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Analysis of Thickness and Layering of Overburden Materials of Volcanic Craters on the Biu Plateau, Borno State, Nigeria

John Abdullahi[1] , J. K. Nyanganji[1] & M. U. Mijinyawa[2]

[1] University of Maiduguri, Faculty of Social Sciences, Department of Geography, Borno State, Nigeria.

[2] University of Maiduguri, Faculty of Science, Department of Geology, Borno State, Nigeria.

Correspondence: John Abdullahi, University of Maiduguri, Faculty of Social Sciences, Department of Geography, PMB 1069, Maiduguri, Borno State, Nigeria. Tel: 080-3682-1438. E-mail: johnabdullahi@ymail.com; nyanganji@yahoo.com; manuba07@yahoo.com

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Abstract

This research examined the thickness and Layering of Overburden Materials of volcanic craters on the Biu plateau. The objectives of the study are to identify the craters, the geomorphic processes involved in their modifications; analysed the thickness and Layering of the overburden materials of the craters. Data used for this research were generated from field observations, topographic map and resistivity sounding. Three sampled craters namely Kumba, Tilla and Jali Tagurmi were purposively selected for the study. The thickness of the overburden in the crater were determined using the SAS ABEM 300C sounding technique at ten sample points. The data were processed and interpreted using the IXID inversion computer software. Denudational processes observed on the rims of the craters include weathering, sheet, rill, gully erosions and mass wasting (rock fall, soil creep, debris creep and slides). Results showed that there are fourteen craters on the Biu plateau; four large (> 300m) in diameter, five medium (200-300m) and five small (< 200m). The resistivity sounding results revealed that most of graphic curve models belong to the K and KH while layered models ranges from three to four layers beneath each VES station. The lithology could be described as clay, weathered Basalt, partly weathered/ fractured Basement and newer basalt. The resistivity values of the layered models ranges from 18.16 to 2280.6 Ωhm across the three craters. Based on the thickness of the overburden, it is evident that the materials deposited on the floor of the crater were eroded from the rims of the craters. From the findings of the research it is recommended that public enlightenment campaign on environmental management be conducted, sustainable environmental management of land based resources be ensured.

Keywords: geomorphic processes, crater, overburden and layering

1. Introduction

A volcanic crater is a relatively circular depression on the earth's surface caused by volcanic activity. It is typically a basin, within which a vent is located from which lava erupts in form of gases, and ejecta are emitted. A crater can be of various sizes and sometimes of great depth. During climactic eruptions, the volcano's magma chamber may evacuated for the area above it to subside to form a crater or a caldera. In typical volcanoes, the crater is situated at the top of the cone, formed by pyroclastic materials (or debris). In some, the craters may be situated on the flanks of volcanoes and these are commonly referred to as flank craters. Most volcanic craters may either be fully or partially filled with runoff or melted snow to form a crater lake.

Volcanoes are therefore spectacular landforms produced by the effects of the internal processes and subsequently modified by external processes. Examples of volcanic features include volcanic hills, valleys, plateau and Crater (Faniran and Ojo, 1980).Landforms in general can be classified into two basic groups; as the initial landforms and the sequential landforms. The initial landforms are produced directly by tectonic processes such as volcanoes. The initial landforms that are fashioned by processes of denudation such as weathering, erosion, transportation, deposition and mass movement are termed sequential landforms. The term sequential derives from their mode of evolution as envisaged in the Davisian cycle of erosion (Sparks, 1970, citing Davis, 1899). They are landforms created by denudation from tectonic landforms. Hence, the tectonic and denudation processes in geomorphology present themselves as antagonistic processes.

Thus, internal processes are regarded as constructive while external processes are regarded as destructive. In this regard, landforms modification is an important aspect of earth sciences and involves complex physical interaction and other environmental factors, such as underlying rock type, tectonics, and climate and human/animal activities, occurring over a wide range of spatial and temporal scales. In order to be able to improve, maintain and predict the sustainability of the physical environment and reduce the impact of contemporary earth surface processes that lead to natural hazards such as landslides, gully erosion and floods, a basic understanding of the general configuration of landforms, the surface processes and environmental factors involved in evolution is necessary, especially in volcanic landscapes like the Biu plateau.

1.1 Statement of the Problem

Biu is a volcanic plateau, characterized by various spectacular geomorphic features which make the area very unique when compared to its surrounding environment. Some studies consider the Biu plateau as the end of the North-North West (NNW) branch of the continental sector of the Cameroon Volcanic Line (CVL) (Turner, 1978; Fitton, 1980; Halliday,*et al*, 1988 and Lee, *et al*, 1996). It has been observed that the Biu and Jos Plateaux have similar major and trace elements and that the Jos Plateau lavas have similar range of isotopic compositions, overlapping the lava of the CVL as a whole (Rankenburg, *et al*., 2004). According to Turner, (1978), the Biu Plateau evolved in three stages during two periods of volcanism: an early fissure type eruption; formation of relatively large tephra ring volcanoes and building up of localized thick lava piles up to 250m in the southern part of the plateau. According to studies carried out by Barfod *et al*. (1999), based on diffusional constraints of "He" in mantle xenoliths of the CVL and pollen dating by Salzmann (2000) of maar sediments from the Tilla crater on the Biu plateau, the rough estimate of the age of the last magmatic period is put at < 50 million and > 25 million years.

A base line socio-economic survey, carried out by Amaza *et al.* (2007), revealed that about 68% of the people on the Biu Plateau are farmers engaged in various agricultural activities on the plateau that lead to the modification of the plateau (Amaza, 2007). However, no similar study has focused on the volcanic craters, as spectacular features on the Biu plateau. Therefore, this study intends to fill this gap by focusing on the identification of the volcanic craters, the geomorphic processes responsible for their modification, thickness and layering of the overburden materials of in the craters on the Biu plateau.

