologic sections along the stable segments of the road show generally resistive topsoil with resistivity values ranging from 130-600 Ωm. Beneath the unstable segments, the geoelectric sections show low resistivity clay topsoil (20-120 Ωm), water absorbing substratum, and near-surface water table. The electrical profiling indicates conductive zones beneath the unstable sections. The high and low values of the apparent resistivity data of the electrical profiling may be an indication of the natural variation in the composition of the subsurface or the presence of linear features such as fracture, buried ditch/stream channel or shear zones. The unstable sections which correspond to pavement failure can hence be delineated using geophysical investigations and thus enabling necessary remedial actions to be taken when constructing a new road.
Key words: Vertical electrical sounding, Mangoro, Geoelectric Section, Resistivity, Pavement failure, electrical profiling.

INTRODUCTION

Road pavement section can be described as structural materials placed above a sub-grade layer (Woods and Adeox, 2002). In asphaltic pavement (common on Nigerian roads), these structural materials include the sub-base, base and the surfacing. Road pavement is supposed to be a continuous stretch of asphalt laid for a smooth ride or drive, but discontinuity in the road network resulting in cracks, potholes, bulges and depressions gives rise to road failure (Aigbedion, 2007). The sub-grade soil beneath a stable highway pavement is expected to possess sufficient strength to support the structure or wheel load imposed on it. Unfortunately, due to the heterogeneous nature of the soil and the subsurface geological structures, the above condition is rarely met and hence the strength of the sub-grade decreases and eventually, the pavement on it fails. In 2006, a total of 3 billion naira was said to have been spent on the rehabilitation of federal government road network along Akwa Ibom/Calabar axis (Aigbedion, 2007) and between 2001 and 2007 the sum of 113 billion naira was spent on federal government roads in Nigeria (Kashim, 2009).

Road failure, therefore, is a problem that every Nigerian should be concerned about with a view to finding a lasting solution. In the light of our present economic situation, we need to devise measures to curtail the large amount of money spent on road repairs and reduce the daily loss of lives and property due to bad roads. Needless to say, therefore, that if these must be achieved, sufficient technological data and investigations on the causes of highway failure must be carried out. Field observations carried out by Adegoke-Anthony and Agada (1980), Mesida (1981) and Ajayi (1987) have shown that road failures are not primarily due to usage or design construction problems alone, but can equally arise from inadequate knowledge of the characteristics and behaviour of the residual soils on which the roads are built. This present research has investigated and identified those geological factors responsible for the incessant road failures witnessed within the study area using resistivity geophysical technique. Geophysical surveys are efficient and cost-effective in providing geotechnical information since they combine high speed and appreciable accuracy in providing subsurface information over large areas (Momoh et al., 2008).

GEOLOGY OF THE STUDY AREA

The study area (Latitude 09 ° 52ˈN and Latitude 09 ° 58ˈN; and Longitude 07 ° 12ˈE and 07 ° 28ˈE) lies within the basement complex of North-Central Nigeria. The rocks within this basement complex are grouped into three categories; these are the older granites, gneiss and magnetite; the older metasediments; and the younger metasediments. According to Ajibade and Wright (1980), the rocks of the basement complex are believed to have evolved in at least four orogenic events namely: the Pan African (600±150My), The Kibaran (1100±200My), The Eburnean (2000±200My) and the Liberian (2800±200My) orogenies.

SITE AREA DESCRIPTION

Figure 1 shows the location of the study area. Sarkin Pawa is about 87 km from Minna, Niger State Capital. The distance between Mangoro and Sarkin Pawa is about 20 km, and within this distance lies the study area. The elevation above sea level ranges from 500 metres to 555 metres.

