Chapter

Is a Volcanic Eruption Possible in Nigeria?

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Abstract

The Jos and Biu Plateaux volcanic provinces occupy the northeastern half of Nigeria bordering the Cameroon Volcanic Line, dotted with conspicuously visible number of dormant volcanoes with no reported activity. These dormant volcanoes represent potential future eruption sites. The ejecta materials of these volcanoes are essentially basaltic in composition and consist of sequence of pyroclastic materials, basalts, scoria and ash and are formed by strombolian and effusive styles of eruption. The volcanoes are represented by well-preserved cones and lava flows. In places the lava flows have been lateritized and eroded leaving remnants of weathered basalt boulders and a number of plugs and dome-like outcrops lacking any preserved cones. The basalts display essentially similar compositions consisting of phenocrysts of both olivine, plagioclase (bytownite–labradorite), with minor pyroxene (diopside-augite) embedded in a groundmass of plagioclase laths (labradorite), and accessory magnetite, ilmenite, k-feldspars, and volcanic glass. Geochemical data shows that these basalts are mainly alkaline olivine basalts derived from the deep mantle source enriched in incompatible elements similar to that of the Ocean Island basalts (OIB). Preliminary ^{40}Ar-^{39}Ar ages on the some of the basalts revealed Quaternary ages (Pleistocene epoch). The significant change in the composition of the Pidong Lake marked by decreasing pH is indicative of a probable input of juvenile fluids into the Lake. Also, the several incidences of volcanic eruptions along the close-by Cameroon volcanic line are pointers to the possibility for the reactivation of any of the dormant volcanoes in Nigeria. This work focuses on the need to assess the hazard level of some of these volcanoes for effective monitoring, disaster preparedness and land use planning as more people live and farm in these potentially endangered volcanic prone areas, unaware of the inherent risk.

Keywords: volcanoes, eruption, Jos Plateau, Biu Plateau, Nigeria

1. Introduction

An inventory of all the volcanic prone areas on the Jos and Biu Plateaux were carried out, followed by detailed update of the Geology of two major volcanic areas on the Jos Plateau volcanic provinces (Kassa and Kerang volcanoes). The geochemistry (major, trace and REEs compositions) of these volcanoes were determined and a few dating using ^{40}Ar-^{39}Ar technique were performed on the Kassa basalts. Hydrogeochemical investigations of the Pidong Volcanic Crater Lake have also been carried out to constraint the chemical element sources into the Lake. Also, ^{40}Ar-^{39}Ar

dating of the basalts of the Kassa volcanic field has revealed young ages spanning from 2.5, 1.97, 1.66, 1.39 to 1.34 Ma confirming the recent but short interval and multiple successive episodes of eruptions associated with volcanic activity in the region. Similar ages in the range of 2.1–0.9 Ma have been reported from basaltic rocks from the Benue Trough and a dolerite dyke from the region [1]. These same range of ages (of 2.83–0 Ma) have been obtained on basaltic rocks from the near-by Cameroon Volcanic Line (CVL) [1]. The Jos Plateau basalts vary in composition from basalt proper to trachyandesitic varieties of alkaline basalt magma series and some tholeiitic affinity [2]. Contrarily to the general notion that volcanoes are only associated with plate margins alone, the volcanoes in Nigeria are emplaced within the continent, associated with mantle Hot Spots. Records of gas emissions at Lakes Monoun and Nyos in Cameroon Republic in 1984 and 1986 respectively destroyed

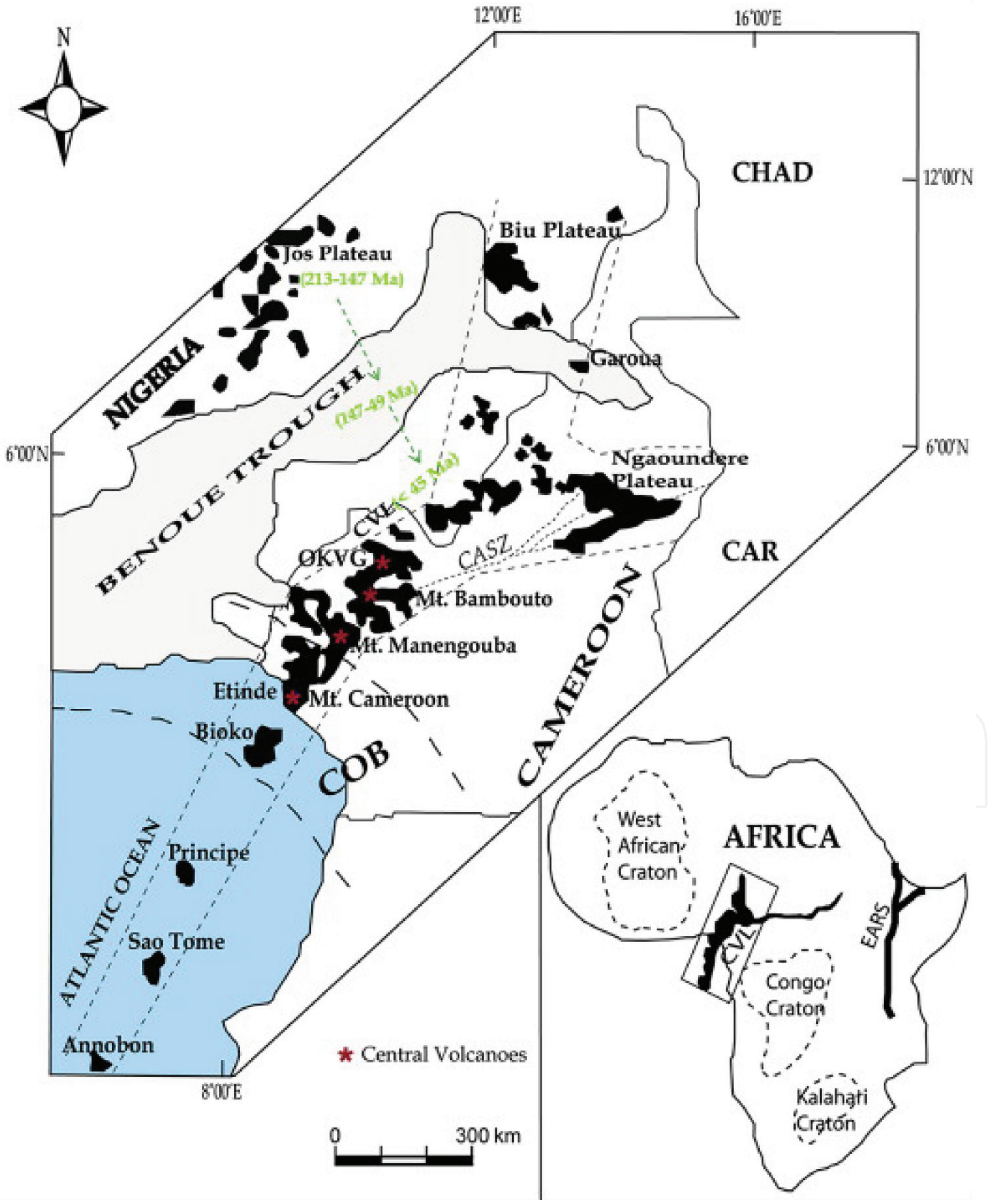

Figure 1.
Locations of the Jos and Biu Plateaux Volcanic Provinces, Nigeria.

lives and properties within 14 km radius to a large extent, affected some communities in Nigeria (Mambilla Plateau and Katsina-Ala River banks) [3]. This research attempts to provide answers as to whether it is possible that the dormant volcanoes in Nigeria with no recorded history of eruption could roar back to life? Some reported successive minor volcanic activities within the Cameroon Volcanic Line (CVL) (1909, 1922, 1954, 1959 and 1982) are pointers to the possibility of the reactivation of some dormant volcanoes in Nigeria.

2. Geologic settings

An understanding of the geology is important in studying natural hazards related to volcanism because the geology influences tectonic movement which leads to the disequilibrium of the ecosystem and other environmental components.

The Nigeria-Cameroon Volcanic Provinces lie within the Pan-African collision belt of West Africa (**Figure 1**). In Nigeria, the volcanic provinces (Jos Plateau, Biu Plateau, Benue Valley, etc.) are confined to the northeastern and central regions [4]. The volcanic provinces are characterized by numerous volcanic cones and lava flows consisting of alkaline olivine basalts together with less important trachyte and phonolite intrusive rocks [5].

Apparently, the large volcanic province of Nigeria suggests that volcanic activity during the Quaternary, was intense on the Jos Plateau, the Benue trough and along the northeast to southwest Cameroon line. Like the Jos Plateau volcanic regions, most of the main volcanic provinces such as the Bamenda Highlands, the Mambilla Plateau and the Adamawa Plateau are characterized by basement uplift [5].

The Cameroon Volcanic Line which extends from the Gulf of Guinea, Island of Annobon, Sao Tome and Principe and Fernando Po splits into two branches, one extending into northern Nigeria forming the Biu Plateau while the other extending eastward forming the Ngoude Plateau of Eastern Cameroun (**Figure 1**). Thus, in Nigeria, the volcanic provinces occur as relicts of volcanism in the form of scattered volcanic plugs and cones in some cases [5]. On the relatively uplifted Jos Plateau region, volcanic rocks are represented by volcanic cones and calderas [2].

Some of these cones generally rise only few hundred meters above the Plateau surface and are steep-sided with a central crater which may measure up to 450 m usually emerging at a breached in the crater wall. They are mainly built of basaltic scoria, volcanic ash, lava and with some variety of inclusions.

3. Materials and methods

3.1 Field mapping

Reconnaissance visits were carried out to past volcanic eruption sites where a careful and systematic mapping of each of the volcanoes visited were carried out so as to determine its nature, size and composition. Other information acquired was their physical surface weathering features, morphology, outcrop patterns and the extent of vegetation cover.

3.2 Petrographic and geochemical studies

Rock samples were collected for petrography, geochemistry and geochronology. Both petrographic and geochemical studies were done in the Department of Geology, University of Jos, Nigeria. ^{40}Ar-^{39}Ar dating on the basalts was done in

Netherlands, Geological Survey Laboratory. For quality control, a duplicate geochemical analysis on the same basaltic rocks was carried out at the University of Cardiff, Wales using the Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

3.3 Hydrogeochemical monitoring study

A constant monitoring of the Pidong Crater Lake through continuous water sampling 24–36 calendar months was done. The following physical parameters were recorded in the field using MT 806/pH/EC/TDS/Temp portable meter (pH, Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS)). The water samples were collected in 100 ml polyethylene plastic bottles for cations and anion analysis. The sample for cations analysis was acidified with 0.1 M Nitric acid to prevent precipitating and bacterial growth. The following cations: Mg, Ca, Na, K, Cr, Ni, Co, Sc, V, Cu, Pb, Zn, Bi, Cd, Sn, W, Ma, As, Sb, Rb, Cs, Ba, Sr., Ga, Li, Ta, Nb, Hf, Zr, Y, Th, U, B, Fe & REEs were analyzed using ICP-MS method at Bureau Veritas Minerals Laboratory Limited, Canada while the anions: SO_4, Cl, HCO_3, NO_3, F, Br and PO_4 were carried out using colometry method at Maxxam Laboratory, Vancouver, Canada (subsidiary of Bureau Veritas Ltd).

