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Geophysical Investigation of the Subsurface Fractures Zones Using Vertical Electrical Sounding in Kassa Volcanic Field (KVF) on the Jos Plateau, North central, Nigeria

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Abstract

A geophysical investigation using geo-electrical resistivity method was carried out in the Kassa Volcanic Field (KVF) on the Jos Plateau to reveal the subsurface structural lineaments as indicated in the satellite images covering the area. The electrical resistivity method utilized the Schlumberger technique along 3 profiles. A total of 36 Vertical Electrical Soundings (VES) stations with AB/2 (current electrode spacing) from 1.5 to 215m with intervals of 50m and depth penetration capability of 70m was carried out. The results obtained revealed 3-5 lithologies sequence with thicknesses ranges between 0.1 and 70m and resistivity values of between 34 Ωm and 2222 Ωm. Nineteen major fractures at various depths were intercepted at various VES stations and these are probably the zones through which the basaltic lava out poured apart from the central volcanic vent. The VES results revealed heterogeneous nature of the subsurface geological sequence. The geologic sequence beneath the study area is composed of hard pan top soil (clayey and laterite), weathered basaltic rock layers, partly weathered or fractured and fresh basement rocks.

Keywords: Geo-electric section, Subsurface, Vertical Electrical Sounding, Kassa Volcanic Field, Schlumberger Array, Jos Plateau

1. Introduction

Kassa Volcanic Field is a geological edifice on the Jos Plateau, north central Nigeria. This structure consists of eight volcanic cones aligning in a NE-SW and NW-SE trends, each overlapping one another. The lava flows out poured by these volcanoes covered a large superficial area of about 45.5 km^2.

Vertical electrical sounding (VES) has proved very popular with groundwater prospecting and in geotechnical studies of the subsurface. Resistivity images have also been used in the studies which include soil and bedrock property characterization, detection of bedrock voids and fractures.

In the present research, data obtained were plotted in bi-log graphs and analysed both qualitatively and quantitatively by curved matching and computer iteration using the WinRESIST software to obtain the formation strata and the actual depth to the bed rock in the study area. The results from the analysis of the field data were interpreted to obtain the geo-electric sections of the Kassa Volcanic Field (KVF).

1.1 Geology of the Study Area

The Jos Plateau lies precisely within the North Central Basement Complex of Nigeria. The Basement Complex rocks of the lower Palaeozoic to Precambrian ages underlie about half of its entire landmass. These rocks are represented by gneiss-migmatites and intrusive into these Basement rocks are the Pan-African granites and the predominant Jurassic non-orogenic alkaline Younger Granites (Turner, 1976).

Tertiary and Quaternary basaltic rocks are the youngest in the area and overlie directly on the Basement and in some places on the Younger Granites (Wright, 1970). Two main basaltic subtypes have been distinguished based on their periods of emplacement and textural differences. They are termed as the Older (Tertiary) and the Newer (Quaternary) Basalts (MacLeod et al., 1971, Lar and Tsalha., 2005).

Kassa the study area (Fig. 1), falls within Ropp Complex in the central region of the Jos Plateau and covers roughly triangular area of about 240 km^2. The area is characterized by four different rock formations, these are: the Older Granite (Pan African), Younger Granite (Jurassic), the Older Basalts, and the Newer Basalts (Quaternary – Tertiary). The Older Granites is the oldest formation in this area followed by the Younger Granite and then the basalts are the youngest. Laterites are not actually substantial rock masses, but they feature prominently in northern and southern extremities of the study area. The lava flow around Kassa Volcanic Field is believed to be erupted by about eight volcanic cones that appeared to be structurally controlled. The southern volcanic cones lava flows are dark grey, very fine texture and with olivine, plagioclase and augites minerals appearing as phenocrysts even in hand specimen, these are considered the Newer Basalts. Generally, they are aligned in the NNW-SSE directions corresponding to the trend of dolerite dykes (MacLeod et al., 1971).

