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Major Elements Geochemistry of Basaltic Rocks from the Kerang Volcanoes, Jos Plateau, Central Nigeria.

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ABSTRACT

This study focuses on classifying, tracing the origins of, and describing the main constituents that make up the basaltic rocks of the Kerang volcanoes. The Kerang volcanoes are a pair of particularly massive composite volcanoes that are prominent landmarks in the Jos Plateau Volcanic Province of central Nigeria. They have well-preserved volcanic cones—built product of eruptive lapilli, scoria, breccias, basalts, and pyroclastic materials (ash, granitic, lava flow, etc.). The volcanic edifices extruded the Precambrian Basement migmatite–gneiss complex, the Pan-African biotite granites (Older Granites) and are aligned in an NNW–SSE direction that is controlled by a major deep-seated structure within the host Precambrian Basement Complex. Thirty carefully chosen basaltic rocks from lava flows and volcanoes were sampled for major oxide studies using XRF. The basalts from the Kerang volcanoes show a steady decline in main oxide concentrations (Al_2O_3 , Fe_2O_3 , MgO , CaO , P_2O_5 , and K_2O) compared to SiO_2 . The progressive decline with rising $Mg\#$ was also shown in the plot of $Mg\#$ vs these oxides. Such significant elements association follows the typical patterns of fractional mineral crystallization and/or accumulation in a mafic melt of olivine and olivine + clinopyroxenes. The Kerang volcanoes' rocks are categorized as alkaline basalts according to their total alkaline silica classification diagram. These geochemical findings imply that these rocks evolved at vast depths through partial melting that produced rocks with low silica saturation. Additionally, there was no discernible difference in their geochemical signatures between the basaltic rocks formerly thought to be older and newer. In essence, they are more recent basalts.

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Volcanic activity was widespread and occurred intermittently in Nigeria between the Tertiary and Recent periods (Kogbe, 1989; Wright, 1989). The largest outcrops are located in Nigeria's northeastern and central regions (Fig. 1), specifically the Benue Trough, Biu, Longuda, Mambilla, and Jos Plateaux. (Black et al., 1985; Burke, 1996; Kogbe, 1989). The majority of the prominent volcanic provinces in Africa, including the Bamedia Highlands, the Mambila Plateau, the Adamawa Plateau, numerous alkaline olivine basalts, and minor intrusive trachyte and phonolites in the Benue Trough and Jos Plateau, are

characterized by basement uplift (Coulon et al., 1996; McCurry, 1971; Turner, 1976 and 1983; Umeji, 1985; Uriah et al., 2020). These essentially basaltic rocks are found to either directly overlie the preexisting basement rocks or to crosscut both the Younger Granite rocks of the Jos Plateau (Idi, 2012; Mackay et al., 1949; Wright 1969, 1976 and 1985; Lar et al., 2007). According to the degree of their weathering and morphologies, the Jos Plateau volcanoes were divided into two main types named older and newer basalts (Macleod et al., 1971; Wright, 1985). The older basalts were believed to have been formed during the Tertiary times and the newer basalts during the Quaternary.

1. INTRODUCTION

However, recent ages by Mohammed et al. (2014), using the Ar–Ar dating method on some of the basaltic rocks from the composite volcanoes of Kassa and the Panyam volcanic lines, gave ages spanning from 2.5 Ma to 1.3 Ma and 1.37 Ma to 7 Ma, respectively. This confirms successive episodes of eruptions associated with volcanic activities on the Jos Plateau which is Quaternary, and not as earlier suggested by pioneer workers such as Mackay et al. 1949; Macleod et al. 1971; Wright, 1985 and other workers who based their interpretation on the intensity of weathering of these volcanoes. Since there are no distinctions between the more recent and older basalts, the Jos Plateau volcanoes' emplacement time is contemporaneous, particularly for the Kerang basaltic rocks. (CGGT, 2014; Mohammed et al., 2014; Lekmang, 2019). Along the Cameroon volcanic line, synchronous basaltic rocks of Quaternary dates (6 Ma and 4.8 Ma) have also been discovered at Annobon Island (Njonfang et al., 2011; Nyako et al., 2006).

The Kerang volcanoes are situated at Kerang town and the surrounding areas in Mangu Local Government Area, of Plateau State, Nigeria (Fig. 2). The research region, which is a portion of

Pankshin Sheet 190 (NW), has an aerial extent of 40 km² and is bounded by latitudes 9°20'02" and 9°22'05"N and longitudes 9°08'02" and 9°14'02"E. The basaltic rocks extruded the porphyroblastic gneiss and porphyritic biotite granite rocks (Fig. 3). The Kerang volcanoes are made up of two gigantic volcanoes named Kerang I and Kerang II. The Kerang I volcano has a peak elevation of 1456m above sea level and a 300m crater diameter. The Kerang II volcano features three craters, the largest of which is 1510 meters above sea level, and whose diameters range from 600m to 1km. The volcanic piles are composed of ash, lapilli, scoria, pumice, breccia, basalt, boulders, and pyroclastic debris of varying sizes. Recently, some undergraduate and graduate students at the Department of Geology at the University of Jos have researched the geology and geochemistry of the volcanic soil along the Panyam volcanic line (Bakari, 2007; Gusikit, 2010; Idi, 2012; Igwillo, 2012, Suleiman, 2007). There is consequently, no comprehensive major elements geochemical analysis of the Kerang volcanoes. Additionally, their classification and evolution (the process of formation) is still unknown. In addition to categorizing the Kerang volcanoes, this study aims to comprehend their geochemical composition and formation process.