3.4 Isotope study

Oxygen-18 ($\partial^{18}O$) and deuterium ($\partial^{2}H$), and ($\partial^{3}H$) and Carbon-14 (^{14}C) isotopes of the Pidong Crater Lake, Bwonpe Volcanic Spring and rainfall were analyzed at Activation Laboratory Ontario, Canada using cavity Ring down spectroscopy (CRDS) model L11 02-1 California, USA with V-SMOW standards with typical standards deviation for $^{18}O \pm 0.1\%$ and 1% for Tritium unit (TU).

4. Field investigations

Field investigations have revealed the existence of about 22 dormant volcanoes on the Jos Plateau region alone (**Table 1**) and are generally aligned in series of NNW–SSE trend [6–8] (**Figure 2**). None of these volcanoes have record of any activity in recent past [8, 9]. They are composed mainly of basaltic scoria and pyroclastic materials.

Tables 1 and **2** present the inventory of the dormant volcanoes on the Jos Plateau and the Biu Plateau, respectively. From the NNW end are the Ganawuri volcanic line, Hoss volcanic line, Panyam (Sura) volcanic line and Gu (Jiblik) volcanic line (**Figure 2**). The Ganawuri line comprises from the north to south of the Bum, Jal, and Kwakwi volcanoes. The Hoss volcanic line consists of two volcanoes; Miango in the north and Hoss volcano in the south. The Miango line consists of five volcanoes from the north to the south viz.: Rukuba, Miango north, Miango south, Vom and Kassa volcanoes. The Southern-most end members are namely the Panyam and Gu volcanic lines. The Panyam volcanic line consists of seven volcanoes aligned in a NNE–SSW trending directions along a hypothetical fracture line [6, 10]; Dai volcano (referred to as Wushik volcano), Amshel volcano (referred to as Kugol volcano), Dutsin volcano, Kerang volcano, Tingyaras volcano, Ampang volcano (referred to as Mufil volcano), Pidong Crater Lake.

The Kerang twin volcanoes are located at Kerang town and its environs in the present Mangu Local Government Area, about 120 km from Jos, Plateau State (**Figure 1**). The Kerang I (Dustin) volcano has a peak of 1456 m above sea level and a crater diameter of 300 m. The volcanic pile consists of ash, lapilli, scoria, pumices,

S. No.	Name/ locality	Coordinates	Estimated population of people at risk	Type of volcano	Diameter of crater	Elevation (ASL)	Materials deposited
1	Bum		200,000	Cone			Basaltic
2	Jal		150,000	Cone			Basaltic
3	Kwakwi		250,000	Cone			Basaltic
4	Miango volcano I	N09° 51′.365″; E008° 43′.961″	For 1 & 2 250,000	Cone	350 m	1297 m	Scoraceous basalt/ pyoclastics
5	Miango volcano II	N09 51. 000′; E008 44″. 191′		Cone	650 m	1303 m	‘’
6	Kassa volcanoes	Highest Peak: N09° 36′.119″; E008° 53′.521″	100,000	Cluster (6 overlapping volcanoes)	Average 300 m	Average 1342 m	Olivine basalt, scoria, tuff, breccia/volcanic bomb
7	Sha 1	N09° 10′. 543″;E008° 47′. 955″;	20,000	Dome	200 m	1310 m	Pyroclastics (granite fragments/lava)
8	Sha 2	N09°10′. 846″;E008° 48′. 05″;	10,000	Dome	200 m	1294 m	Weathered basaltic materials capped by iron concretions
9	Passakai	N09° 10′. 543″;E008° 47′. 955″	10,000	Dome	300 m	1375 m	Lateritized
10	Wushik (Lakas) volcano	N09° 24′ 165″; E009° 10′ 554″	10,500	Cone	250 m	1300 m	Scoria/ pyroclastics
11	Kogul (Nyeis) volcano	N09° 22′ 573″;E009° 11′ 068″	80,000	Cone	250 m	1250 m	Scoria/ pyroclastics
12	Kerang I	N09° 20′ 286″;E009° 11′ 643″;	I to IV put together 200,000	Cone	600 m	1400 m	Scoria/basaltic rocks with large phenocrysts of olivine, garnet and pyroxene
13	Kerang II	N09° 20′ 392″;E009° 11′ 502″;		Cinder Cone	1000 m	1450 m	Scoria/basaltic rocks with large phenocrysts of olivine, garnet and pyroxene
14	Kerang III volcano (Swan junction)	N09° 20′ 306″;E009° 10′ 561″		Cone	1000 m	1486 m	Scoria/ pyroclastics
15	Kerang IV	N09° 11′ 283″;E008° 12′ 547″		Cluster (with 2 craters)	1.5 km	1372 m	Pulverised basement and lava

S. No.	Name/ locality	Coordinates	Estimated population of people at risk	Type of volcano	Diameter of crater	Elevation (ASL)	Materials deposited
16	Pidong volcano	N09° 17′ 650″;E009° 12′ 312″	50,000	Crater Lake	700 m	1378 m	Scoria/ pyroclastics
17	Jiblik volcano	N09° 16′ 591″;E009° 16′ 890″	100,000	Cinder Cone	1 km	1228 m	Scoraceous basalt +garnet/ pyroclastics
18	Kagu volcano	N09° 13′ 901″; 008° 16′ 383″	50,000	Cone	1 km	1060 m	Scoraceous basalt/ pyroclastics
19	Katul volcano	N09° 11′ 264″;E009° 15′ 795″	5000	Cone	700 m	976 m	Scoraceous basalt/ pyroclastics
20	Lakdak		7000	cone			Scoraceous basalt/ pyroclastics

Table 1.
Inventory of the volcanoes of the Jos Plateau, Nigeria.

breccias, basalts, boulders, and pyroclastic materials of various sizes. The Kerang II (Kerang) volcano has three craters with a peak height of 1510 m above sea level with a crater diameter ranging from 600 m to 1 km (**Table 1**). This volcano (Kerang II) is the second largest volcano on the Jos Plateau compared to the Jiblik volcano which has a peak height of 1670 m above sea level. The volcanic pile of the Kerang II volcano is composed of ash, lapilli, scoria, breccias, bombs, basaltic boulders and pyroclastic materials (lapilli, granitic and lava flows).

The Pidong volcano (Maar) has a series of three craters and aligned along the general North-South trend of the Panyam Volcanic Line [10]. The Pidong Maar consists of a sequence of pyroclastic materials (mixture of large fragments of basement rocks/pyroclastics, scoria and ash) and indicative of violent eruption [9]. The Gu volcanic line consist of five volcanoes from NW to SW namely Jiblik, Kagu, Katul and Lagdak volcanoes. The volcanic cones are composed essentially of volcanic ash, lapilli, bombs, tuff agglomerates, basalts and scoria. Most of them occur as single cinder cones (like at Miango, Wushik, Kerang Swan junction, etc.) but rarely as clusters of two or more volcanoes (for example Jiblik, Kassa, Kerang twin volcanoes, Pidong, etc.)

Also, the relatively large sizes of some of these volcanoes (Miango, Kassa, Jiblik, Kerang, etc.) suggest that quite a large volume of ejecta materials were spewed out covering quite a large landmass (valleys and low-lying plains) as lava flows. Lava flows apparently from the Jiblik volcanic can be traces to several kilometers south of the Jos Plateau escarpment. If any of these volcanoes erupt today with the same intensity and volume presumed, a large expanse of land would be buried and about 2 million people living around these volcanoes are potentially at risk.

The volcanoes of the Biu Plateau (**Table 2**) present similar physical and petrographic characteristics as those of the Jos Plateau region. The volcanoes also form near linear alignments from the north to the south and extend right through the low-lying Basement complex into the sedimentary formations of the Benue valley (Garkida-Gombi-Song areas in Adamawa State). The volcanoes are simple and never in clusters, but with very large craters of greater than 1 km, (Caldera). The volcanoes extruded directly the basement rocks and therefore are of lower

