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Full Length Research Paper

Aquifer characteristics and groundwater recharge pattern in a typical basement complex, Southwestern Nigeria

B. S. Badmus[1]* and O. B. Olatinsu[2]

[1]Department of Physics, University of Agriculture, Abeokuta, Nigeria.
[2]Department of Physics, University of Lagos, Lagos, Nigeria.

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A geophysical survey involving thirty four vertical electrical sounding (VES) was carried out at Federal College of Education, Osiele, Abeokuta, southwestern Nigeria using Schlumberger electrode array. The locations were selected based on the existing boreholes drilled in the past within the study area. The results revealed a maximum of five geoelectric layers, viz: topsoil, sandy clay, clayey sand, shale/clay, sandstone, fractured basement and fresh basement. Three probable aquifer units and one aquitard were delineated with clayey sand occurring in 50%, sandy clay constitutes 24%, fractured basement 24% and shale/clay 2%. VES 10, 26 and 30 with weathered layer (shale/clay) of thicknesses 14.7, 23.5 and 9.9 m respectively revealed very low yield (not productive). Borehole drilling in the study area should be executed in the peak of the dry seasons during which groundwater level is expected to be low because recharge of the existing boreholes in the study area is largely due to falling precipitation. Existing boreholes located within the study area characterized by unconfined aquifer while some are confined under pressure between relatively impermeable materials. With this, the problems of recharging and drying up of borehole can be solved.

Key words: Resistivity, fractured basement, lithology, aquifer, geoelectric layers.

INTRODUCTION

Fractured crystalline bedrock aquifers are good sources of potable water in many parts of the world. However, sitting of highly productive wells in these rock units remains a challenging and expensive task because fracture development at the regional scale is both heterogeneous and anisotropic (Manda et al., 2006). Using low cost electrical resistivity data to determine units of rock that have similar lithologic and fracture characteristics can greatly reduce time, cost and energy spent on determining areas with better than average aquifer productivity. Basement aquifers are developed within the weathered overburden and fractured bedrock of crystalline rocks of intrusive and/or metamorphic origin which are mainly of Precambrian age (Wright, 1992).

Groundwater development may be primarily restricted to the aquifer in the weathered overburden or completed in the fractured bedrock in locations where the overburden is relatively thin. Viable aquifers wholly within the fractured bedrock are of rare occurrence because of the typically low storativity of fracture systems (Clark, 1985). An intrinsically low porosity limits the quantity of water stored in fractured crystalline rock. Sustainable well yields for bedrock, therefore, may strongly depend on the quantity of water stored in surficial materials that can leak downward into bedrock and on periodic replenishment by recharge (Lyford, 2004).

This study presents the use of electrical resistivity method in the delineation of bedrock structures, depth to possible aquifer units and to infer the groundwater potential of the basement complex area. This work becomes very necessary as a result of: (i) the frequent high failure rate of boreholes, being much higher where the weathered overburden is thin; (ii) shallow occurrence and fissure permeability of the bedrock aquifer unit which makes for susceptibility to surface contaminants; and (iii) the low storage capacity of fractured aquifers which are

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*Corresponding author E-mail: badmusbs@yahoo.co.uk

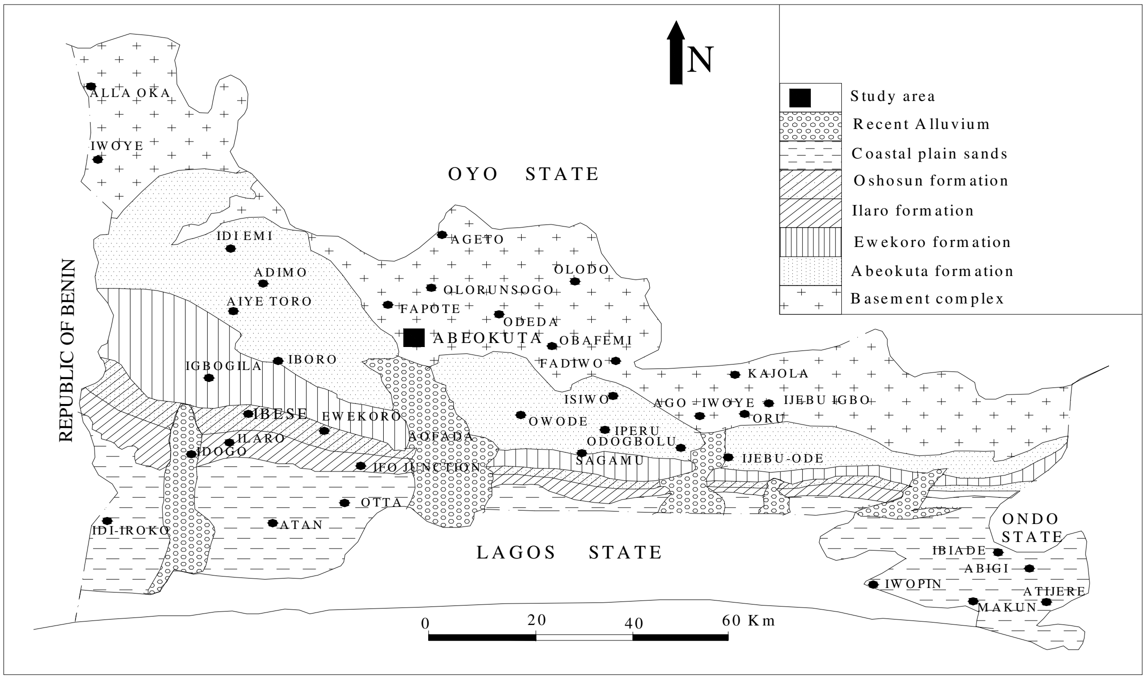

Figure 1: Geological map of Ogun State, showing the study area.

easily depleted during dry seasons. Therefore to meet the ever increasing demand of water in the study area, there is need for a detailed geophysical survey so as to site viable locations for withdrawal wells. This will also require understanding the geologic and hydrogeologic characteristics of the crystalline bedrock as well as the regional tectonic setting which are critical to identifying favourable areas to site large groundwater wells (Talkington, 2004).

Physoigraphy, geology and hydrogeology

The study area is the Federal College of Education, Osiele, Abeokuta, Southwestern, Nigeria. The area falls under the Basement Complex area of Ogun State, Southwestern Nigeria (Figure 1). The basement rocks comprise of folded gneiss, schist, quartzite, older granite, and amphibolites/mica schist (Jones and Hockey, 1964, Rahman, 1975). The occurrence of groundwater in crystalline rocks depends on the extent and depth of weathering and fracturing. Basement aquifers are developed within either the regolith (relatively high storativity but low permeability) or the fractured bedrock (low storage capacity with a relatively high permeability). The groundwater is contained in the weathered/ fractured formations and is primarily recharged through surface precipitation and secondarily through lateral flow from rivers and tributaries.