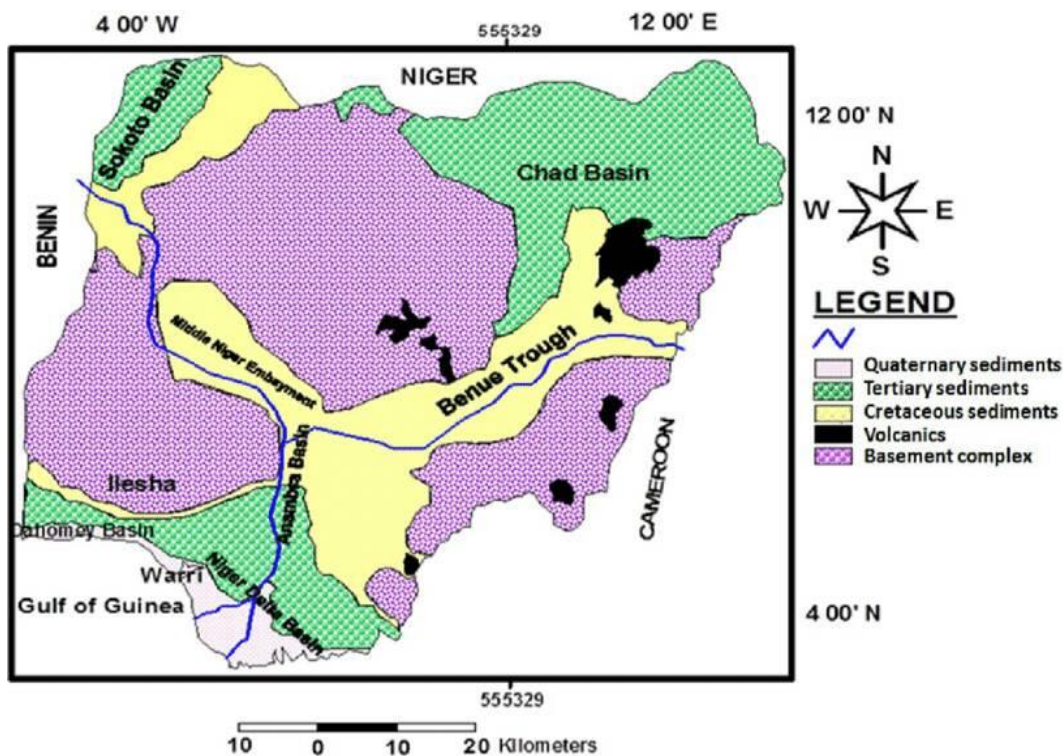


Figure1. Simplified Geological Map of Nigeria (after Ologe et al., 2014).