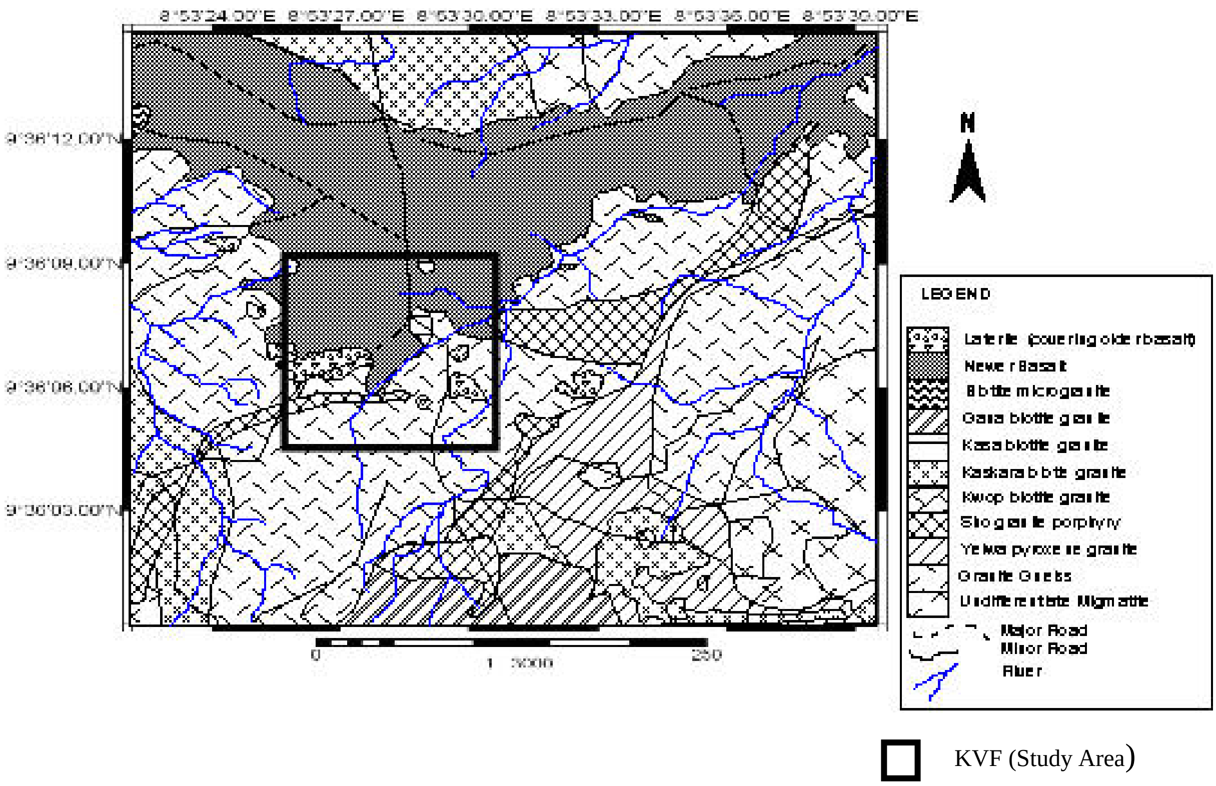


Figure 1: The Geologic Map of the Kassa Volcanic Field (study area)

1.2 Description of Study Area

The area under study is part of Naraguta Sheet 168, SE. It is bounded by latitudes 9^0 $36^1 06^{11}$ and 9^0 36^1 10^{11} N and longitudes 8^0 53^1 24^{11} and 85^0 53^1 38^{11}. It covers an approximately 45.5km^2 extending from Heipang to Kassa Hausa village. The area is accessible principally by the main road through Heipang – Kassa - Barkin Ladi road, as well as several minor paths and the main paths linking villages, farms and settlements. Most of the secondary roads are motor able during the dry season (Iloeje, 1981).

The area has an average elevation of 1342m above sea level. It falls within the semi arid zone of Nigeria and lies within the Guinea Savannah (Iloeje, 1981).

The climate of the study area is characteristic of temperate climate with two demarcated seasons known as the rainy (wet) and dry seasons. The rainy season is between March and October while the dry season is between November and February. The latter is characterized by cold, dusty and harmattan wind (Iloeje, 1981).

2. Materials and Method

A total of 36 VES using Schlumberger arrays were carried out along 3 profiles (*i.e* 12 stations at each profile). A direction of E-W direction cutting across the suspected lineaments within the area of study was carried out in the orientation of the 3 lines of 215m, at intervals of 50 m.

Two ABEM Terrameters (SAS 1000 and 4000) systems were used and employing Schlumberger configuration which requested 8 steel electrodes arranged and pinned collinearly into the Earth with the current electrode spacing much greater than the potential electrodes and ensuring that AB/2 ≥5 MN/2. Two Global Positioning Systems were used to record the geographic coordinates and the altitude of the VES stations.

The largest current electrode spacing AB used was 215m, that is ½ AB = 70m. The apparent resistivity values ρa measured with the geometric factor "G"(Formula 1).

[G= πL2/2L]. .... (1)

Current electrode spread AB/2 was also varies from1m to 65m. The apparent resistivity values 'ρa' were calculated by multiplier the resistance 'R' measured with the geometric factor 'G' (Equation 2).

