Geophysical Investigation of a Suspected Foundation Failure at Ogbomoso, Southwestern, Nigeria.

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ABSTRACT

A geophysical investigation was carried out around the abandoned Ogbomoso North Local Government Secretariat Complex Building with a view to identifying the cause(s) of the failure of the foundation of the building.

Twenty (20) Vertical Electrical Soundings (VES) were carried out using Schlumberger electrode array. Dipole-dipole 2-D imaging was also undertaken along four traverses each 130 m long. The VES data were interpreted quantitatively using the partial curve matching method and computer assisted 1-D forward modeling. The VES interpretation results were used to generate geoelectric sections. The Dipole-Dipole data were inverted into 2-D subsurface images using the Dippro Software.

The geoelectric sections reveal four subsurface layers which include the topsoil, with resistivity values that vary from 69 – 1161 ohm-m and thicknesses of between 0.4 and 1.8 m. The weathered layer is characterized by resistivity values ranging from 34 – 364 ohm-m and thicknesses of between 0.7 and 10.1 m. The partly weathered/fractured basement was identified beneath VES 14 and 19 with resistivity values of 27 – 784 ohm-m and thicknesses of 2.4 – 4.2 m. The basement bedrock has resistivity values of between 724 and ∞ ohm – m with depth to the geoelectric bedrock of between 3.2 and 15 m. The 2-D images delineate three major subsurface layers – a topsoil (generally in blue color band), the weathered layer (in green color band) and a basement bedrock (in yellowish/reddish/purple color band). The resistivity structures identify a major linear feature suspected to be a fault that cut across the building site. The faulted zone is about 20 – 30 m wide.

It is suspected that the failure of the building foundation may have been precipitated by differential settlement within the suspected faulted zone.

(Keywords: electrical resistivity, basement complex, subsurface layers, fault, foundation failure.)

INTRODUCTION

In recent time, there has been a spate of building collapse in both sedimentary and basement environment, across the country. The usually adduced reasons for the collapse are poor quality of construction materials, design error, and poor construction practice. The nature and state of the earth materials on which the buildings are founded are rarely considered as possible cause(s) of foundation failure. All civil engineering structures (e.g. buildings, roads, dams etc.) are founded on earth materials (soil/rocks).

The geophysical methods that suit such investigations are the electrical resistivity, gravity and seismic refraction methods (e.g., Ako, 1976; Olorunfemi and Meshida, 1987, Boyce and Koseoglu, 1996; Aina et al., 1996; Olorunfemi et al., 2000a&b; Olorunfemi et al., 2005 and Olorunfemi, 2008). Of these methods the electrical resistivity method is the most commonly employed as it combines speed, accuracy and cost effectiveness in the identification of faults, fractures, buried metallic pipes, vertical rock contacts and leachate/seepage paths. The electrical resistivity method was therefore used to investigate the cause(s) of a suspected foundation failure of the abandoned Ogbomoso North Local Government building complex located at Ogbomoso in Oyo State (Figure 1).

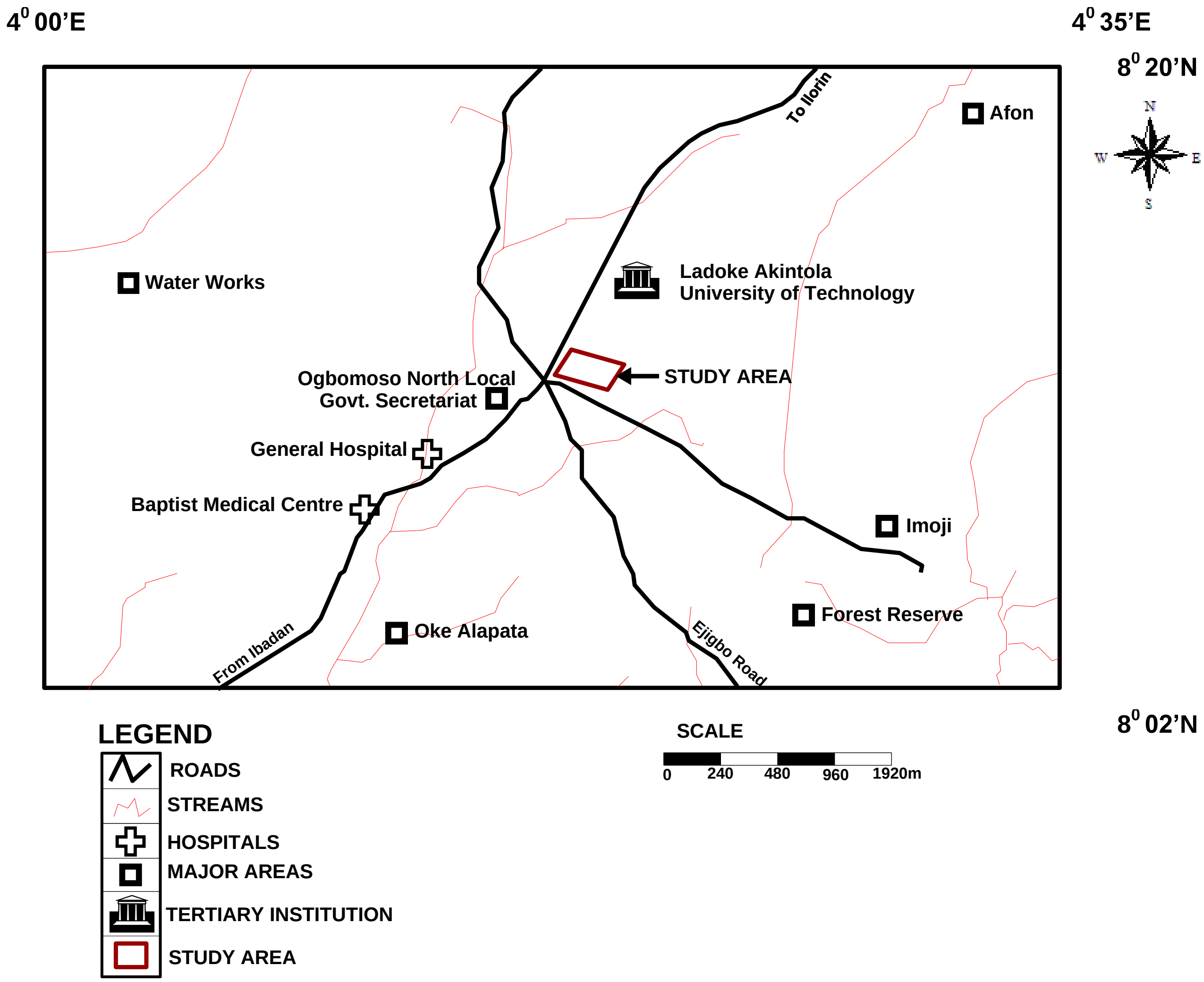


Figure 1: Map of Ogbomoso Showing the Study Area.

The failure manifests as a major crack accompanied by a vertical displacement at the second floor of the building which is suspected to have been precipitated by foundation settlement (Figure 2).