Climate and vegetation

The study area falls within the humid tropical region which is characterized by wet and dry seasons. The wet season usually occur from March to October and is dominated by heavy rainfall. The dry season occurs from November to March when the area is under the influence of North-easterly winds. The annual rainfall is estimated to be about 1600 mm. The mean monthly temperature ranges between 25.7°C in July and 30.2°C in February, and the average annual temperature is 26.6°C. High humidity (generally above 50%) and long wet season ensures adequate supply of water and continuous presence of moisture in the air. Hence, the study area is characterized by high diurnal and annual temperature, lack of cold season, high precipitation, low pressure, high evapo-transpiration and high relative humidity.

Data acquisition and processing

Thirty four (34) vertical electrical sounding were carried out at different locations within the study area, using the ABEM 300 SAS Terrameter. The electrode arrangement was Schlumberger with electrode separation of 200m. The VES locations were chosen very close to the existing boreholes at a distance of between 1.0 and 2.0 m in most cases while few are along the traverse of these existing boreholes.

The layouts of the VES locations are as shown in data acquisition map (Figure 2). From the field data, the apparent resistivity values were computed by multiplying the geometric factor with the field resistivity values. Data processing was carried out with the use of WingLink, software developed by GEOSYSTEM. This was used to mask individual data points, create smooth and layered inversion model for each VES station. The final results are summarized in Tables 1 and 2.

RESULTS AND DISCUSSION

VES analysis

The VES analysis shows a minimum of three and a maximum of five geoelectric layers which compose of the

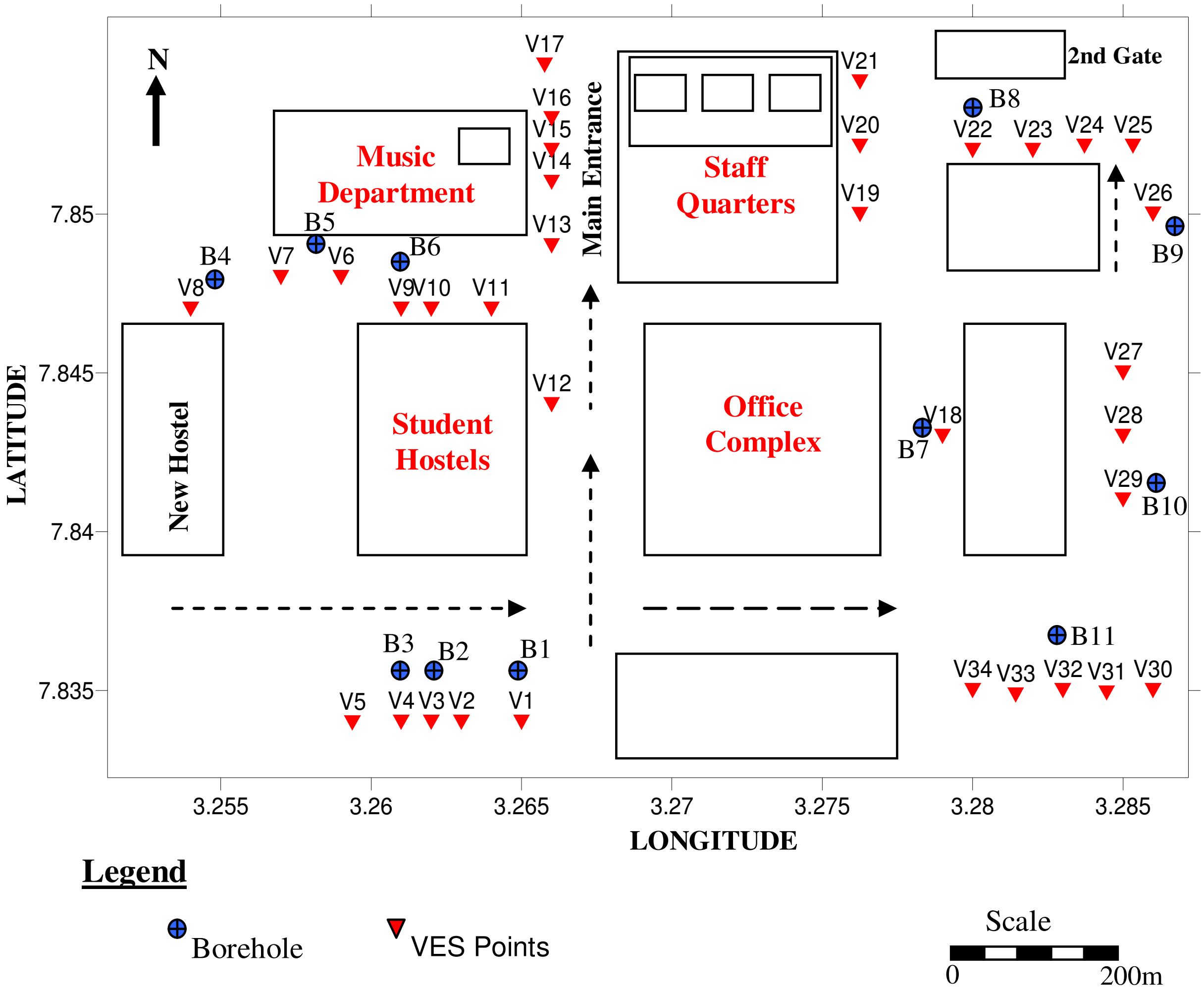

Figure 2. Data acquisition map of the study location.

following lithologies: topsoil, shale/clay, sandy clay, clayey sand, sandstone, fractured bedrock and fresh bedrock as depicted in the geoelectric sections (Figures 3a - g).

The study area was divided into seven profiles. Profile I consists of VES 1 - 5. Clayey sand with resistivity value 398 Ωm and thickness 28.6 m as revealed in VES 1 is inferred as the most probable aquifer unit along this profile. Profile II with VES 6 -11 also has clayey sand of resistivity value 600Ωm in VES 9, indicating good aquifer unit.

The thickness could not be determined but the depth to this aquifer is 31.4 m. At profile III which com-prises of VES 12 - 17, sandy clay layers with resistivity values 132, 103 and 107 Ωm and thicknesses 15.8, 23.9 and 26.9 m at VES 14, VES 15 and VES 17 are the likely aquiferous units along this profile. These locations are not recommended for borehole drilling due to the sandy clay nature. Profile IV with VES 18 - 21 has an aquifer unit in VES 19. This has fractured bedrock of resistivity 843 Ωm and depth to this layer is 37.9 m.

Sandy clay with resistivity 104 Ωm and thickness 18.6 m in VES 25 is the main aquifer unit along profile V which consists of VES 22 - 25. At profile VI where VES 26 - 29 are located, clayey sand layer with resistivity 388 Ωm at a depth of 24.5 m in VES 28 is a good aquifer unit along this section. The overburden thickness at profile VII is generally small. The clayey sand with resistivity value 512 Ωm at a depth of 8.2 m could still be prospective borehole location (Tables 1 and 2).

Recharge pattern

Recharge is important not only on account of the small storage capacity of basement aquifers but also because a better understanding of the processes and amount involved increases the knowledge of the occurrence and potential (Wright, 1992). Recharge, as it relates to groundwater, is simply the replenishment condition of

Table 1. Summary of VES analysis.