METHODOLOGY

Geophysical survey involving vertical electrical sounding (VES) and horizontal electrical profiling were carried out using the ABEM SAS 300 terrameter along both the stable and unstable sections of the road. The vertical electric sounding was carried out along two traverses P_A and P_B each measuring 1350 metres long, one on either side of the road pavement. 28 vertical electrical soundings spaced at a station interval of 50 metres were carried out on each traverse. A maximum current electrode spacing (AB) of 200m was used. The electrical profiling with electrode separation of 10 metres was carried out on a stretch of 1150 metres on traverse P_A. A current variation in the range of 0.2-1.0A, found suitable in the basement terrain (Badmus et al., 2005), was used in the survey.

DATA ANALYSIS AND INTERPRETATION

The interpretation of geophysical data involves expressing the information obtained from the surface measurements into geological section/form, from which both qualitative and quantitative deductions can be made. The apparent resistivity values at each sounding point have been calculated from the resistance values recorded on the field and the geometric factors for the Schlumberger layout used. The apparent resistivity values calculated are presented as sounding curves for all the VES points using IPI2Win, a software designed for interpreting vertical electrical sounding data (Bobachev, 2001). Nine curve types have been identified within the study area. These are A, H, K, AK, HK, HA, AH, KH, and QH type with the H type as the predominant curve type (Figure 2). Typical curve types obtained from the field are shown in Figure 3 along with their model interpretations. The 2D geoelectric and geologic sections for the two traverses P_A and P_B are shown in Figures 4 and 5. Four geological subsurface layers comprising the top soil, weathered layer, partly weathered/fractured basement and the fresh basement have been delineated. The top soil is composed of sandy clay or clayey sand or laterite with resistivity values of 20-600 Ωm. It has average thickness of about 2.5 metres. It is, however observed from the two geoelectric sections that VES 5 to 10, 13 to 18 and VES 22 to 26 are the ones characterized with top soil of low resistivity values ranging between 20-120 Ωm suggesting clayey top soil with possibly high moisture content.The second layer is the weathered basement with resistivity values that vary between 20-450 Ωm and thickness of between 2.5-20.0 metres. It indicates a high degree of saturation, suggesting that the layer corresponds to the aquiferous zone in the area. The resistivity values of this second layer between VES 5 to 10, 13 to 18 and VES 22 to 26 are between 24-150 Ωm indicating that these sections are predominantly composed of clay or sandy clay materials.

The third layer is the partially weathered/fractured basement with resistivity values of 300-800 Ωm. It also suggests that the presence of fractures within the basement is responsible for the weathering action taking place within the layer. The fourth layer is the fresh basement whose resistivity values are 900 Ωm and above and extends to an infinite depth. The layer found the bedrock of the entire study area and is part of the basement complex rocks. Depth to the bedrock varies from 3.5-35.0 metres. The groundwater in the area is mostly located in the weathered and fractured layers. In most of the unstable sections, the groundwater level is found to be near to the surface. This suggests that the road pavement in the unstable section is founded on an incompetent layer which accounts for the incessant failures being observed along the road sections. Table 1 shows the thickness of the overburden, the depth to the weathered/aquiferous layer and that to the fresh basement. It is shown from the table that the depth to the top of the aquiferous layer is between 1.5-2.5 metres in the unstable section and 3.5- 5.5 metres in the stable sections of the road. For the horizontal electrical profiling, the apparent resistivity values have been plotted against distance along the profile. Figure 6 shows this plot and the corresponding geologic section. Qualitative interpretation was done by visual inspection of the plot. The apparent resistivity values vary between 20 and 895 ohm-m. The presence of low resistivity values within the distances 190.0-280.0 metres, 560.0-680.0 metres and 930.0-1150.0 metres is indications that the subsurface within these segments of the road is highly saturated and may likely contain clay and clay material. The presence of series of irregular resistivity values observed on the profile is indicative of either lateral natural variation in composition of the subsurface or presence of near surface geological features such as lineaments, fractures, joints, etc.