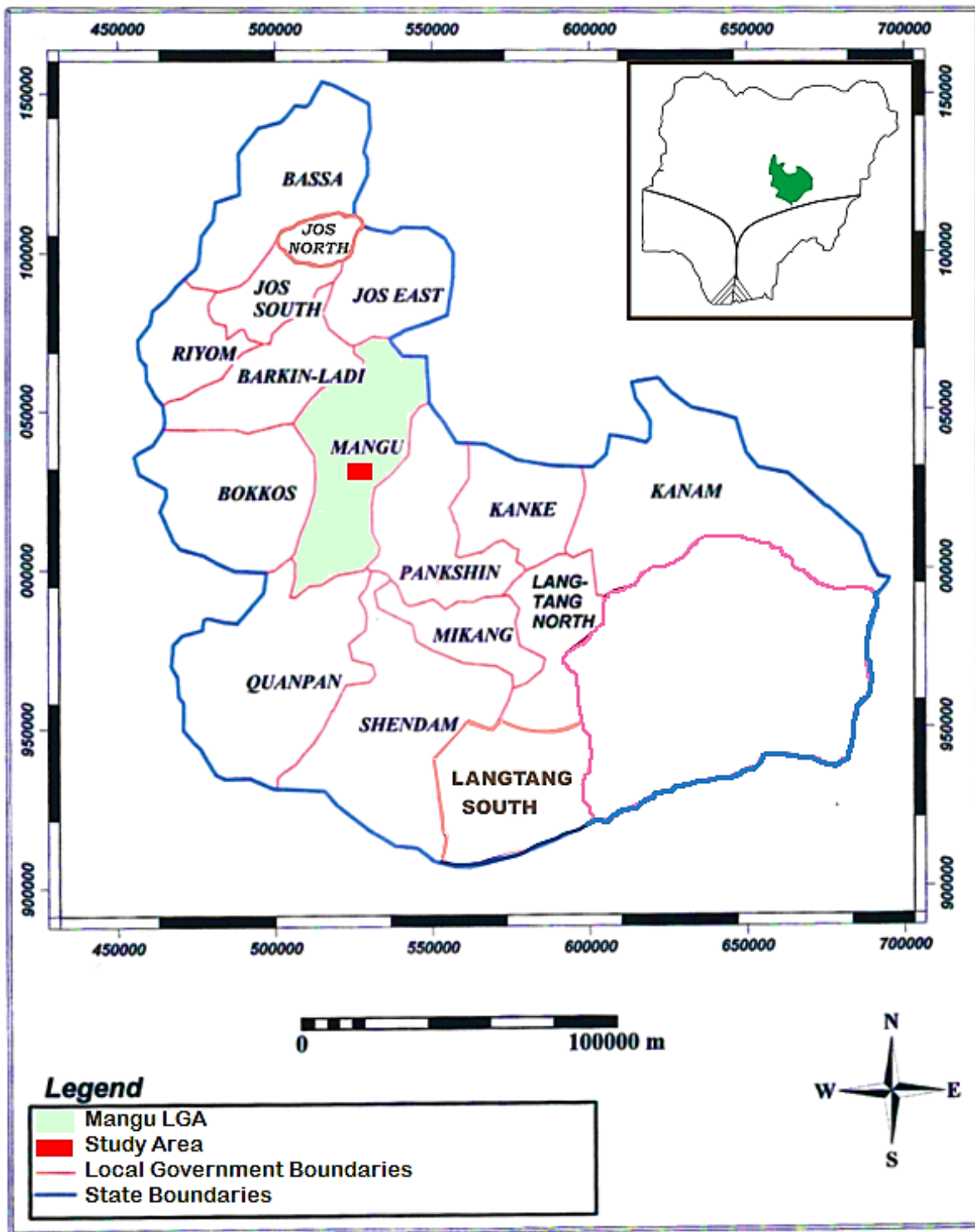


Figure2. Location map of the study area (Modified from Google Earth).

