Interpretation of Electromagnetic and Geoelectric Sounding Data for Groundwater Resources around Obanla-Obakekere, near Akure, Southwestern Nigeria.

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ABSTRACT

To investigate the groundwater prospect in the crystalline basement area of Obanla -Obakekere, near Akure, Southwestern Nigeria, electromagnetic (EM) profiling and Schlumberger sounding data from the area were interpreted. The EM results revealed that the raw real and filtered real amplitudes vary from -30.2 to 45.1% and -51.8 to 55.0%, respectively. Structural features of significance to groundwater development were clearly evident in the color modulated Karous–Hjelt EM sections. The interpretation of the VES data enabled the characterization of three to five geoelectric layers, but three distinct lithologic layers, from which aquifer units were delineated. Overburden and bedrock–based aquifer units were delineated across the area. The composite thickness of the overburden/bedrock – based aquifer units varies from 1m to 41.6m in the area. The aquifer thickness parameters enabled the hydrogeologic zonation of the area into groundwater prospect zones. Areas with thick units are inferred to have higher groundwater prospects while zones with thin aquifer units are believed to have low groundwater prospects. The survey demonstrates the utility of EM profiling and depth soundings to characterize local hydrogeology and define areas suitable for groundwater development.

(Keywords: electromagnetic profiling, depth sounding, geoelectric layers, lithologic layers, aquifer units, hydrogeologic framework)

INTRODUCTION

The campus of the Federal University of Technology, Akure, Southwestern Nigeria is located in Obanla-Obakekere (Figure 1) on the outskirts of the city. After about twenty-five years of existence, the institution has yet to be connected to a municipal water source. Recent growth in student and staff populations has imposed significant stress on the existing inadequate water scheme, based solely on groundwater abstraction from boreholes around the campus. Consequently, it became very expedient to expand the existing water scheme. The focus was to delineate the area into hydrogeologic zones in order to increase the number of effective boreholes in the area.

Groundwater occurrence in the crystalline basement terrain can be very irregular due to abrupt discontinuity in lithology, thickness, and electrical properties of the overburden and weathered bedrock (Satpathy and Kanugo, 1976: Offodile, 1983; Olorunfemi and Fasuyi, 1993). Consequently, groundwater exploration within such geologic setting requires integration of geophysical data types to effectively characterize the hydrogeologic zones and to enhance successful identification of well locations.

Electromagnetic (EM) profiling and vertical electrical sounding (VES) geophysics have been complementarily used in the delineation of basement regolith and fissured media and associated deep weathering (Beeson and Jones, 1988; Hazel et al., 1988; Bernard and Valla, 1991).

Palacky et al. (1981), Olayinka et al. (2004) and Sundararajan et al. (2007) have shown that such an integrated approach often enhance the reliability of data interpretation and hence the success rate of water well location. Similar studies (Omosuyi et al., 2003) used only the VES data to characterize the area into groundwater prospect zones. In this study however, the EM and depth sounding data were used to map the hydrogeologic units and characterize the area into groundwater resources zones for the location of water wells.

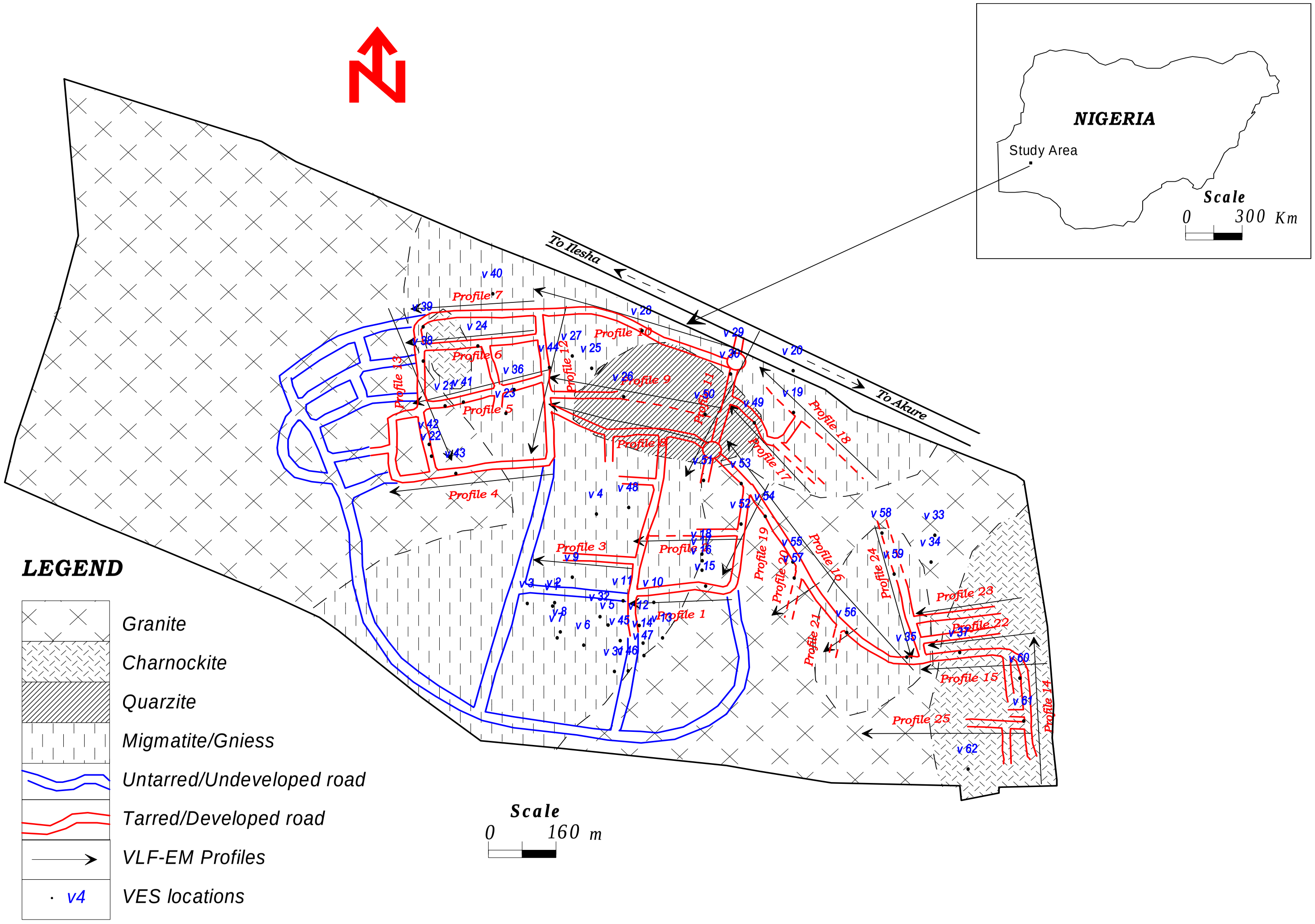


Fig. 1: Geological Map of the Study Area, showing the VES locations and the VLF-EM Profiles. (Inset: Map of Nigeria.)