ENGINEERING SUBSURFACE EVALUATION OF THE STUDY AREA

The stable sections, which serve as control in this research, are underlain by high resistive subsurface. The top soil and the sub-grade are lateritic, significantly thick (up to a maximum 4.0m) and thick enough to support the imposed wheel load. The weathered basement is less clayey with resistivity values of 160-450 Ωm. The groundwater table is far below the road pavement. The unstable sections of the road are underlain by lithological units which may be weathered clay, sandy clay and clayey sand. The top soil and the sub-grade are generally clayey with low resistivity values between 20-120 Ωm. This indicates the accumulation of water within the weathered basement, and possibly suggests that the layer which is clayey is not permeable and hence does not drain water quickly. There is also an indication that the water table is near the pavement. The presence of near surface geological features such as faults, fractures etc. also enhance road failure. All these allow groundwater to percolate into the sub-grade from where it weakens the pavement. Table 2 shows the resistivity values and description of the layers delineated from the study area.

CONCLUSION

From the findings in this research, it is evident that the clayey nature of the topsoil and the sub-grade contribute significantly to the failure of the unstable sections of the road. Clay, though highly porous, is not very permeable owing to the poor connectivity of its pores and thus retains water without releasing it; this makes the clay to swell up and collapse at the exertion of pressure and this subsequently leads to the pavement failure.
Near surface linear features such as faults, fractures; buried ditch, old stream channel that has been covered with sand over time etc. within the subsurface beneath a road pavement allow water seepage and accumulation and eventually lead to pavement subsidence, thereby enhancing pavement failure. Another possible cause of road failure is the closeness of the aquiferous layer to the road pavement. This implies that the road pavement may be resting directly on the water table. This will allow quick access of groundwater to the sub-grade thereby weakening the pavement and subsequently results into road failure.

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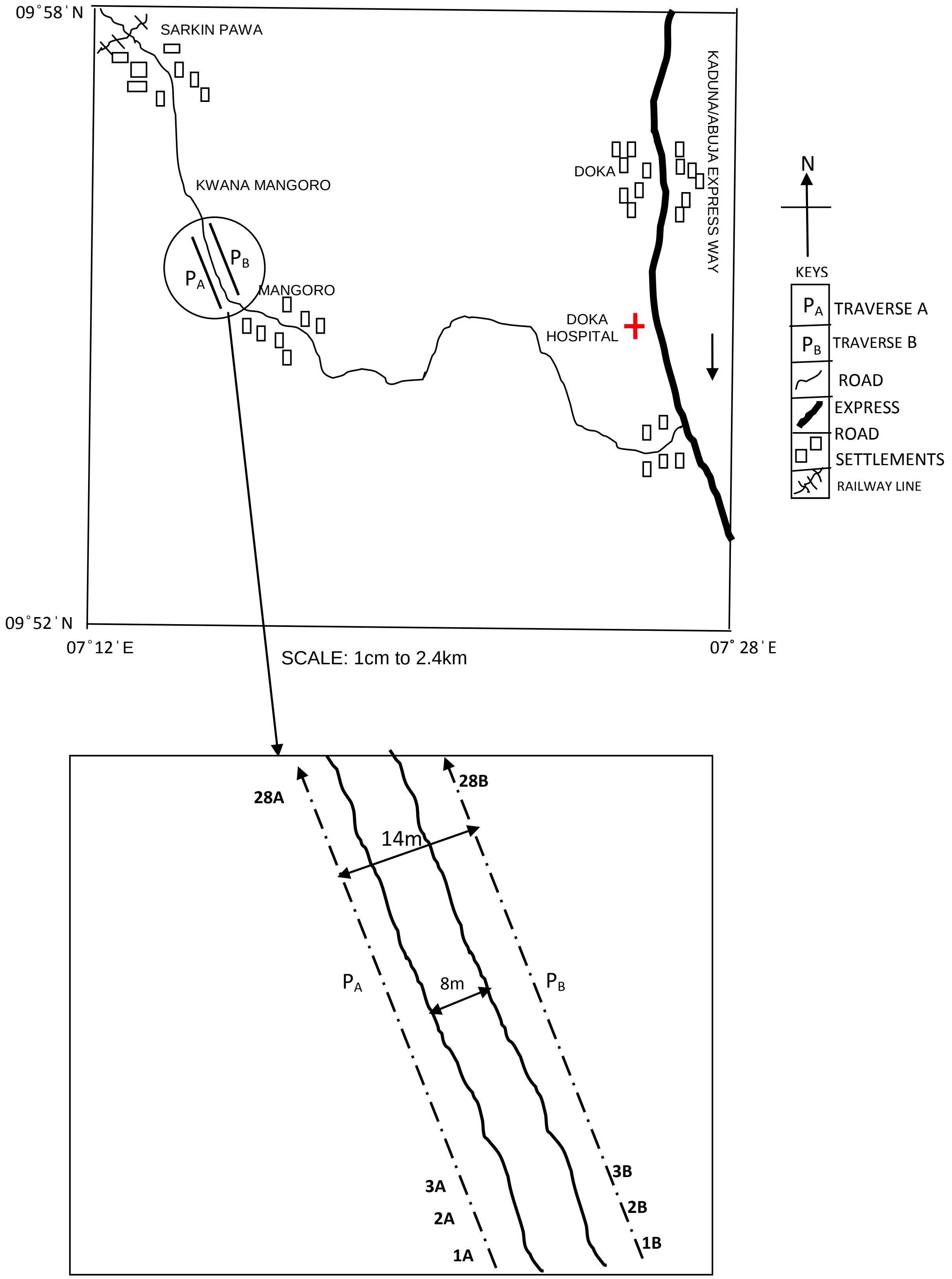