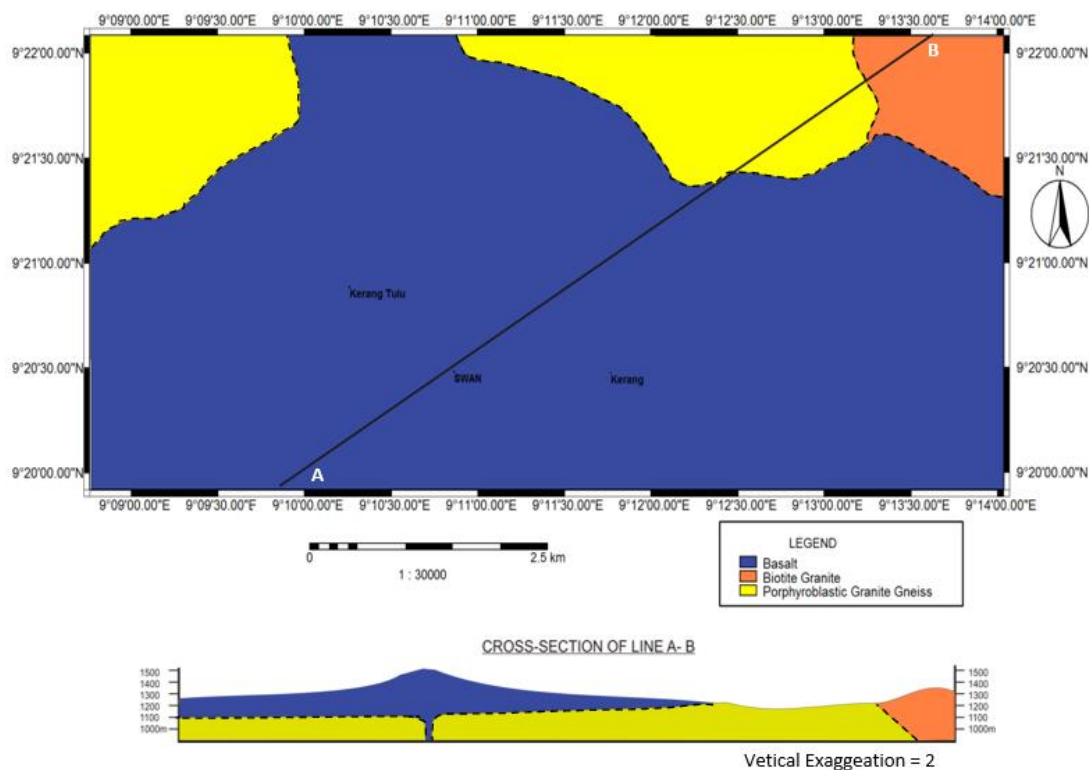


Figure3. Geological Map of the Study Area

2. Geologic setting of Jos plateau volcanoes

The Jos Plateau is located precisely within Nigeria's north-central Basement Complex, which is bounded by latitudes 9°00' and 10°00'N and longitudes 8°30' and 9°30'E. About half of its landmass is underlain by the Lower Paleozoic to Precambrian basement complex rocks (Fig. 1). The major Jurassic non-orogenic alkaline Younger Granites, Pan-African Granites (Older Granite), gneiss-migmatites, and volcanic rocks are among these rocks. (Turner, 1976). Alkaline olivine basalts made up the majority of the basaltic volcanism in the Jos Plateau, which is represented by sporadic volcanic cones, domes, and thin lava flows (Wright, 1969 and 1985; Irving and Price, 1981; Turner, et al., 1994). According to reports, this volcanism began in the early Tertiary and continued until the Quaternary (Dautria, et al., 1983; Hossain et al., 1986; Kogbe, 1989; Wright, 1976; Nyako, et al., 2006; Wilson and Guiraud, 1992). 22 dormant volcanoes on the Jos Plateau have been identified through field research and are thought to have erupted

between the Tertiary and Recent eras (CGGT, 2014; Ugodulunwa & Schoeneich, 1994; Laretal., 2007). These basaltic volcanoes on the Jos Plateau have been connected to the extensive Cenozoic volcanism that affected Africa and was a component of the regional volcanic events that took place after the separation of the South American and African plates (Black and Giraud, 1970; Burke et al., 1971; Baudin, 1992; Ebinger and Sleep, 1998; Guiraud, et al., 1987; Wilson, 1989). It even reaches into the southwest of Cameroon. This volcanism in Nigeria, which is basaltic as opposed to acidic, is the most widespread. Furthermore, it has been linked to the reactivation of significant deep mantle-seated lithospheric fracture zones (Dautria and Girod, 1991; Guiraud & Maurin, 1992; Baudin, 1992). It is discovered that many of Africa's volcanic fields are located upon large basement uplifts (e.g. Hoggar in Algeria; Tibesti in Chad; Jebel Marr in Sudan; Cameroon and Nigeria) (Burke, 1996; Mckenzie & Onions, 1991;

Njonfangetal., 2011; Pavoni, 1991; Turneretal., 1996).

3. Methodology

The traverse mapping method was used for this study. A reconnaissance visit was made to all the seven (7) member volcanoes within the Panyam Volcanic Line. The Kerang volcanoes were then delineated for further detailed geological and geochemical investigation. The detailed field study involved an intensive, careful, and systematic mapping of the Kerang volcanoes on a scale of 1:10,000. Outcrops in the field were sampled along an N–S and E–W grid running across the volcanoes (Fig. 4). The nature, size, physical characteristics such as weathering, morphology, and the outcrop pattern of the volcanoes were determined and tabulated in the field notebook. Field measurements of the diameters of their craters were determined, and photographs taken were also recorded in the field notebook. Alongside field mapping, sixty-four (64) basaltic rock samples were collected. The samples were described visually (hand

specimen) in the field, and observations were recorded. Mappable rock boundaries were also inferred based on changes in soil color and rock types. Then, 30 fresh representative samples were chosen for whole-rock geochemistry. Using a jaw crusher and a tungsten carbide spex mill, the samples were first crushed into a 0.063 μ m powder. For geochemical investigation utilizing the X-ray fluorescence (XRF) analytical method, two grams of each crushed rock sample were packed into tiny polythene bags and sent to Acme Laboratory Vancouver in Canada. A pulp of 0.2g of the powdered samples was fused with 1.5g LiBO₂ and then dissolved in 100ml of 5% HNO₃. Loss on ignition (LOI) was determined according to weight difference at 1000°C. The following major oxides SiO₂, Al₂O₃, MnO, MgO, CaO, Na₂O, K₂O, TiO₂, P₂O₅ were analyzed. The detection limit for the major elements was 0.01%. The instrument was calibrated using recommended international rock standards at each time. The precision and accuracy of the data were lower than 0.01%.