PHYSIOGRAPHIC, GEOLOGIC AND HYDROGEOLOGIC SETTING

The university campus lies between latitudes 70 17’N and 70 18’N, and longitudes 50 08’E and 50 09’E. Topographic elevation ranges between 365m and 415m above the sea level. The area is characterized by dry (November to March) and wet (April to October) seasons and mean annual rainfall ranging between 1000mm and 1500mm. The vegetation is mostly secondary, due to intense cultivation, with pockets of typical tropical rainforest rainfall vegetation occurring in the undeveloped portion.

The area is underlain by the Precambrian basement complex rocks of southwestern Nigeria (Rahaman, 1976). Rock types identified within the campus include the gneissic rocks (granite gneiss and biotite gneiss), quartzite and charnckite (Kareem, 1995). Outcrops of biotite gneiss occur mostly in the central part of the area. Granite gneisses were observed as intrusives within the biotite gneiss. The suites are dissected in places by quartzofeldpathic veins and bands, giving them conspicuous foliation characteristics. Quartzite occurs as a low gradient hill in the north-cental part of the area (Figure 1), while charnockite occurs as intrusive in the low-lying outcrops within the biotite gneiss. Field observations show that the granitic rocks constitute the most extensive units in the area.

In tropical and equatorial regions, weathering process creates superficial layers, with varying degrees of porosity and permeability. The unconsolidated superficial materials often constitute reliable aquifer units if significantly thick and appropriately porous and permeable (Lashkaripour, 2003). The concealed crystalline basement rocks, on the other hand, may contain incipient joints, highly faulted, and fracture systems, derived from multiple tectonic events they have experienced. The delineation of these fissured zones may facilitate the delineation of groundwater prospect zones, since they are known to house abundant groundwater (Omosuyi et al., 2003).

DATA ACQUISITION AND ANALYSIS

The EM response was measured using the ABEM WADI VLF-EM instrument. The instrument measures the electrical properties of subsurface materials as detailed in Mc Neil (1980a). EM data were collected at 20m intervals along twenty-five (25) profiles, with profile lengths ranging from 160m to 820m (Figure 1).

The VLF-EM data were presented as EM profiles, showing plots of raw real and filtered real values against station positions (Figure 2). The EM profiles were quantitatively analyzed (McNeil, 1980a and Palacky et al., 1981).

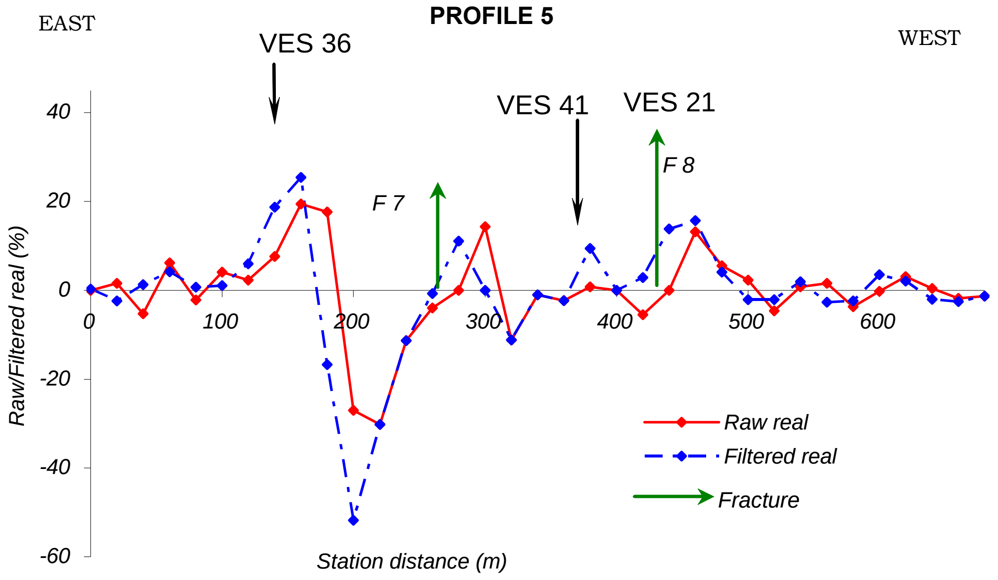
The quantitative analysis enabled the identification of profiles where positive amplitude of filtered real crossover the inflection points of the raw real as points of anomaly for vertical electrical sounding (Sundarajan et al., 2007). The VLF-EM sections are plotted as Karous-Hjelt filtered real component (Karous and Hjelt, 1983). The R-50 Soil Test Conductivity Meter was used for resistance measurements, engaging the Schlumberger array (Zohdy et al., 1974).

The soundings were conducted at points of anomaly quantitatively delineated from the EM profiles. Sixty-two (62) depth soundings were conducted, with maximum half-current electrode spacing (AB/2) of 100m. The field curves were manually interpreted (Koefoed, 1979), using master curves (Orellana and Money, 1966) and auxiliary point charts (Zohdy, 1965; Keller and Frishnecht, 1966).

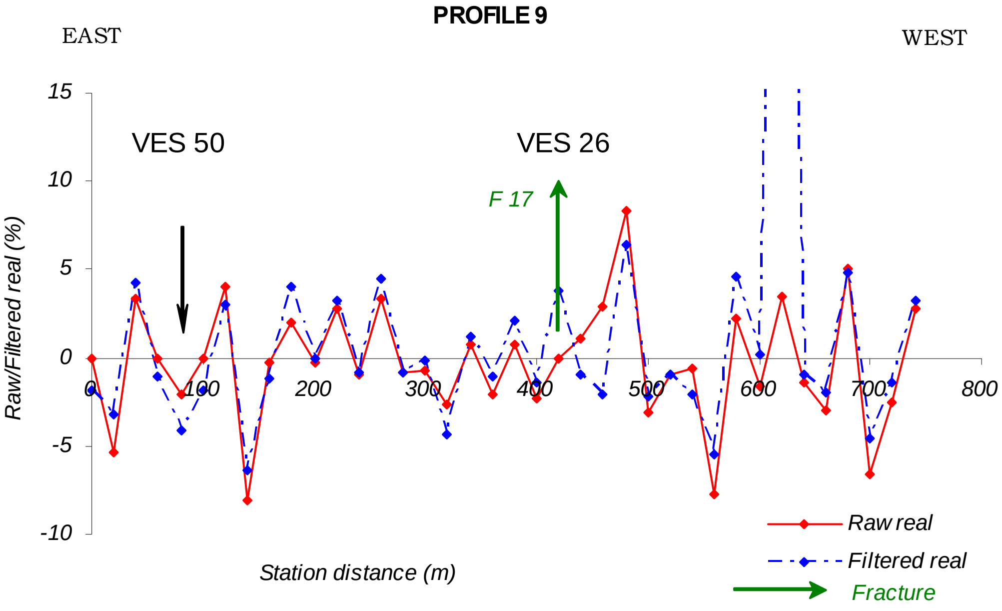
Geoelectric parameters obtained from manual interpretation were later used as a starting model for computer-assisted interpretation (Vander Velpen, 1988). The interpreter enters an initial geoelectric model. Through an iterative process, the program varies the thickness and electrical resistivity of each layer, but not the number of layers, until it finds a final geoelectric model that satisfactorily best fits the data (Figure 3).