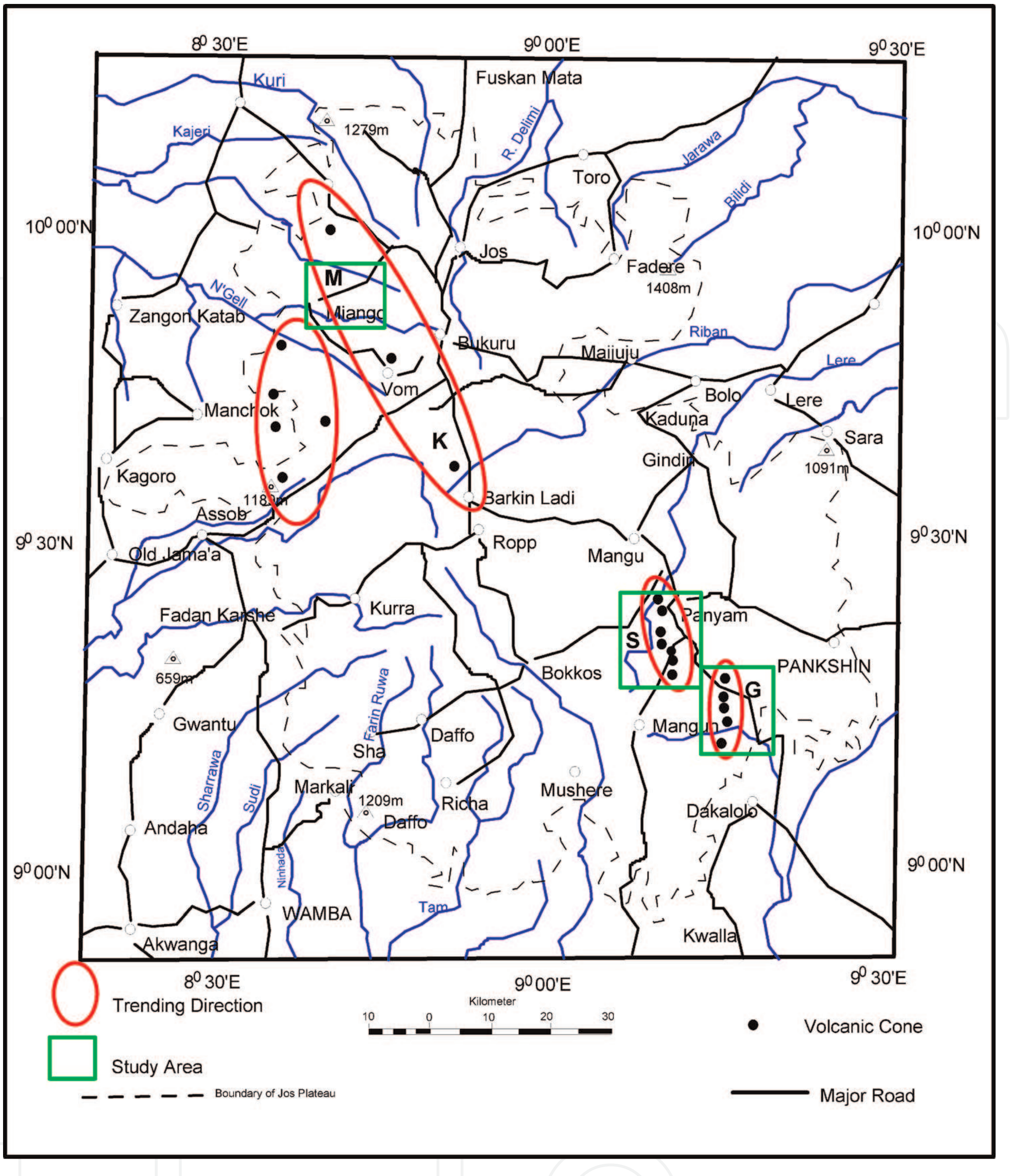

Figure 2.
Geological map of the 22 dormant volcanoes of the Jos Plateau showing sample locations. M = Miango volcanoes, K = Kassa volcanoes, S = Sura volcanoes, and G = Gu volcanoes.

altitude above sea level relative to those of the Jos Plateau, which extruded the already high-level Younger Granite bodies.

Also, unlike the volcanoes of the Jos Plateau, those of Biu Plateau are constituted by a large volume of volcanic ash and pyroclastic materials (for example, at Gwamya, Tilla Crater Lake, Gadam, Batadeka, Buratai, Katla volcanoes, etc.) (**Table 2**), suggesting that there was a tremendous spewing of ejecta materials (ashes and gases) into the atmosphere prior to the violent eruptions and/or in-between the eruptions.

5. Geochemical results and interpretations

The major and trace elements geochemical compositions of the basaltic rock samples collected from the various volcanic cones in the Jos Plateau volcanic

S/ No.	Name/ locality	Coordinates	Estimated population of people at risk	Type of volcano	Diameter of crater	Elevation (asl)	Materials deposited
1	Tasha Village	N10°17′388″ E011° 24′406″	5000	Cluster of 3 volcanic cones.	50 m	426 m asl	Massive basaltic rocks
2	After Tasha Village	N10° 16′.661″ E011° 27′.143″	5000	Dome		427 m	Massive/ vesicular basaltic rocks
3	Tagwaye (twin) volcanoes (In Kwaya Kusar LGA of Borno State)	N10° 30′.530″ E011° 30′.402″	15,000	2 Cones	200 m	512 m	Olivine basalts/ Agglomerates.
4	Gadam Volcano (Kwayar Kusar LGA, Borno State)	N10° 31′.951″ E011° 53′.485″	30,000	Cone	250 m	479 m. asl	Olivine Basalt
5	Location 5	N10° 32′.876″ E011° 57′.751″	Inhabited	Plug		683 m	Basaltic boulders/ Agglomerates/ tuff
6	Location 6	N10° 30′. 279″ E011° 50′ 726″	Inhabited	Dome		826 m	Vesicular Basaltic boulders/ Agglomerates/ tuff
7	TUM	N10° 36′. 254′ E012° 06′ 564″	10,000	Dome		643 m asl	Scoraceous basalt with olivine/ zeolite/ Columnar basalt.
8	Wakama (a) (BCG Village)	N10° 36′.472′ E012° 07′ 126″	2500	Cone	1 km	677 m	Scoraceous basalt
9	Wakama (b)	N10° 37′.211′ E012° 08′ 886″	2500	Caldera	10 km	701 m	Scoraceous basalt
10	Gwamya Volcano	N10° 33′.496″ E012° 06′. 341″	6000	Cone	500 m	752 m	Scoraceous basalt/ pyroclastic pile
11	Tilla Volcanic Hill	N10° 32′.549″ E012° 08′.477″	2500	Cone	500 m	910 m	Scoraceous basalt/ pyroclastic pile
12	Tilla Crater Lake	N10° 32′.336″	10,000	Caldera	2 km	751 m	Scoraceous basalt/

S/ No.	Name/ locality	Coordinates	Estimated population of people at risk	Type of volcano	Diameter of crater	Elevation (asl)	Materials deposited
		E012° 07′. 945″					pyroclastic pile
13	Versu Volcano	N10° 39′.759″ E012° 08′.457″	3000	Seasonal Crater Lake	700 m	782 m asl	Olivine basalt
14	Dragna Volcano	N10°27′.132″ E012° 05′.820″	5000	Caldera filled up by collapsed materials.	3 km	750 m asl	Weathered scoraceous basa Basalt
15	Marama Volcano	N10° 27′.746″ E012° 09′.093″	150,000	Cone	1 km	735 m	Scoraceous basalt/ pyroclastics
16	Gwaram volcanic hill	N10° 39′.214″ E012° 08′.092″	8000	Cone	1 km	942 m	Boulders of scoriaceous basalt
17	Batadeka (i) Volcanic hill	N10° 41′. 673″ E012° 07′.707″	3000	Cone	700 m	884 m	Weathered scoriaceous basalt
18	Batadeka (ii) Volcanic hill	N10° 42′. 067″ E012° 07′.542″	3000	Cone	1 km	1053 m asl	Weathered scoriaceous basalt
19	Kwatla Crater Lake	N10° 42′.117″ E012° 06′.433″	Inhabited	Seasonal Crater Lake	1.5 km	752 m asl	Weathered scoriaceous basalt
20	Maldau	N10° 43′.500 E012° 06′.979″	Inhabited	Cone	350 m	907 m asl	
21	Buratai Volcanic Hill	N10° 53′.926″ E012° 02′.800′	5000	Dome	700 m	718 m asl	Weathered scoriaceous basalt/ pyroclastics
22	Kona Uku Volcanic hills	N10° 49′.814″ E012° 07′.062″	10,000	3 Cones clustered together	2 km	879 m asl	Weathered scoriaceous basalt/ pyroclastics
23	Dutsen Kura (Bogur) Volcanic hill	N10° 49′.313″ E012° 05′.978″	5000	Seasonal Crater Lake	1.2 km	1011 m asl	Weathered scoriaceous basalt/ pyroclastics
24	Kukuwa (Gabai lga Yobe State)	N11° 06′.387″ E011° 53′.689″	5000	Plug	200 m	429 m asl	Columnar basalt

S/ No.	Name/ locality	Coordinates	Estimated population of people at risk	Type of volcano	Diameter of crater	Elevation (asl)	Materials deposited
25	Kukuwa II	N11° 06′. 443″ E011° 53′. 534″	5000	Several Plugs	200 m	435 m asl	Columnar basalt
26	Kurara Volcanic Hill (Garkida junction Adamawa State)	N10° 22′.460″ E012° 34′.284″	50,000	Cone	1 km	661 m asl	Weathered scoriaceous basalt/ pyroclastics
27	Song (Song-Gombi Road)	N9° 51′.036″ E012° 36′.383″	50,000	Cone	700 m	477 m	Weathered scoriaceous basalt/ pyroclastics
28	Song (Hawul Mountains)	N9° 49′.504″ E012° 37′.155″	10,000	4 different cones aligned N-S	250 m each	420-1000 m asl	Weathered scoriaceous basalt/ pyroclastics

Table 2.
Inventory of the volcanoes of the Biu Plateau, Nigeria.

province are presented in **Tables 3** and **4**. The volcanic cones situated at the northern end of the volcanic line here referred to as the north-western group are represented by Miango (M1 & M2) and Kassa (K1–5), while the south-eastern end group are represented by Jiblik (G1 &G2), Tingyaras (S1), Ampang (S2), Pidong (S3), Wulshik (S4), Kugol (S5) and Kerang (S6).

The rocks display similar SiO_2 wt% contents (44.84–50.06 wt%) for the north-western group of volcanoes (M1&2 and K1–5) and 45.26–46.25 wt% for S1–6 and 49.69 wt% for the Jiblik volcano (G1). However, the sample G2 from Jiblik with high SiO2 content of 64.21 wt% is exceptionally acidic and does not seem to be a basalt. Many of the rocks from the Kassa volcanoes (K1, K3, K4, and K5) display the highest SiO_2 content (46.99–50.06 wt%) as opposed to those from Miango volcanoes (M1 &M2) and the southern volcanoes (S1–6) whose SiO_2 contents are typical of a normal basalt (45.26–46.25 wt%).The Miango and the Kassa volcanoes display higher Fe_2O_3 contents (12.33–12.61 and 10.42–11.35 wt% respectively). The southern group (G1 & S1–6) displays lower Fe_2O_3 content; 9.83 wt% for the Jiblik volcano (G1); and a relatively higher but similar concentrations of between 11.25 and 11.92 wt% for the Panyam Volcanic line members (S1–6).

In general, the Al_2O_3 contents of all the basalts from the different volcanic cones are significantly high but vary narrowly inter/intra the volcanic cones (13.87–18.07 wt % for the north-western group and 12.41–18.07 wt% for the southern group (G1 & S1–6)). In terms of the MgO content, the southern group (S1–6) presents relatively higher values of between 10.71 and 12.58 wt% as against an average of 8.00 wt% for the northern group (M1–2 & K1–5). The CaO, Na_2O, K_2O and TiO_2 contents for all the volcanoes vary narrowly; averagely 8; 3; 1.5 and 2 wt%, respectively.