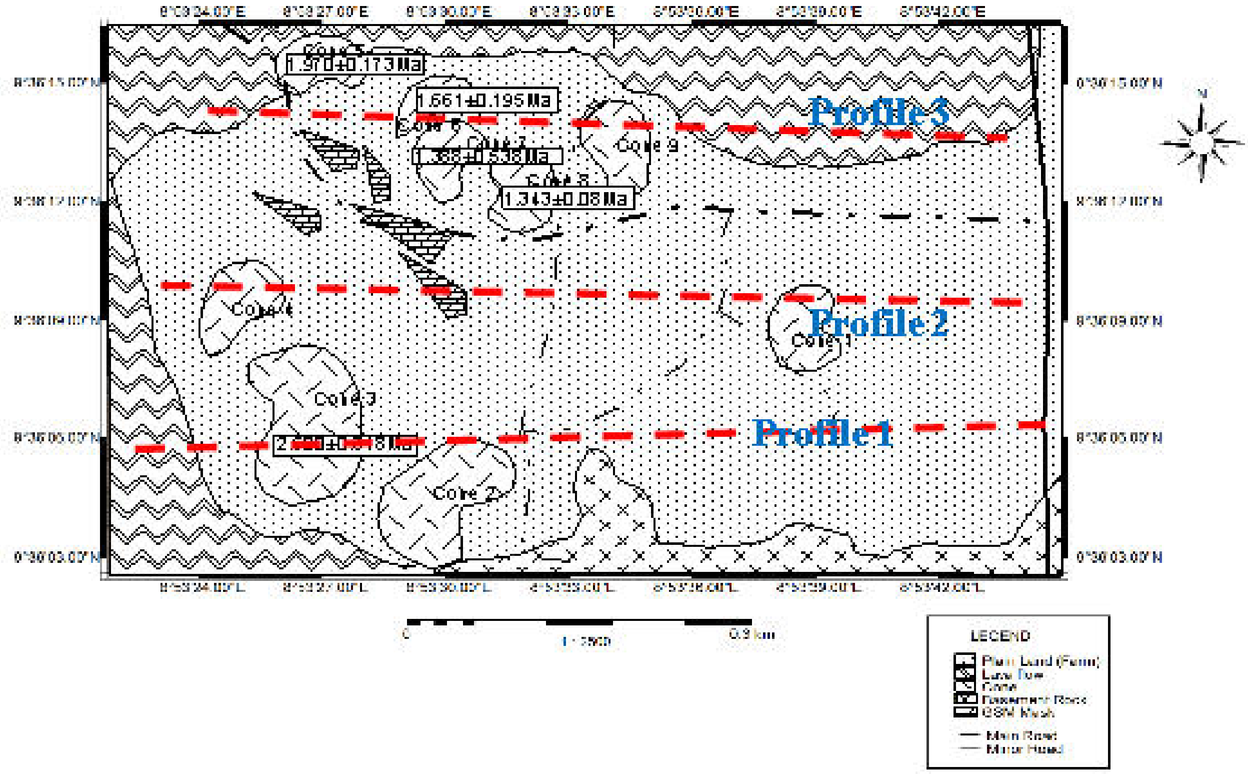
[G= πL2/L] .... (2)

Where:

L = AB/2, and 1= MN/2

The apparent resistivity measurements at each VES stations were plotted against electrode spacing on the bi-logarithmic graph sheets. The resulting curves were then inspected visually to determine the nature of the subsurface layering delineated by the array. The results of the curve matching (layer resistivity and thickness) were fed into the computer as starting model parameter in an iterative forward modelling technique using

WINRESIST software (Vander Velper, 1988). The three different profiles generated revealed the geo-electric sections from the results interpreted (Fig 2). The layer parameter charts were also generated from the results obtained from the interpreted results. WinResist was able to determine the smoothed resistivities and thickness of other layers.



Geologic Map of the KVF Showing the VES Profiles

3. Results and Discussion

The results of this research are presented as field curves, tables and geo-electric sections. The Schlumberger array data is presented in Table 1. The qualitative and quantitative analyses delineate three – five different subsurface layers by field curves generated from the arrays and nineteen prominent fractures were also intercepted at some of the sounding stations.

Based on the lineament map derived from the satellite imagery covering the study area (Fig. 2), the Vertical Electric Soundings (VES) was carried out in 3 strategic profiles in E-W directions to reveal the geo-electric layers and subsurface geological structures beneath the area under study.

In the first layer, the lithologies subsurface consists of topsoil/laterite with a thickness ranging from 0.1 and 5m and with resistivity value ranges from 173-540 Ωm and weathered basaltic rocks with variable thickness of between 0.1 and 50m which characterized by major fractures intercepted in P1, P2, P5, P7, P8, P9, P10 and P11 (Fig.3).