1.2 Aim and Objectives of the Study

The study examines the Analysis of the thickness and Layering of Overburden Materials of Volcanic Craters on the Biu Plateau. The specific objectives of the study are:

i.to identify the Volcanic Craters on the Biu Plateau;

ii.identify the geomorphic processes that are involved;

iii.determine the thickness and layering of the overburden materials of the craters.

2. Research Questions

i. How many Craters are there on the Biu plateau?

ii. What are the geomorphic processes responsible for the modification of the craters?

iii. What is the thickness and layering of the overburden materials?

3. Methodology

Both primary and secondary sources of data were used for this study. The primary data include the observation of geomorphic processes in the field, the use of terrameter for determining the thickness and layering of sediments within the craters. Secondary sources of data were obtained from the use of the Biu topographic sheet 133 (1:100,000).

3.1 Types of Data Required

The types of data used in this research include:

i.Inventory of volcanic craters on the Biu plateau.

ii.Types of geomorphic processes.

iii.Thickness and layering of sediment deposited within the craters using the resistivity

3.2 Sampling Techniques

Using the topographic map of Biu sheet 133 on the scale of 1:100,000 and ground truth, the craters were categorised into three major groups based on the diameter of their rims as follows: Large (> 300 meters), Medium (200 – 300 meters) and Small (< 200 meters).The craters with rim diameter less than 200 m is termed as a small rim size, those with rim sizes between 200- 300 m as Medium rim sizes and those with rims greater than 300 m as large rims. Purposive sampling technique was used to select one crater from each of the three groups for detailed study.

3.3 Instrumentation and Resistivity Determination

The Instrument used during the survey was ABEM SAS 300C .The ABEM SAS 300C is a family of instruments for the survey of resistivity and Self Potential. ABEM SAS 300C is a complete transmitter/receiver system. The continuously updated running average is presented automatically on display. This continues until the operator is satisfied with stability of the result. SAS results are more reliable than those obtained using single shot systems. Moreover, SAS results are easy to check than results obtained using signal stacking.

For this study, the arrangement in which the potential gradient is measured, called the Schlumberger arrangement were adopted. The Schlumberger arrangement was chosen from other electrode configurations for the following reasons:

i.The effect of near lateral in homogeneities are less apt to affect measurement.

ii.It has ease of operation in that two electrodes are moved at a time unless occasionally when the potential electrode spacing is also increased.

iii.The configuration gives greater probing depth.

iv.The interpretation techniques are more fully developed and diversified (Zohdy *et al*, 1990).

Geophysical investigation was carried out in the three selected sampled craters with the view to evaluating the thickness of the overburden materials on the floor of the craters since their formations by assessing the thickness of the overburdens, the layers, and the types of materials as well as the lithological variations. Vertical Electrical Sounding (VES) using the Schlumberger Array was carried out at ten VES stations, four in Kumba, three in Tilla and three in Jali Tagurmi craters as shown in Plates 1.

Plate 1. Vertical Electrical Sounding in Kumba crater

Source: Fieldwork, 2013

Resistivity Soundings were carried out at the following GPS points; Kumba crater (Lat. N 10^o 43'56.1", Long. E 12^o 07'20.8"), Tilla crater (Lat.N10^{o}32'25.7", Long.E12^o 07.56.2") and Jalli Tagurmi (Lat. N 10^o 41' 53.2", Long. E 12^o 09' 32.5"). The type and thickness of sediments in the craters were determined and described. Ten vertical electrical soundings points were conducted with electrode spread of AB/2=100 m. The survey started at a short distance of AB/2, which was then increased progressively as the survey continued. At a certain period, the potential distance MN was increased especially when it becomes too small to give reliable reading of resistance. However, the condition of AB/2 ≥ 5 MN was fulfilled. Measurement of resistance was taken directly from the Resistivity meter which was then multiplied by the K factor to calculate the apparent resistivity. This was then plotted on a bi-logarithmic paper and the distance AB/2 (m) against the resistivity (ρ) value was measured for further processing.

A Computer software program, the IX1D (2003) inversion was used to interpret the data collected. It is worth mentioning at this point that the program IX1D inversion allows the user to enter resistivity data in a standard geo-soft format. It also smoothens the field curve through the process of filtering technique that involves single point correction, eccentricity correction and vertical curve segment shift. Interpretation of the layer parameters was also carried out.

4. The Craters on the Biu Plateau

Using the Biu topographic map, sheet 133 (1: 100,000) and ground truthing, four (4) large craters, five medium size craters and five small craters were identified which gives a total of 14 craters on the Biu plateau as shown on Table 1 and Figure 1.