Figure 1 The location of the study area with arrow showing the traverse positions P_A and P_B

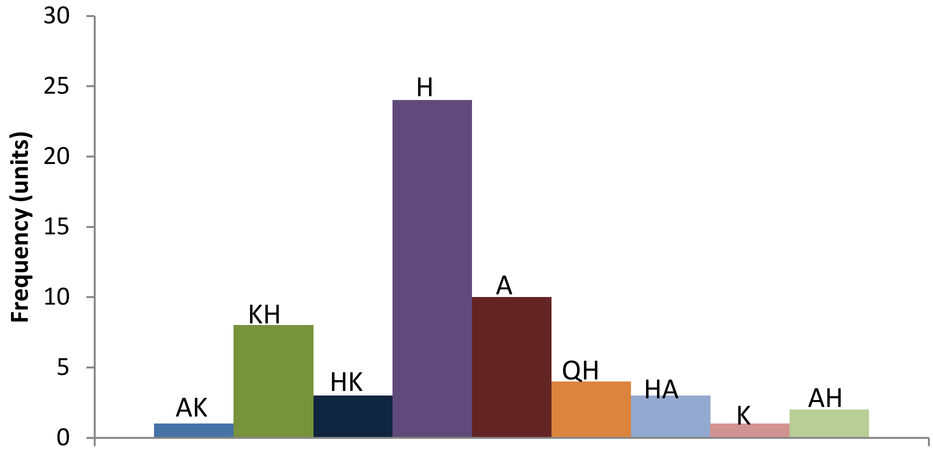
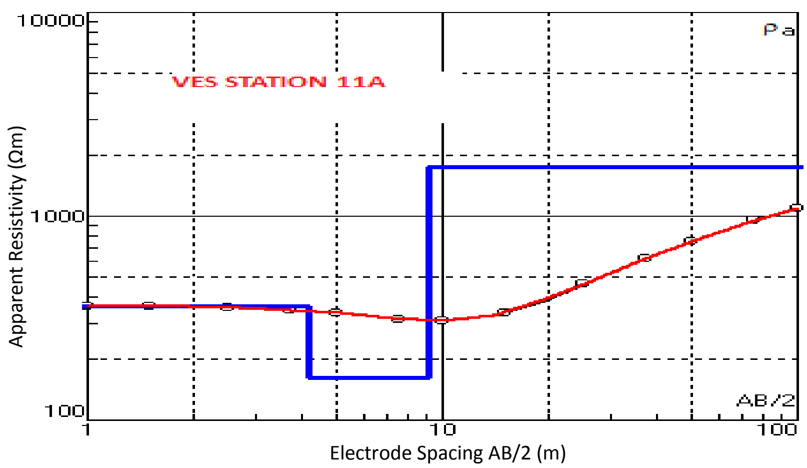
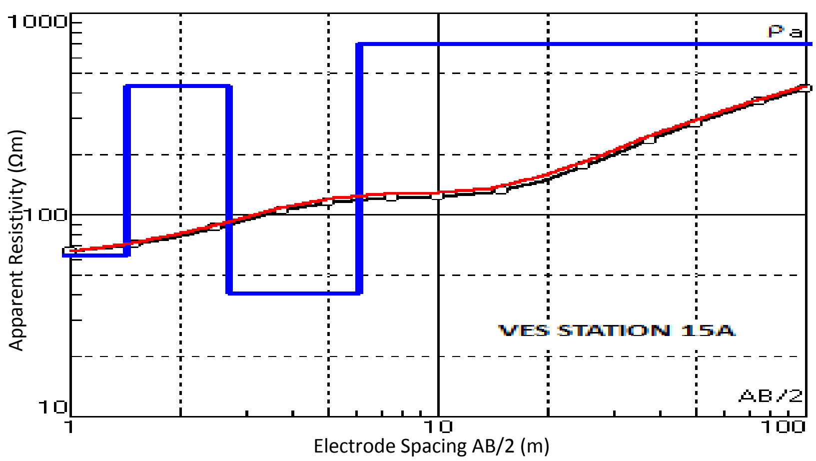