LOCATION, GEOMORPHOLOGY, AND GEOLOGY

The study area is located at Ogbomoso in Oyo State, Nigeria. The failed complex is located along Ogbomoso – Ilorin Road, not far from the Ladoke Akintola University of Technology (LAUTECH) (Figure 1). It is located within longitudes $4^{0}15.6^{I}$E and $4^{0}15.62^{I}$E and latitudes $8^{0}09.8^{I}$N and $8^{0}09.93^{I}$N. The site is accessible through the Ilorin-Ogbomoso road and the South gate of Ladoke Akintola University of Technology, Ogbomoso.

The area exhibits the typical tropical climate of averagely high temperature, high relative humidity and generally two rainfall maxima regimes during the rainfall period of March to October. The dry season extends from November to February. The mean temperature is highest at the end of the Harmattan (averaging 28^{0}C), that is from the middle of January to the onset of the rains at the middle of March. The vegetation is the rain forest type and is composed of tall crowned trees mixed with thick undergrowth. The area around Ogbomoso is underlain by the Basement Complex Rocks (Rahaman, 1971 & 1973). The lithological units are composed of quartzites, banded-gneiss, and granite gneiss. The quartzites are light colored and may be part of the Migmatite-Gneiss-Quartzite complex. The study area is underlain by banded-gneiss. The banded gneiss is the most abundant type and consists of alternating parallel light and dark colored bands.

METHODOLOGY

The electrical resistivity method was adopted for the geophysical survey. The survey utilized the Schlumberger Vertical Electrical Sounding (VES) and the dipole-dipole horizontal profiling techniques. The Digital Ohmega Resistivity Meter was used for the data collection. The site layout for the survey is shown in Figure 2. Four (4) traverses were established parallel to the orientation of the building in northwest – southeast direction. Five (5) VES stations were occupied along each of the traverses and located at both side of the building. The Schlumberger electrode spacing was varied from 1 to 65m. For the dipole-dipole profiling, the same four traverses were used for the data collection. The length of the traverses varied from 130 to 135m. The dipole length for the dipole-dipole was 10m, with an expansion factor, n, ranging from 1 to 5. Twenty (20) VES stations were occupied. The GPS was used to record geographical coordinates (in UTM) of the VES stations and the traverse lines.

RESULTS AND DISCUSSION

The resistivity curves obtained from the survey are the A, H, HA, KH, HKH, and HKHA Type, with the H-Type being dominant (Figure 3). The depth sounding interpretation results (Table 1) are presented as 2-D geoelectric sections (Figure 4). The 2-D subsurface images obtained from the inversion of the dipole – dipole data are presented in Figure 5.

Geoelectric Sections

The 2-D geoelectric sections along the four traverses (Figures 4(a-d)) delineate four subsurface geologic units which comprise the topsoil, weathered layer, partly weathered/fractured basement and the fresh basement bedrock. The topsoil has resistivity values that vary from 69 – 1161 ohm-m and thickness values ranging from 0.4 – 1.8 m. It is composed of clay, sandy clay, clayey sand and laterite. The second layer is the weathered layer. It is characterized by resistivity values ranging from 34 – 364 ohm-m and thicknesses varying from 0.7 – 10.1 m. It is composed of clay and sand clay. The partly weathered/fractured basement third layer (beneath VES 14 and 19) has layer resistivity values of 27 – 784 ohm-m and thicknesses of 2.5 to 4.2m. The basement bedrock which is fresh in most places has layer resistivity values of 724 – 18176 ohm-m. The depth to the geoelectric bedrock varies from 3.2 to 15 m.

Dipole – Dipole Pseudosections

The observed dipole-dipole pseudosections generated along Traverses (TR) 1, 2, 3 and 4 show both lateral and vertical variations in the apparent resistivity values (Figures 5 – 8). The 2-D resistivity structures are the subsurface images inverted from the apparent resistivity values. The 2-D images delineate three major subsurface layers – a topsoil (generally in blue color band), the weathered layer (in green color band) and the basement bedrock (in yellowish/reddish/purple color band), the yellowish color band is a transition zone between the fresh basement and the weathered layer.

The 2-D resistivity structure beneath Traverse (TR 1) (Figure 5) displays a thin (<2m) and clayey topsoil with resistivity values of <100 ohm-m. The weathered layer, in green color, has resistivity values of between 100 and 500 ohm-m with average thickness of about 10m. The basement bedrock has resistivity values greater than 500 0hm-m and in yellowish/reddish/purple color band.

The interface between the weathered layer and the basement bedrock is gently undulating. Depth to the basement bedrock is between 10 – 15 m. A vertical discontinuity which manifests as anomalously low resistivity zone within high resistivity zone and suspected to be a fault, is located beneath VES 4 (between distances 95 – 110 m). This suspected linear feature has a depth extent of up to 30 m. The 2-D image significantly correlates with the geoelectric section along this traverse (see Figure 4a).

Table 1: VES Interpretation Results and the Lithological Description.

VES Station	Curve Type	No. of Layers	Resistivity Value (Ωm)	Depth (m)	Lithological Description
		1	69	0.4	Topsoil
	KH	2	432	1.2	Laterite
1		3	53	3.4	Weathered Layer
		4	3599	-	Fresh Basement
2		1	1161	0.8	Topsoil
	H	2	125	8.9	Weathered Layer
		3	10934	-	Fresh Basement
3		1	98	0.9	Topsoil
	H	2	173	10.1	Weathered Layer
		3	1778	-	Fresh Basement
		1	930	1.8	Topsoil
4	H	2	170	8.5	Weathered Layer
		3	1198	-	Fresh Basement
5		1	536	1.5	Topsoil
	H	2	104	7.2	Weathered Layer
		3	6467	-	Fresh Basement
		1	100	0.6	Topsoil
6	KH	2	457	1.2	Laterite
		3	119	3.7	Weathered Layer
		4	20678	-	Fresh Basement
		1	841	0.9	Topsoil
7	H	2	126	6.1	Weathered Layer
		3	1960	-	Fresh Basement
8		1	519	1.4	Topsoil
	H	2	89	5.1	Weathered Layer
		3	891	-	Fresh Basement
9		1	945	1.7	Topsoil
	H	2	140	6.6	Weathered Layer
		3	1468	-	Fresh Basement
10		1	620	1.3	Topsoil
	H	2	169	8.0	Weathered Layer
		3	3664	-	Fresh Basement

11	A	1	70	1.1	Topsoil
		2	131	8.8	Weathered Layer
		3	724	-	Fresh Basement
12	HA	1	450	0.4	Topsoil
		2	47	1.4	Weathered Layer
		3	861	2.9	Partly weathered/fractured basement
		4	1601	-	Fresh Basement
13	H	1	984	0.5	Topsoil
		2	154	4.0	Weathered Layer
		3	2313	-	Fresh Basement
14	HKH	1	1021	0.4	Topsoil
		2	32	0.9	Weathered Layer
		3	1606	1.1	Fresh Basement
		4	84	5.3	Fracture Basement
		5	2817	-	Fresh Basement
15	HA	1	881	1.8	Topsoil
		2	364	10.0	Weathered Layer
		3	8363	11.1	Fresh Basement
		4	12206	-	Fresh Basement
16	KH	1	117	0.6	Topsoil
		2	198	1.3	Laterite
		3	62	2.9	Weathered Layer
		4	2070	-	Fresh Basement
17	H	1	75	0.5	Topsoil
		2	35	1.5	Weathered Layer
		3	3008	-	Fresh Basement
18	H	1	193	1.0	Topsoil
		2	40	3.0	Weathered Layer
		3	18176	-	Fresh Basement
19	HKHA	1	1694	0.4	Topsoil
		2	34	0.7	Weathered Layer
		3	245	1.4	Fresh basement
		4	27	2.4	Fractured basement
		5	784	3.2	Fresh basement
		6	14761	-	Fresh Basement
20	H	1	462	1.8	Topsoil
		2	116	5.9	Weathered Layer
		3	3826	-	Fresh Basement