VES stations	Probable aquifer				Aquifer type
	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	
1	397.72	28.57	30.35	Clayey sand	Confined
2	748.01	-	29.33	Fractured bedrock	Unconfined
3	534.71	-	13.29	Clayey sand	Confined
4	379.28	3.20	4.93	Clayey sand	Confined
5	527.85	-	20.18	Clayey sand	Confined
6	991.52	-	14.33	Fractured bedrock	Confined
7	734.35	-	12.02	Fractured bedrock	Confined
8	347.82	-	9.77	Clayey sand	Confined
9	600.39	-	31.43	Clayey sand	Confined
10	23.73	11.11	14.69	Shale/Clay	Confined
11	848.75	-	31.55	Fractured bedrock	Confined
12	910.24	-	2.60??	Fractured bedrock	Confined
13	340.11	4.84	6.96	Clayey sand	Unconfined
14	132.17	15.82	24.61	Sandy clay	Unconfined
15	346.07	6.60	8.99	Clayey sand	Confined
16	126.21	5.48	5.73??	Sandy clay	Unconfined
17	106.50	26.86	28.06	Sandy clay	Unconfined
18	455.47	4.46	6.43	Clayey sand	Confined
19	843.27	-	37.88	Fractured bedrock	Confined
20	296.51	3.92	6.96	Clayey sand	Confined
21	493.88	5.02	10.50	Clayey sand	Confined
22	859.47	6.93	9.21	Clayey sand	Confined
23	278.06	2.15	2.45	Clayey sand	Unconfined
24	188.62	2.62	2.84	Sandy clay	Unconfined
25	103.65	18.57	20.27	Sandy clay	Unconfined
26	54.64	21.21	23.35	Shale/Clay	Unconfined
27	895.56	-	19.14	Fractured bedrock	Confined
28	387.59	-	24.50	Clayey sand	Confined
29	548.97	-	28.06	Fractured bedrock	Confined
30	37.62	8.25	9.92	Shale/Clay	Unconfined
31	113.28	6.31	7.90	Sandy clay	Unconfined
32	141.75	4.70	5.37	Sandy clay	Unconfined
33	178.84	-	7.44	Sandy clay	Confined
34	511.49	-	8.21	Clayey sand	Confined

boreholes.

The principal source of recharge of groundwater can be falling precipitation that eventually percolates seepage from stream flow, lakes and reservoir, seepage from irrigation canals and purposeful application of water to augment groundwater supplies.

Basement aquifers are distinctive in that their occurrence and characteristics are largely a consequence of the interaction of weathering processes related to recharge and groundwater through flow (Wright, 1992).

The basement aquifer, even where continuous, has low permeability and the main groundwater flow systems are localized between recharge on watersheds to discharge by runoff or evaporation in valley bottomlands. All methods of estimating recharge are subject to considerable uncertainty (Simmers, 1988). This is generally more for basement aquifer as a result of their heterogeneity and the complex nature of the flow system (Simmers, 1988). Geology controls the rate of groundwater movement.

The size of the cracks in rocks, the size of the pores between soil and rock particles, and whether the pores are connected determine the rate at which water moves into, through and out of an aquifer.

Table 2. Summary of resistivity value, layer thickness and litholgy.

VES station	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
1	1	122.88	0.77	0.77	Topsoil
	2	31.80	1.01	1.78	Shale/clay
	3	397.72	28.57	30.35	Clayey sand
	4	1276.49			Sandstone
2	1	19.69	0.26	0.26	Topsoil
	2	149.41	29.07	29.33	Sandy clay
	3	748.01			Fractured bedrock
3	1	63.12	1.50	1.50	Topsoil
	2	130.35	11.79	13.29	Sandy clay
	3	534.71			Clayey sand
4	1	130.75	1.30	1.30	Topsoil
	2	18.92	0.43	1.73	Clay /shale
	3	379.28	3.20	4.93	Clayey sand
	4	4.18	1.15	6.08	Shale/clay
	5	1023.76			Sandstone
5	1	75.59	2.18	2.18	Topsoil
	2	37.38	18.00	20.18	Clay/shale
	3	527.85			Clayey sand
6	1	221.45	0.98	0.98	Topsoil
	2	612.42	2.11	3.09	Clayey sand
	3	39.36	11.24	14.33	Clay/shale
	4	991.52			Fractured bedrock
7	1	293.72	0.91	0.91	Topsoil
	2	37.45	11.11	12.02	Clay/shale
	3	734.35			Fractured bedrock
8	1	168.54	2.11	2.11	Topsoil
	2	21.61	7.66	9.77	Clay/shale
	3	347.82			Clayey sand
9	1	115.34	1.09	1.09	Topsoil
	2	54.93	3.85	4.94	Shale/clay
	3	24.18	26.49	31.43	Shale/clay
	4	600.39			Clayey sand
10	1	346.93	0.43	0.43	Topsoil
	2	105.77	3.15	3.58	Sandy clay
	3	23.73	11.11	14.69	Shale/clay
	4	5725.29			Fresh bedrock
11	1	40.47	0.42	0.42	Topsoil
	2	236.65	1.17	1.59	Clayey sand
	3	39.23	29.96	31.55	Shale/clay
	4	848.75			Fractured bedrock

Table 2. Contd.

12	1	62.20	1.56	1.56	Topsoil
	2	119.66	1.04	2.6	Sandy clay
	3	910.24			Fractured basement
13	1	128.12	2.12	2.12	Topsoil
	2	340.11	4.84	6.96	Clayey sand
	3	1039.58			Sandstone
14	1	187.26	3.73	3.73	Topsoil
	2	810.41	5.06	8.79	Compacted clayey sand
	3	132.17	15.82	24.61	Sandy clay
	4	2637.87			Fresh bedrock
15	1	239.04	0.94	0.94	Topsoil
	2	70.16	1.45	2.39	Shale/clay
	3	346.07	6.60	8.99	Clayey sand
	4	103.47	23.92	32.91	Sandy clay
	5	1973.88			Fresh bedrock
16	1	470.20	0.25	0.25	Topsoil
	2	126.21	5.48	5.73	Sandy clay
	3	59.12	4.53	10.26	Shale/clay
	4	4016.34			Fresh bedrock
17	1	887.32	1.20	1.20	Topsoil
	2	106.50	26.86	28.06	Sandy clay
	3	4750.50			Fresh bedrock
18	1	142.42	0.78	0.78	Topsoil
	2	67.39	1.19	1.97	Shale/clay
	3	455.47	4.46	6.43	Clayey sand
	4	76.87	14.98	21.41	Shale/clay
	5	1156.37			Fresh bedrock
19	1	96.03	0.32	0.32	Topsoil
	2	345.60	0.65	0.97	Clayey sand
	3	173.47	6.67	7.64	Sandy clay
	4	41.61	30.24	37.88	Shale/clay
	5	843.27			Fractured bedrock
20	1	212.70	1.40	1.40	Topsoil
	2	57.13	1.64	3.04	Shale/clay
	3	296.51	3.92	6.96	Clayey sand
	4	46.89	13.31	20.27	Shale/clay
	5	1353.24			Fresh bedrock
21	1	424.77	0.93	0.93	Topsoil
	2	153.83	4.55	5.48	Sandy clay
	3	493.88	5.02	10.5	Clayey sand
	4	80.46			Shale/clay

Table 2. Contd.