Figure 2 Histogram of curve types obtained from the study area



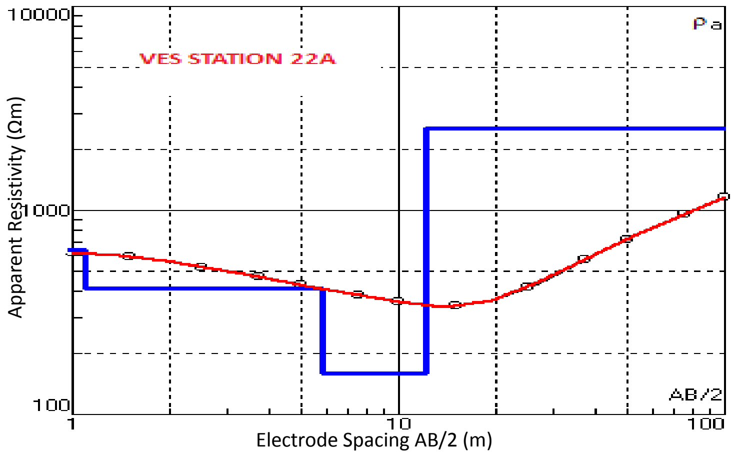
N	ρ	h	d
1	362	4.2	4.2
2	161	4.9	9.1
3	1739		

Figure 3(a) VES Station 11A (curve type H)



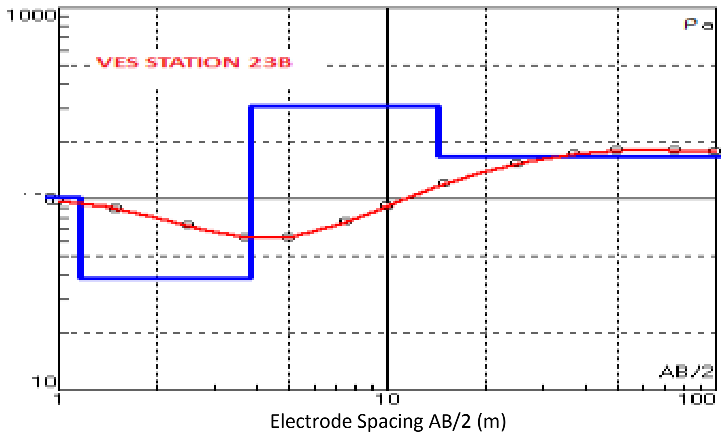
N	ρ	h	d
1	63	1.4	1.4
2	435	1.3	2.7
3	41	3.4	6.1
4	698		