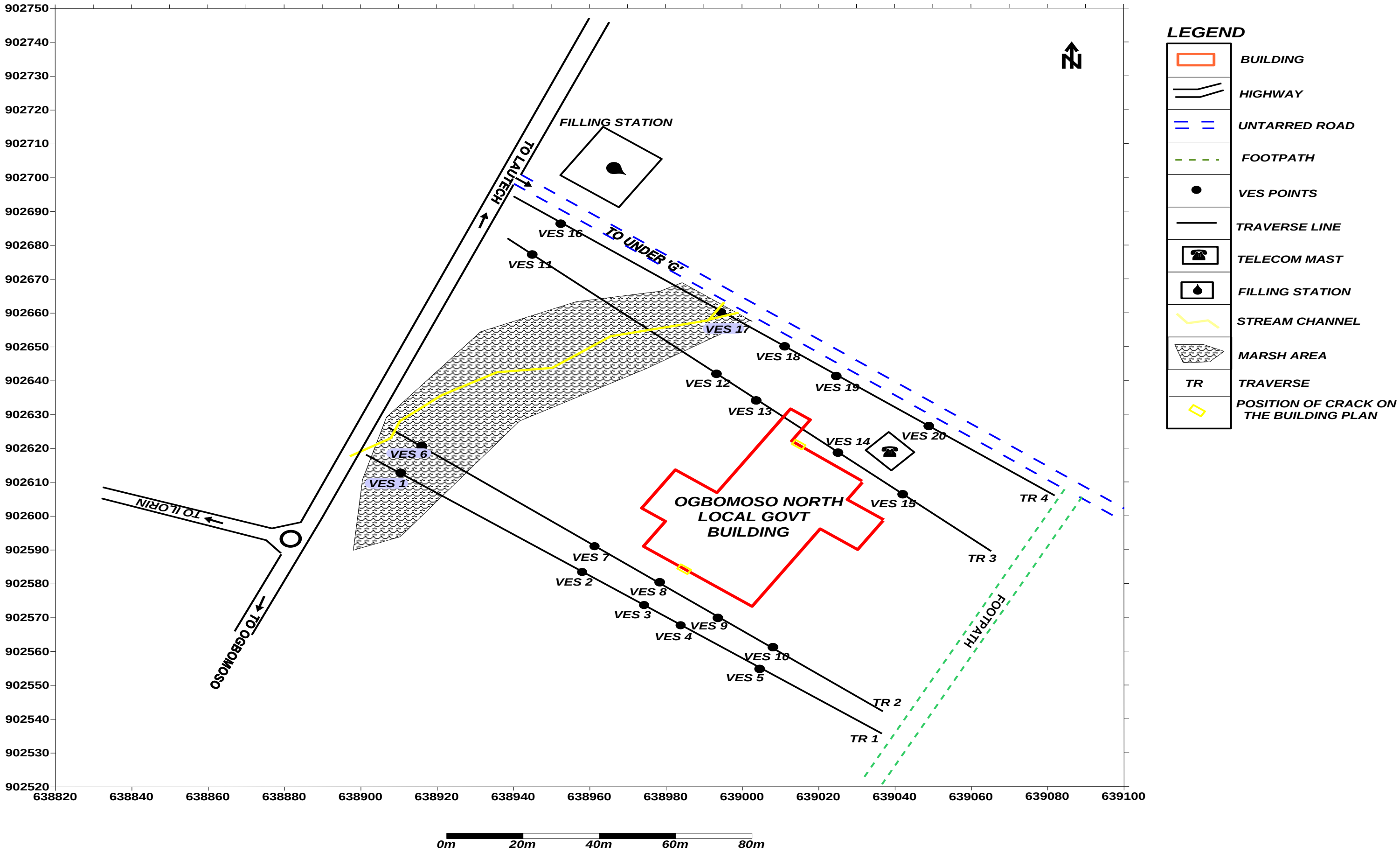


Figure 2: Geophysical Data Acquisition Map

The 2-D resistivity structure beneath Traverse TR2 (Figure 6) also displays a relatively thin (average of about 2.5 m) topsoil with relatively low resistivity values of < 200 ohm-m. The weathered layer, in green color band, has layer resistivity of 200 – 500 ohm-m. The interface between the weathered layer and the basement bedrock is undulating with overburden thickness varying from about 5 – 15 m. The basement bedrock has resistivity values that are greater than 500 ohm-m. A vertical discontinuity, also suspected to be a fault, exists beneath VES 8 & 9 (between distances 90 – 110m) along the traverse line. The depth extent seems greater that 30m. The 2-D image correlates significantly with the geoelectric section (see Figure 4b).

The 2-D resistivity structure beneath Traverse TR3 (Figure 7), shows a topsoil that is generally very thin (<1) and virtually merges in resistivity range with the weathered layer. The weathered layer resistivity ranges in value from 100 – 362 ohm-m. The overburden thickness averages about 5 m. A major vertical discontinuity exists beneath VES 14 (between distances 85 – 115 m). It manifests as a low resistivity zone within a high resistivity basement bedrock. This feature is characteristic of a fault. VES 14 identifies a confined fractured basement column (see Figure 4c). The 2-D image correlates significantly with the geoelectric section developed along this traverse (see Figure 4c).

The 2-D resistivity structure beneath Traverse TR 4 (Figure 8) shows a topsoil with resistivity of <100 ohm-m with an average thickness of about 2.5 m thick. The weathered layer with resistivity of up to 500 ohm-m overlies the basement bedrock at depths ranging from about 10 – 16 m. The basement bedrock interface is gently undulating.