Table 1. Inventory of Volcanic craters on the Biu Plateau

S/No	Large (> 300 m)	GPS Coordinates (Northing)	Easting
1.	Kumba Crater (Gar Kidi)	10^{o} 48’20.486” N	12^{o} 7’81.533” E
2.	Gurara Crater (Gar Gurara)	10^{o} 36’36.616” N	12^{o} 9’43.291” E
3.	Zamta Crater (Gar Zamta)	10^{o} 40’56.895” N	12^{o} 1’13.285” E
4.	Padam Crater (Gar Padam)	10^{o} 50’47.798” N	12^{o} 7’22.654” E
	Medium (200-300 m)		
5.	Kidi Crater (Gar Kidi)	10^{o} 46’20.485”N	12^{o} 7’8.153” E
6.	Hujiga Crater (Gar Hujiga)	10^{o} 49’26.901”N	12^{o} 4’16.184”E
7.	Kufakana Crater (Gar Kufakana)	10^{o} 44’ 31.449”N	12^{o} 9’11.084”E
8.	Hizhi Crater (Gar Hizhi)	10^{o} 40’28.757” N	12^{o} 4’42.026”E
9.	Tilla Crater (Gar Tilla)	10^{o} 39’ 50.066”N	12^{o} 8’47.014”E
	Small (> 200 m)		
10.	Jali Tagurmi Crater (Gar Jali Tagurmi)	10^{o} 42’38.896”N	12^{o} 7’40. 186 E
11.	Tilla Crater (Nkwar Tilla) (Gar Nkwar Tilla)	10^{o} 38’37.079”N	12^{o} 9’57.136”E
12.	Sugur Crater (Gar Sugur)	10^{o} 44’34.966”N	12^{o} 5’58.185”E
13.	Pidarta Crater (Gar Pidarta)	10^{o} 55’22.147”N	12^{o} 0’27.156”E
14.	Sugwi Crater (Gar Sugwi)	10^{o} 53’15.524” N	12^{o} 1’29.767”E

Source: Fieldwork, 2014

The craters are very conspicuous on the contour map as shown in Figure 1. The result also revealed that the pattern of the distribution of the craters on the Biu plateau is not evenly distributed as most of the large, medium and small craters with the exception of Tilla and Nkwar Tilla are all located around the Miringa volcanic area which could be described as random in pattern as shown in Figure 2.

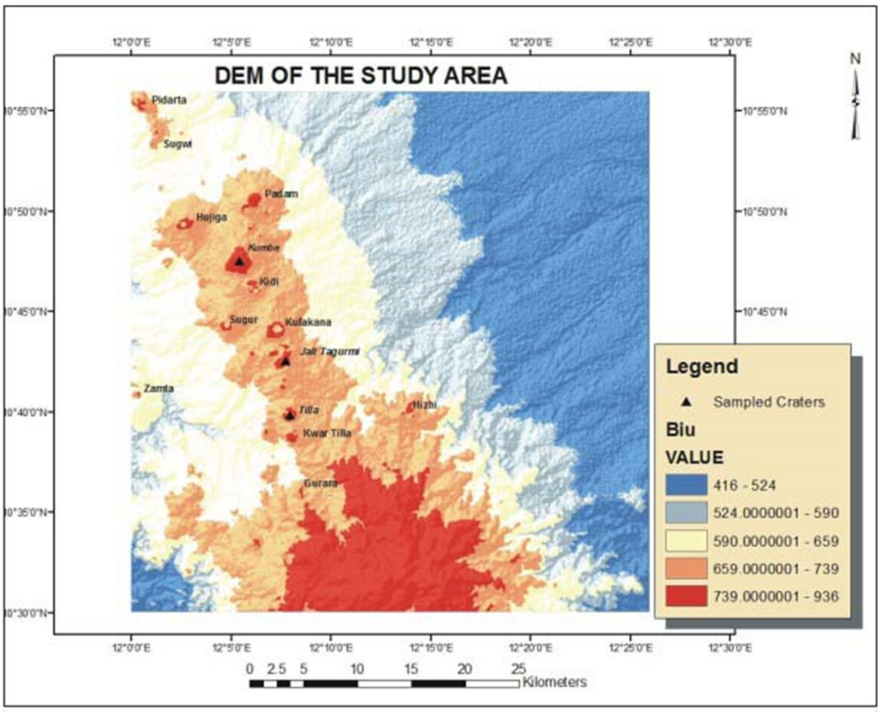

Figure 1. DEM of the study Area

Source: Generated from SRTM DEM

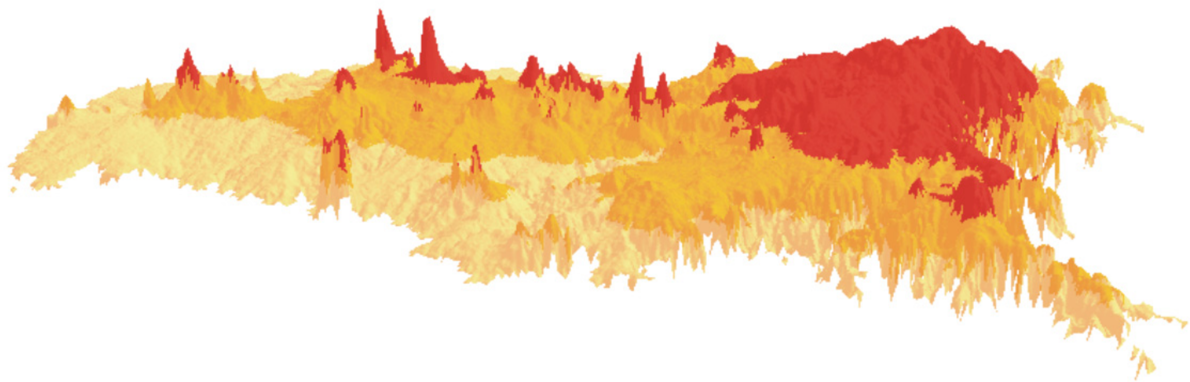

Figure 2. Biu Volcanic Plateau showing the Distribution of craters

Source: Generated from SRTM DEM

3.4 Types of Geomorphic Processes Identified

Field survey result revealed that sheet erosion, rill erosion, gully erosion, transportation, deposition, physical, and biological weathering are the most prominent geomorphic processes operating in the area. The rims of the craters that serve as divide, generate run off which tends to increase as it descends the steep slopes that joined the rims and the floor of the crater. It is transformed into sheets erosion and later transformed into rills along the gentle slopes where it is transported and finally deposited on the floors of the craters. This findings agree with a similar statement of Faniran and Ojo (1980) that deposition depends on the discharge, stream gradient, channel characteristics and changing pattern of flow. A change from a steep to a low gradient usually leads to a loss of energy in the river or runoff and consequent deposition of sediments. In other words, deposition of materials eroded from the crest of the rims of the craters and transported from the steep slopes will finally be deposited at the gentle slope and foot slopes as observed in the three craters.