Figure 3(b) VES Station 15A (curve type KH)



N	ρ	h	d
1	641	1.1	1.1
2	415	4.7	5.8
3	159	6.3	12.1
4	2527		

Figure 3(c) VES Station 22A (curve type QH)



N	ρ	h	d
1	102	1.2	1.2
2	38	2.7	3.9
3	306	10.5	14.4
4	167		

Figure 3(d) VES Station 23B (curve type HK)

ρ-Layer resistivity in Ωm
h-Layer thickness in metres
d-Interface depth in metres
N-Layer number

Field curve
Synthetic curve
Model

Figure 3 Examples of sounding curve types obtained from the study area and their model interpretation.

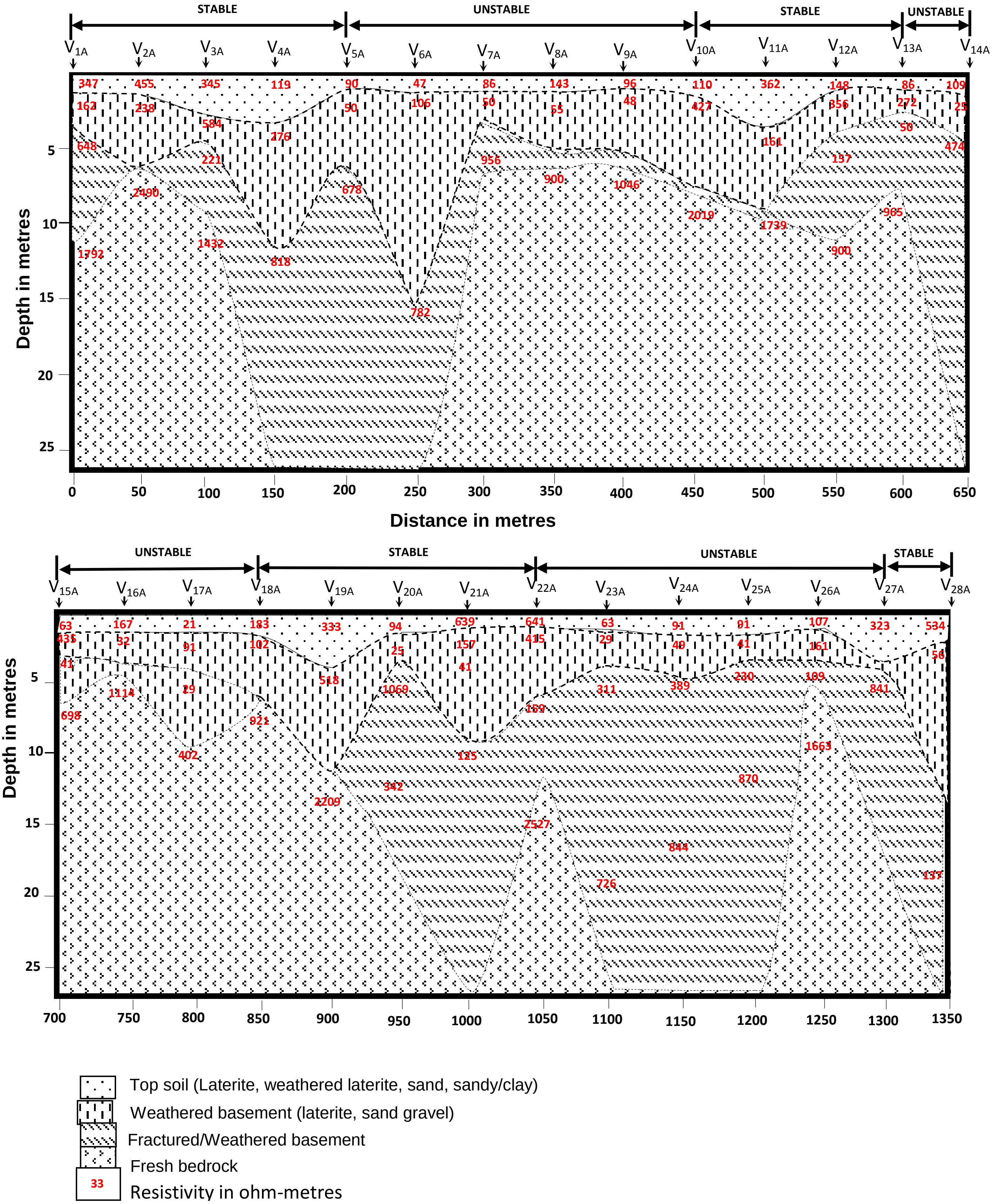