RESULTS AND DISCUSSION

The VLF electromagnetic profiling data are presented as plots of filtered real and filtered imaginary (in %) against station position. Typical EM profiles from the study area are shown in Figure 2. Figure 3 shows typical sounding curves from the area while layer thickness and resistivity values are given in Appendix 1. Figures 4 and 5 show a comparison of the Karous-Hjelt filtered real component (Karous and Hjelt, 1983) and geoelectric section along profiles 5 and 9.



(Figure 2-A)



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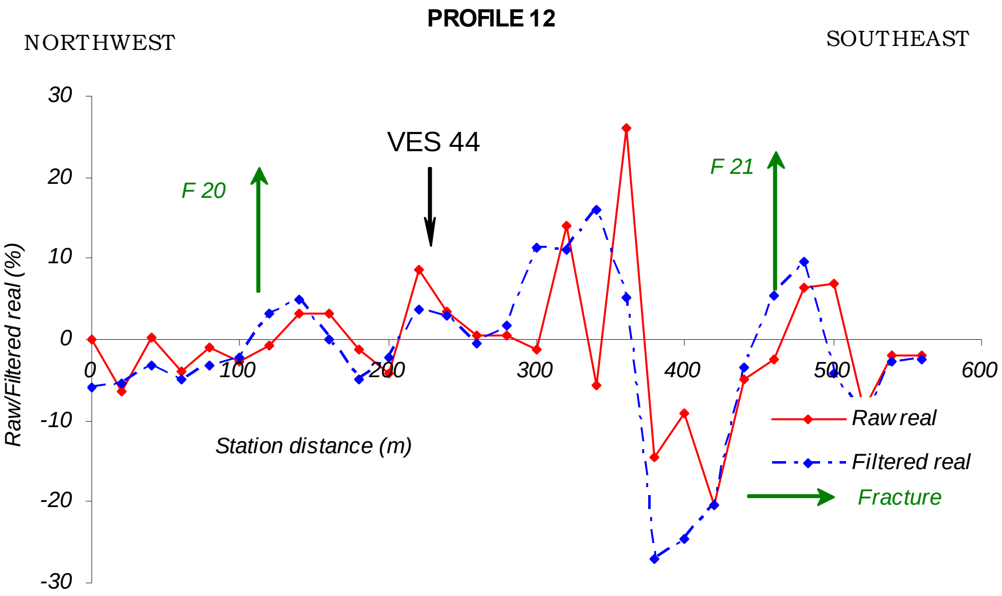

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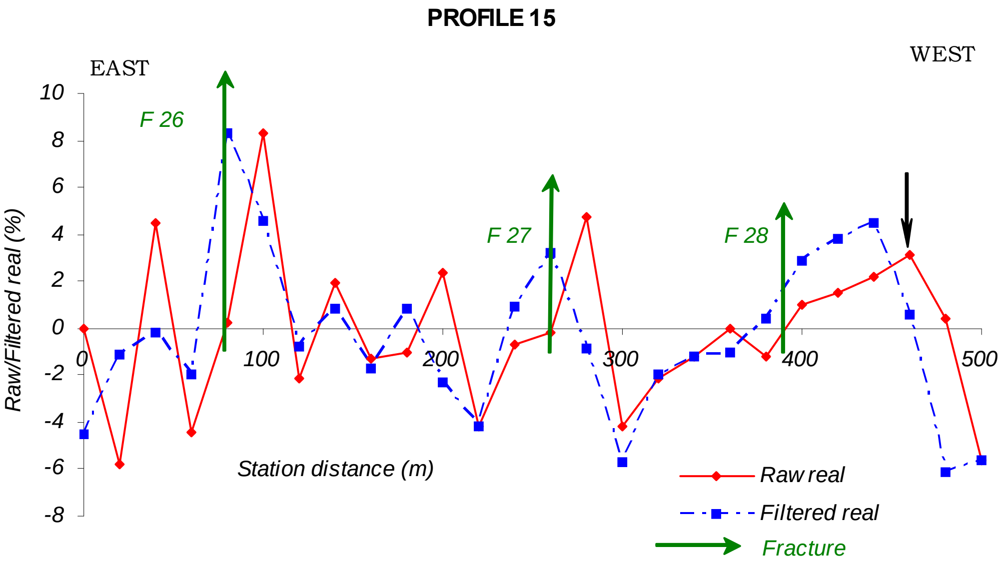

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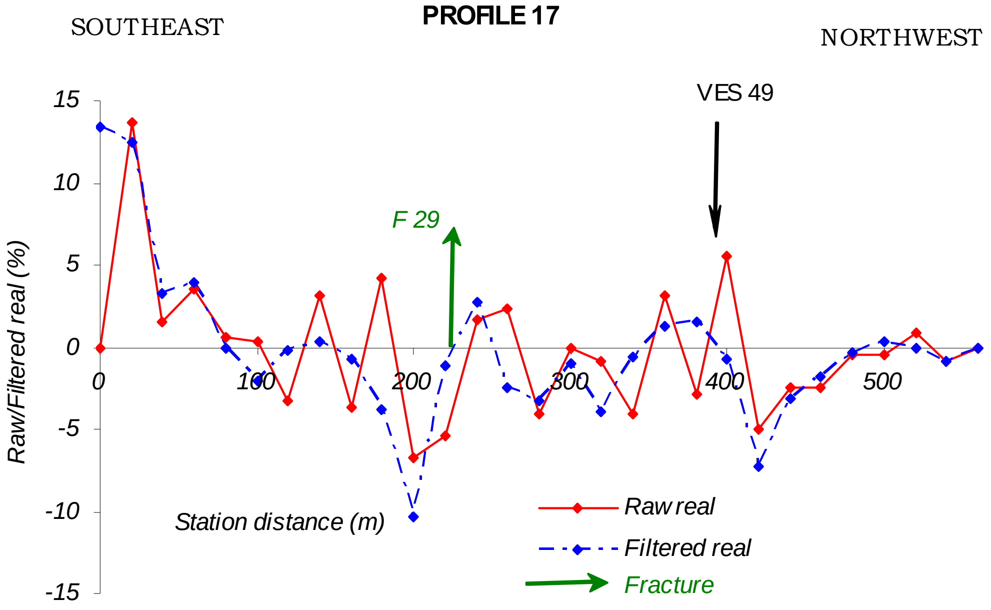


(Figure 2-E)

Figure 2: Typical VLF – EM Profiles from Obanla – Obakekere.