3.5 Thickness and Layering of the Overburden Materials

The results of the VES conducted at the craters are presented in Tables 2 to 4 and Figures 2 to 11. The modelling of the Vertical Electrical Sounding (VES) data obtained from the ten points were used to derive the graphic curve and layered models as shown in Tables 2 to 4 and Fig 2 to 11. The results revealed that most of the graphic curve models are K and KH model type while the layered Model are either three or four layered beneath each station. The geological sequence beneath the three sampled craters are as follows;

Table 2. Kumba Crater VES Results

(a) Point 1

S/No	Ωhm-m	Thickness in m	Depth in m	Lithology
1.	217.65	0.47	0.47	Clayey topsoil
2.	28.16	5.22	5.70	Weathered basalt
3.	1185.4	-	-	Newer basalt
	Fitting error 1.4 %			
	(b) Point 2			
1.	73.4	0.40	0.40	Clay
2.	18.16	6.60	7.00	Weathered basalt
3.	8920.1	-	-	Newer basalt
	Fitting error 1.7 %			
	(c) Point 3			
1.	411.8	0.23	0.23	Clay
2.	48.67	11.13	11.37	Weathered basalt
3.	2123.1	-	-	Newer basalt
	Fitting error 1.4 %			
	(d) Point 4			

1.	231.9	0.25	0.25	Clay
2.	54.83	4.14	4.38	Weathered basalt
3.	1987.7	-	-	Newer basalt
	Fitting error 1.2 %			

Table 3. Tilla Crater VES Results

(a) Point 1

S/No	Ωhm-m	Thickness in m	Depth in m	Lithology
1.	24.30	2.47	2.47	Clayey topsoil
2.	11.63	18.12	20.60	Weathered basalt
3.	37.71	-	-	Weathered/fractured
	Fitting error 0.6 %			
	(b) Point 2			
1.	17.34	0.63	0.63	Clayey topsoil
2.	39.87	12.67	12.89	Weathered/fractured basalt
3.	21.14	-	-	Fractured basalt saturation
	Fitting error 0.8 %			
	(c) Point 3			
1.	9.87	2.65	2.65	Clayey topsoil
2.	17.58	23.13	25.78	fractured basalt
3.	11.11	-	-	Weathered Fractured saturated
	Fitting error 0.9 %			

Table 4. Jalli Tagurmi Crater VES Results

(a) Point 1

S/No	Ωhm-m	Thickness in m	Depth in m	Lithology
1.	23.19	7.09	7.09	Clayey topsoil
2.	667.82	2.77	9.86	fractured basalt
3.	1392.2	-	-	Newer basalt
	Fitting error 1.4 %			
	(b)Point 2			
1.	27.38	8.47	8.47	Clayey topsoil
2.	658.27	2.60	11.08	fractured basalt
3.	2008.4	-	-	Newer basalt
	Fitting error 1.8 %			
	(c)Point 3			
1.	201.7	6.15	6.15	Clayey topsoil
2.	654.23	2.55	8.70	fractured basalt
3.	2280.6	-	-	Newer basalt
	Fitting error 1.8%			

Source: Fieldwork, 2014

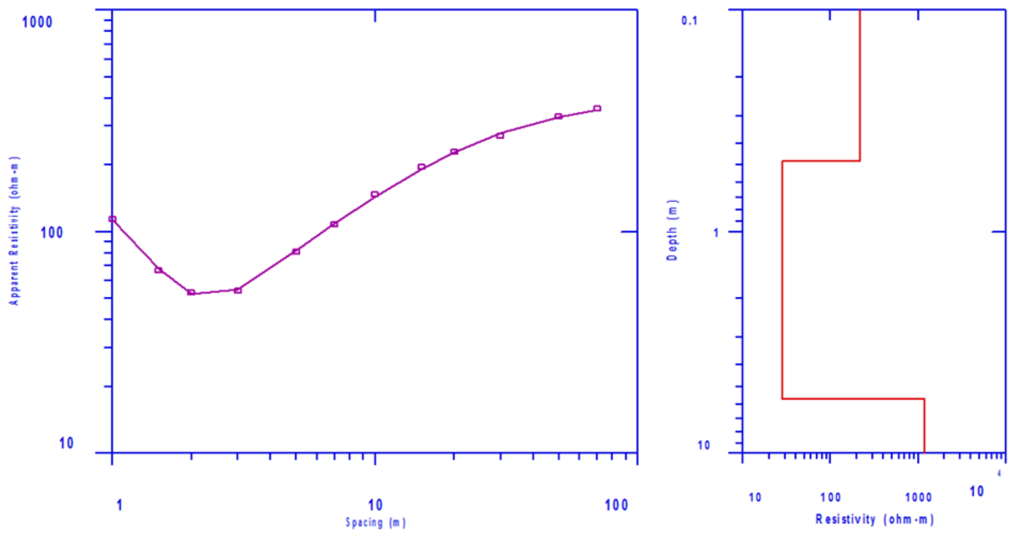

Figure 3. Kumba Crater Layered Model (3 layers) Graphic Curve Model (K type) at Point 1