Their Al_2O_3/TiO_2 ratios vary narrowly and could be on that basis be subdivided into two groups; those with ratios between 5.53 and 5.69 and then those between 6.39 and 6.62 for the entire volcanic line (N-S) (**Figure 3**). This is further a

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Analyte symbol unit	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MnO (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	P_2O_5 (%)	LOI (%)	Total (%)	Al_2O_3/TiO_2	CaO/TiO_2	Al_2O_3/CaO
M1	44.84	15.02	12.33	0.166	8.50	8.86	4.09	1.88	2.668	0.76	<0.01	98.83	5.63	3.32	1.70
M2	43.80	15.01	12.61	0.166	8.54	8.32	3.40	1.87	2.727	0.74	1.5	98.68	5.50	3.05	1.80
G1	49.69	14.90	9.83	0.142	8.10	7.07	3.34	1.70	1.659	0.47	1.33	98.81	9.03	4.26	2.11
G2	64.21	14.74	5.60	0.087	2.37	3.91	3.29	3.54	1.124	0.43	0.96	100.3	13.11	3.48	3.77
S1	44.97	12.41	11.51	0.166	12.85	9.43	3.13	1.62	2.213	0.59	0.03	98.92	5.61	4.26	1.32
S2	44.77	12.48	11.34	0.165	12.74	9.39	2.96	1.50	2.194	0.57	0.47	98.58	5.69	4.28	1.33
S3	45.75	16.00	11.92	0.161	6.34	8.16	3.58	2.21	2.849	0.70	0.99	98.66	6.62	2.86	1.96
K1	46.99	13.99	11.36	0.630	8.36	9.47	3.74	1.53	2.176	0.60	0.52	98.95	6.43	4.35	1.48
K2	50.06	14.23	10.83	0.149	7.16	8.9	3.50	1.22	2.158	0.37	<0.01	98.57	6.59	4.12	1.60
K3	48.02	18.07	10.42	0.164	3.30	7.74	5.28	2.80	2.516	0.84	0.12	99.27	7.18	3.08	2.33
K4	47.49	14.17	11.35	0.167	7.81	9.29	3.82	1.58	2.211	0.64	0.20	98.74	6.41	4.20	1.53
K5	47.05	13.87	11.28	0.160	8.17	9.36	3.55	1.59	2.17	0.64	0.67	98.52	6.39	4.31	1.48
S4	45.26	13.52	11.34	0.162	10.71	9.47	3.28	1.70	2.397	0.62	0.32	98.78	5.64	3.95	1.43
S5	44.77	12.82	11.40	0.166	11.50	9.58	2.83	1.65	2.318	0.61	1.08	98.73	5.53	4.13	1.34
S6	46.27	13.02	11.25	0.163	11.24	9.21	3.51	1.69	2.262	0.69	0.23	99.35	5.76	4.07	1.41

Table 3.
Major element compositions (in weight percentage) of volcanic rocks from the Jos Plateau Volcanic Province.

Analyte symbol unit	Ba ppm	SR ppm	Y ppm	Sc ppm	Zr ppm	Be ppm	V ppm	Ba/Sr	Zr/Y
M1	619	840	25	19	234	2	161	0.74	9.36
M2	865	799	26	19	239	2	153	1.08	9.19
G1	518	637	18	15	205	2	122	0.81	11.39
G2	1215	723	26	12	328	3	121	1.68	12.62
S1	530	654	22	23	193	2	185	0.81	8.77
S2	554	646	21	22	190	2	178	0.86	9.05
S3	794	1098	24	15	228	2	174	0.72	12.00
K1	571	782	25	18	177	2	161	0.73	7.08
K2	551	460	43	20	155	2	171	1.20	3.06
K3	820	983	26	7	258	3	155	0.83	9.92
K4	672	758	38	19	176	2	164	0.89	4.63
K5	523	1095	24	18	177	2	157	0.48	7.36
S4	569	748	23	21	212	2	178	0.76	9.22
S5	585	697	23	23	204	2	180	0.84	8.84
S6	688	766	23	20	215	2	172	0.90	9.35

Southeastern volcanoes: G1—basalt of Jiblik volcano; S1—basalt of Timjagha'as volcano; S2—basalt of Ampang volcano; S3—basalt of Pidong volcano; S4—basalt of Wushik volcano; S5—basalt of Kogul volcano; S6—basalt of Kerang volcano. Northwestern volcanoes: M1—basalt of Miango North volcano; M2—basalt of Miango South volcano; K1—basalt of Kassa volcano; K2—basalt of Kassa volcano; K3—basalt of Kassa volcano; K4—basalt of Kassa volcano; K5—basalt of Kassa volcano.

Table 4.
Trace elements compositions (in ppm) of the basaltic rocks from the Jos Plateau Volcanic Province.

reflection of the variations in Al_2O_3 contents of the basalts since TiO_2 contents remain relatively constant. Similarly, their CaO/TiO_2 and Al_2O_3/CaO ratios vary from 2.6 to 4.31 and 1.34–1.60 respectively. Such narrow difference in these ratios is expected from a low degree of magmatic differentiation of the same parent material by partial melting process (**Figures 3** and **4**).

Similarly, the rocks present subtle variations in incompatible element ratios Ba/Sr. and Zr/Y (0.73–0.90 and 8.77–9.35, respectively); all supportive of their subjection to low degree of magmatic differentiation and/or similar source.

5.1 Silica versus major oxides correlation plots

In the SiO_2 versus MgO wt% plot, the southern volcanoes overwhelmingly display higher MgO contents as opposed to the lower values for the northern group of volcanoes (**Figure 5c**). It is expected that the Kassa volcanoes (K1–5) which are more differentiated (by their higher SiO_2 contents) than the others to present lower MgO contents but instead display similar MgO contents. This scenario is true of their Fe_2O_3 contents. However, there is a weak negative correlation between Fe_2O_3, MgO, TiO_2 and MnO versus silica indicating a progressive decrease of these oxides with differentiation (Miango-Southern group-Kassa) corresponding to compositional variations related to the removal of different proportions of olivine/pyroxenes from the melt as it becomes more felsic (**Figure 6a–d**).

The Kassa volcanoes in the northern group and those of the southern group exhibit higher CaO contents compared to lower CaO values at Miango (M1&M2) and also of the northern group. The observed high CaO content suggest the

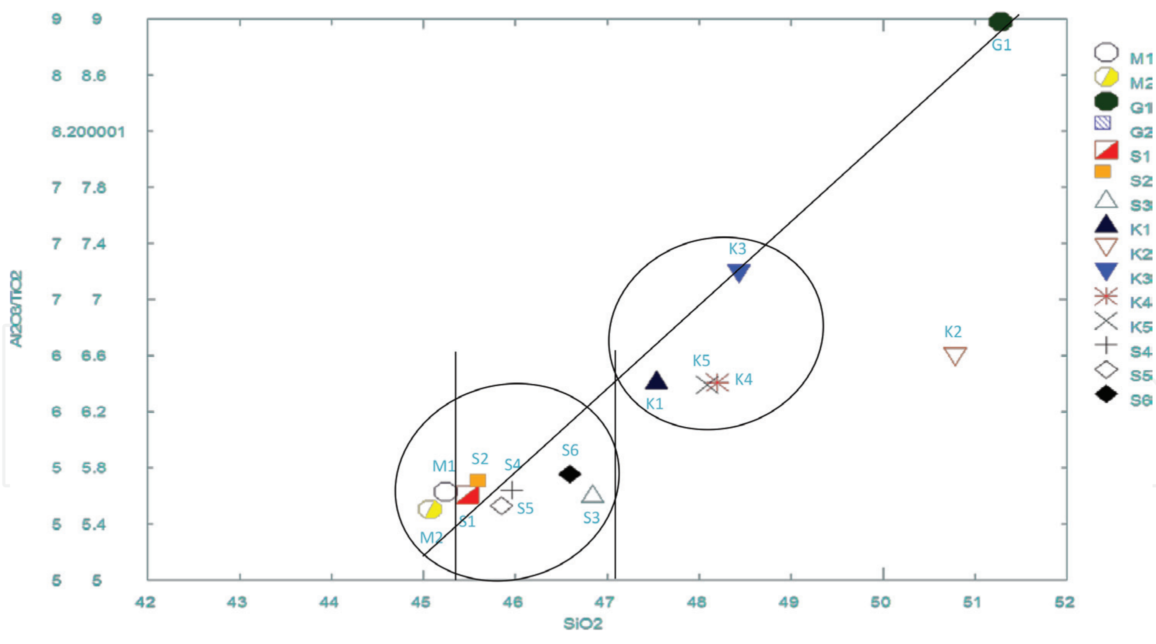

Figure 3.
Plot of SiO_2 versus Al_2O_3/TiO_2 ratios.

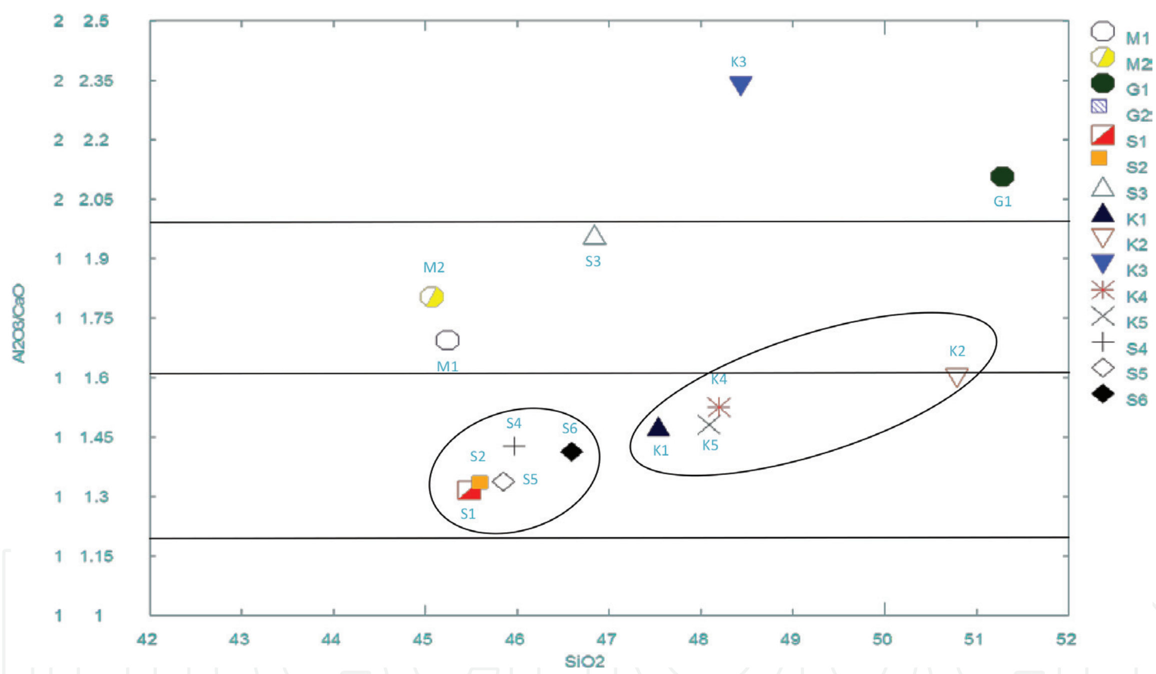

Figure 4.
Plot of SiO_2 versus Al_2O_3/CaO ratios.