22	1	217.67	1.65	1.65	Topsoil
	2	51.97	0.63	2.28	Shale/clay
	3	859.47	6.93	9.21	Clayey sand
	4	85.77			Shale/clay
23	1	42.89	0.30	0.30	Topsoil
	2	278.06	2.15	2.45	Clayey sand
	3	37.34	17.96	20.41	Shale/clay
	4	1107.80			sandstone
24	1	95.34	0.22	0.22	Topsoil
	2	188.62	2.62	2.84	Sandy clay
	3	82.02			Shale/clay
25	1	71.95	0.38	0.38	Topsoil
	2	273.55	1.32	1.7	Clayey sand
	3	103.65	18.57	20.27	Sandy clay
	4	3746.16			Fresh bedrock
26	1	231.68	2.14	2.14	Topsoil
	2	54.64	21.21	23.35	Shale/clay
	3	1696.06			Fresh bedrock
27	1	240.93	1.28	1.28	Topsoil
	2	71.35	17.86	19.14	Shale/clay
	3	895.56			Fractured bedrock
28	1	121.84	1.00	1.00	Topsoil
	2	68.73	8.88	9.88	Shale/clay
	3	17.55	14.62	24.5	Shale/clay
	4	387.59			Clayey sand
29	1	56.33	0.36	0.36	Topsoil
	2	183.57	6.23	6.59	Sandy clay
	3	34.56	21.47	28.06	Shale/clay
	4	548.97			Fractured bedrock
30	1	341.64	0.75	0.75	Topsoil
	2	2539.87	0.92	1.67	Compacted sandstone
	3	37.62	8.25	9.92	Shale/clay
	4	2644.44			Fresh bedrock
31	1	316.83	1.59	1.59	Topsoil
	2	113.28	6.31	7.9	Sandy clay
	3	1289.14			Fresh bedrock
32	1	105.50	0.18	0.18	Topsoil
	2	796.69	0.49	0.67	Compacted clayey sand
	3	141.75	4.70	5.37	Sandy clay
	4	2016.07			Fresh bedrock

Table 2. Contd.

33	1	227.57	3.07	3.07	Topsoil
	2	1791.67	4.37	7.44	Compacted sandstone
	3	178.84			Sandy clay
34	1	403.54	3.24	3.24	Topsoil
	2	57.12	4.97	8.21	Shale/clay
	3	511.49			Clayey sand
32	1	105.50	0.18	0.18	Topsoil
	2	796.69	0.49	0.67	Compacted clayey sand
	3	141.75	4.70	5.37	Sandy clay
	4	2016.07			Fresh bedrock
33	1	227.57	3.07	3.07	Topsoil
	2	1791.67	4.37	7.44	Compacted sandstone
	3	178.84			Sandy clay
34	1	403.54	3.24	3.24	Topsoil
	2	57.12	4.97	8.21	Shale/clay
	3	511.49			Clayey sand

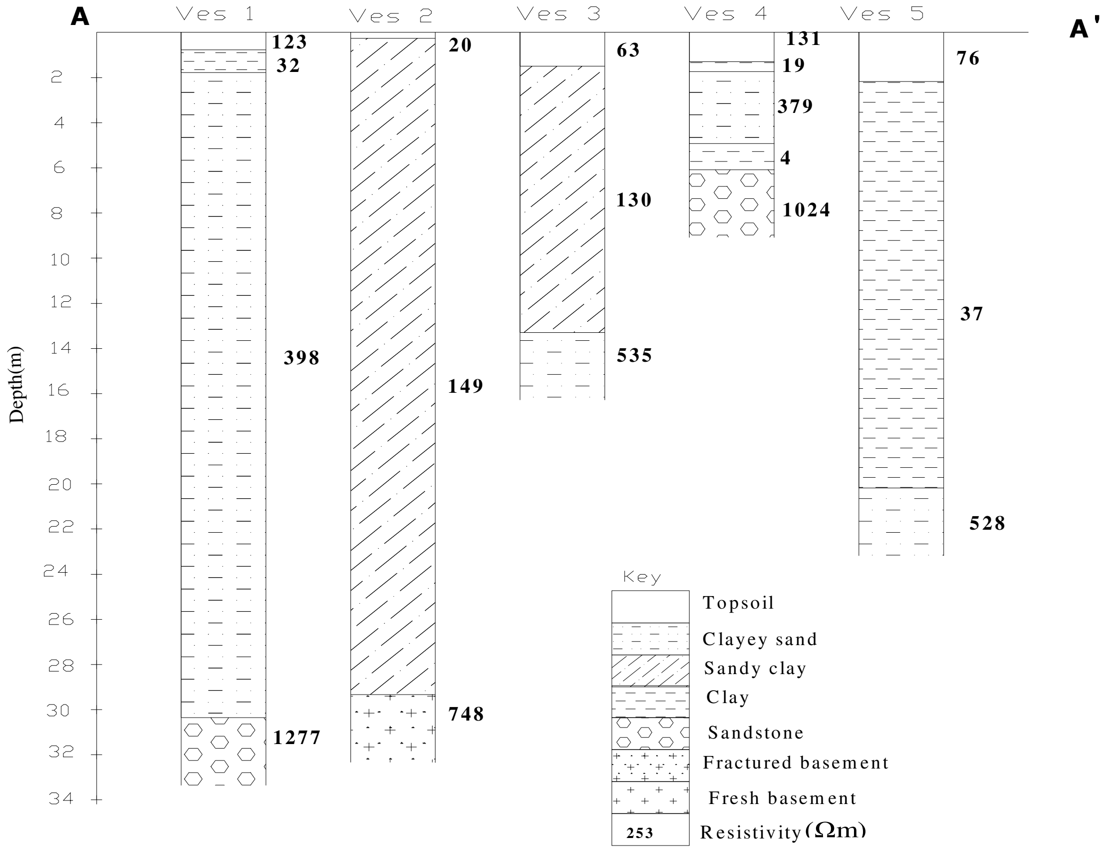

Figure 3a. Geoelectric sections beneath profile AA'.