The second profile (Fig. 4.) revealed 3 main geo-electric layers which consists of topsoil/laterite at a depth between 0.9 and 5 m with resistivity value ranges between 625 and 635 Ωm; the second depth ranges between 2.5-35m and characterized by resistivity values of 24-300 Ωm, the third layer consists of basalt/granite with resistivity value of 123 to 920 Ωm within the fresh Basement/Granite layer. Major fractures were intercepted on points P15, P16, P17, P18 and P23.

In profile 3 (Fig. 5), three main geo-electric layers have been identified with the first layer consisting of topsoil and laterite at depth ranges between 0 and 6 m and resistivity values ranging from 0-5m and also characterized by the highest resistivity values that ranges between 55 and 2222 Ωm. The second layer consists of weathered basalt (clay) at depth ranges between 0.9 and 40 m and characterized by resistivity value range of 36 to 68Ωm. The third layer consist a mixture of slightly weathered and fresh basalts and granite with resistivity value range of 70-656mity of the Ωm. Major fractures were intercepted at various depths on P25, P27, P28, P29, P31 and P32

The fractures systems delineated along profile 1 and 2 intercepted a good number of fractures around the clusters of the volcanic cones in the northern extremity of the study area. This corresponds to the lineaments extracted from the Google Earth images covering the study area.

Figure 3: The Lineation Map covering the Kassa Volcanic Field, Jos Plateau
Each geo-electric soundings were interpreted and geo-electric sequence produced (Fig. 4-6).
stations (1-6) in the Kassa Volcanic Field (KVF)

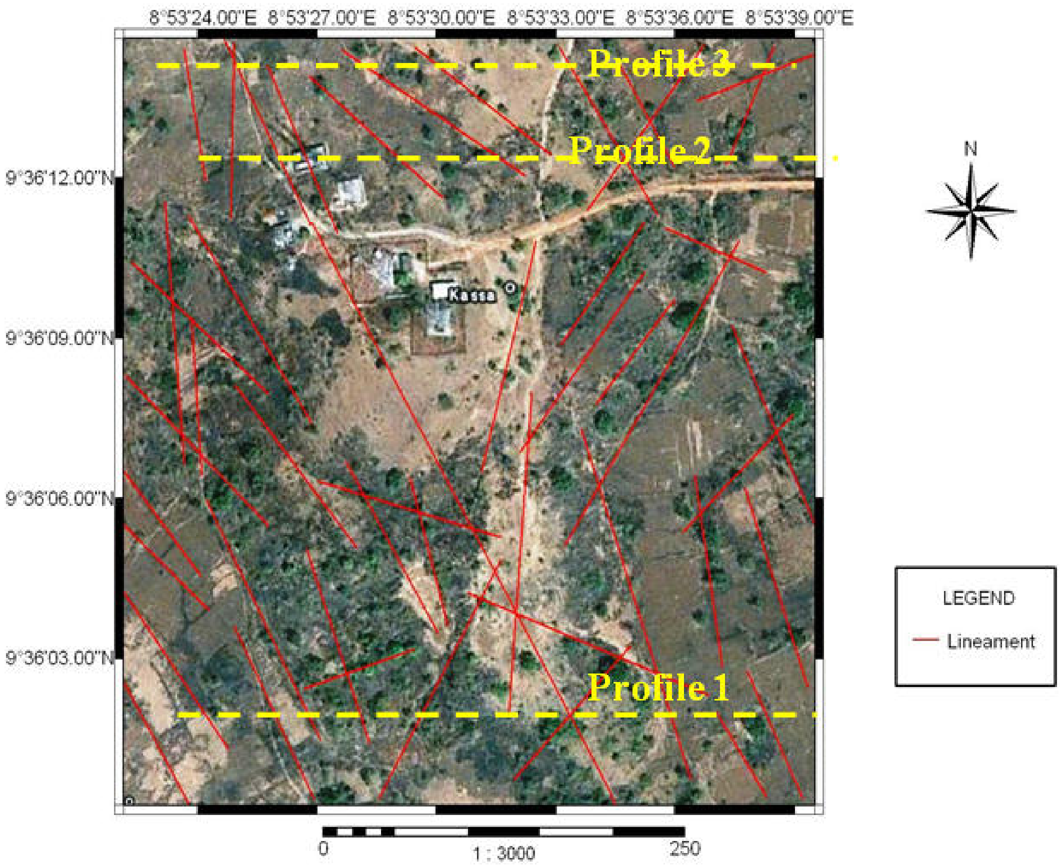


Figure 3: The Lineation Map covering the Kassa Volcanic Field, Jos Plateau

Each geo-electric soundings were interpreted and geo-electric sequence produced (Fig. 4-6).