recrystallization of clinopyroxenes in the early stages of crystallization. In general, there is a positive correlation depicting a progressive increase of CaO with differentiation from Miango to the southern group to Kassa (**Figure 5a–f**). This increase is not visible at the level of one volcano but several of them put together. The high Fe_2O_3, MgO and CaO could be as a result of the bulk crystallization of olivine, pyroxene and plagioclase during the early stages of differentiation. The progressive increase in the contents of Al_2O_3 corresponds with the increase in the alkaline metals content (Na_2O + K_2O) suggesting the crystallization of plagioclase with increased degree of differentiation. The alkaline oxides (Na_2O + K_2O) are correspondingly highest in the most differentiated rocks (K1–5) (**Figure 6d**). In a silica versus total alkali diagram (**Figure 7**), the rocks fall within the alkaline field and are therefore classified as predominantly alkaline basalts. Only a few rocks fall in the

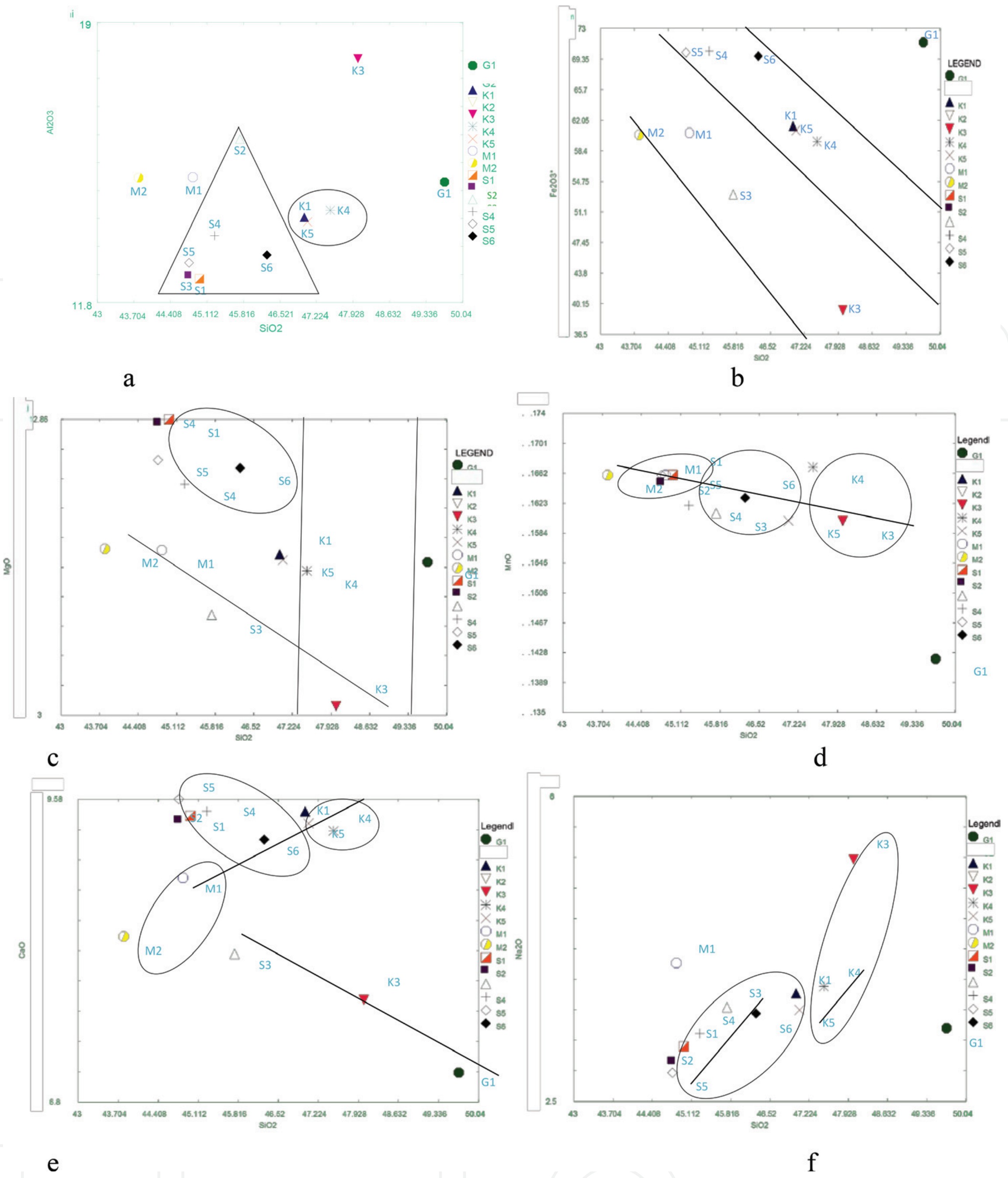

Figure 5.
(a–f) Plots of SiO_2 versus major oxides of the volcanic rocks of the Jos Plateau Volcanic Province.province.

sub-alkaline field which could be of tholeiitic character (high silica and Fe Contents). Furthermore, in a log (Zr/TiO_2) versus SiO_2 diagram (**Figure 8**), the bulk of the rocks fall in the alkaline field reaffirming their alkaline nature (**Figure 9**).

In respect to their Mg#, it varies very narrowly within the individual volcano signifying a subtle degree of differentiation (partial melting) and thus reflecting a low degree of magmatic differentiation and the consequent subtle compositional variations observed. However, for the entire volcanoes put together, the Mg# vary significantly from 27 to 56 suggesting formation of the rocks by fractional crystallization at larger scale. The southern volcanoes (S1–6) have the highest Mg# relative to those of the northern group (K1–5 and M1 & M2) (**Figure 10a–d**). When the rocks are plotted in Mg# versus Fe_2O_3 diagram (**Figure 10b**), a positive correlation is obtained indicating a progressive decrease in Fe_2O_3 with increasing degree of magmatic differentiation. The relatively similar Ba/Sr. and Zr/Y ratios for these rocks but with progressive decrease in Mg# lends credence to their derivation from

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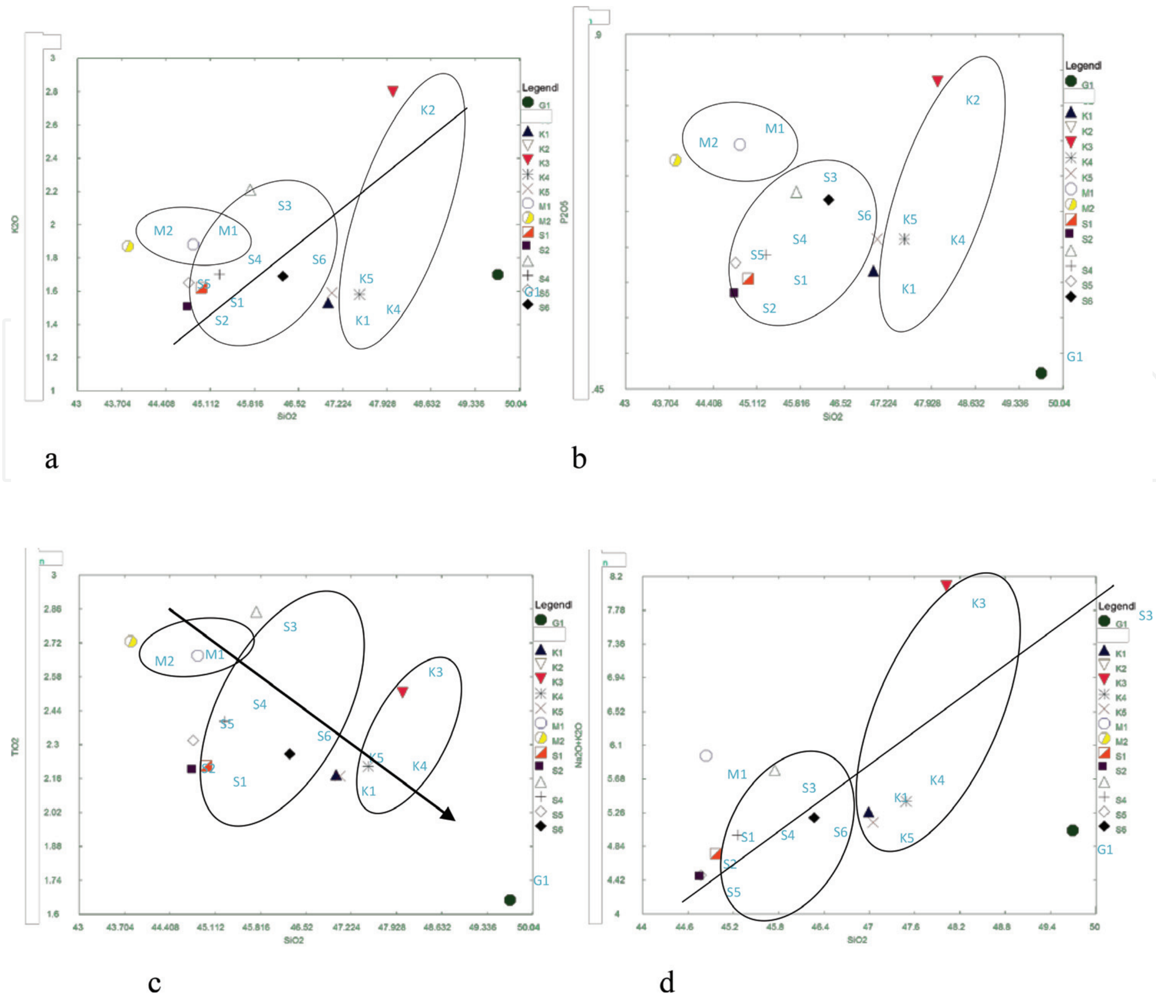

Figure 6.
(a–d) Plots of SiO_2 versus major oxides of the volcanic rocks of the Jos Plateau Volcanic Province.