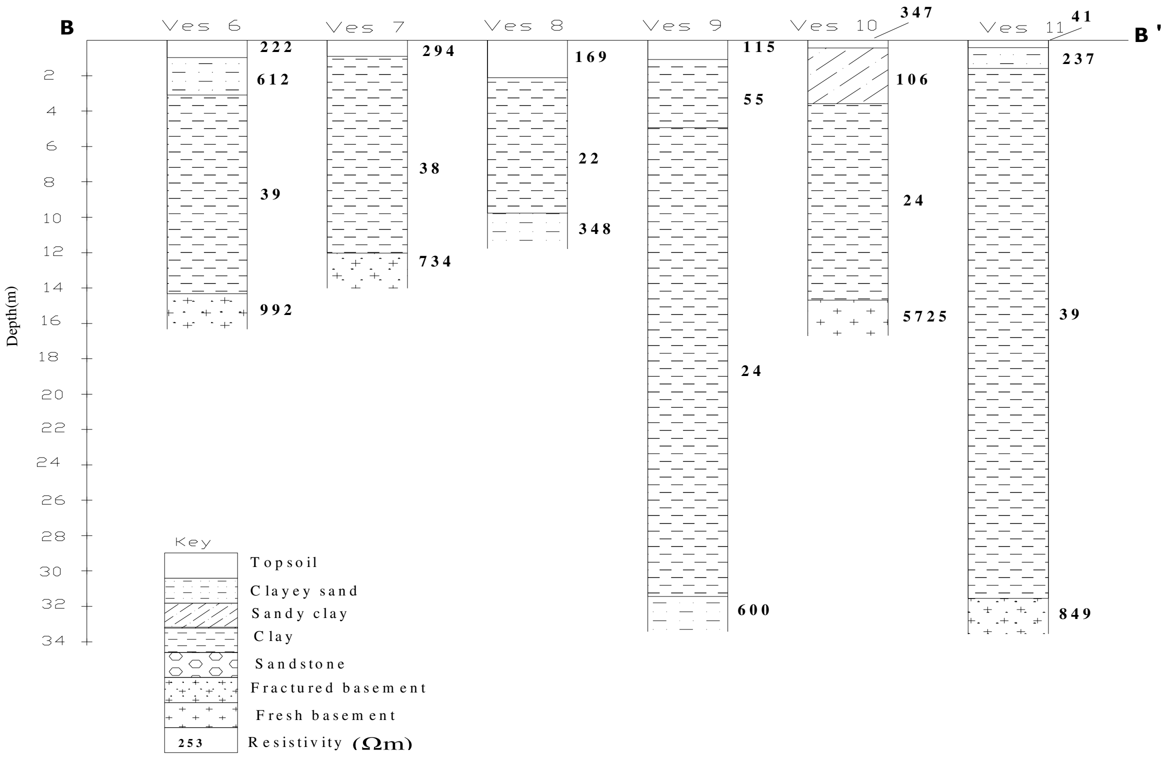

Figure 3b. Geoelectric sections beneath profile BB'.

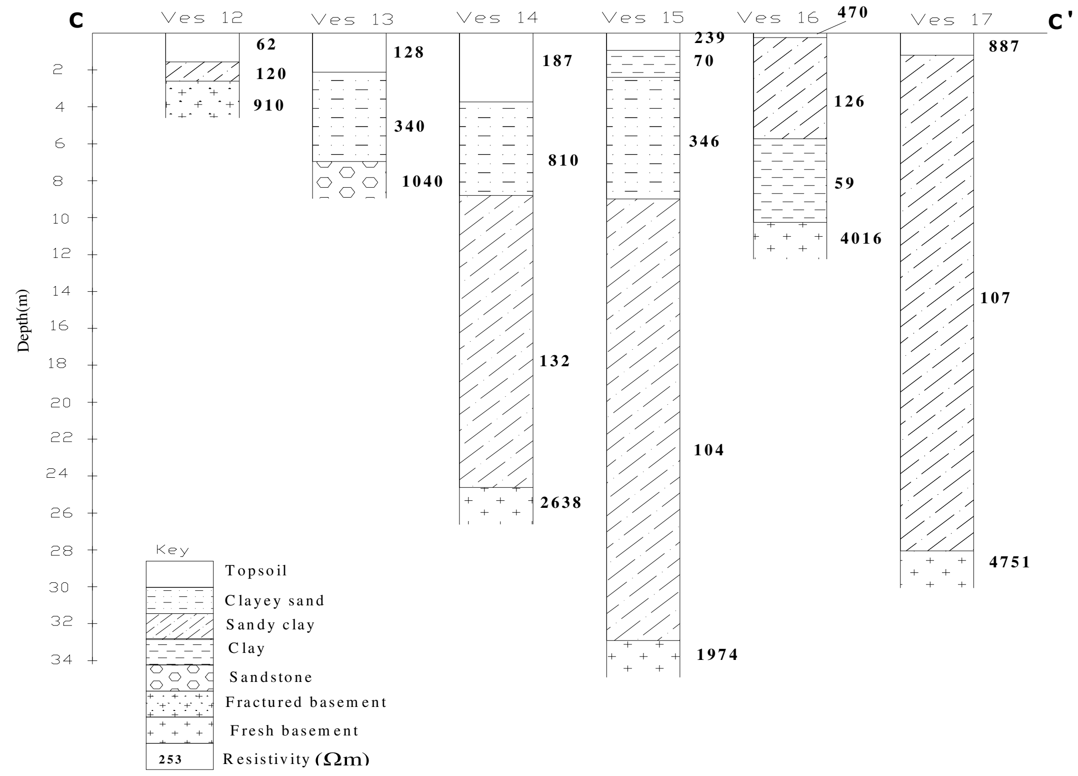

Figure 3c. Geoelectric sections beneath profile CC'.

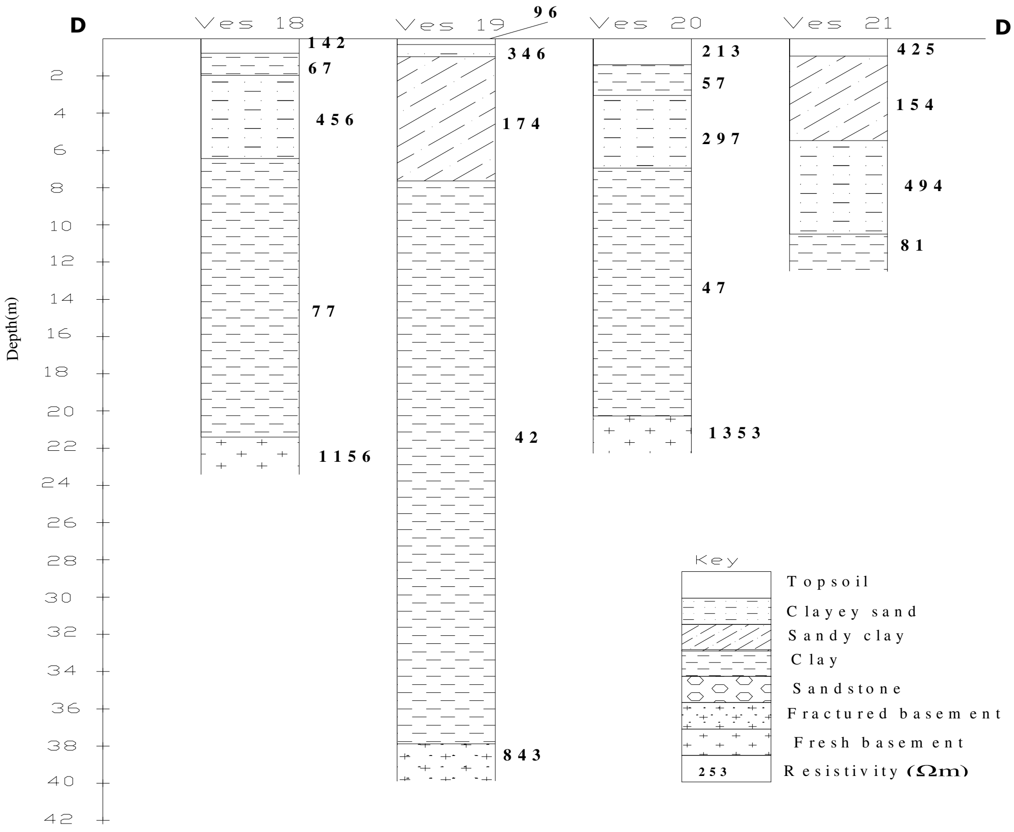

Figure 3d. Geoelectric sections beneath profile DD'.