Figure 4 Geoelectric and geologic sections along profile P_A

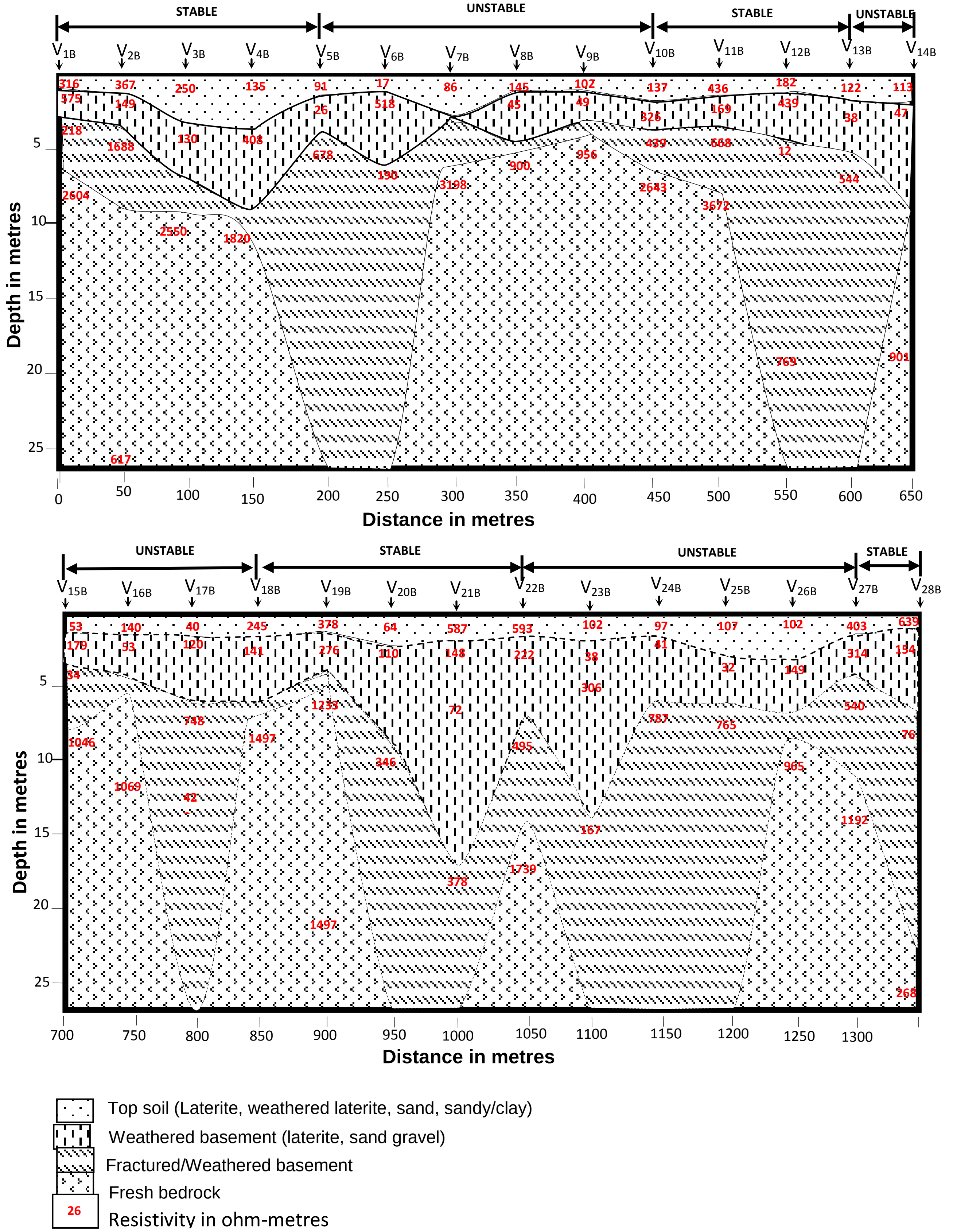


Figure 5 Geoelectric and geologic sections along profile P_B

Table 1 Thickness of the overburden, depth to the aquiferous layer and depth to the basement

	Stable section	Unstable section
Thickness of the overburden (m)	2.5 – 17.0	3.5.- 15.0
Depth to the aquiferous layer (m)	3.5 – 5.5	1.5 – 2.5
Depth to the fresh basement (m)	3.5 – 35.0	5.0 – 35.0

Table 2 Resistivity values of different layers obtained from the study area

Layers	**Resistivity Values (Ωm)**	**Description**