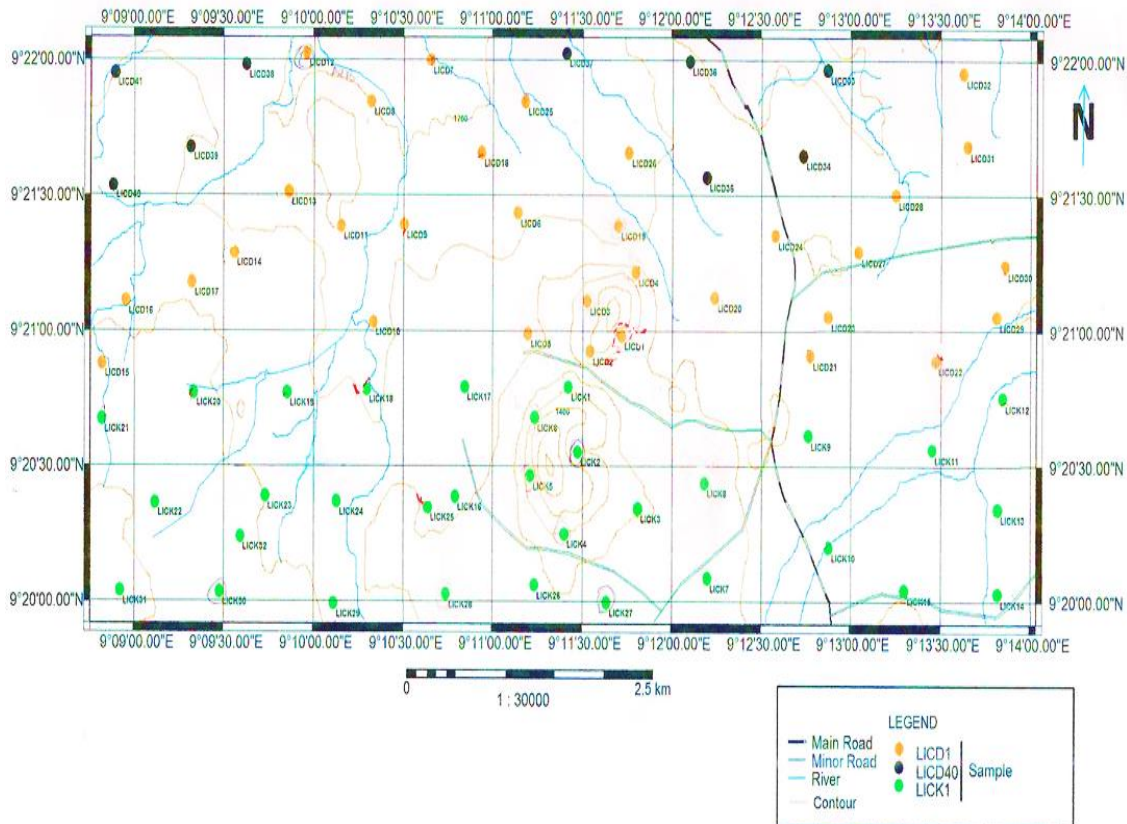


Figure 4. Grid Sample Location Map of the Study Area

4. Result

Tables 1 and 2, which are given as weight percentages (wt.%), are the detailed geochemical data for the basaltic rocks of the Kerang volcanoes. The Kerang volcano samples are represented by LICD and LICK. The basaltic rocks from these volcanoes range in silica concentration from 43.97 to 48.39 wt.%; Al₂O₃ varies from 12.91–17.01 wt.%; Fe₂O₃ ranges between 10.26–16.43 wt.% with LICD31 having the highest value; CaO varies between 7.73–10.67 wt.% with LICD9 having the highest (10.67 wt.%) value. Their MgO contents vary from 6.14 wt.% to 11.40 wt.%; while Na₂O ranges from 1.26–4.24 wt.%; while K₂O ranges between 1.21–1.84 wt.%. The content of MnO, TiO₂, and P₂O₅, ranges from 0.13–2.93 wt.%; 1.99–2.73 wt.% and 0.35–0.91 wt.% respectively. Their Mg# varies from 43.51–51.05 [Mg# = 100XMgO/(MgO+Fe₂O₃)]. Based on their SiO₂ content (43.97–48.39 wt.%) and Mg# (43.51–51.05), imply that they are undersaturated rocks.

On Cox et al., (1979) classification diagram, the basaltic rocks from the Kerang volcanoes plot in the alkaline basalts field (Fig. 5) with silica deficient samples (<45 wt.%) plotting in the basanite to tephrite composition (LICD3, 6, 12A & 12B and LICK14, 17, 27, 28 & 30). These samples have higher values of MgO and Fe₂O₃ (Tables 1 & 2) than the others. Samples from LICK basaltic rocks have higher Na₂O+K₂O (6.40 wt.%) values than those from LICD (5.77 wt.%) (Tables 1 & 2). From Figure 6 of Le Bas et al., (1986) Total Alkali-Silica (TAS) classification diagram, those silica-deficient rocks defined earlier in the diagram of Cox et al. 1979 (Fig. 5) and fall in the Tephrite–Basanite field, are more alkaline (>Na₂O+K₂O; >5.77 wt.%). Two of the rocks with similarly high Na₂O+K₂O values (LICD4 & LICK19) and corresponding to higher silica values, fall in the Trachy-basalt field, implying that the magma from which the rocks (Kerang I & II) evolved was basic (Wood et al., 1979; Yan, 2008).

Table 1 Major Oxide Compositions (wt.%) of Kerang I Basaltic Rocks.