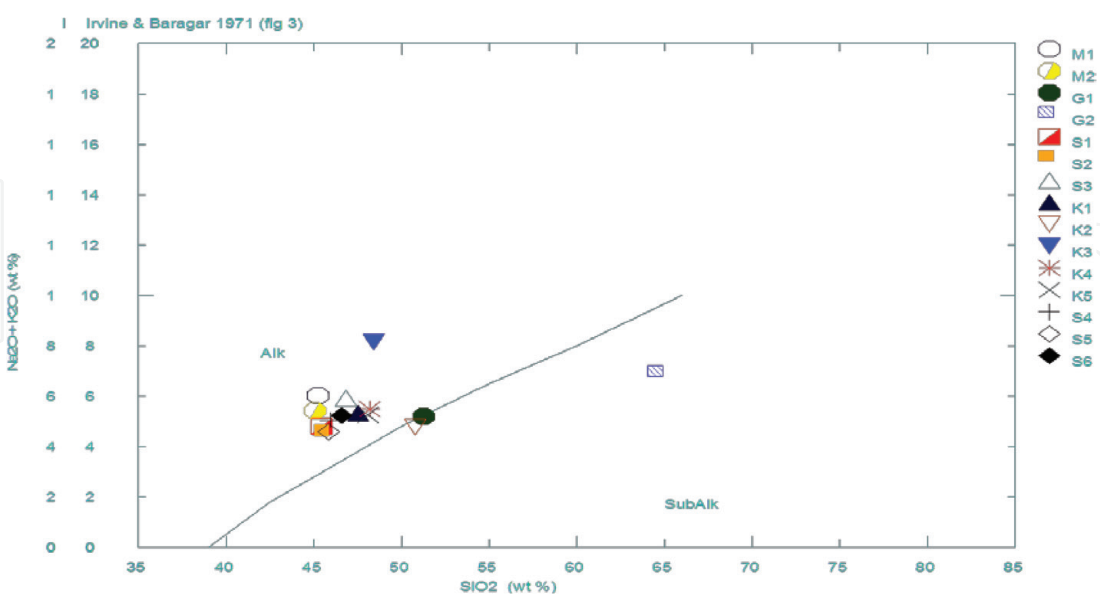

Figure 7.
Silica versus Total Alkali diagram [11] of the volcanic rocks of the Jos Plateau (Alk = alkaline and Subalk = subalkaline).

the same magma reservoir by differentiation. It appears that the rocks with the highest Mg# (samples S1–6) present compositions that are close to that of the parent materials since the magma did not suffer high degree of differentiation giving rise to a variety of rocks. The subtle variation of Mg# and the incompatible

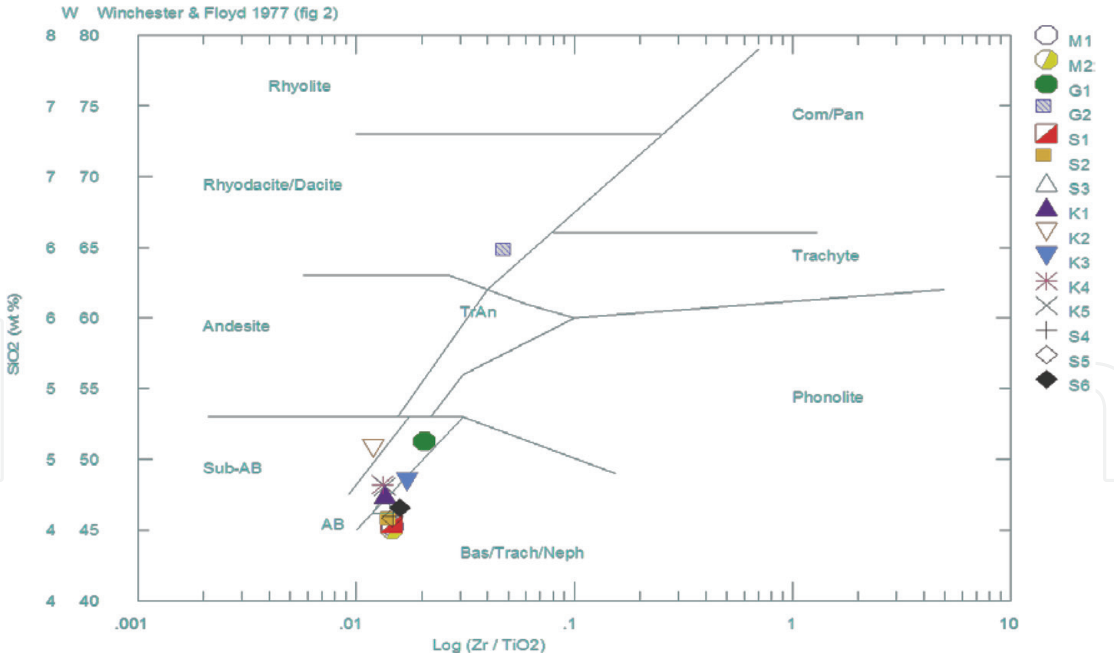

Figure 8.
Plot of Log (Zr/TiO$_2$) ratio versus SiO$_2$ [12] of the volcanic rocks of Jos Plateau Volcanic province (Sub-AB = subalkaline basalts, AB = alkaline basalts).

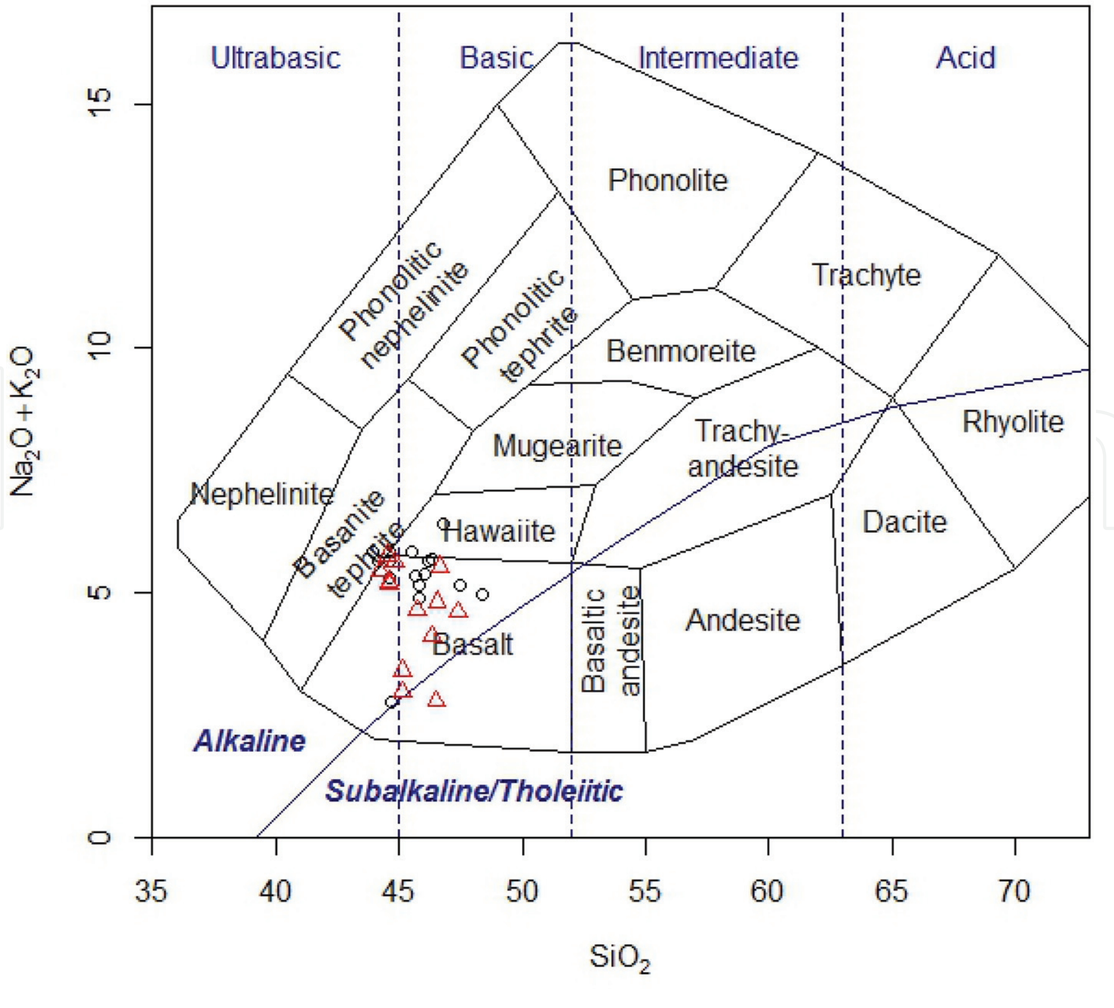

Figure 9.
SiO$_2$ versus Na$_2$O + K$_2$O classification diagram of basalts of the Jos Plateau volcanoes [13].

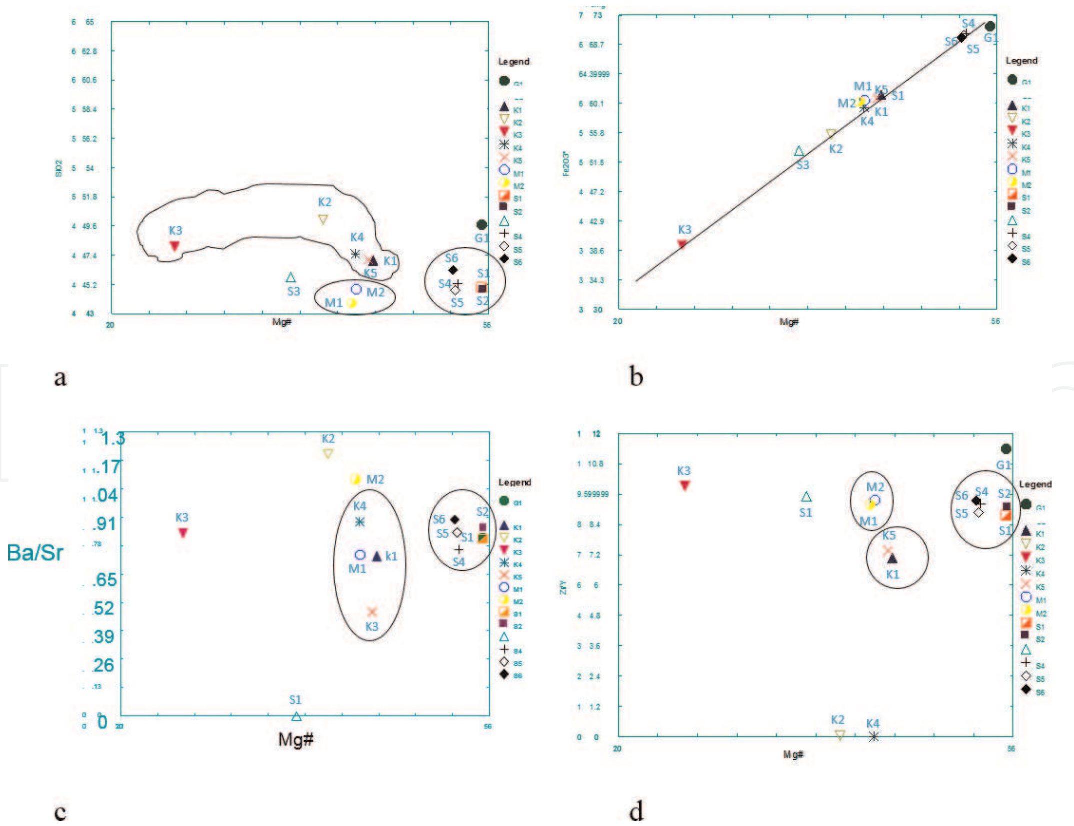

Figure 10.
(a–d) Plot of some selected major oxides versus Mg# for the volcanic rocks of the Jos Plateau volcanic province.

element ratios highlighted above are supportive of the derivation of these basalts by partial melting process of a magma from the same source.