The EM anomalies vary significantly; some are sharp while others are broad, and are characterized with varying width extent. Zones with peak positive filtered real anomalies are inferred conductive, typical of water–filled fissures (Alvin et al., 1997), or effect of appreciable depth to bedrock (White et al., 1988). These zones are considered priority areas for depth sounding.

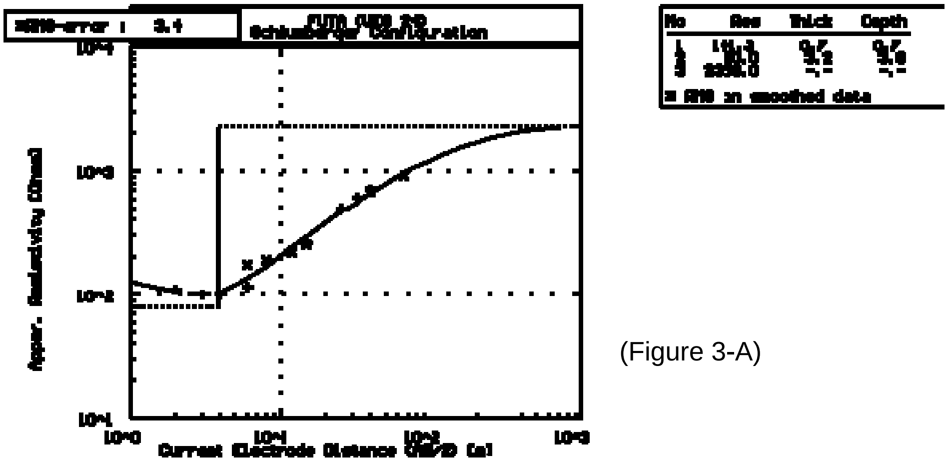
Figure 4 shows the linearly filtered real and imaginary components of the vertical magnetic field of the VLF data along profile 4 (Karous and Hjelt, 1093) and the corresponding geoelectric section along the profile. The section shows conductors at distance 280m and 440m, designated F7 and F8, respectively. In the three depth soundings (VES 36, 41 and 21) along this profile, weathered layer/fracture was delineated only in VES 21, and at depth of about 11.9m, corresponding to VLF-EM amplitude of 15.7% (filtered real) recorded around the zone.

This depth closely correlates with the depth of 12m obtained from the filtering of the VLF-EM data (Figure 4). Basement fractures contribute significantly to groundwater yield in a typical basement complex area (Ademilua & Olorunfemi, 2000).

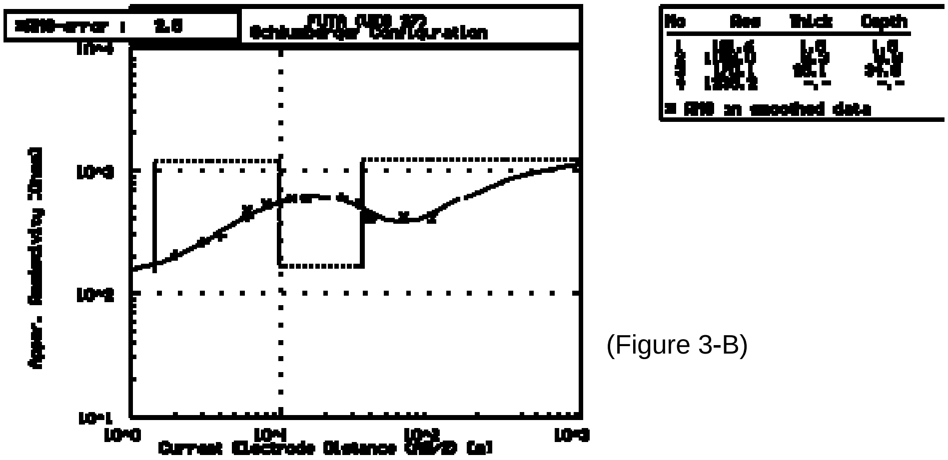
The VLF-EM/geoelectric section along profile 9 in the area is shown in Figure 4. This section revealed occurrence of a major fracture zone at distance of 420m and at depth of about 30m. The depth of occurrence of the fracture (28-69.6m) delineated from the interpretation of the VES data (VES 21) along this profile closely correlates with the EM anomaly pattern.

GEOELECTRIC CHARACTERIZATION AND LITHOLOGIC DELINEATION

Figure 3 shows typical VES curves from the study area. Electrical resistivity methods primarily reflect variation in ground resistivity. The electrical resistivity contrast between discrete geoelectric layers, or lithological sequences (Barker, 1980; Dodds and Ivic, 1998; Lashkarispour, 2003) in the subsurface are generally adequate to enable the characterization of geoelectric layers. This further assists the delineation and identification of aquiferous or non-aquiferous layers and reliable geological deductions.



(Figure 3-A)



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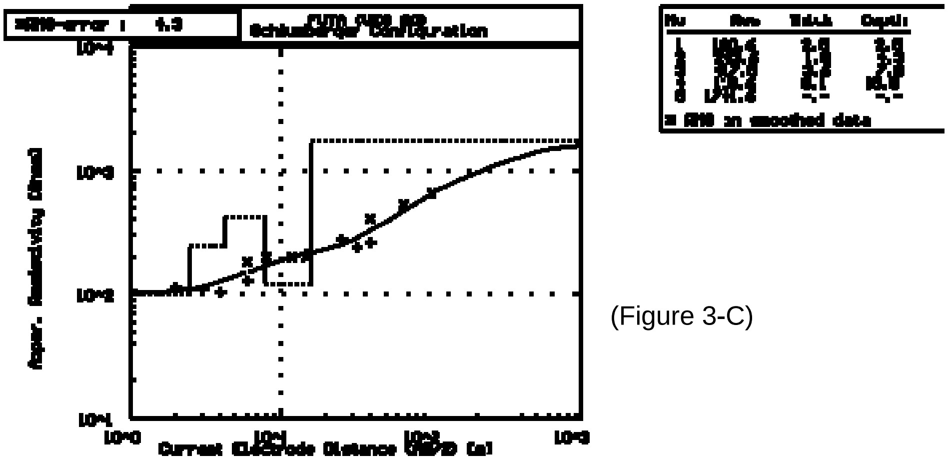


(Figure 3-C)

Figure 3: Typical VES Curves from Obanla -Obakekere.