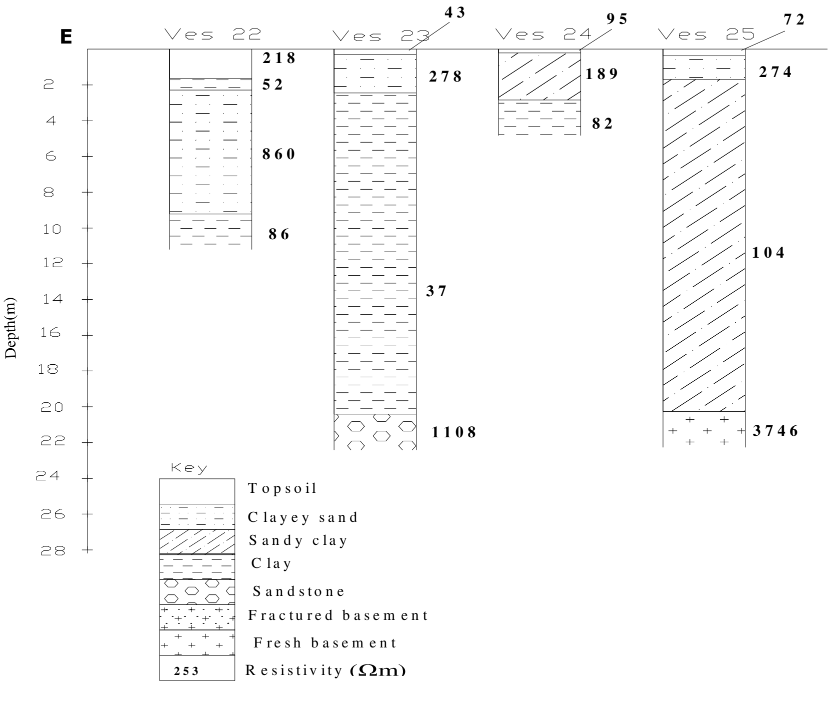

Figure 3e. Geoelectric sections beneath profile EE'.

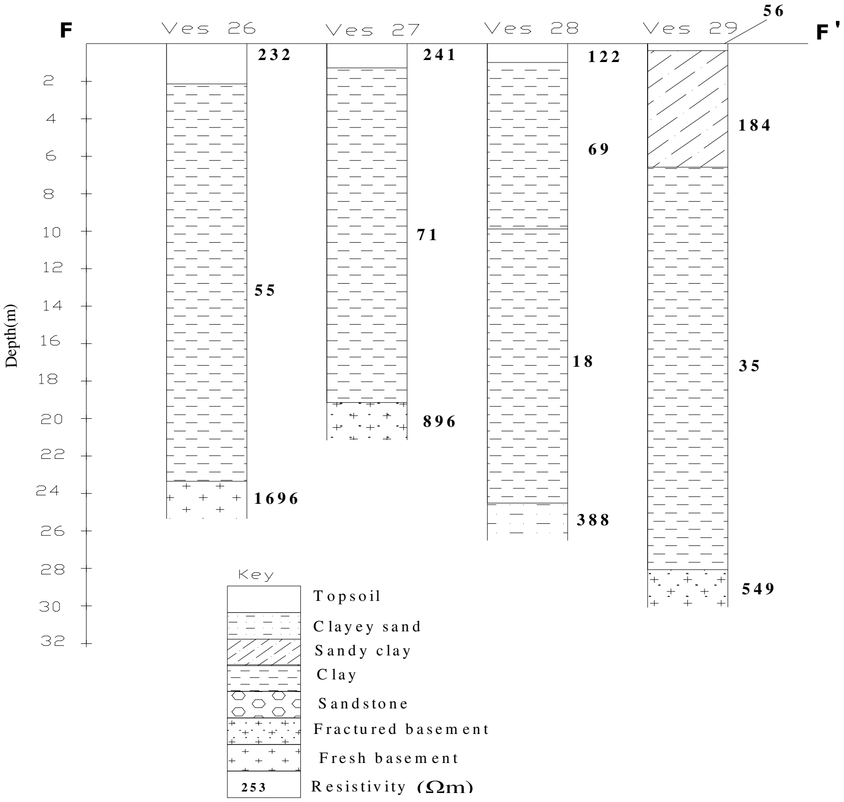

Figure 3f. Geoelectric sections beneath profile FF'.

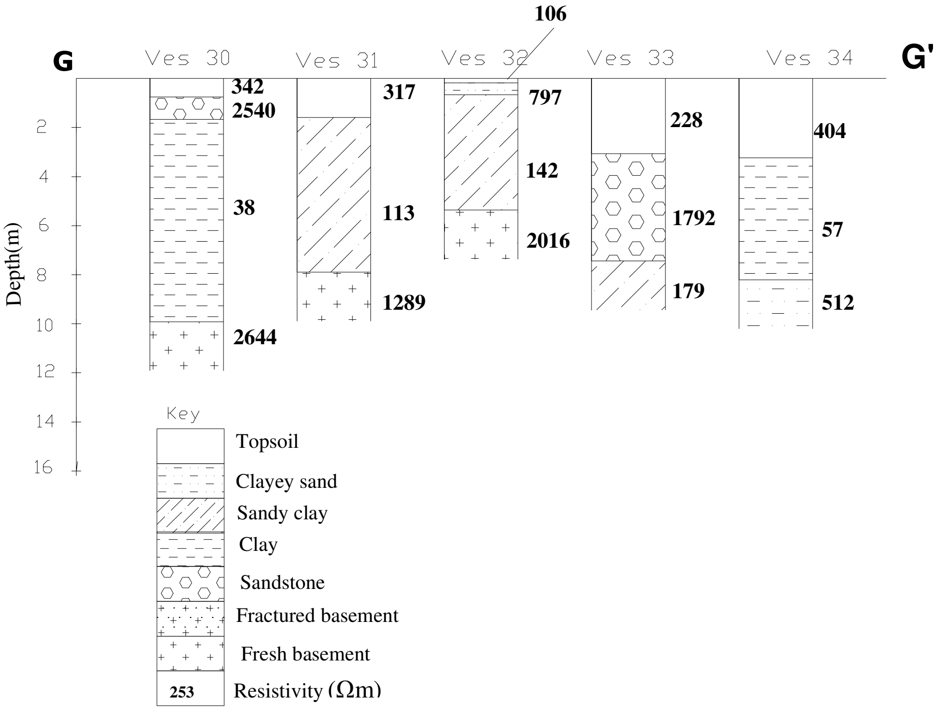

Figure 3g. Geoelectric sections beneath profile GG'.