3.1 Geo-electric Profile (Line 1)

Geo-electric profile (Fig.4) with VES Nos: P1-P14 revealed two main geo-electric layers which consist of topsoil/laterite with thicknesses of between 0.1 and 5m with resistivity values of 173-540Ωm and weathered basaltic rock with variable thickness of 0.1-50m and characterized by major fractures intercepted on P1, P2, P5, P7, P8, P9, P10 and P11.

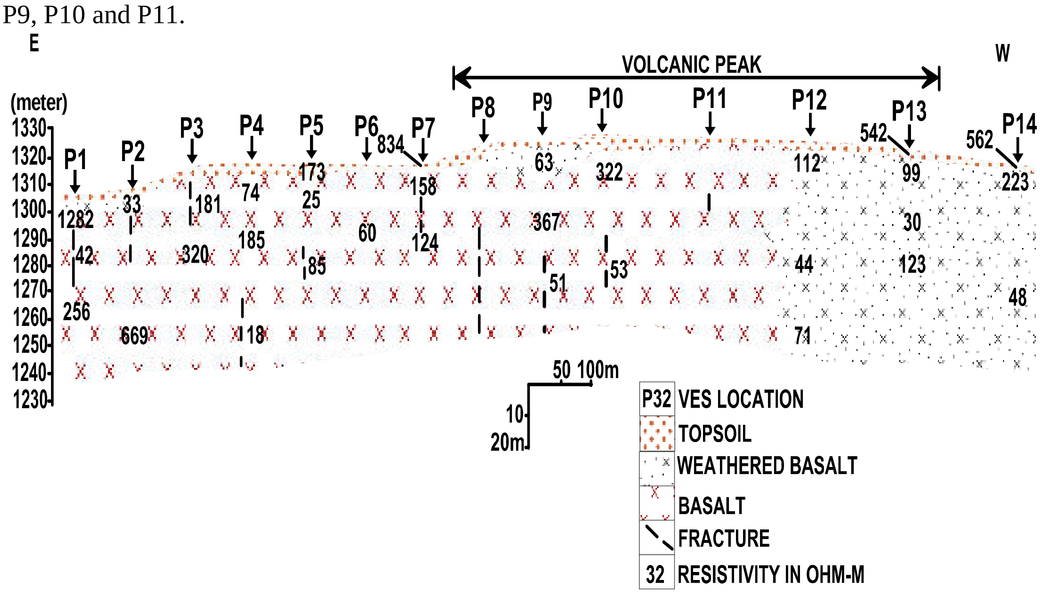


Figure. 4: Geo-electric Profile along Line 1.

3.2 Geo-electric Profile (Line 2)

Figure 5 revealed three geo-electric layers which consists of topsoil/laterite with thicknesses of 0.9-5m and resistivity values ranges between 625 and 635Ωm; the second depth ranges between 2.5 and 35m and characterized by resistivity values of 24-300Ωm, the third layer consists of basaltic rock and granite with resistivity values of 123 to 920Ωm within the fresh Basement/Granite layer. Major fractures were intercepted on P15, P16, P17, P18 and P23.