Analyte		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	Total
Unit		%	%	%	%	%	%	%	%	%	%	
MDL		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Sample ID	Coordinates											
LICD1	N09°19'887"/ E009°10'100"	46.54	15.96	10.26	6.90	7.73	3.38	1.43	2.09	0.13	0.45	94.87
LICD2	N09°19'997"/ E009°10'009"	45.73	13.71	11.10	10.59	8.32	2.98	1.66	2.15	0.15	0.50	96.89
LICD3	N09°20'587"/ E009°11'109"	44.84	13.28	12.26	11.27	9.78	3.93	1.71	2.57	0.18	0.80	100.62
LICD4	N09°20'795"/ E009°11'998"	46.68	13.22	11.47	10.49	9.14	3.89	1.64	2.39	0.17	0.65	99.74
LICD5	N09°20'370"/ E009°11'655"	44.58	13.08	12.19	11.2	9.68	3.59	1.64	2.53	0.18	0.78	99.45
LICD6	N09°21'511"/ E009°11'856"	44.53	13.58	12.42	9.6	9.86	4.16	1.61	2.68	0.19	0.87	99.50
LICD7	N09°20'805"/ E009°11'910"	47.38	13.95	10.89	10.4	8.54	2.97	1.63	2.09	0.15	0.49	98.49
LICD8	N09°20'905"/ E009°11'955"	46.33	14.56	11.04	10.16	8.41	2.71	1.41	2.19	0.15	0.48	97.44
LICD9	N09°21'468"/ E009°11'605"	45.13	16.14	15.38	6.14	10.67	1.76	1.21	2.09	0.34	0.41	99.27
LICD12A	N09°20'940"/ E009°12'010"	44.22	13.21	12.47	10.53	9.89	3.72	1.73	2.61	0.19	0.9	99.47
LICD12B	N09°21'750"/ E009°12'511"	44.63	13.21	11.75	10.65	9.72	3.38	1.79	2.52	0.17	0.76	98.58
LICD13	N09°20'196"/ E009°12'256"	45.13	16.14	15.38	6.14	10.67	1.76	1.21	2.09	0.34	0.41	99.27
LICD22	N09°21'850"/ E009°13'810"	45.16	15.14	15.41	6.14	10.16	1.91	1.50	1.99	0.37	0.35	98.13
LICD31	N09°21'880"/ E009°10'980"	46.53	15.53	16.43	6.15	10.40	1.26	1.53	2.73	0.40	0.49	101.45

MDL= Minimum Detection Limit

Analysis by XRF

Table 2 Major Oxide Compositions (wt. %) of Kerang II Basaltic Rocks

Analyte		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	Total
Unit		%	%	%	%	%	%	%	%	%	%	
MDL		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Sample ID	Coordinates											
LICK2	N09°20'305"/ E009°11'310"	44.65	13.21	12.13	11.13	9.64	3.91	1.74	2.59	0.18	0.80	99.98
LICK4	N09°20'401"/ E009°11'210"	46.04	13.13	11.65	11.00	9.13	3.73	1.65	2.42	0.17	0.67	99.59
LICK5	N09°20'640"/ E009°11'360"	46.34	13.20	11.65	10.89	9.35	3.90	1.78	2.41	0.17	0.68	100.37
LICK6	N09°20'451"/ E009°11'300"	46.17	13.16	11.59	10.84	9.28	3.89	1.77	2.42	0.17	0.68	99.97
LICK8	N09°20'430"/ E009°12'420"	45.69	13.01	11.34	10.61	9.52	3.51	1.84	2.3	0.17	0.67	98.66
LICK9	N09°20'805"/ E009°12'910"	45.79	13.58	11.20	8.130	9.57	3.49	1.65	2.23	0.80	0.63	97.07
LICK10	N09°20'950"/ E009°13'810"	44.68	15.16	16.01	6.160	10.26	1.35	1.41	2.3	0.43	0.41	98.17
LICK12	N09°21'205"/ E009°13'980"	48.39	13.57	11.33	8.230	9.20	3.54	1.43	2.14	0.50	0.61	98.94
LICK14	N09°21'550"/ E009°13'510"	44.13	13.42	12.35	9.820	9.83	4.18	1.46	2.69	0.18	0.84	98.9
LICK17	N09°21'350"/ E009°10'303"	45.80	12.91	11.29	10.75	9.76	3.24	1.64	2.27	0.17	0.64	98.47
LICK19	N09°20'610"/ E009°11'651"	46.80	17.01	10.87	3.670	8.89	4.08	2.32	2.74	2.93	0.81	100.12
LICK27	N09°19'065"/ E009°11'451"	43.97	13.01	12.53	10.92	9.88	4.04	1.81	2.56	0.20	0.91	99.83
LICK28	N09°19'015"/ E009°10'351"	44.58	13.60	12.58	9.690	9.92	4.24	1.60	2.67	0.20	0.87	99.95
LICK30	N09°20'650"/ E009°14'413"	44.58	13.14	12.33	11.40	9.63	3.68	1.63	2.54	0.18	0.79	99.9
LICK32	N09°20'059"/ E009°09'040"	45.55	14.08	12.06	7.330	8.98	4.08	1.75	2.33	0.21	0.66	97.03
LICK36	N09°20'650"/ E009°10'670"	47.51	13.41	11.46	8.570	9.07	3.65	1.50	2.19	1.51	0.64	99.51