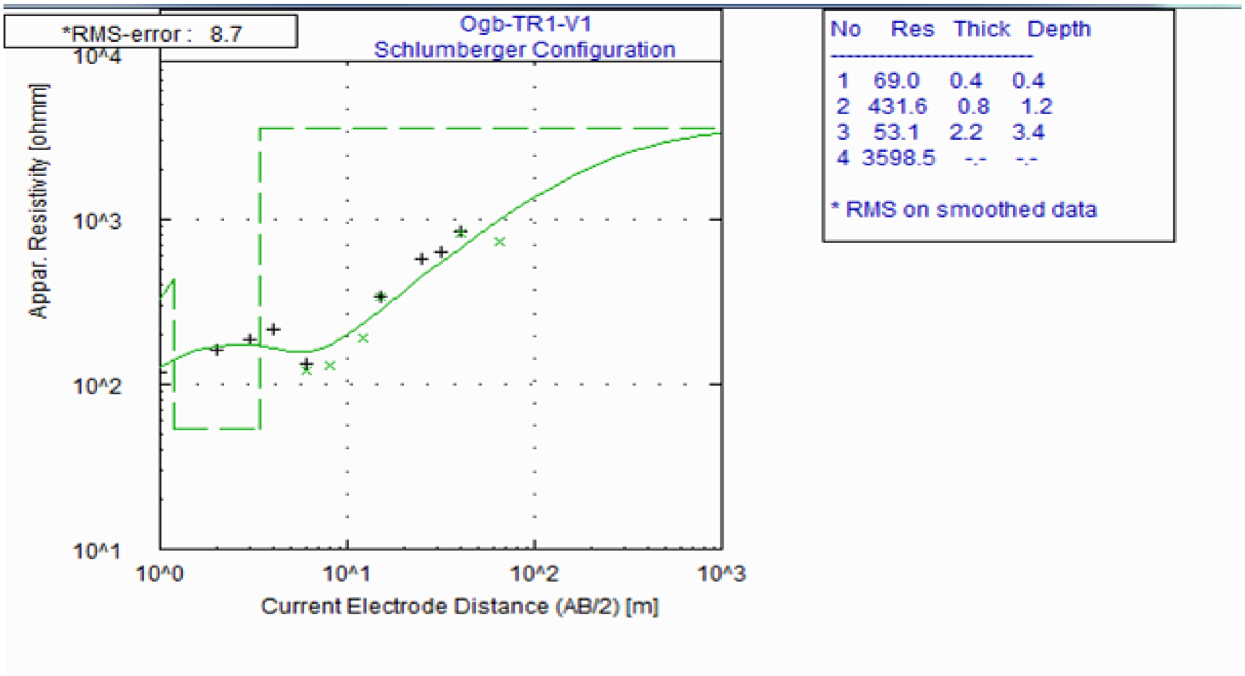


Figure 3a: Vertical Electrical Sounding (VES) KH Type Curve from the Study Area**.**

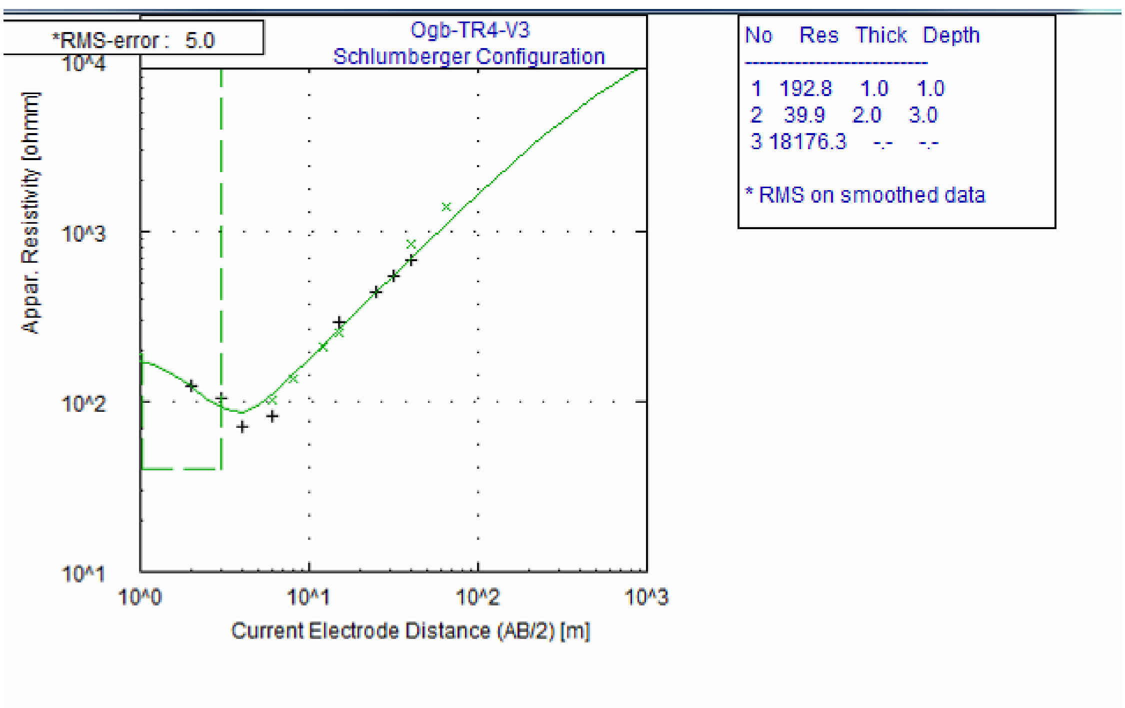
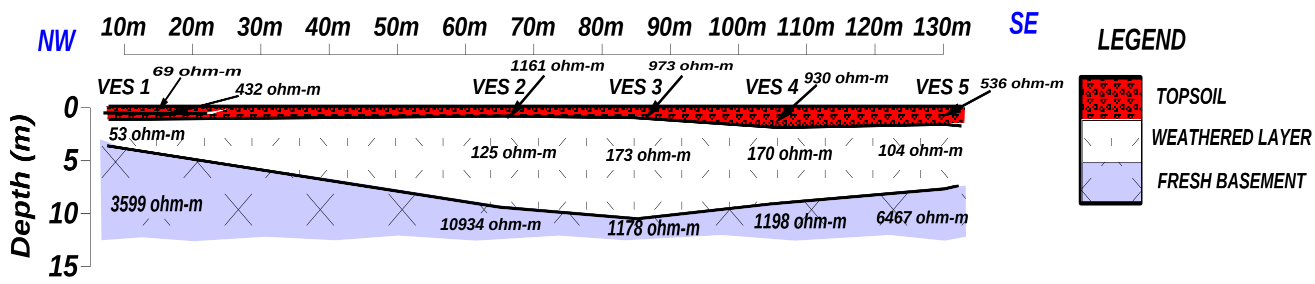
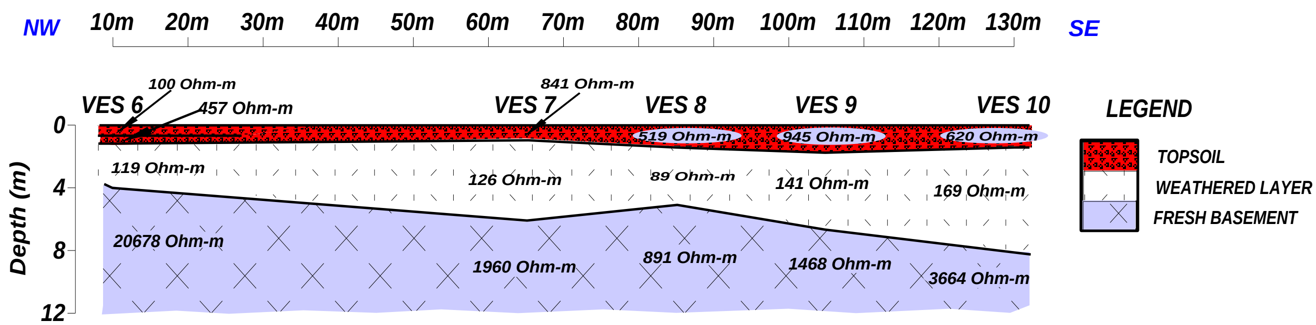


Figure 3b: Vertical Electrical Sounding (VES) H Type Curve from the Study Area.