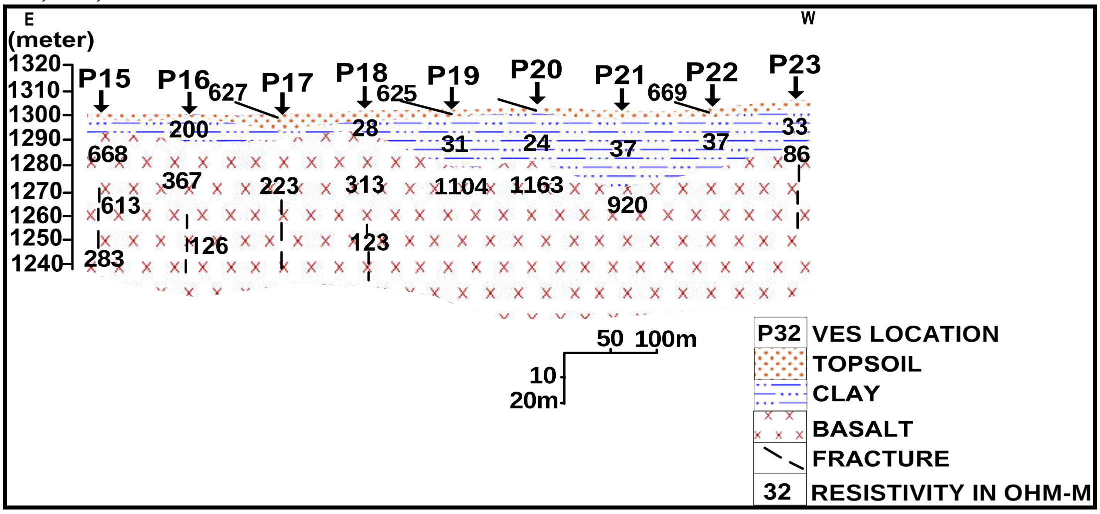


Figure 5: Geo-electric Profile along Line 2

3.3 Geo-electric Profile (Line 3)

Fig. 6 revealed three geo-electric layer/sequence which consist of topsoil and laterite from 0-6m with resistivity values ranging from 0-5m and characterized by resistivity values ranges from 55 and 2222Ωm; the second layer consists of weathered basalt (clay) from 0.9-40m and characterized by resistivity value range of 36 to 68Ωm; the third layer consists mainly of slightly weathered and fresh basalt and granite with resistivity value range of 70-656Ωm. Major fractures were intercepted at various depths on P25, P27, P28, P29, P31 and P32 (Fig. 7).

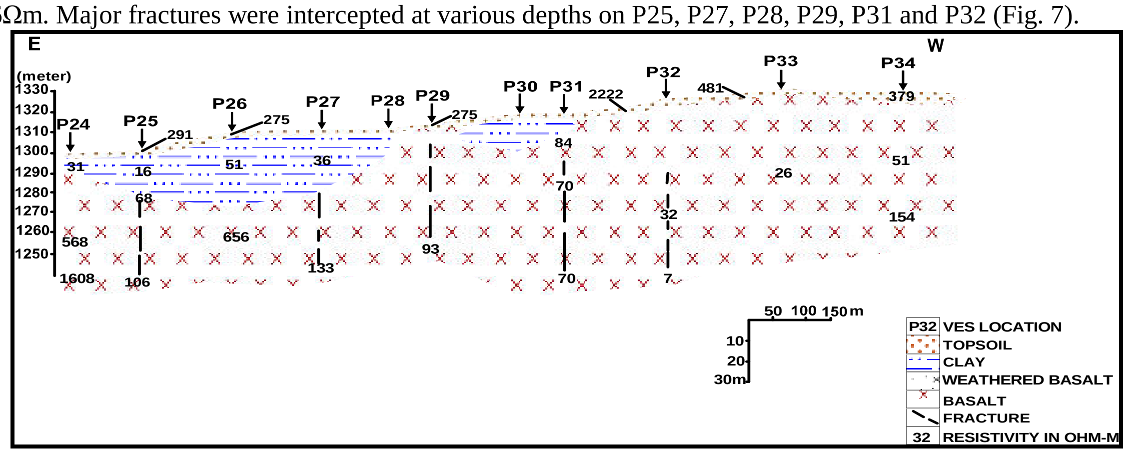
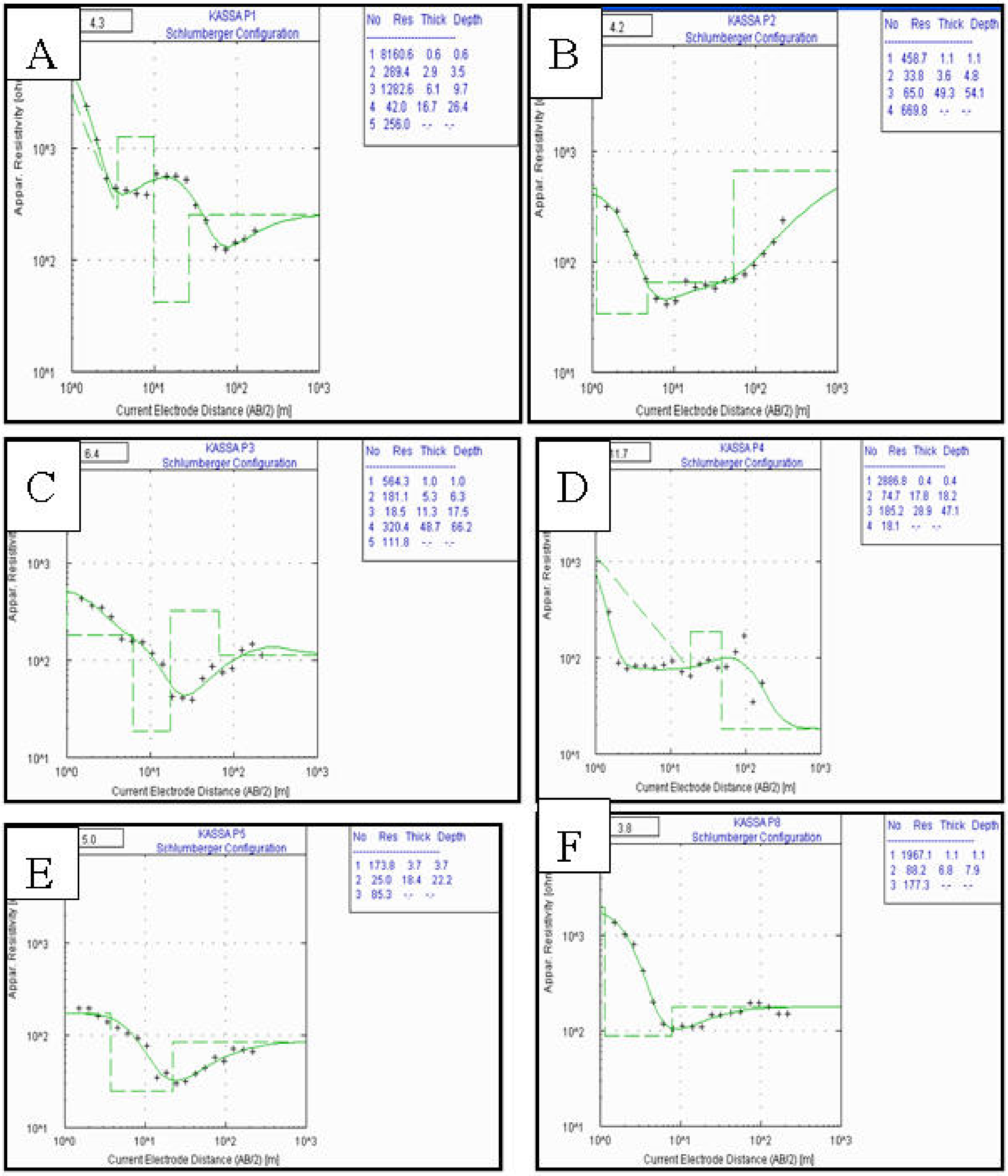