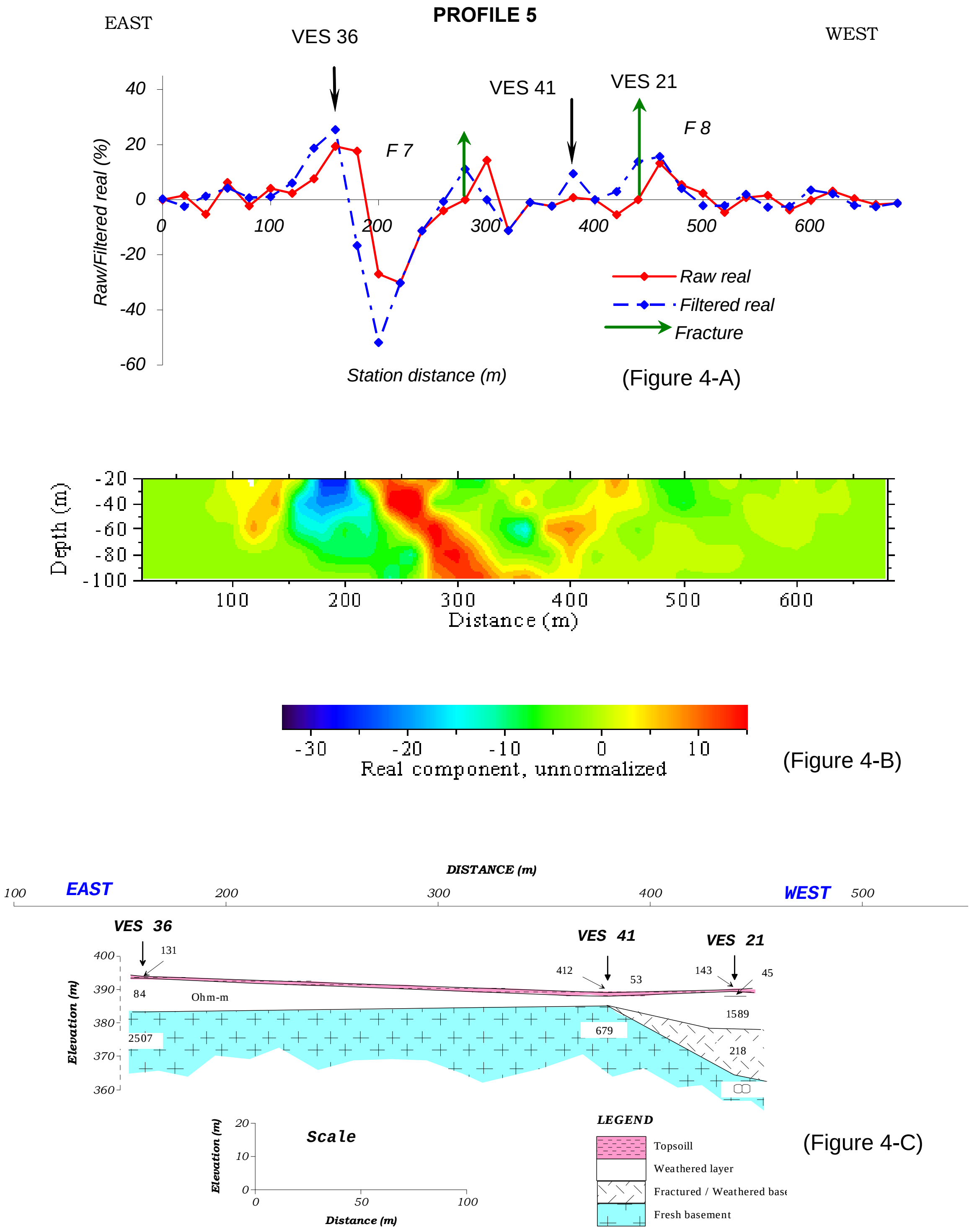
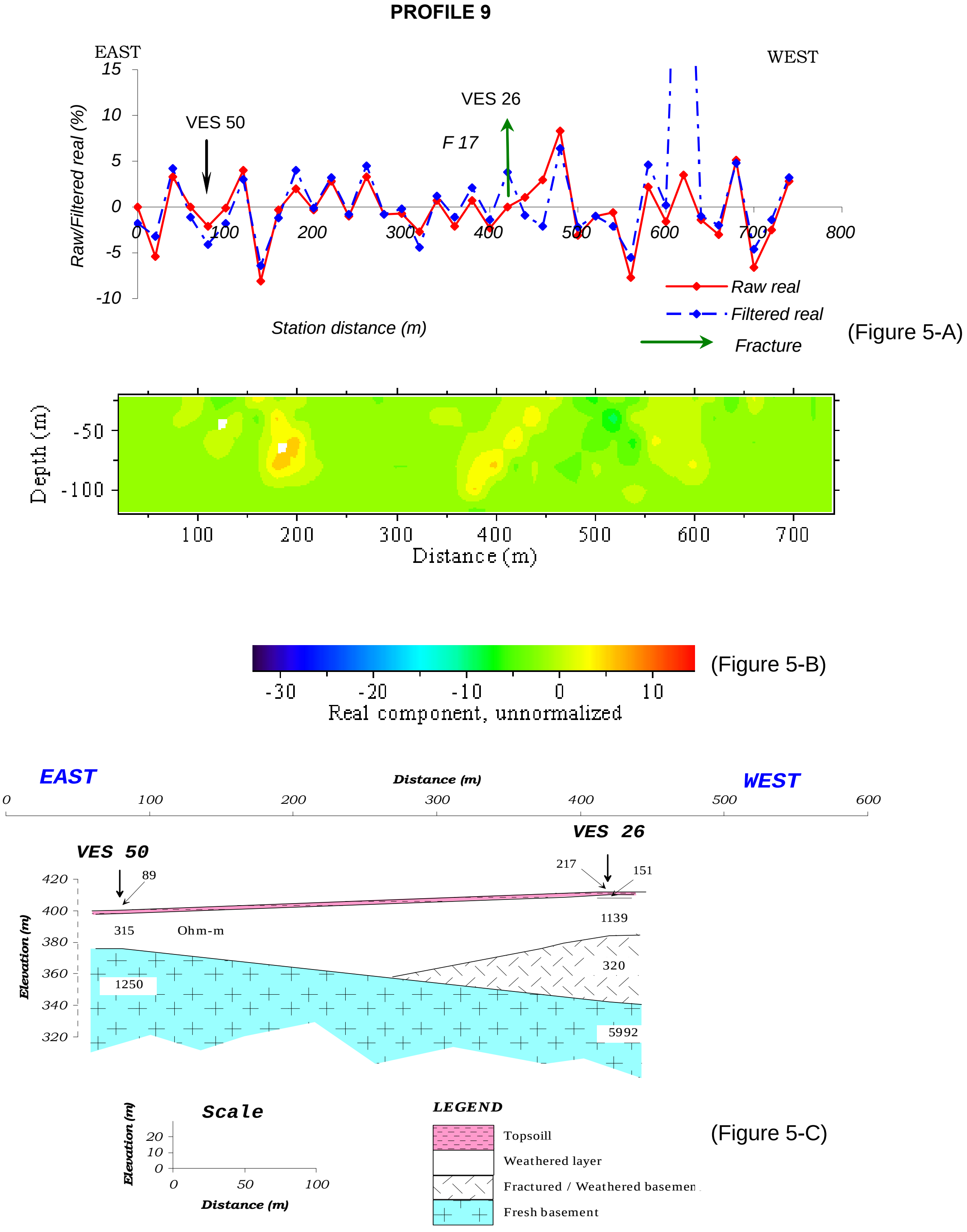