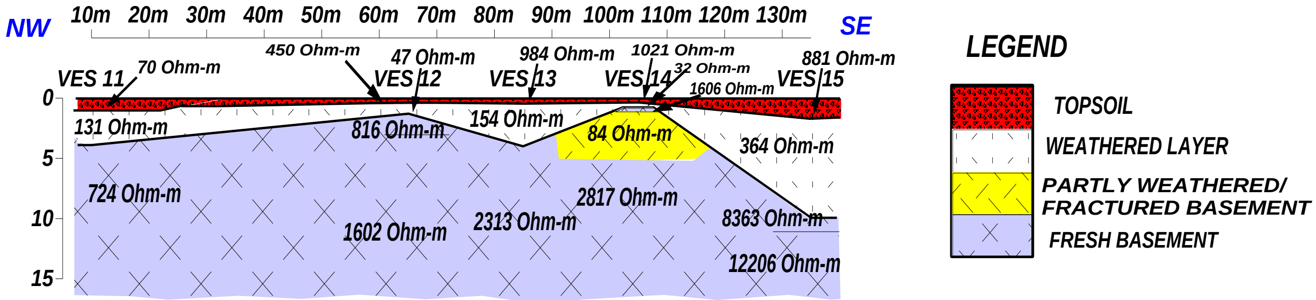


(a)

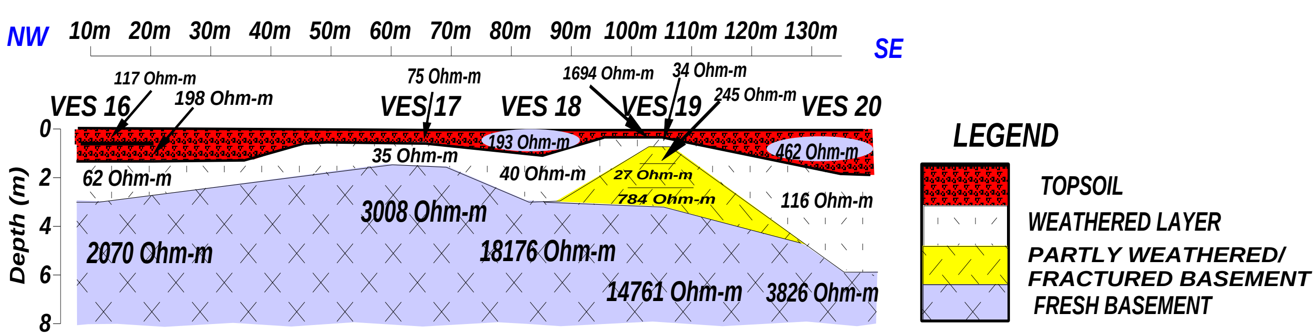


(b)

Figure 4a: Geoelectric Section Beneath Traverse 1(a), and 2 (b) relating VES 1 – 10.



(c)



(d)

Figure 4b: Geoelectric Section Beneath Traverse 3(c) and Traverse 4(d) relating VES 11 – 20.

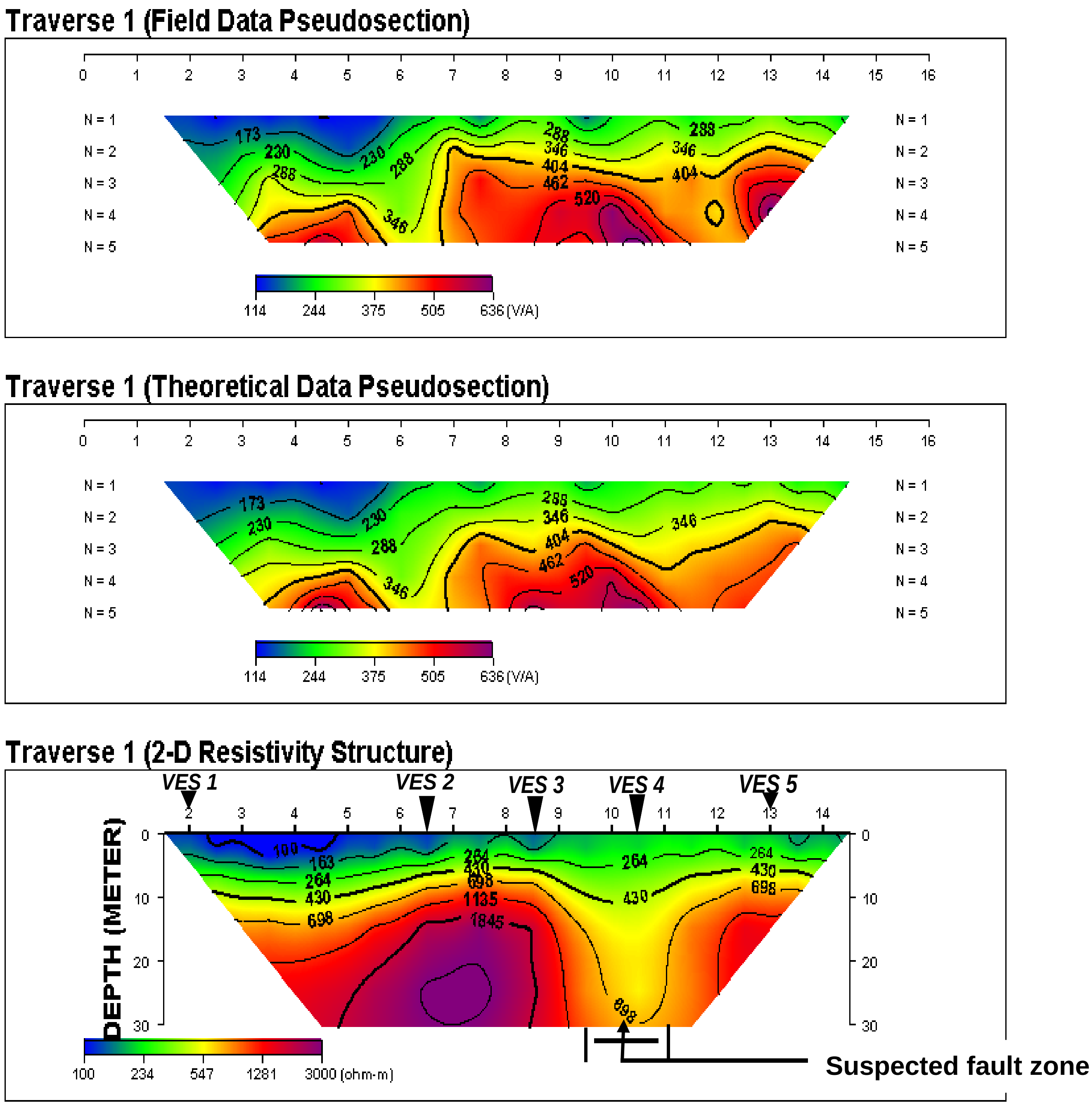


Figure 5: Dipole-Dipole Pseudosection along Traverse 1 with VES 1 - 5.