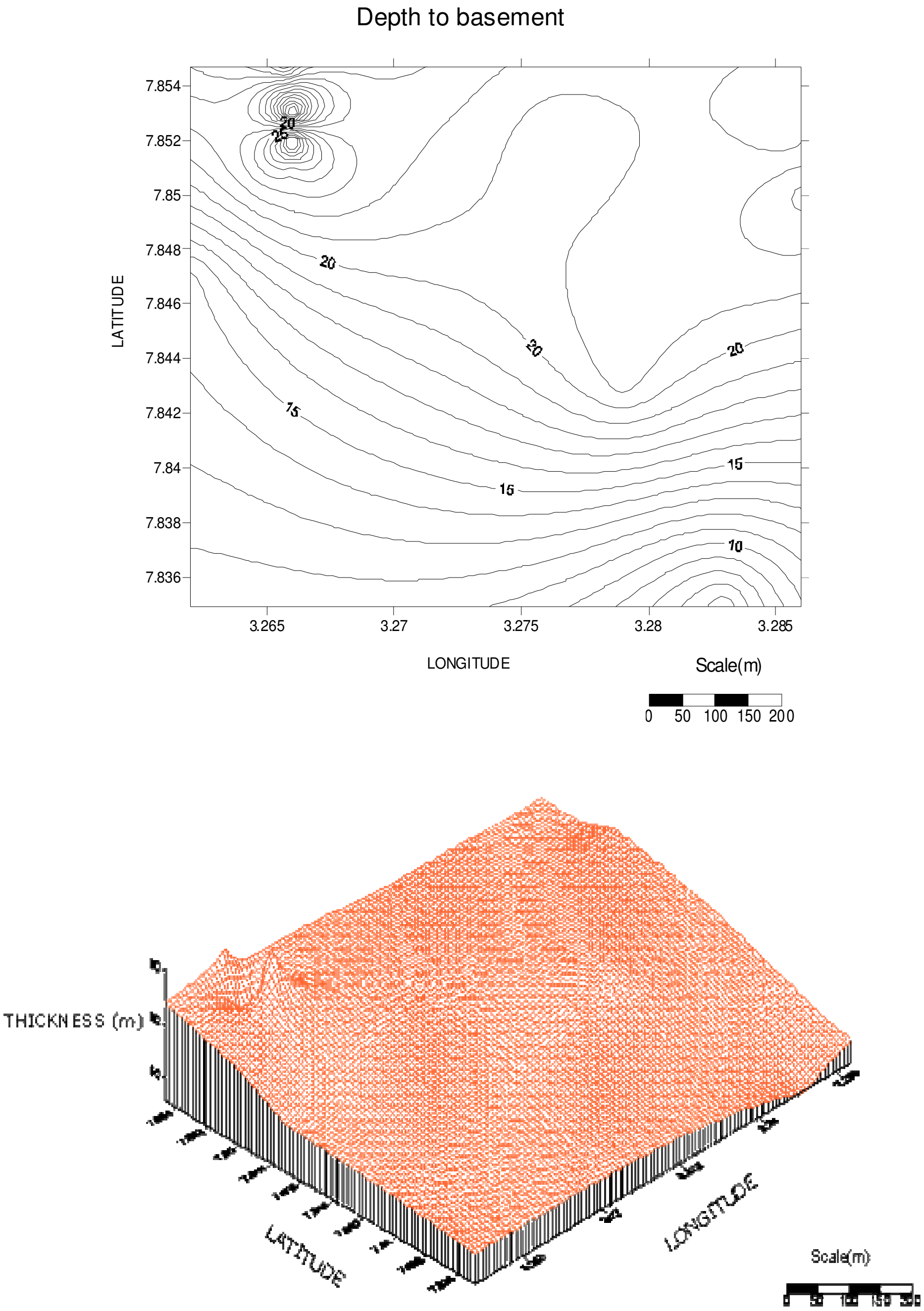

Figure 4a. Contour maps showing depth to basement and 3-D view.

The recharge of the existing boreholes in the study area is largely due to falling precipitation. Three boreholes are located close to VES 1 - 5 along profile AA. BH1 is characterized by unconfined aquifer. Water is prevented from entering or discharged from the aquifer. BH2 and BH3 have very good yield because the groundwater is confined under pressure between relatively impermeable materials.

Contour maps and 3-D view

Contour technique was also used for the interpretation of the resistivity values obtained from the field data, using “Suffer soft ware”. Three types of contour maps (depth to basement, overburden thickness and aquifer thickness) were prepared as well as the 3-dimensional views (Figures 4a - 4c). The depth to basement map shows the