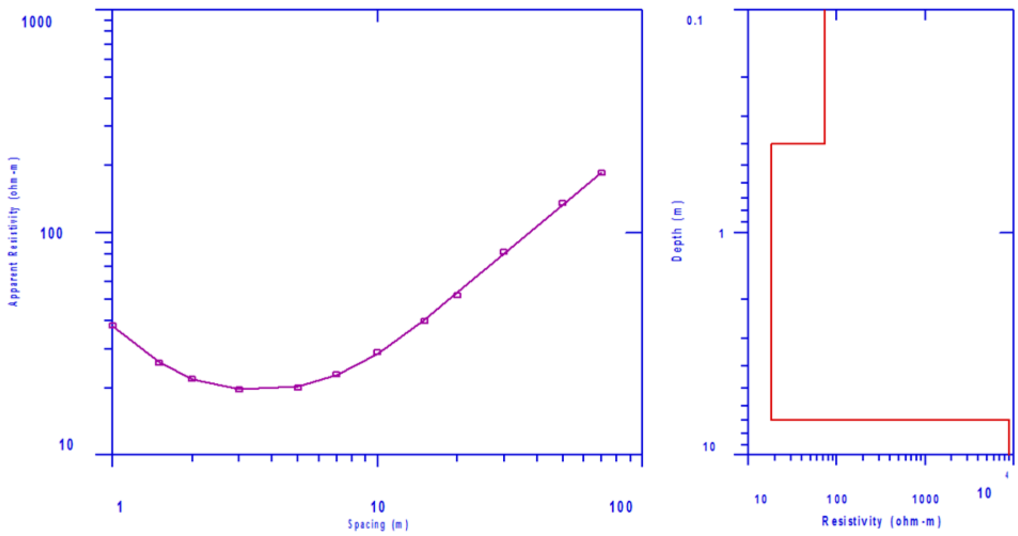

Figure 4. Kumba Crater Layered Model (2 layers) Graphic Curve Model (K type) at Point 2

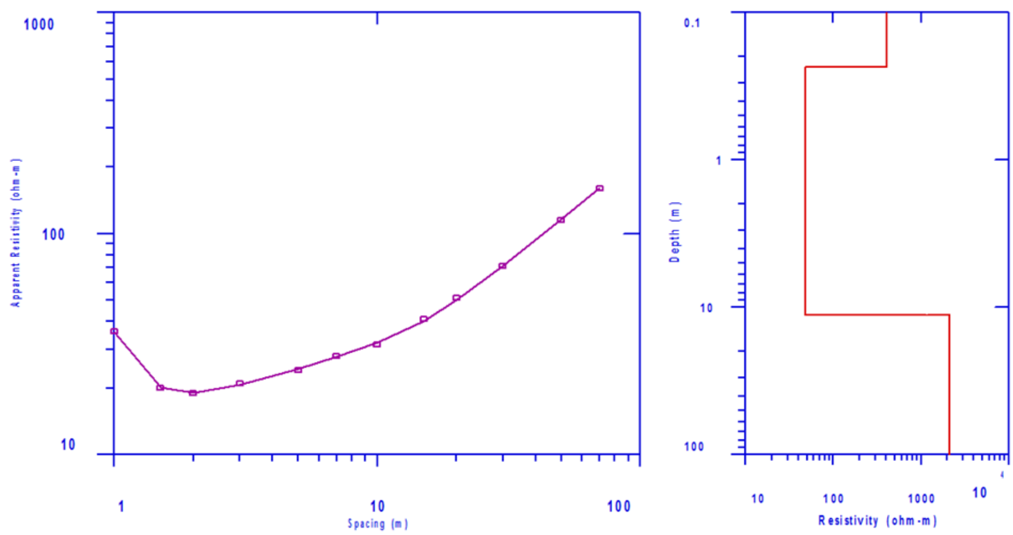

Figure 5. Kumba Crater Layered Model (2 layers) Graphic Curve Model (K type) at Point

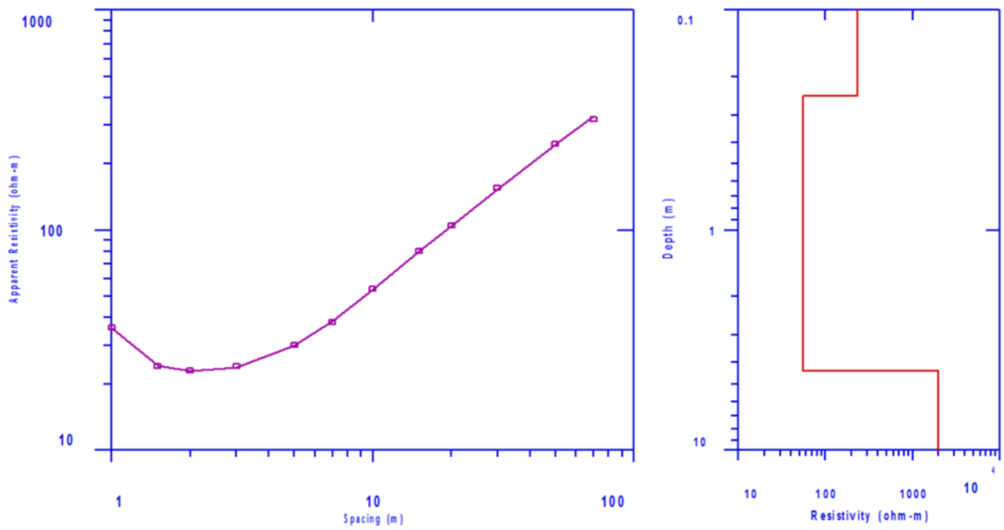

Figure 6. Kumba Crater Layered Model (2 layers) Graphic Curve Model (K type) at Point 4