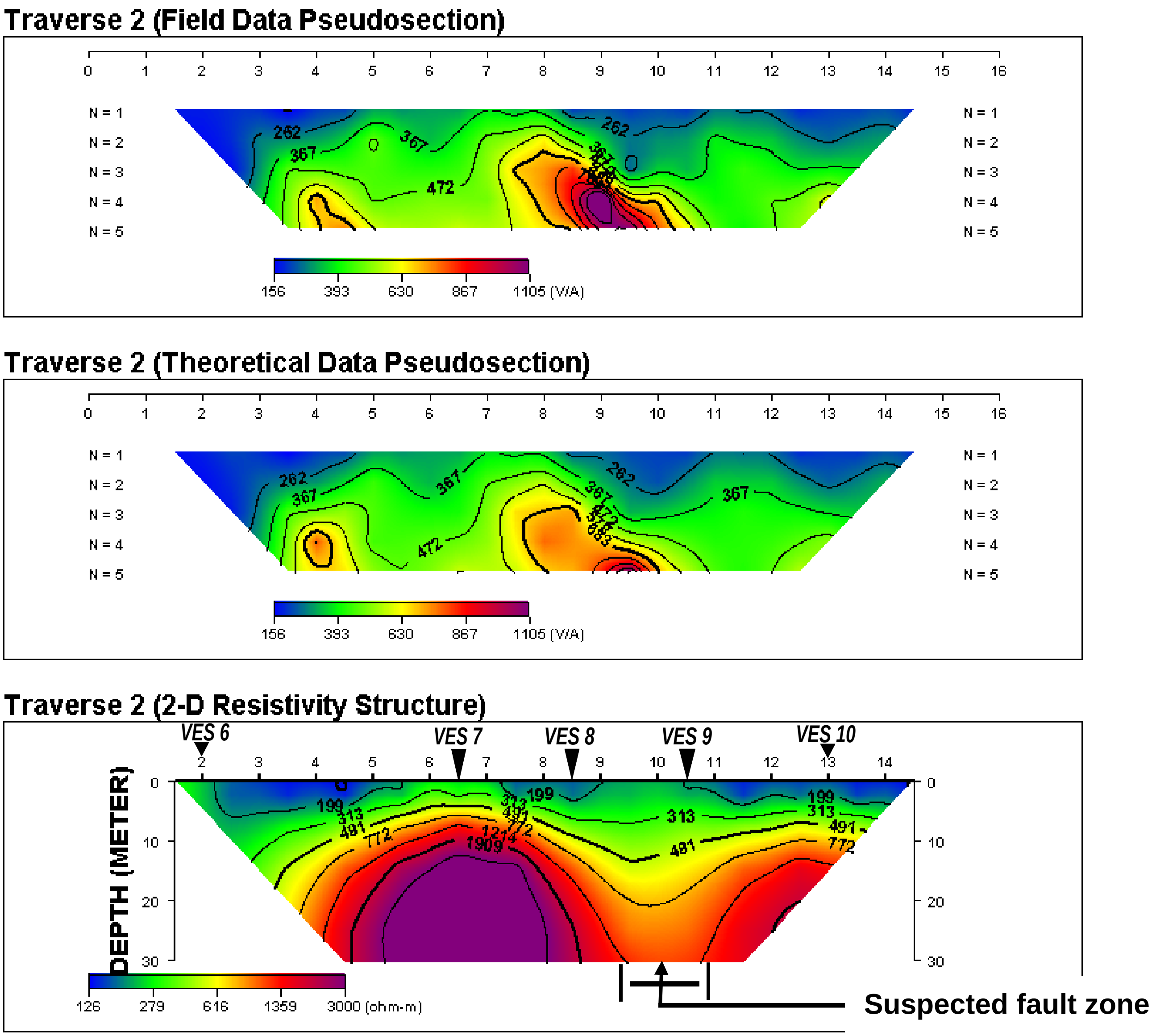


Figure 6: Dipole-Dipole Pseudosection along Traverse 2 with VES 6 – 10.

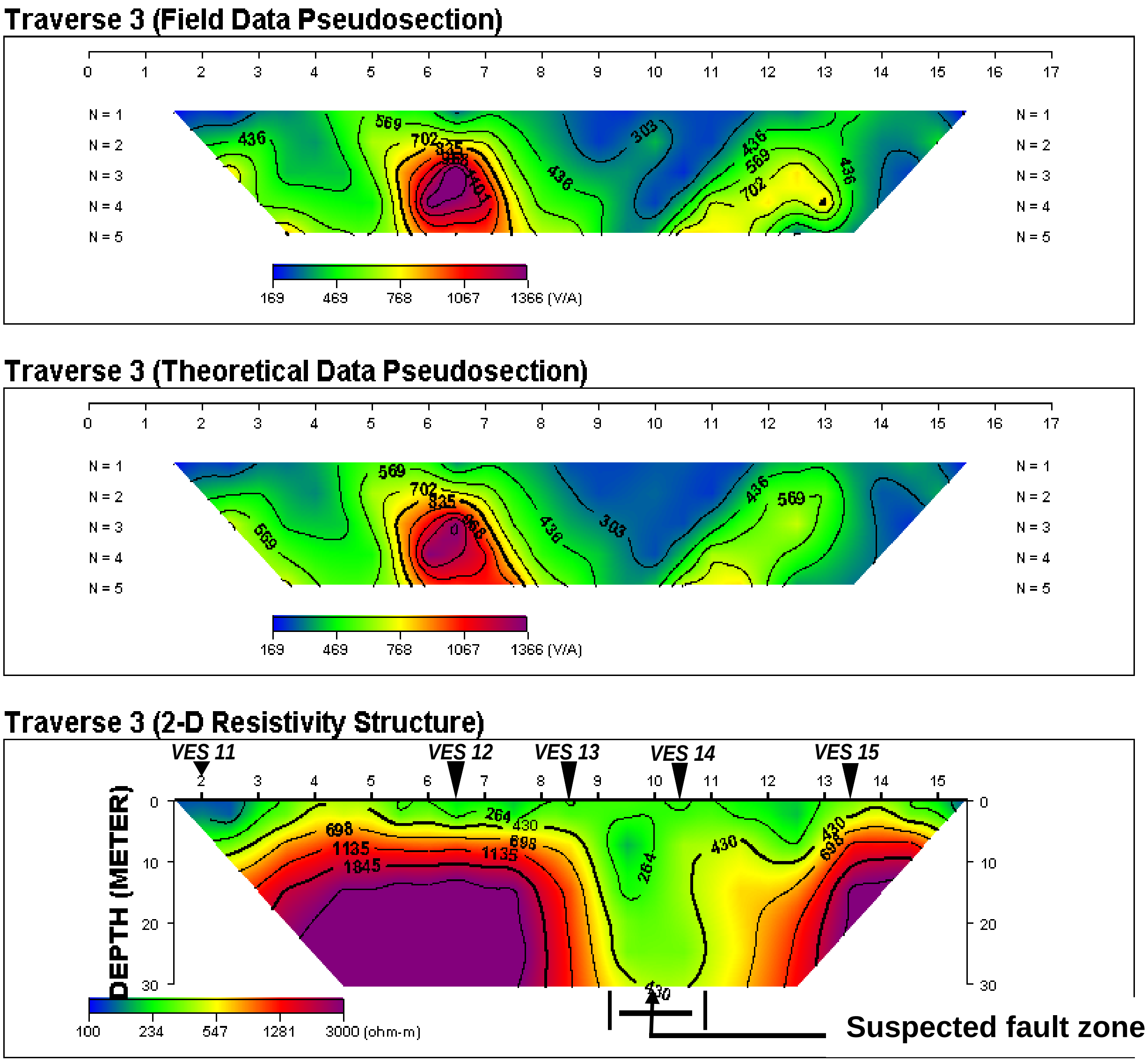


Figure 7: Dipole-Dipole Pseudosection along Traverse 3 with VES 11 – 15.