MDL= Minimum Detection Limit

Analysis by XRF

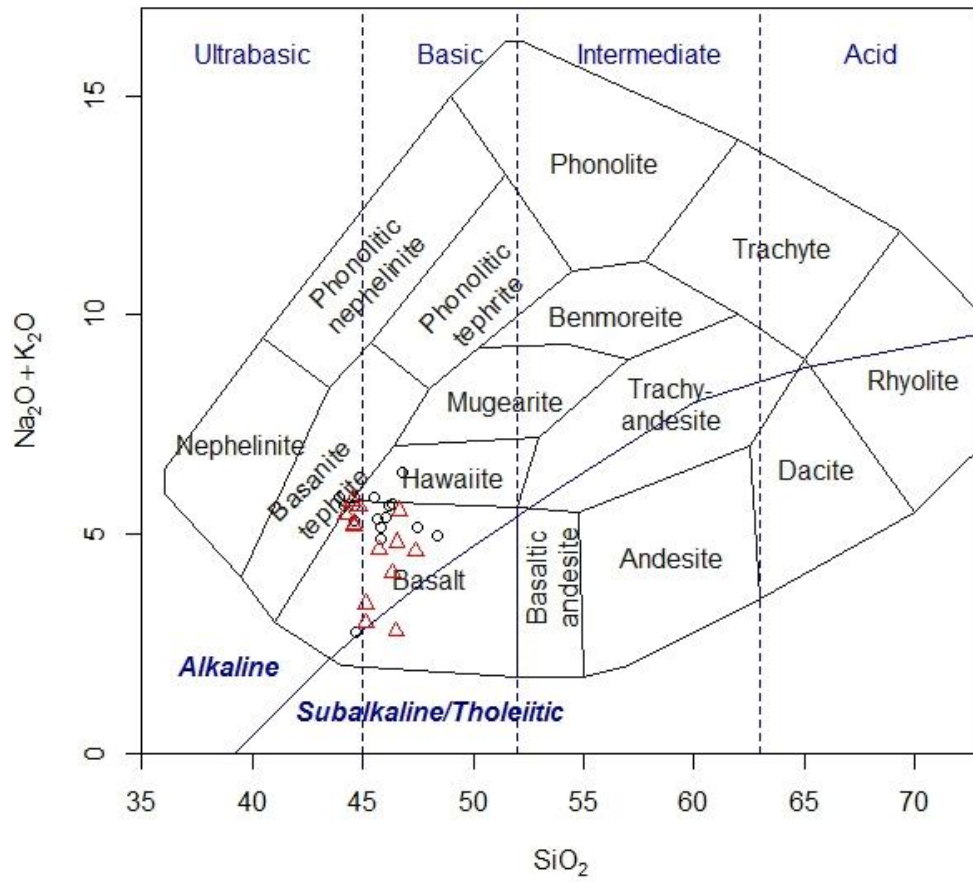


Figure 5. SiO_2 versus $Na_2O + K_2O$ classification diagram of Kerang basaltic rocks (after Cox et al., 1979).

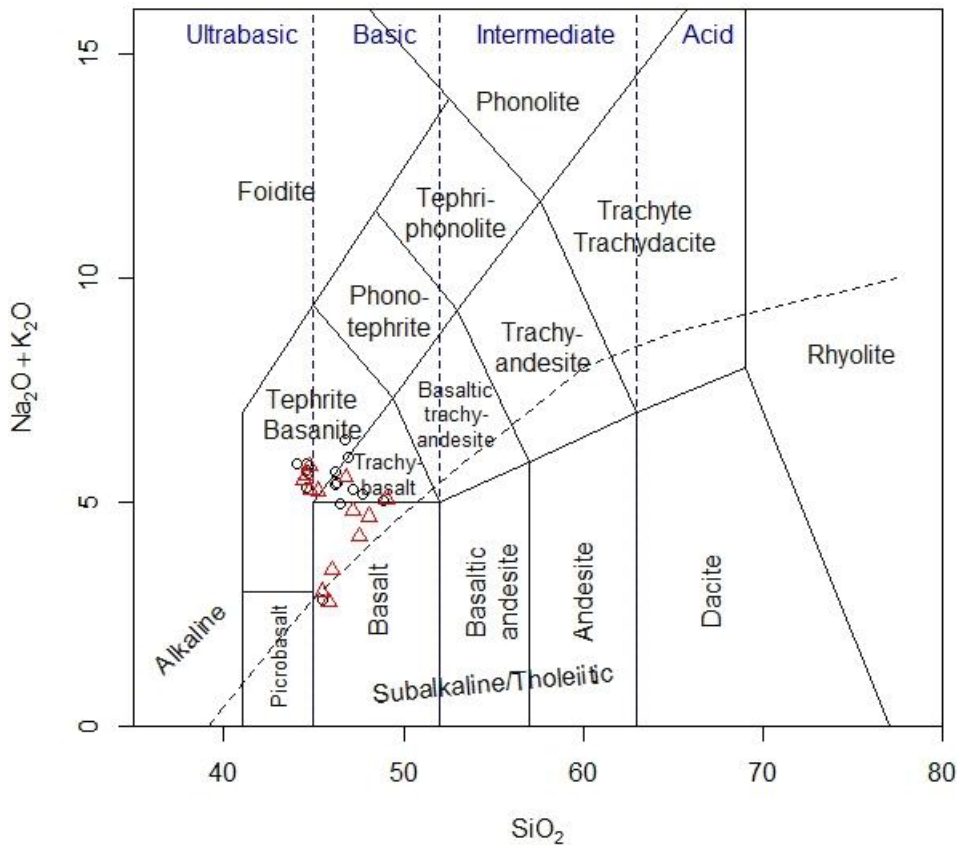


Figure 6. Classification of the rocks from Kerang basaltic rocks as plotted in a SiO_2 Versus Na_2O+K_2O , after Le Bas et al. (1986).