Figure 4: VLF–EM and Geoelectric Section along Profile 5.



(Figure 5-A)

(Figure 5-B)

(Figure 5-C)

Figure 5: VLF–EM and Geoelectric Section along Profile 9.

Figure 6-A shows a typical geological section based on the VES data interpreted. Three/four geoelectric layers underlie the northwest-southeast flank of the area. The first layer has resistivity values ranging from 98 to 198 Ohm-m, representing clayey sand/sand topsoil. It has an average thickness of 1.2m. It is underlain by clayey/sandy/lateritic layer, with resistivity ranging from14 to 1825 Ohm-m and average thickness of 7.0m.

The geoelectric basement is at depth ranging from 4.1m to 25.1m, with resistivity grater than 674 Ohm-m. The thickness and resistivity parameters of unconsolidated materials (over-burden) overlying the basement is important factor in the evaluation of groundwater potential in the crystalline basement area (Caruthers and Smith, 1992).

Figure 6B shows interpreted geological section taken along the north-south direction. The interpretation of the four VES data along this section reveals three/five geoelectric layers, but three distinct lithologic layers: the topsoil, with resistivity values ranging from 168 to 1420 Ohm-m and thickness varying from 0.5 to 1.8m; the weathered layer, with resistivity of 60 to 385 Ohm-m and average thickness of 14.5m; the basement, with resistivity values ranging from 396 to 1828 Ohm-m.

HYDROGEOLOGICAL ZONATION

In crystalline basement terrains, aquifers may occur within the overburden and/or the bedrock. The thickness, the lateral extent and the resistivity parameters of any of these aquifer units are important groundwater prospect evaluation in the area (Adegoke, 2008). Due to the heterogeneous nature of the basement terrains, the above parameters constantly vary. Hence, the need for hydrogeological zonation.

The maps (Figures 7 and 8) is a contour map derived from the composite thickness of the aquifer units delineated across the study points. Areas with thick aquifer units, or extensive fracture zones, are considered priority areas for groundwater development. (Palacky et al. 1981; Ademilua and Olorunfemi, 2000; Olayinka et al., 2004; Sundararajan et al., 2007).

CONCLUSIONS AND RECOMMENDATIONS

An attempt has been made to zone Obanla-Obakekere into groundwater prospect zones using an integrated electromagnetic profiling and vertical electrical sounding survey. The EM profiling shows that the VLF-EM anomaly varies from -30.2 to 45.1 in the raw real component, and from -51.8 to 55.0 in the filtered real component in the area.

Conductive features, which are characteristic of appreciably positive VLF-EM amplitudes, were interpreted as probable geologic fissures, capable of holding significant quantity of water. Further evaluation with the vertical electrical sounding enabled the delineation of the aquifer units and determination of the spatial variation of their thicknesses.

The composite thickness of the aquifer units varies from 1m to 41.6m across the area. This range of thickness enabled the characterization of the area into hydrogeologic zones. Areas with thick units are thought to have higher groundwater prospects while zones with thin aquifer units are believed to have low groundwater prospects. The former hydrogeologic zones are considered suitable for groundwater development.

The study reveals that the groundwater prospect in the study area is generally low. It is however noted that aquifer thickness is not the sole parameter in the evaluation of groundwater prospect of a place. Resistivity parameters, lithology and facies characteristics are relevant considerations. If these other parameters are constant, zones with thick aquifer units may have brighter groundwater prospects than areas with thin aquifer units.

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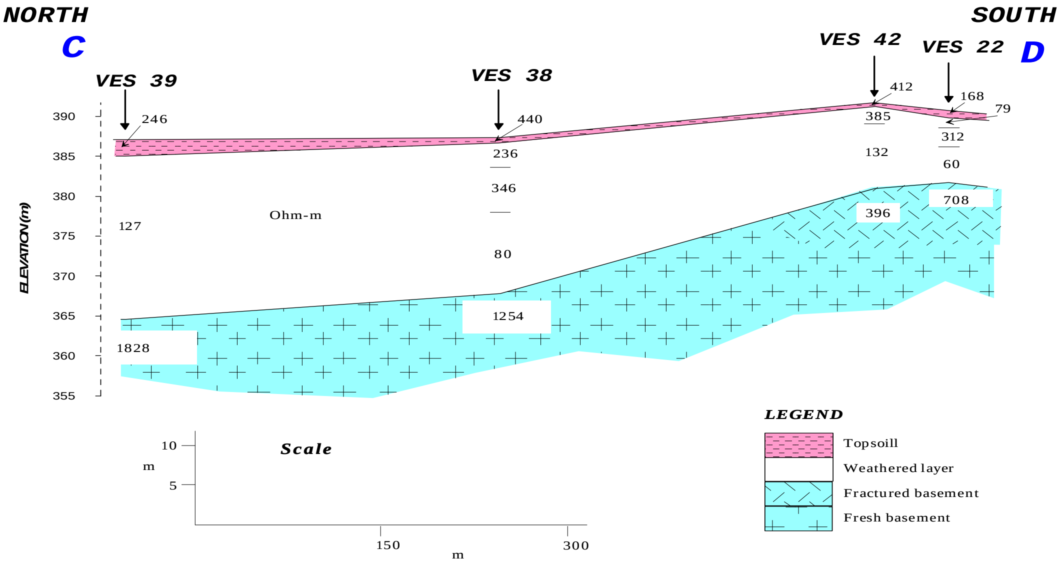

Figure 6a: Geoelectric Section along the North – South direction in the area.