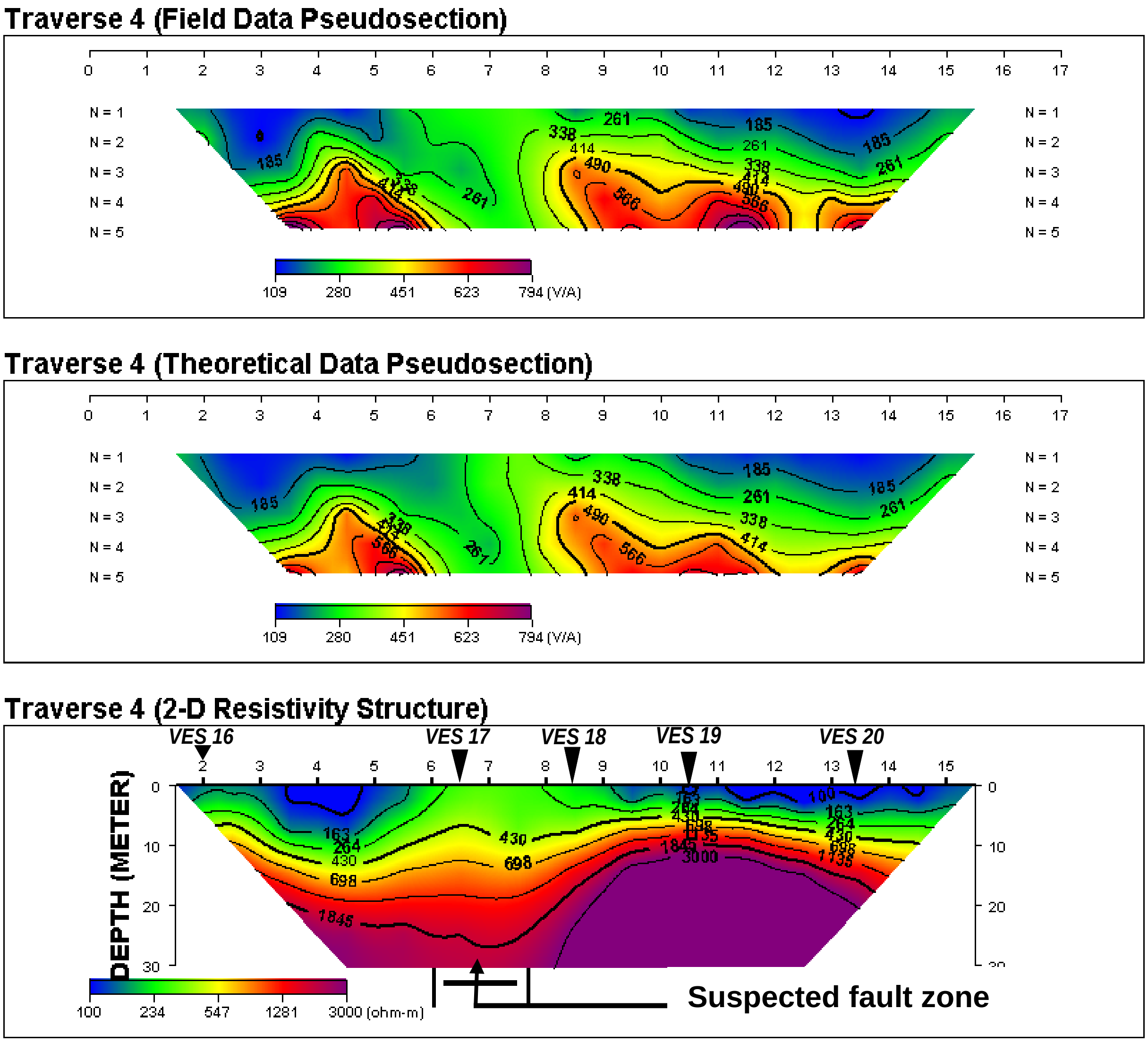


Figure 8: Dipole-Dipole Pseudosection along Traverse 4 with VES 16 – 20.

A shadow of what looks like a minor vertical discontinuity occurs between VES 17 and 18 (between distances 65 and 85 m). The suspected fault zone may not be well defined along the traverse because its orientation is at low angle to the traverse line (see Figure 10)

Except for the delineation of confined fractured basement columns beneath VES 14 and 19, the geoelectric sections did not identify the vertical discontinuity suspected to be faults within the basement. This could be explained from the point of view of the 1-D nature of the VES data and its interpretation model.

Figure 9 correlates the faulted zone across resistivity structures obtained beneath Traverses 1 – 4. Figure 10 displays the suspected linear structure (fault) in plan. The failed segment of the building is located within the zone. The foundation failure may have been precipitated by settlement within the suspected fault zone. The failed segments of the NNPC filling station wall in the northwestern flank of the survey area fall within the projection of the faulted zone, corroborating the inference above (see Figure 10).