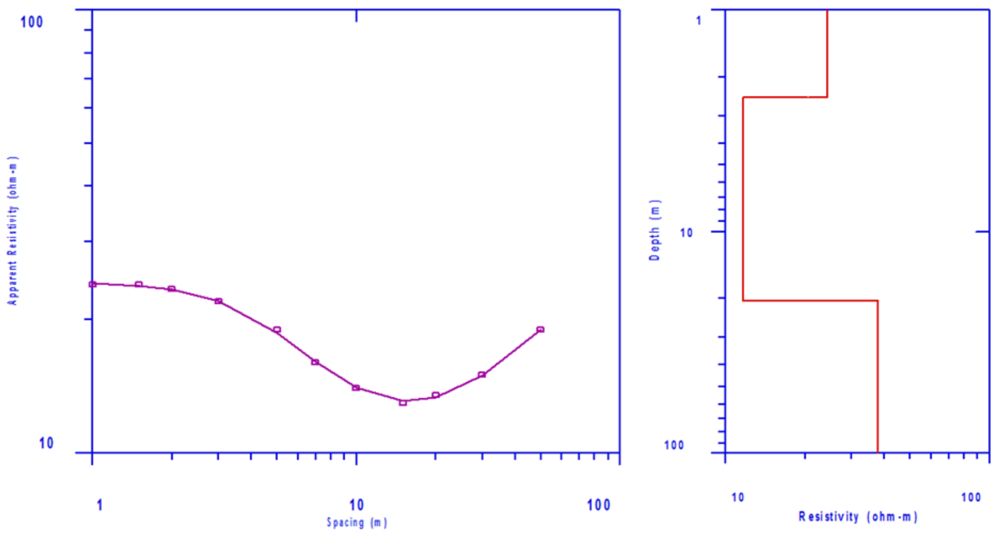

Figure 7. Tilla Crater Layered Model (2 layers) Graphic Curve Model (K type) at Point 1

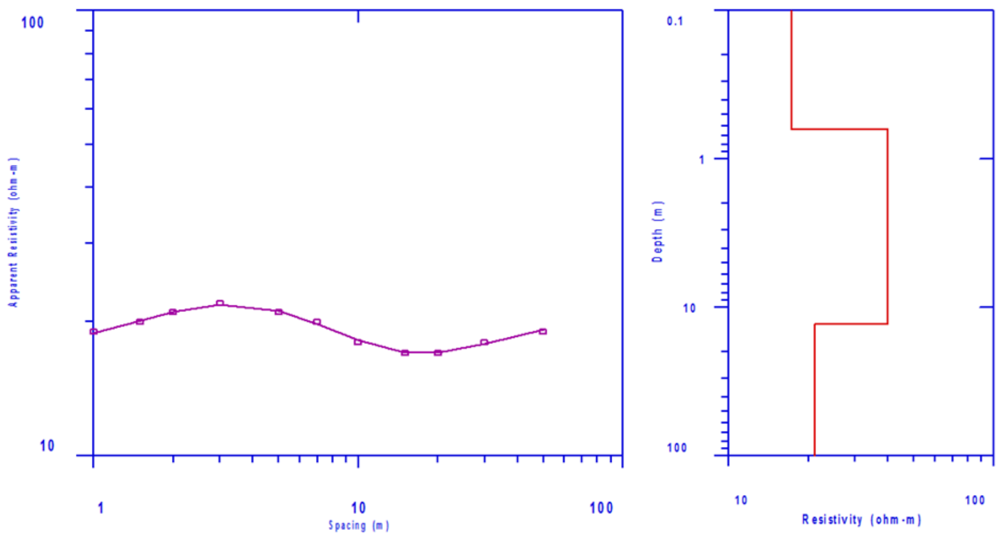

Figure 8. Tilla Crater Layered Model (2 layers) Graphic Curve Model (KH type) at Point 2

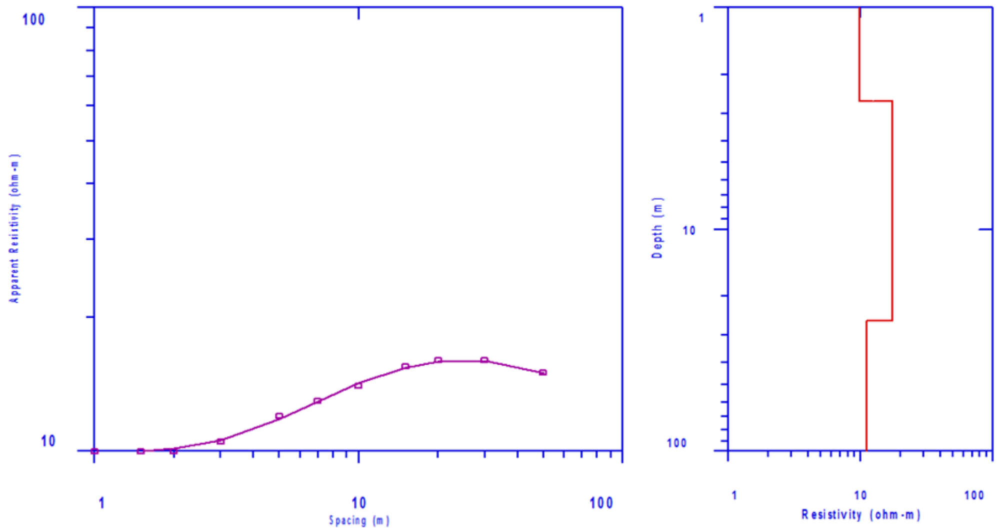

Figure 9. Tilla Crater Layered Model (2 layers) Graphic Curve Model (K type) at Point 3