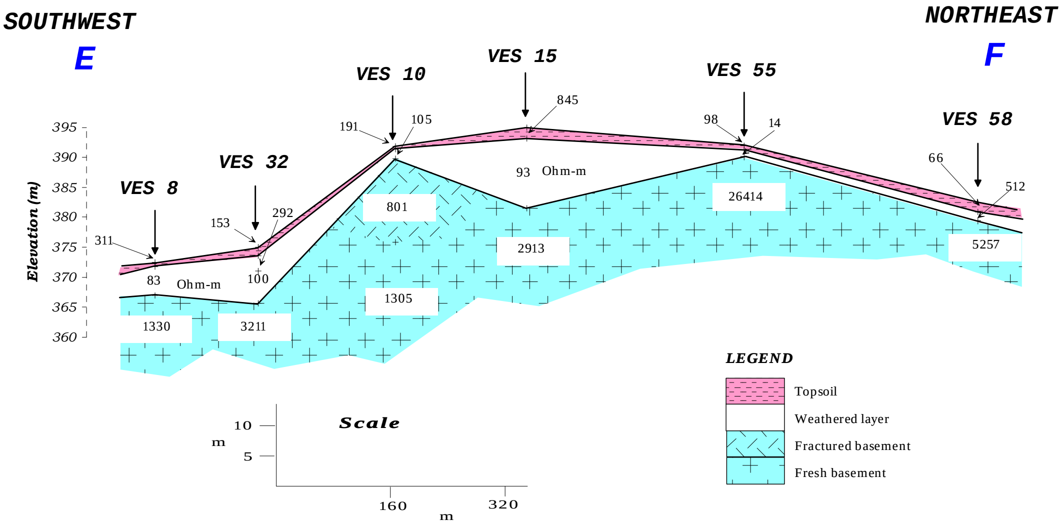

Figure 6b: Geoelectric Section along Southwest – Northeast direction in the area.

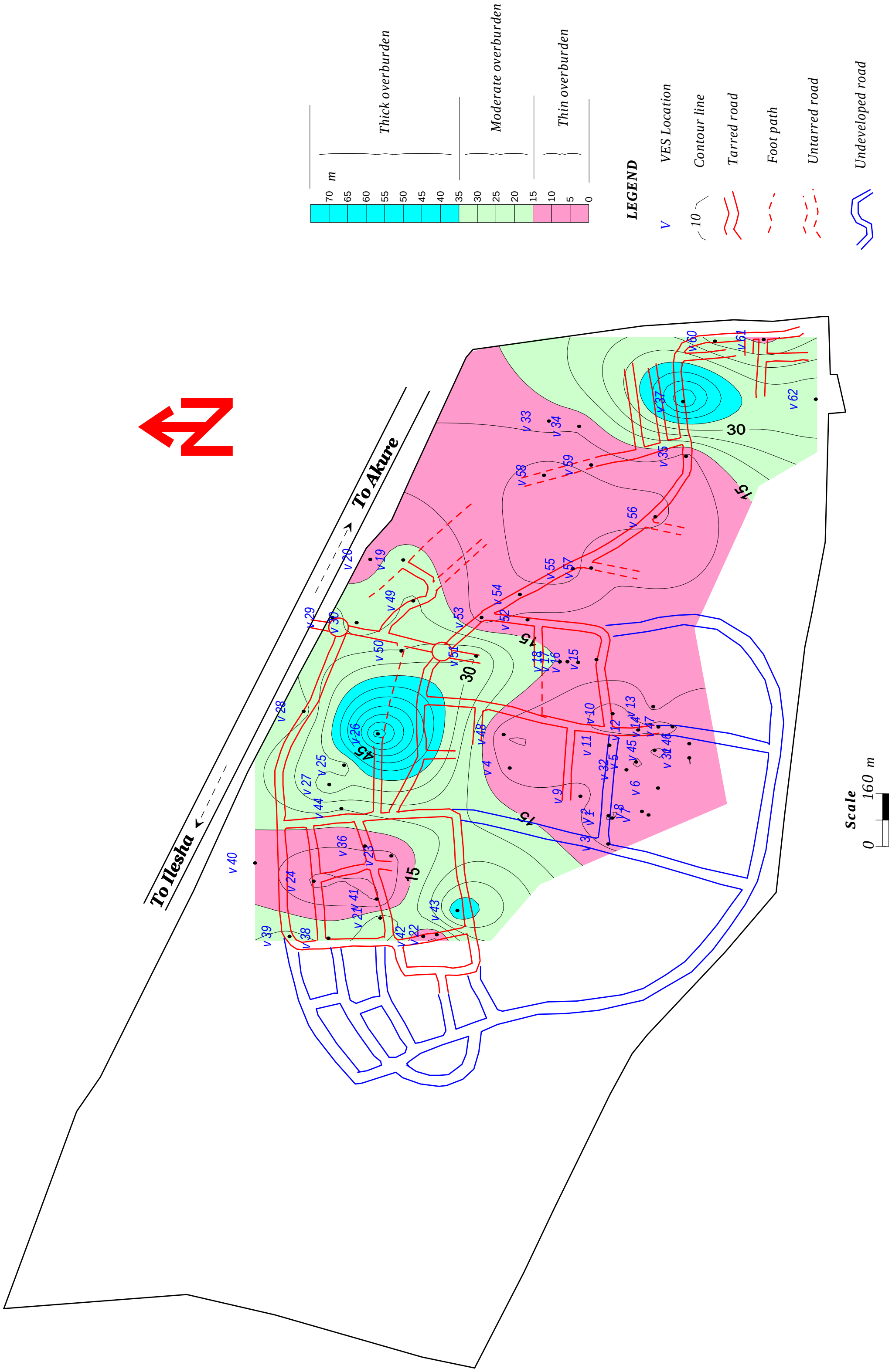

Fig. 7: Overburden Thickness Map of Obanla - Obakekere Area.