Surface Layer	20-120 130-600	Top soil, consists of saturated clay materials Top soil, consists of sand and laterite material
Second Layer	20-150 160-450	Weathered Basement, highly saturated with clay Weathered Basement, partially saturated, good as aquiferous layer
Third Layer	300-800	Fractured Basement, considered as the aquiferous zone, as it indicates water accumulation
Fourth layer	>900	Fresh Bedrock, consists of gravel materials

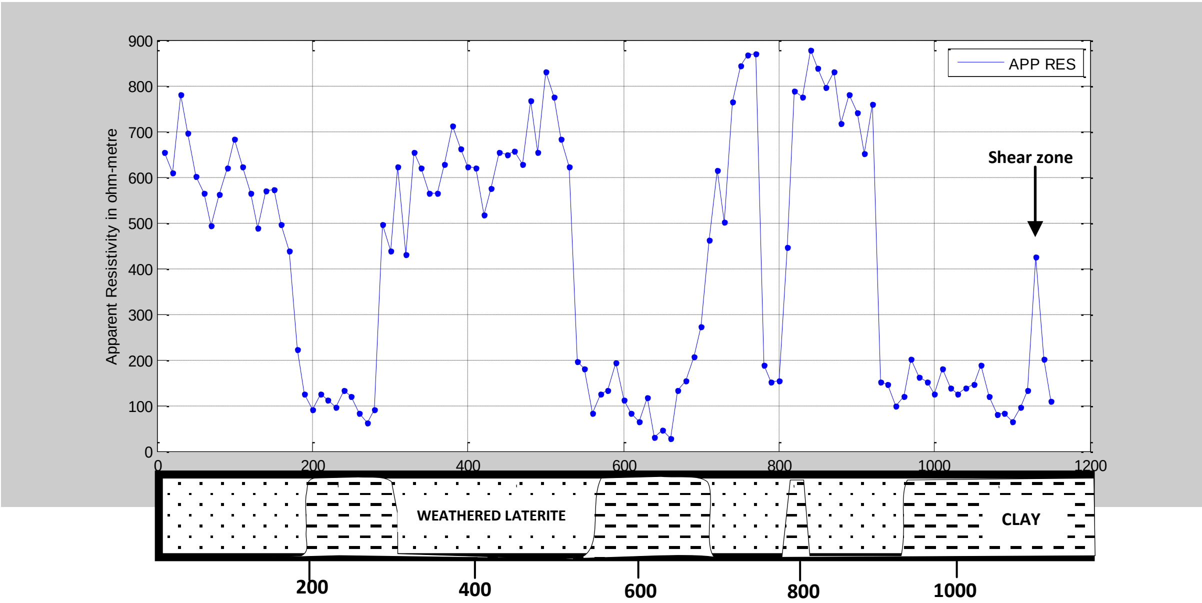


Figure 6 **Horizontal electrical profiling along traverse P_A and the corresponding geologic section**