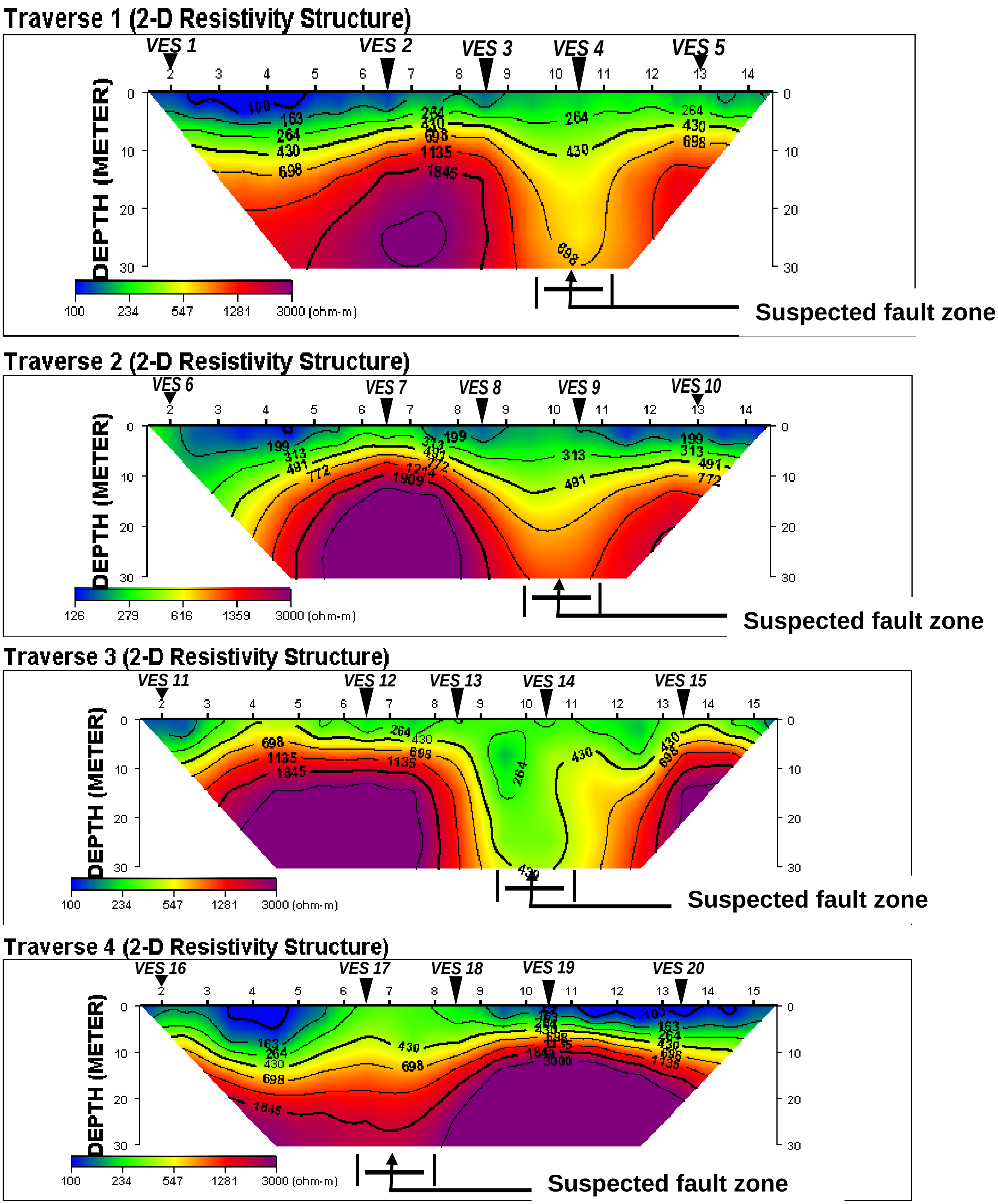


Figure 9: Correlation of the Faulted Zone along Traverses 1 – 4.

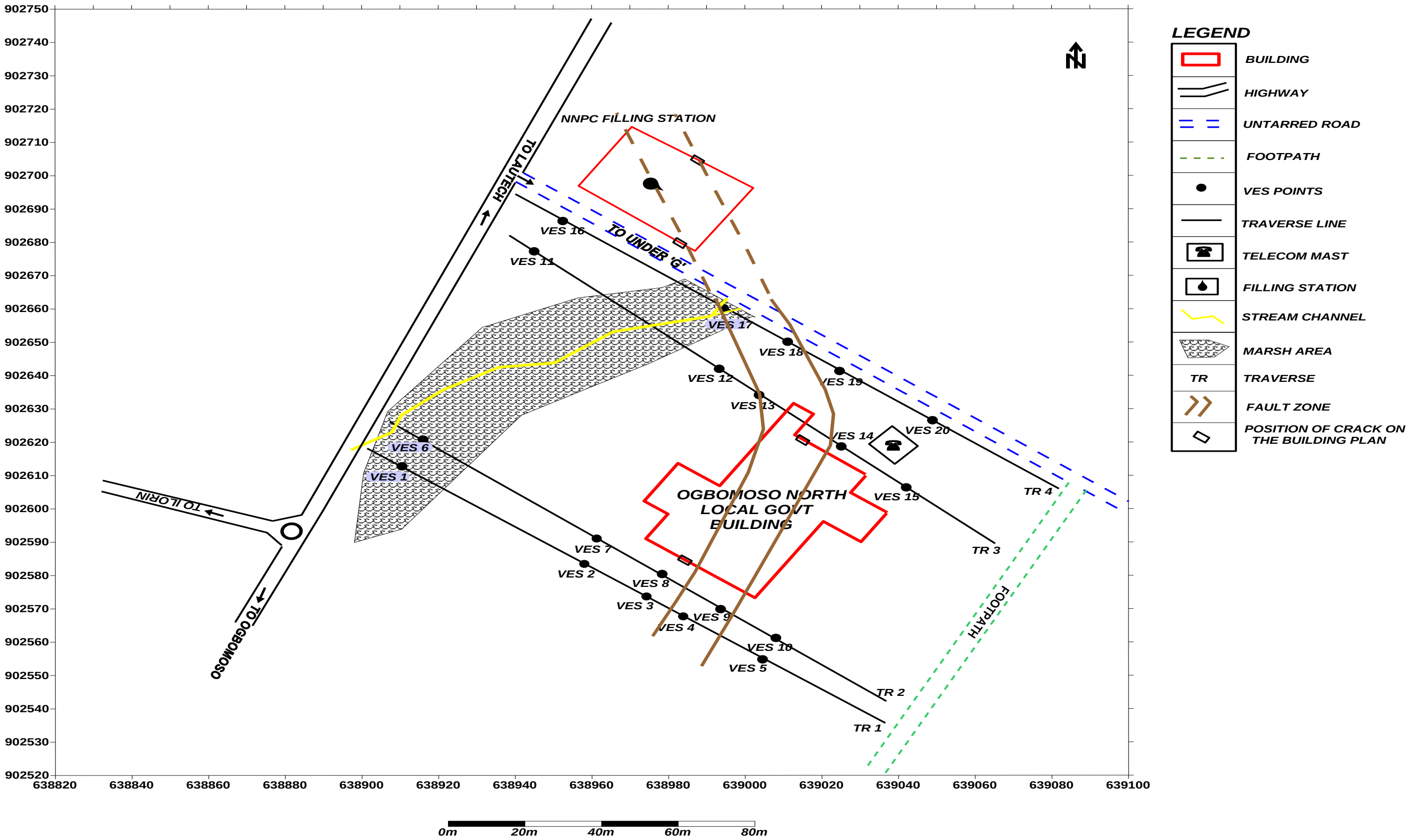


Figure 10: Structural Map of the Study Area.

SUMMARY AND CONCLUSION

Geophysical investigation involving the Vertical Electrical Sounding (VES) and dipole-dipole horizontal profiling techniques was carried out within the premises of abandoned Ogbomoso South Local Government Secretariat Complex in Ogbomoso, Oyo State with a view to identifying the cause(s) of the failure of the foundation of the building. The study area is located within a basement complex environment.

Four (4) traverses, each 130m long, were established parallel to the orientation of the building, in the West – East direction. Five VES stations were occupied along each of the traverse line. The VES survey identified six characteristic sounding type curves, namely A, H, HA, KH, HKH, and HKHA. The interpretation results of these curves delineated four geologic units comprising the topsoil, weathered layer, partly weathered/fractured basement and fresh basement bedrock. The topsoil has resistivity values that vary from 69 – 1161 ohm-m and thicknesses of between 0.4 and 1.8 m. The weathered layer is characterized by resistivity values ranging from 34 – 364 ohm-m and thicknesses of between 0.7 and 10.1 m. The partly weathered/fractured basement was identified beneath VES 14 and 19 with resistivity values of 27 – 784 ohm-m and thicknesses of 2.4 – 4.2 m. The basement bedrock has resistivity values of between 724 - ∞ ohm – m with depth to the geoelectric bedrock of between 3.2 and 15 m.

The 2-D images delineate three major subsurface layers – a topsoil (generally in blue color band), the weathered layer (in green color band) and a basement bedrock (in yellowish/reddish/purple color band). The resistivity structures identify a major linear feature suspected to be a fault that cut across the building site. The faulted zone is about 20 – 30 m wide. It is suspected that the failure of the building foundation may have been precipitated by differential settlement within the suspected faulted zone.

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