5.2 Tectonic environment of emplacement

The geochemical data plotted in the ternary diagram of Ti/100-Zr-Y*3 [12] show clearly that they were majorly emplaced within the continental crust (**Figures 11** and **12**). This fact distinct these basalts from those of the Island arc and the Mid Oceanic Ridge.

5.3 Incompatible elements spidergraph

The incompatible elements when plotted in a spidergraph normalized to Chondrites in comparison with OIB (**Figure 13**) display a relatively similar pattern with slight enrichment in their incompatible elements. These characteristic features are typical of most alkali basaltic suites derived from a deeper mantle source akin to that of the OIB [12, 14, 16–19].

5.4 Ar^{40}-Ar^{39} dating

A sample by sample result is presented in **Table 5**. The Ar/Ar ages span between 1.3 and 2.5 Ma, confirm the earlier K-Ar ages of 2.1 and 1.9 ± 0.31 Ma reported by [1] on dolerites on the Jos Plateau. The short interval in the radiometric ages suggests volcanic eruptions occurred at discrete times, separated by short periods of non-activity at a mean age average of 0.55 Ma (CN3 = 2.500 ± 0.318 Ma and CN5 = 1.970 ± 0.173 Ma). This long period must have been dominated by profound erosion. The considerable long-time difference from the oldest to the youngest eruption suggests that there was relatively steady magma source overtime.

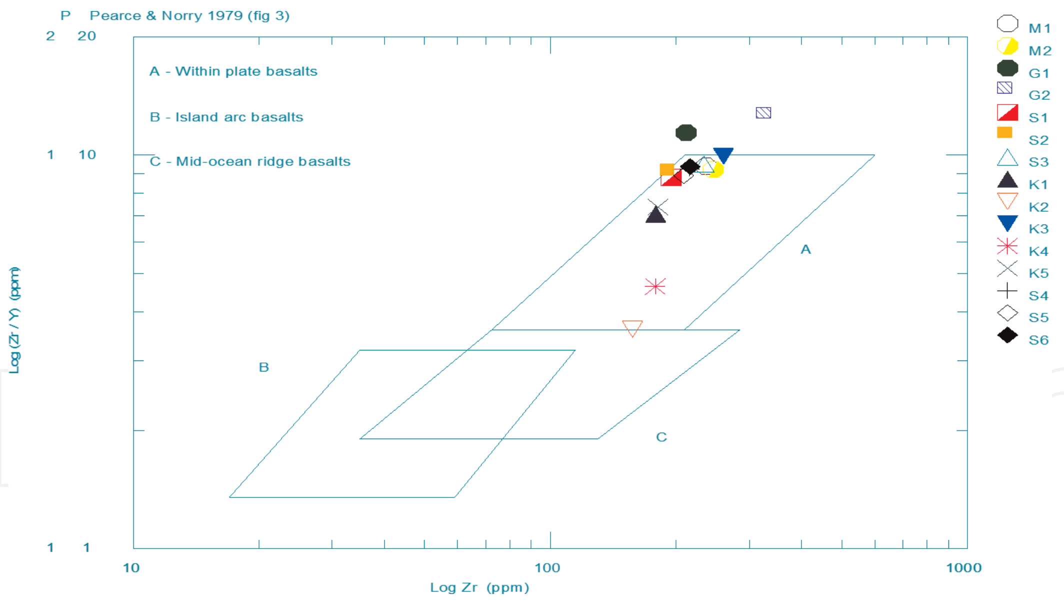

Figure 11.
Log Zr (ppm) versus Log (Zr/Y) (ppm) diagram [14] volcanic rocks of the Jos Plateau Volcanic province.

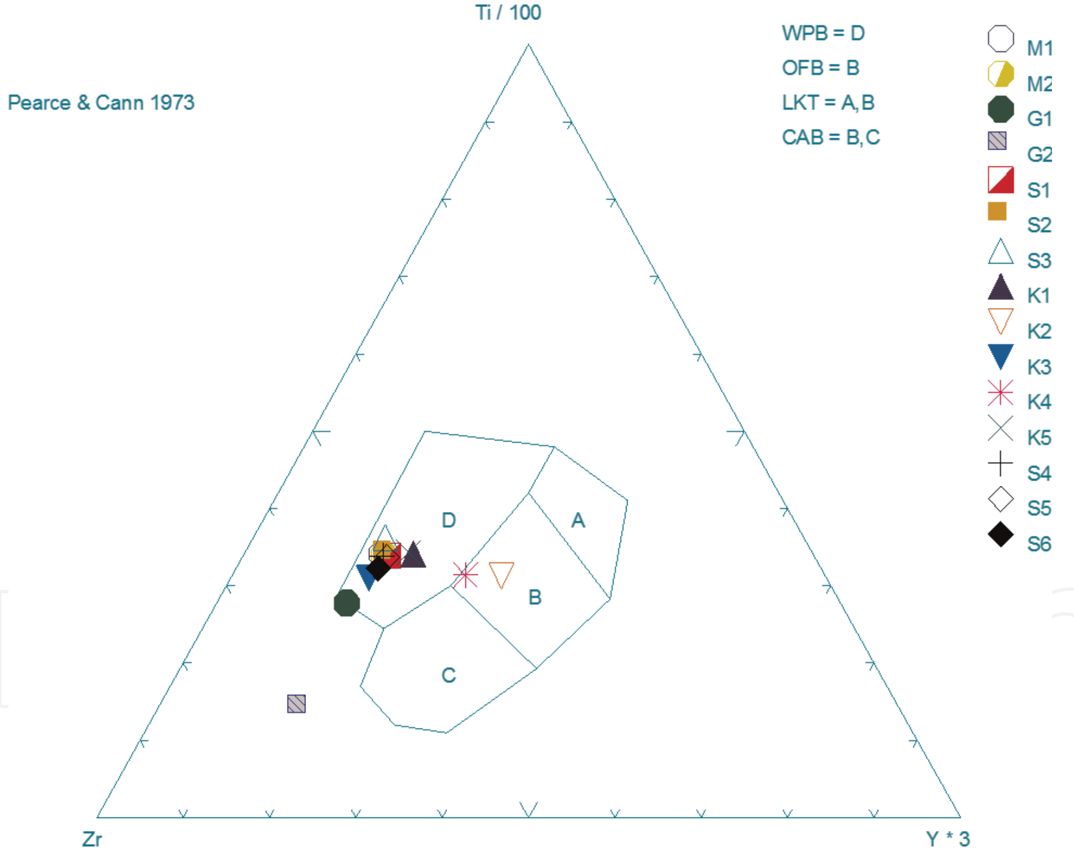

Figure 12.
*Ternary diagram of Ti/100 – Zr – Y*3 [12] for the volcanic rocks of the Jos Plateau Volcanic province. WPB = D, within plate basalts; OFB = B, ocean flood basalts; LKT = A,B low potassium tholeiitic basalts; and CAB = D,C, calc-alkaline basalts.*

5.5 Hydrogeochemistry of the Pidong Crater Lake

Comparative hydrogeochemical parameters of previous study [7] and this present study is presented in **Table 5**. It shows clearly that pH and alkalinity have decreased overtime from 9.35 to ≥7.0 and from 335 to 145 mg/l, respectively as well

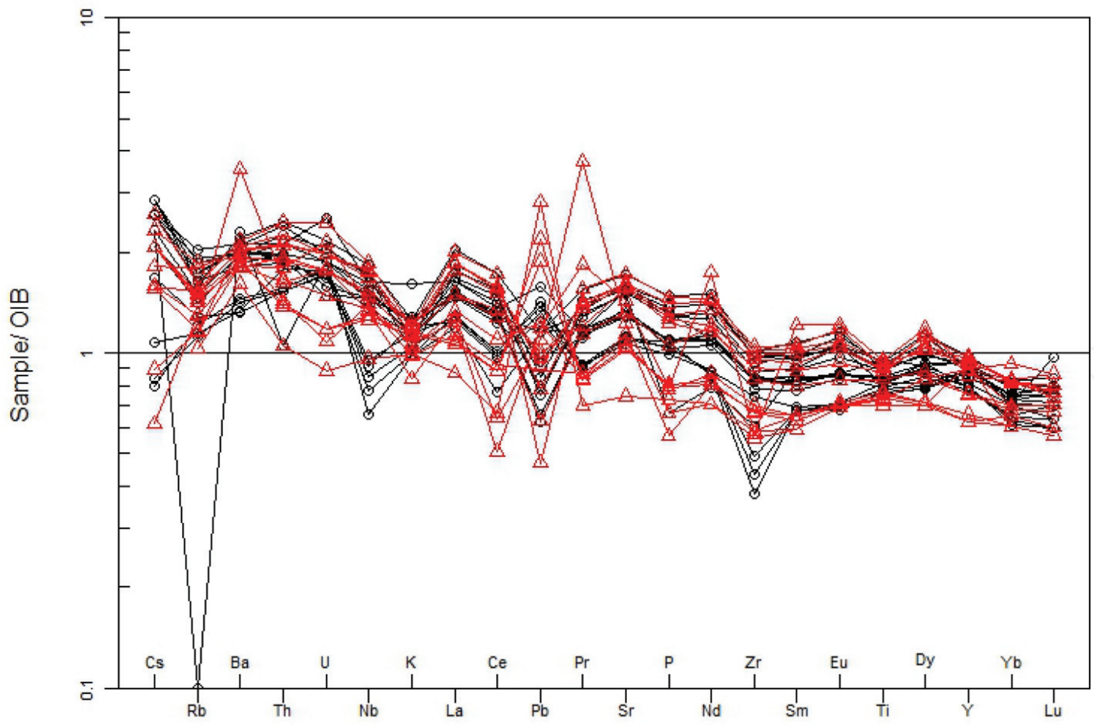

Figure 13.
Spidergraph plot of incompatible element compositions of basaltic rocks from the Plateau volcanoes normalized to OIB [15].

as increase in the concentrations of Cl from 2.5 to 5.6 mg/l; SO_4 from <0.33 to 1.05 mg/l (**Table 5**).

5.5.1 Major element concentration/distribution

In general, the major element concentrations in the Pidong Lake decrease in the order Mg > Ca > K > Na (**Table 5**). The highest concentrations of Mg (30 to ≤40 mg/l), Ca (21–25 mg/l), K (15 mg/l) Na (8–11 mg/l) are observed during the dry season (January–April) while lowest concentrations of Mg (16–25 mg/l), Ca (10–15 mg/l), K (4–7 mg/l) in the rainy season (August–October). The intermittent change of color of the Lake from clear blue to brown has been attributed to the increase in Fe concentrations into the Lake.