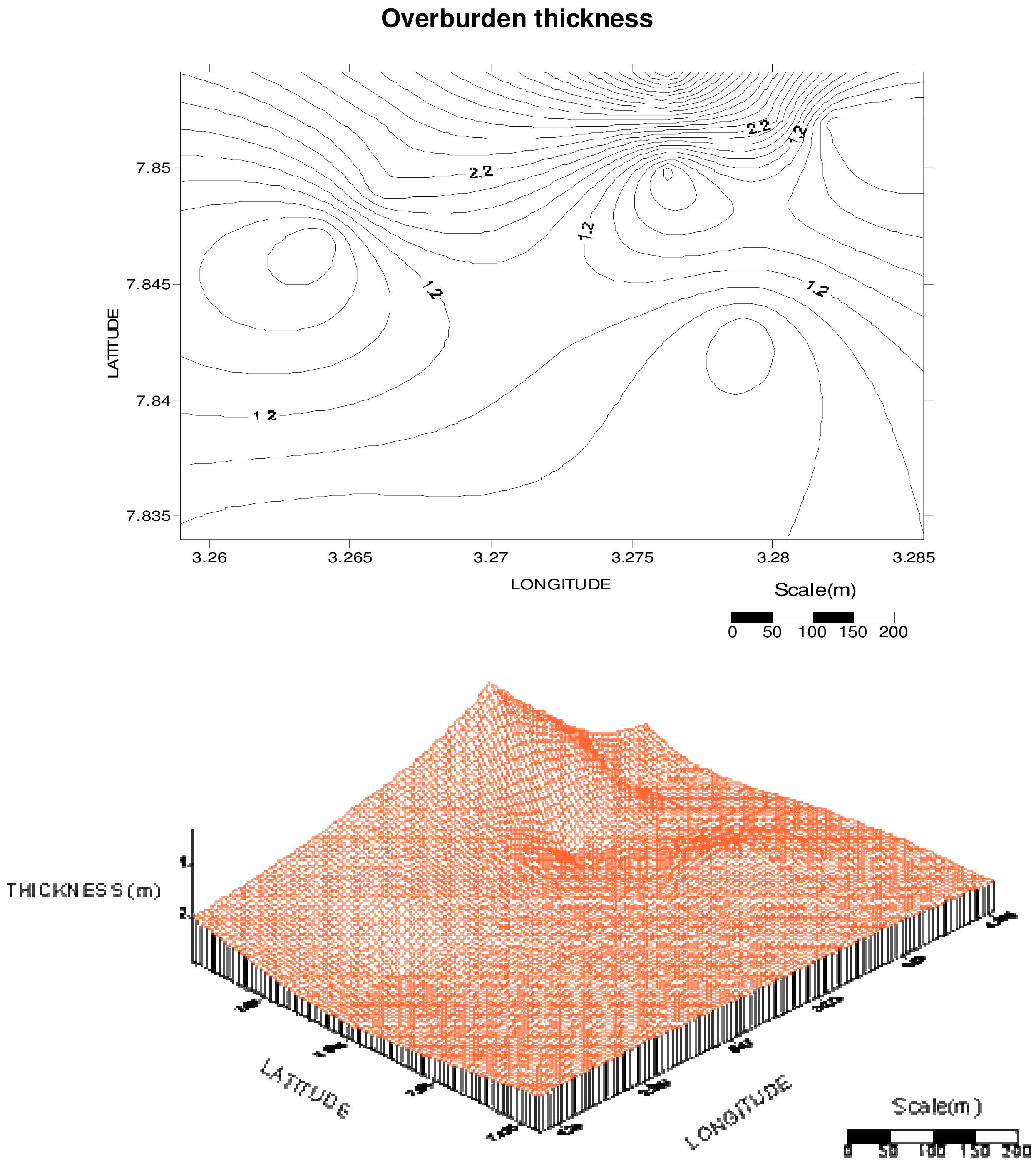

Figure 4b. Contour maps showing overburden thickness and 3-D view.

various total depths of the VES locations while the overburden thickness contour map (Figure 4b) depicts clearly the depth to the aquifer. This shows the area of thick overburden/depression along different profiles. The aquifer thickness map (Figure 4c) depicted various types of aquifer found in all VES locations sounded, an indication of what the groundwater accumulation would be as well as the degree of recharging.

Conclusion

The geophysical investigation carried out at the Federal College of Education, Osiele, Abeokuta, Nigeria has revealed seven major geologic formations. These are topsoil, shale/clay, sandy clay, clayey sand, sandstone, fractured basement and fresh basement. The weathered and fractured basement constitutes the main aquiferous

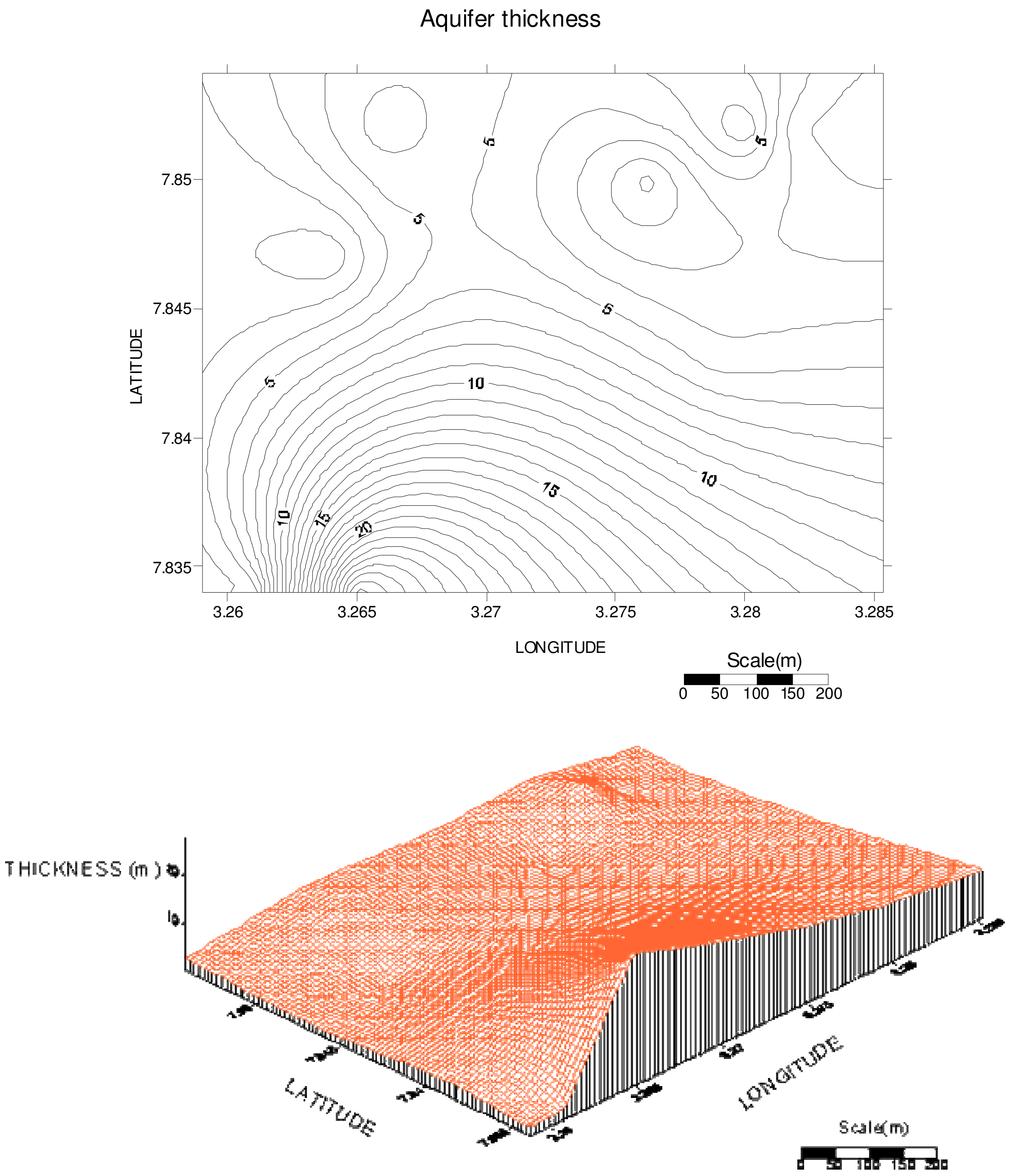

Figure 4c. Contour Maps Showing Overburden thickness and 3-D View.

units in the area. The reasons for borehole failure and poor recharge may be attributed to inadequate geophysical investigation, the depth at which drilling was terminated and the geologic formation of the aquifers. Thus a thorough geophysical survey of this area is necessary so as to determine suitable location for groundwater exploration.

The recommended depth for borehole in basement areas are usually within 35 and 70 m as reported in literature. Therefore good prospect exist for groundwater development in most of the locations surveyed in study area. Such locations include VES 1, 2, 5, 9, 11, 19, 28 and 29 and this is because the depths to weathered layer (clayey sand)/fractured layer falls within the depth range of 20 to 38 m.

However, locations around VES 10, 26 and 30 are not recommended for borehole drilling because the weathered layers, even though with appreciable thickness are composed of shale/clay. This is because shale/clay is an aquitard, which makes groundwater exploration difficult.

ACKNOWLEDGEMENT

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