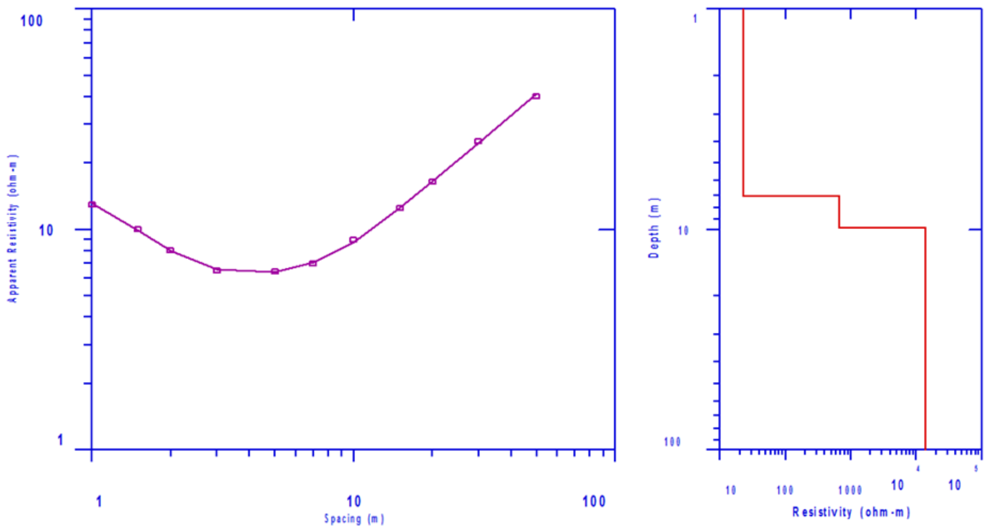

Figure 10. Jali Tagurmi Crater Layered Model (3 layers) Graphic Curve Model (K type) at Point 1

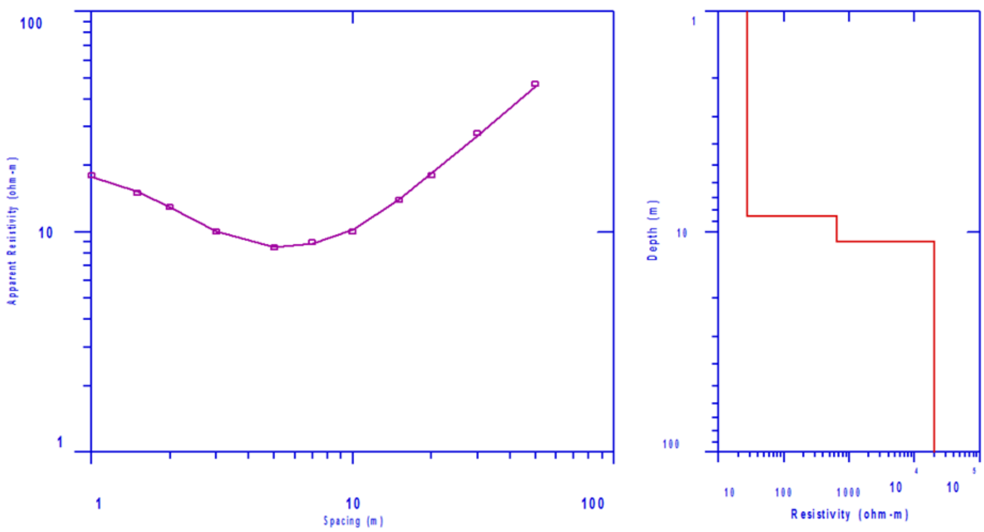

Figure 11. Jalli Tagurmi Layered Model (3 layers) Graphic Curve Model (K type) at Point 2

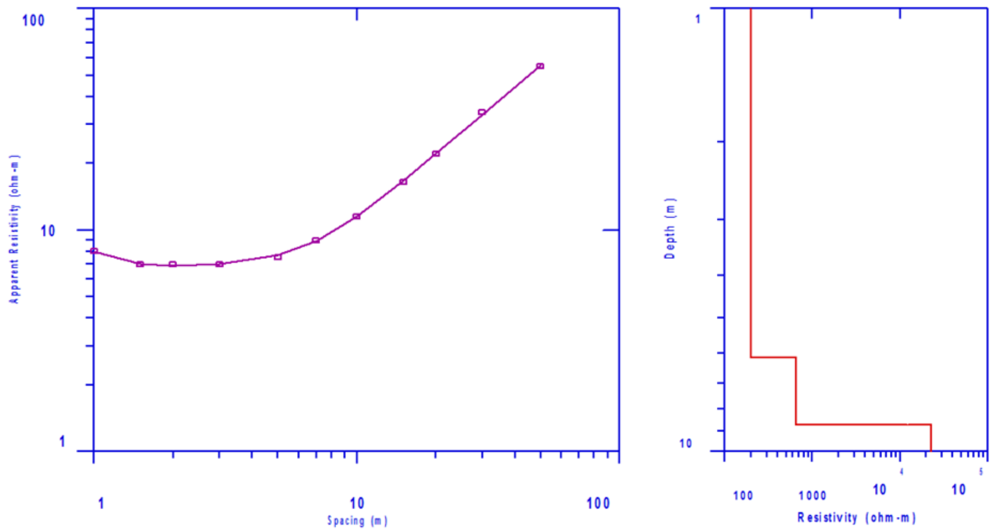

Figure 12. Jali Tagurmi Layered Model (3 layers) Graphic Curve Model (K type) at Point 3

3.6 The Thickness and Layering of Kumba Crater Overburden

The highest thickness of the over burden materials at Kumba is 6.60 m with highest depth of 11.37m as shown on Table 4.2 and Figures 3 to 6. This finding agrees with similar studies conducted by Ako and Osondu (1986) and Bassey (2004).The lithology could be described as being composed of clay, weathered basalt, partly weathered or fractured Basement Complex rock and newer basalt as shown in Tables 2 b and 2c. From the results obtained from the sounding carried out at the floor of the Kumba crater as revealed three geo-electric layer structure of clayey topsoil layer ranging in resistivity from 73.4Ω m to 411.8 Ω m as well as thickness ranging from 0.23 m- 0.47 m was obtained. It also revealed weathered basalt with resistivity of 18.16 Ω to 48.67Ω m as well as thickness from 4.14m to 11.13m and newer basalt with resistivity range from 2123.1 Ω m to 8920.1Ωm as shown in Fig 3, 4, 5 and 6 respectively.