Figure 6: Geo-electric Profile along Line 3

From the interpretations of all the soundings, some bi-log sections were constructed as examples in figures below.



Figures 7A-7F: Field Sounding Curves for some selected stations (1-6) in the Kassa Volcanic Field (KVF)

Table1:Co-ordinates of VES Locations

VES NO	Longitude(^oE)	Latitude(^oN)	Elevation(m)
P1	8.89614	9.60292	1305
P2	8.89565	9.60296	1309
P3	8.89512	9.60299	1320
P4	8.89474	9.60304	1316
P5	8.894213	9.603097	1318
P6	8.89377	9.60325	1320
P7	8.89335	9.60330	1321
P8	8.89287	9.60348	1327
P9	8.89247	9.60354	1332
P10	8.89184	9.60371	1330
P11	8.89097	9.60374	1329
P12	8.889903	9.603705	1324
P13	8.888925	9.603632	1320
P14	8.88786	9.60353	1315
P15	8.88957	9.59575	1300
P16	8.89501	9.59608	1299
P17	8.89422	9.59639	1299
P18	8.89343	9.59672	1301
P19	8.89268	9.59701	1309
P20	8.89189	9.59734	1313
P21	8.89118	9.59757	1303
P22	8.89026	9.59783	1303
P23	8.88945	9.59814	1313
P24	8.89557	9.60891	1302
P25	8.89485	9.60883	1307
P26	8.89390	9.60874	1311
P27	8.89297	9.60863	1313
P28	8.89219	9.60857	1315
P29	8.89144	9.60850	1321
P30	8.89066	9.60840	1322
P31	8.88930	9.60825	1320
P32	8.88833	9.60829	1322
P33	8.88737	9.60834	1327
P34	8.88631	9.60849	1313

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Table 2: The Results of the Interpreted VES Curves

VES STATION	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	CURVE TYPE
1	8160.6	0.6	0.6	
	289.4	2.9	3.5	
	1282.6	6.1	9.7	
	42.0	16.7	26.4	
	256.0			HKH
2	458.7	1.1	1.1	HA
	33.8	3.6	4.8	
	65.0	49.3	54.1	
	669.8			
3	564.3	1.0	1.0	
	181.1	5.3	6.3	
	18.5	11.3	17.5	
	320.4	48.7	66.2	
	111.8			QHA
4	2886.8	0.4	0.4	HK
	74.7	17.8	18.2	
	185.2	28.9	47.1	
	18.1			
5	173.8	3.7	3.7	H
	25.0	18.4	22.2	
	85.3			
6	143.3	0.9	0.9	H
	60.5	62.1	63.0	
	346.6			
7	634.5	0.5	0.5	QH
	158.2	12.3	12.8	
	124.0	38.4	51.3	
	511.3			
8	1967.1	1.1	1.1	
	88.2	6.8	7.9	H
	177.3			
9	145.3	0.5	0.5	HK
	63.2	17.0	17.6	
	367.6	26.9	44.5	
	51.0			
10	116.7	1.2	1.2	HK
	35.0	6.1	7.3	
	322.3	25.7	32.9	
	53.1			
11	174.9	2.9	2.9	H
	124.0	68.0	70.8	
	146.3			
12	729.4	0.6	0.6	HQ
	112.5	7.2	7.8	
	44.0	67.3	75.1	
	71.8			
13	542.3	2.1	2.1	HQ
	99.6	8.7	10.7	
	30.6	25.8	36.5	
	123.3			
14	562.3	1.4	1.4	Q
	223.2	2.7	4.2	