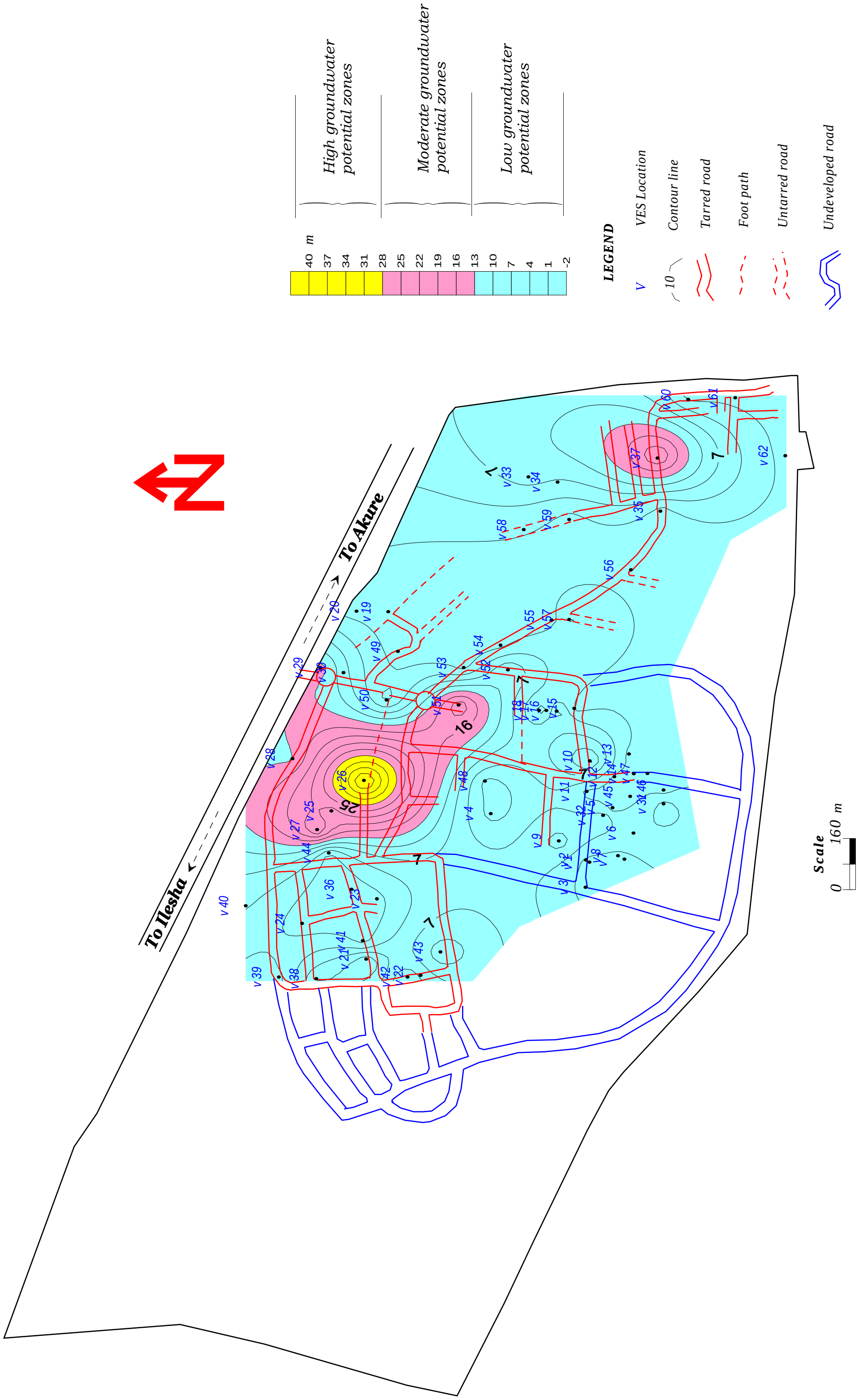

Fig. 8: Groundwater Potential Map of Obanla - Obakekere.

Appendix 1: Summary of Layer Model Interpretation of the Sounding Data from Obanla - Obakekere.

VES NO.	THICKNESS (m)				RESISTIVITY (Ohm-m)				
	h_1	h_2	H_3	h_4	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5
1	0.8	4.3			254	96	969		
2	1.0	3.1			530	66	1487		
3	1.3	8.3			230	89	1530		
4	1.0	6.7			89	141	10835		
5	1.1	2.1			308	20	13642		
6	0.5	1.5	3.7		160	281	111	2224	
7	1.3	6.1			166	89	2152		
8	0.7	4.8			311	82	1330		
9	0.6	2.6	8.5		188	350	79	996	
10	0.4	1.6	13.9		191	105	801	1305	
11	0.7	7.1			151	111	1095		
12	1.3	3.2			125	73	3537		
13	2.7	8.7			98	1378	1527		
14	1.0	1.9			153	29	2112		
15	1.8	12.0			845	92	2913		
16	0.7	2.0	9.7		132	200	50	1731	
17	1.4	12.4			418	115	1175		
18	2.6	12.2			410	124	1578		
19	1.3	17.1			197	52	2773		
20	0.9	8.7			229	56	934		
21	0.7	1.3	9. 9	13.6	143	45	1589	218	100000
22	0.9	1.2	2.4	4.5	168	79	312	60	708
23	0.8	7.6			251	80	5258		
24	0.7	3.2			141	80	2359		
25	1.8	5.0	20.2		216	1876	186	3219	
26	1.6	1.9	24.5	41.6	217	151	1138	320	5992
27	1.5	8.3	25.1		152	1199	170	1235	
28	1.8	2.9	12.6		114	1825	98	674	
29	2.3	6.4	14.5		227	429	190	1445	
30	2.5	1.8	3.6	8.1	100	244	418	120	1742

VES NO.	THICKNESS (m)				RESISTIVITY (Ohm-m)				
	h_1	h_2	h_3	h_4	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5
31	1.2	3.8	5.3		105	988	407	15191	
32	1.4	2.6	5.5		153	292	100	3211	
33	1.6	2.7	8.7		136	851	89	3488	
34	0.4	0.9	2.8	6.8	270	95	706	121	4601
35	0.5	7.8			124	45	1534		
36	0.6	10.3			131	89	2152		
37	1.4	2.4	30.4	22.3	69	26	300	179	100000
38	0.6	3.0	5.9	10.1	440	236	346	80	1253
39	1.8	20.6			246	127	1828		
40	0.5	7.7	4.2		198	260	148	3353	
41	1.0	3.0			412	53	679		
42	0.5	2.1	8.1		230	385	132	396	
43	1.2	2.1	25.4	12.2	82	9	658	92	99668
44	0.5	1.2	3.5	14.0	241	418	131	560	162
45	1.0	10.9			98	155	1760		
46	1.4	4.8			209	119	2937		
47	0.5	4.1			403	7490	1666		
48	0.9	4.0			40	361	989		
49	2.0	18.8			62	160	1400		
50	1.0	24.1			89	315	1250		
51	2.0	6.9	21.5		174	404	138	2129	
52	1.7	10.1			149	500	2629		
53	0.8	6.3			125	147	5862		
54	1.3	5.1			130	57	4138		
55	0.8	1.1			98	14	26415		
56	1.4	2.7			198	62	90224		
57	0.5	1.4	3.6	4.3	497	165	595	204	3870
58	1.6	1.5			66	513	5257		
59	2.3	4.1			53	76	410		
60	1.5	4.2	11.2		49	336	41	2560	
61	0.7	11.7			47	16	323		
62	3.0	5.9	26.4		104	321	71	5575	

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