5.5.2 Rare earth element (REEs) concentrations

Figure 14 presents the REE patterns from the Crater Lake normalized to Chondrites. The REE concentrations are impoverished relative to Chondrite values (<1 × Chondrite). There are significant variations in the LREE (0.03–0.18 × Chondrite for La) relative to HREE (Gd-Lu). An important characteristic of the spectra is the similarities between the LREE patterns indicating similar source. The slight enrichment in LREE must have been influenced by fluid percolation through the host crustal materials (host granite basement) rich in these elements.

5.5.3 Anion concentrations (SO_4, Cl, HCO_3, NO_3, F, Br, and PO_4)

The major anion concentrations from the lake vary in concentrations in the order of $-HCO_3$ > Cl > SO_4. The highest concentration of in the LREE range from <0.5 to 5.5 mg/l and 0.0675 to 0.0321 mg/l, respectively, and were observed during

Period	pH	Temperature (°C)	EC (µs/m)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	Zn (mg/l)	Fe (mg/l)	Cu (mg/l)	Al (mg/l)	SO_4 (mg/l)	Cl (mg/l)	Alkalinity ($CaCO_3$) (mg/l)	F (mg/l)
Patterson (1986) report	9.35	28.5	410	36.4	13.65	12.8	25.8	0.065	0.27	<0.004	—	<0.33	2.5	335	—
Present study (2013–2015)	7.17	26.1	299	29.68	39.67	6.89	11.39	0.064	0.612	0.0039	0.456	1.03	5.67	141.5	0.249

Table 5.
Comparative hydrogeochemical data of 1986 and the present study.

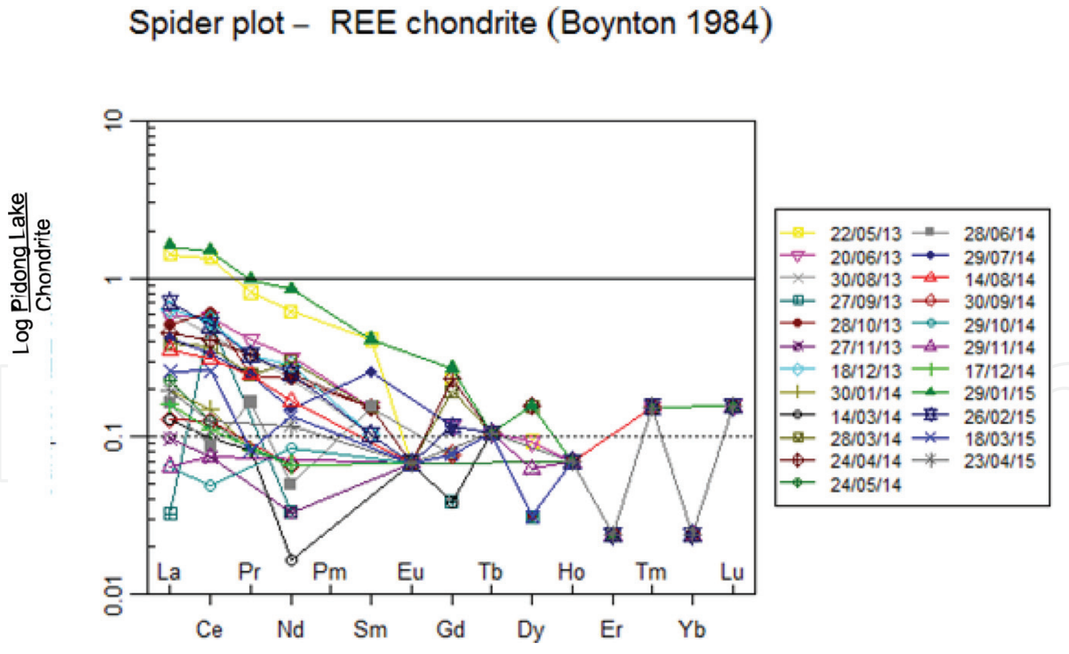

Figure 14.
Spidergraph of rare earth elements (REEs) of Pidong Lake normalized to Chondrite [20].

the dry season (October–April). The concentrations of HCO_3, Cl and F could have been influenced by interacting percolating water and host rock chemistry.

The increase in the concentrations of SO_4^{2-}, Cl^- (<0.33–1.03 and 2.5–5. 67 mg/l, respectively) as well as the decrease in Alkalinity and pH from 335 to 141.5 mg/l and 9.35 to ≈7.00, respectively. These variations in concentrations suggest a possible input of magmatic/fumaroles percolating upwards to shallow groundwater aquifers coming in contact with meteoric water.

The oxygen and hydrogen isotope composition and plot of $\partial\,^{18}O$ and $\partial\,^{2}H$ relative to SMOW line shows that the Pidong Crater Lake is of meteoric origin.

6. Conclusion

i. This work presents and affirms the existence of relicts of past volcanic eruptions (dormant volcanoes) in Nigeria (Jos and Biu Plateaux).

ii. That these volcanic edifices were previous eruption sites suggest they are potential eruption sites. The proximity of these volcanic edifices to those of the Cameroon volcanic line, which has witnessed a series of volcanic activity, is worrisome.

iii. The mafic lavas in both the Jos and the Biu Plateaux volcanic provinces display geochemical compositions that are characteristic of alkaline basalts

iv. Petrologically, the basaltic rocks display compositions varying from basalt proper to basanite-tephrite-hawaiite, emplaced within the host crustal rocks (Basement rocks).

v. The chain of volcanoes evolved from the same basalt parent magma by crystal fractionation each cluster derived by partial melting of the same residual parent magma.

vi. Recent $^{40}Ar/^{39}Ar$ dating of basalts from overlapping volcanic cones from the Jos Plateau province (ranging from 2.5 to 1.34 Ma) confirms the Quaternary age (Pleistocene epoch) of emplacement for these volcanoes and the intermittency of eruptions inter and intra the volcanic line in the provinces.

vii. That these volcanic edifices were previous eruption sites suggest they are potential eruption sites. The proximity of these volcanic edifices to those of the Cameroon volcanic line, which has witnessed a series of volcanic activity, is worrisome. The volcanic eruption of Mount Vesuvius in Italy in the year 2004 known to have been dormant since 24 AD is a clarion call. Furthermore, the recent volcanic eruption in Iceland April 15, 2010 after 200 years of silence should increase the worry. All these information calls for further comprehensive work on these dormant volcanoes for risk assessment.

viii. The minor intermittent fumarolic activities observed within the Pidong Crater Lake marked by the change in the water color from the normal bluish to brown-red color, (due to Fe-input) call for more comprehensive investigation of the volcano and further strengthen the idea of the possibility of the volcano roaring back to life.

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Conflict of interest

We declare that there are no "conflict of interest."

Notes/thanks/other declarations

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Appendices and nomenclatures

Alk	alkali basalt
ASL	above sea level
Ma	million (10^6) years
MORB	mid-ocean ridge basalt
NASRDA	National Space Research and Development Agency
OIB	ocean island basalt
ppb	parts per billion ($1/10^9$)

ppm	parts per million ($1/10^6$)
SMOW	standard mean ocean water
ICP-OES	inductively coupled plasma optical emission spectrometry
∂	stable isotope ratio expressed relative to a standard

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References

[1] Grant NK, Rex DC, Freeth SJ. Potassium-argon ages and strontium isotope ratio measurement from volcanic rocks in northern Nigeria. Contributions to Mineralogy and Petrology. 1972;**35**(3):277-292

[2] Lar UA, Tsalha MS. Geochemical characteristics of the Jos-Plateau Basalts, North-Central Nigeria. Global Journal of Geological Sciences. 2005;**3**(2):4

[3] Akeh LE. Disaster threat in Nigeria. In: Proceedings of a Seminar for the 1999 World Disaster Prediction Campaign in Lagos, Nigeria; Vol. 5; 1999. pp. 56-86

[4] Black R, Girod M. Late Paleozoic to recent igneous activity in West African and its relationship to Basement structure. Journal of African Magmatism and Tectonics. In: Clifford TN, Gass IG, editors. Edinburgh: Oliver and Bovds. 1970:185-210

[5] Turner DC. Volcanoes of Biu basalt Plateau north-eastern Nigeria. Journal of Mining and Geology. 1977;**3**(6):49-62

[6] Macleod WN, Turner DC, Wright EP. The Geology of the Jos Plateau, vol. 1: General Geology. Geological Survey of Nigeria, Bulletin. 1971;**32**:91-95

[7] Patterson G. Lake Pidong—A Preliminary Survey of a Volcanic Crater Lake. UK: Dept. of Geography, University of Durham; 1986

[8] Lar UA, Lekmang IC, Shuaibu MT, Mahmud UM, Yakubu TA. Volcanoes of Nigerian: A preliminary study. Presented at the 7th Conference on African Geology, Assiut, Egypt; 2013

[9] Ugodulunwa FXO, Schoeneich K. Guide book on the field trip to Panyam volcanoes. In: 30th Annual Conference of Nigerian Mining & Geosciences Society; 1994

[10] Lar UA, Mohammed TS, Yakubu TA, Mahmud UM, Haruna ST, Samuel T. Development of geohazards map of Nigeria, mapping of volcanic edifices in Nigeria CGG. In: Toro Project; 2007. Unpublished Manuscript

[11] Irvine TN, Baragar WRA. A guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences. 1971;**8**(5): 523-548

[12] Rollinson HR. Using Geochemical Data: Evaluation, Presentation and Interpretation. UK: Longman Group Ltd.; 1993. 352p

[13] Cox KG, Bell JD, Pankhurst RJ. The Interpretation of Igneous Rocks. London: Allen and Unwin; 1979. 450p

[14] Pearce JA. A User's Guide to Basalts Discrimination Diagrams: Trace Elements Geochemistry of Volcanic Rocks. Geological Associations of Canada Short Course Notes. Vol. 121996. pp. 79-113

[15] Sun SS, McDonough WF. Chemical and isotopic systematics of oceanic basalts: Implications for mantle composition and processes. Journal of the Geological Society, London, Special Publication. 1989;**42**:313-345

[16] Langmuir CH, Hanson GN. An evaluation of major element heterogeneity in the mantle sources of basalts. Philosophical Transactions. Royal Society of London. 1980;**A297**:383-407

[17] Nakamura N. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordiary chondrites. Geochimica et Cosmochimica Acta. 1974;**38**:757-775

[18] Sun SS, Nesbelt RW, Sharaskin AY. Chemical characteristics of mid-oceanic

ridge basalts. Earth and Planetary Science Letters. 1980;**44**:119-138

[19] Thompson RN, Morrison MA, Hendry GL, Parry SJ. British tertiary volcanic province. Scottish Journal of Geology. 1982;**18**:49-107

[20] Bonyton WV. Cosmochemistry of the Rare Earth Elements. Meteorite Studies. Amsterdam: Elsevier Sci. Publ. Co.; 1984. pp. 63-114