3.7 The Thickness and Layering of Tilla Crater Overburden

The highest thickness of overburden materials in Tilla is 23.13m with highest depth of 25.78 m. The lithology is clayey topsoil, weathered basalt and fractured basalt as shown in Table 3c. The result in Tilla crater revealed three geo-electric layer as shown in Fig 7 to 9 and structures of clayey with resistivity of 9.87 Ω m to 24.30 Ω m and thickness of overburden materials ranging from 0.63m to 2.65 m. Weathered basalt has resistivity range between 11.63 Ω m to 39.87 Ω m with thickness of overburden range from 12.67m to 23.13 while fractured basalt has resistivity of 11.11 Ω m to 37.71 Ω m.

3.8 The Thickness and Layering of Jali Tagurmi Crater Overburden

The highest thickness of the overburden materials at Jali Tagurmi is 8.47m and the deepest depth is 11.08 m as shown on Table 4b. The lithology of the materials could be described as clayey topsoil, newer basalt and fractured basalt. Jali Tagurmi is equally characterized by three geo-electric layer structures of clayey topsoil, fractured basalt and fresh basalt. The clayey topsoil has a resistivity of 23.19 Ω m to 201.7 Ω m with a thickness of overburden of 6.15m to 8.47m. The fractured basalt has a resistivity of 654.23 Ω m to 667.82 Ω m with a thickness of overburden of 2.55m to 2.77m while the newer basalt has resistivity of 1392.2 Ω m to 2280.6 Ω m as shown in Figures 9, 10 and 11 respectively. This finding agrees with that of Uba (2011) and Olayinka (2001) who indicated the same range of resistivity and types of overburden materials in their studies.

Overall, the average depth of the overburden to the fresh basalt is 10m. This ranges from 9 to 11m to fresh basalt. This comprises clayey topsoil followed by fractured basalt. Based on the thickness of the overburden which has four layers and types of materials, it is evident that materials were eroded from the rims of the craters, transported over the slopes and finally deposited within crater floors. This has resulted in the modifications of the craters after their formations, hence their present morphologies.

4. Summary, Conclusion and Recommendations

4.1 Summary

The study examinnes the analysis of thickness and Layering of Overburden Materials of Volcanic craters on the

Biu plateau, Borno State, Nigeria and come up with the following results: There are a total of fourteen craters on the Biu plateau with four falling under large category with diameter greater than three hundred meters, five fall under medium category with diameter ranging from two hundred to three hundred meters and five fall under small category with diameter of less than two hundred meters. The result of modelling of the Vertical Electrical Sounding (VES) data obtained from the ten points, which were used to derive the four geoelectric sections revealed that the thickness of the overburden materials at Kumba crater at: VES 1 is 5.7m, VES 2, 7m. VES 3, 11m and VES 4, 7m. The VES results revealed that there are three to four geological layers beneath each VES station. The results of the three VES sounded at Tilla revealed three geoelectric layers with the first layer belonging to clay topsoil and weathered /fractured basalt saturated with water. In Tilla crater, fresh basalt was not encountered though the depth to the water bearing layers range from 13 to 26m. Three VES were sounded at Jali Tagurmi crater.

The average depth of the overburden to the newer basalt is 10m, and ranges from 9 to 11m. This comprises clayey topsoil and fractured basalt. The geological sequence beneath the three sampled craters is composed of clay, weathered basalt, partly weathered / fracture basement and newer basalt. Based on the thickness of the overburden shown by each VES having not less than three to four layers and types of materials, it is evident that much materials were eroded from the rims of the craters, transported along the slopes and finally deposited within the crater floors. These processes are responsible for the modifications of the craters since the time of their formations.

The observed geomorphic processes modifying the craters (over time) were the physical and chemical weathering processes that sets the pace for erosion in form of splash, sheet, rill and gullying.

4.2 Conclusion

It is evident from the study that the Biu plateau is characterised by well-defined craters with breached rims and steep conical sides that had their origin from volcanic processes (exogenouse) during the late tertiary and quaternary volcanic activity.

Since their creation, they have been constantly modified by geomorphic processes. Currently, the results of the study revealed that in the recent past, the craters are not only subjected to geological erosion but also to accelerated erosion such as sheet, rill and gully.

At the rate and manners at which the craters are being modified, if left unchecked, the geomorphic processes will continue to cut down their slopes and both the floors of the craters and their slopes (Rims) would become graded very rapidly. At this level, the rates of removal will be equal to the rates of uplift and the craters will be at a state of dynamic equilibrium and consequently will ceased to be classified as craters in geomorphology. If this happens, the craters will become mere shallow depressions on the landscape.

5. Recommendations

Based on the findings of this research, the following recommendations are made:

There is a need for a public enlightenment campaign at the grassroot to education the local communities by the local Government Authority on the environmental effects of their activities. This is to ensure sustainable use of the craters.

There is also a need to enforce existing Laws by the local government authority to ensure controlled exploitation of land and water resources such as mining, cultivation, grazing and land clearing in and around the craters so as to reduce accelerated soil erosion and deforestation.

The community and government should jointly embark on reforestation of the catchment areas as well as rehabilitate the eroded areas as an effective measure at reclaiming and controlling gully sites on the slopes of the craters.

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