	48.8			
15	479.3	1.1	1.1	HKQ
	82.6	6.4	7.5	
	688.8	22.2	29.6	
	613.3	29.6	59.2	
	282.6			
16	1406.6	0.8	0.8	HKH
	200.9	10.5	11.4	
	367.0	29.0	40.4	
	126.3	24.9	65.3	
	729.7			
17	173.6	8.5	8.5	Q
	263.4	16.0	24.5	
	228.3			
18	741.1	1.1	1.1	HKH
	28.1	7.7	8.8	
	313.4	34.1	42.9	
	123.6	46.9	89.8	
	138.2			
19	625.2	1.3	1.3	H
	31.5	22.6	23.9	
	1104.5			
20	489.8	1.0	1.0	H
	24.8	21.9	22.9	
	1163.9			
21	441.6	2.7	2.7	H
	37.0	30.7	33.4	
	920.0			
22	669.0	1.5	1.5	H
	34.4	24.9	26.4	
	1237.6			
23	1847.8	1.6	1.6	HA
	33.1	18.4	20.0	
	86.5	58.9	78.9	
	116.1			
24	266.3	1.1	1.1	HAA
	71.2	5.5	6.6	
	291.7	23.8	30.5	
	568.9	31.3	61.8	
	1608.6			
25	291.3	2.1	2.1	QHA
	59.9	3.2	5.3	
	16.7	9.1	14.4	
	68.0	10.4	24.7	
	106.9			
26	275.7	2.5	2.5	H
	51.3	32.7	35.1	
	656.1			
27	104.2	2.9	2.9	QHK
	115.1	9.3	12.2	
	36.7	14.7	26.9	
	247.7	56.3	83.2	
	133.9			
28	212.2	0.9	0.9	H
	67.8	12.6	13.6	
	177.5			

29	275.1	1.1	1.1	Q
	93.2	51.4	52.5	
	63.0			
30	359.6	2.4	2.4	
	66.4			
31	707.9	1.7	1.7	Q
	84.1	11.1	12.9	
	70.2	74.0	86.9	
	21.2			
32	2222.1	2.5	2.5	HK
	32.5	44.7	47.2	
	0.7			
33	481.5	2.9	2.9	
	26.4			
34	379.8	4.1	4.1	H
	51.9	39.8	43.9	
	154.4			
35	1013.8	0.8	0.8	HKH
	44.6	1.7	2.5	
	880.5	6.1	8.5	
	90.3	21.7	30.2	
	378.6			
36	55.3	13.0	13.0	K
	519.7	22.2	35.2	
	36.2			

4. Conclusion

A total of 36 Vertical Electrical Soundings (VES) along 3 profiles of 215m long and 50m intervals were carried out in E-W direction cutting across the main volcano swarm (Fig. 2 and 3). The geo-electric sections revealed lineaments which are predominantly N-S, NE-SW, NW-SE directions which is in conformity with most of the directions of dolerites dykes on the Jos Plateau and also with the lineaments exposed by the satellite imageries covering the study area. The volcanic cones from all indications are structurally controlled. The co-ordinates and elevations above sea level of the VES points occupied indicated an average height of about 1340m above sea level as indicated in Table1.

The result of this investigation revealed that KVF consist of 3-5 geoelectric sequences indicating heterogeneous geological formations. The first layer of the line 1 consist top soil and laterite with average thicknesses of 0.1 to 5 m. A corresponding resistivity values ranges between 173 and 540Ωm were recorded. The second layers are weathered basaltic rocks with variable thicknesses of 0.1 to 50m and this was characterized by 8 prominent fractures encountered along the profile. Profile 2 consists of 3 layers of various thicknesses and resistivity values ranges between 24 and 920Ωm and 5 major fractures were delineated. 3 layers were encountered in profile 3, various thicknesses ranges of 0 to 40m and resistivity values ranging between 36 and with a high resistivity value of 2222 Ωm were recorded along this profile.

This research, therefore, revealed subsurface structural information of the Kassa Volcanic Field (KVF) to have fractures zones trending in E-W directions which served as conduits for the multiples eruptions episodes in the area.

The field curves and geo-electric sections, showed the interrelationship between rock units in the study area. The cross plots of the interpreted parameters (layer thickness and resistivity) for the delineated layers were produced. The results show interpreted parameters using Schlumberger arrays are in conformity with the structural geologic features of this area.

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