In the Total Alkali Silica (TAS) diagram after Irvine and Baragar, (1971), all of the basaltic rocks from the Kerang volcanoes, are classified as alkaline basalts, except for a single sample (LICD31) with higher Fe_2O_3 (>16.43 wt.%; Fig. 7) value, which falls in the subalkaline series. This is reaffirmed by their Nb/Y versus Zr/Ti classification diagram of Pearce, (1996) (Fig. 8) with some few falling in the foidite field, affirming their alkalinity. The total alkali ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) content for the Kerang basaltic

rocks is >5.77 wt.% (Table 1 & 2) further supporting their alkaline character. These geochemical signatures displayed by the basaltic rocks from the Kerang volcanoes are consistent with the fractionation/removal of ferromagnesian minerals (olivine and pyroxenes) in a mafic melt (Kerr, et al., 2019; Langmuir and Hanson, 1980; Rollinson, 1993; Oyan, et al., 201; Pandey, et al., 2013; William, 1985; Wood, et al., 1979; Yan, et al., 2008; Yucel, et al., 2017).

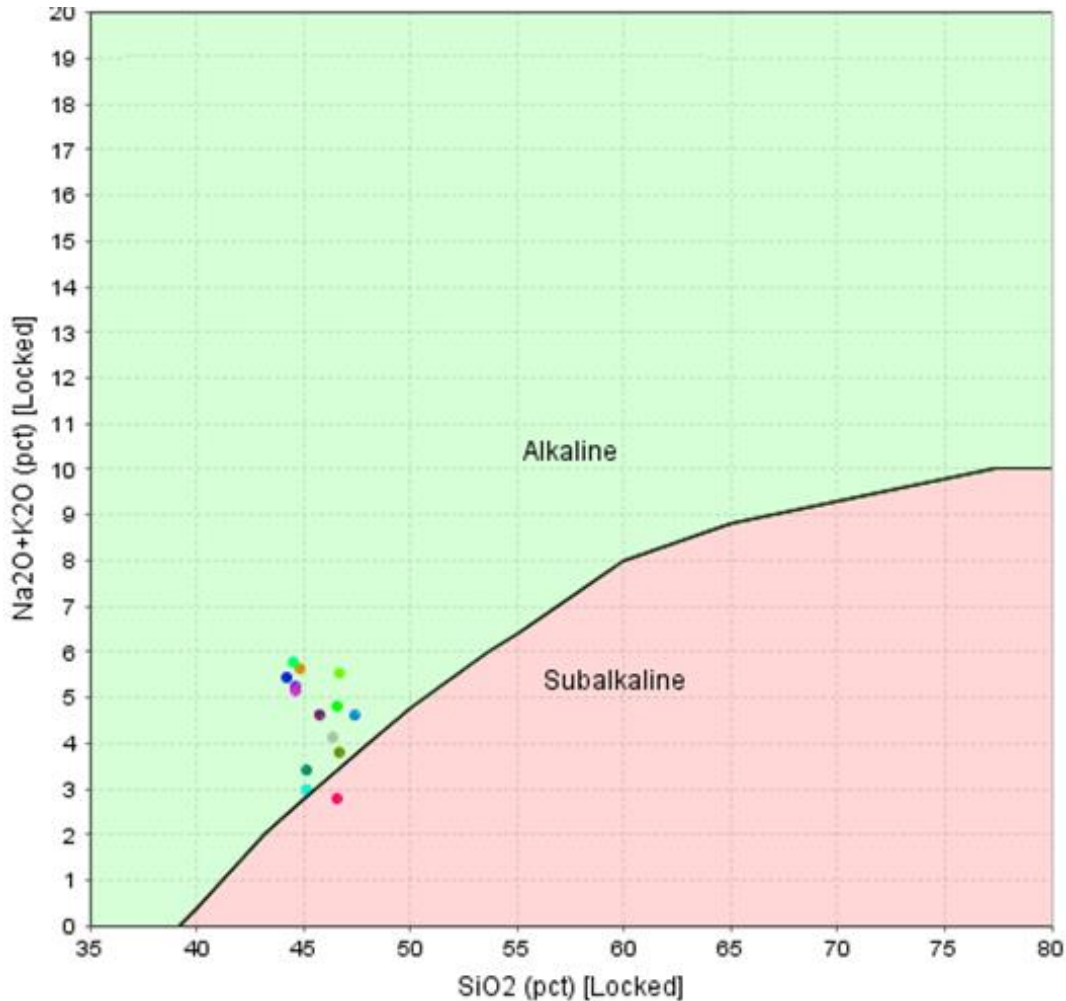


Figure 7. Classification of basaltic rocks from the Kerang volcanoes as plotted in a SiO_2 Versus $\text{Na}_2\text{O}+\text{K}_2\text{O}$ (wt. %) after Irvine and Baragar, (1971).

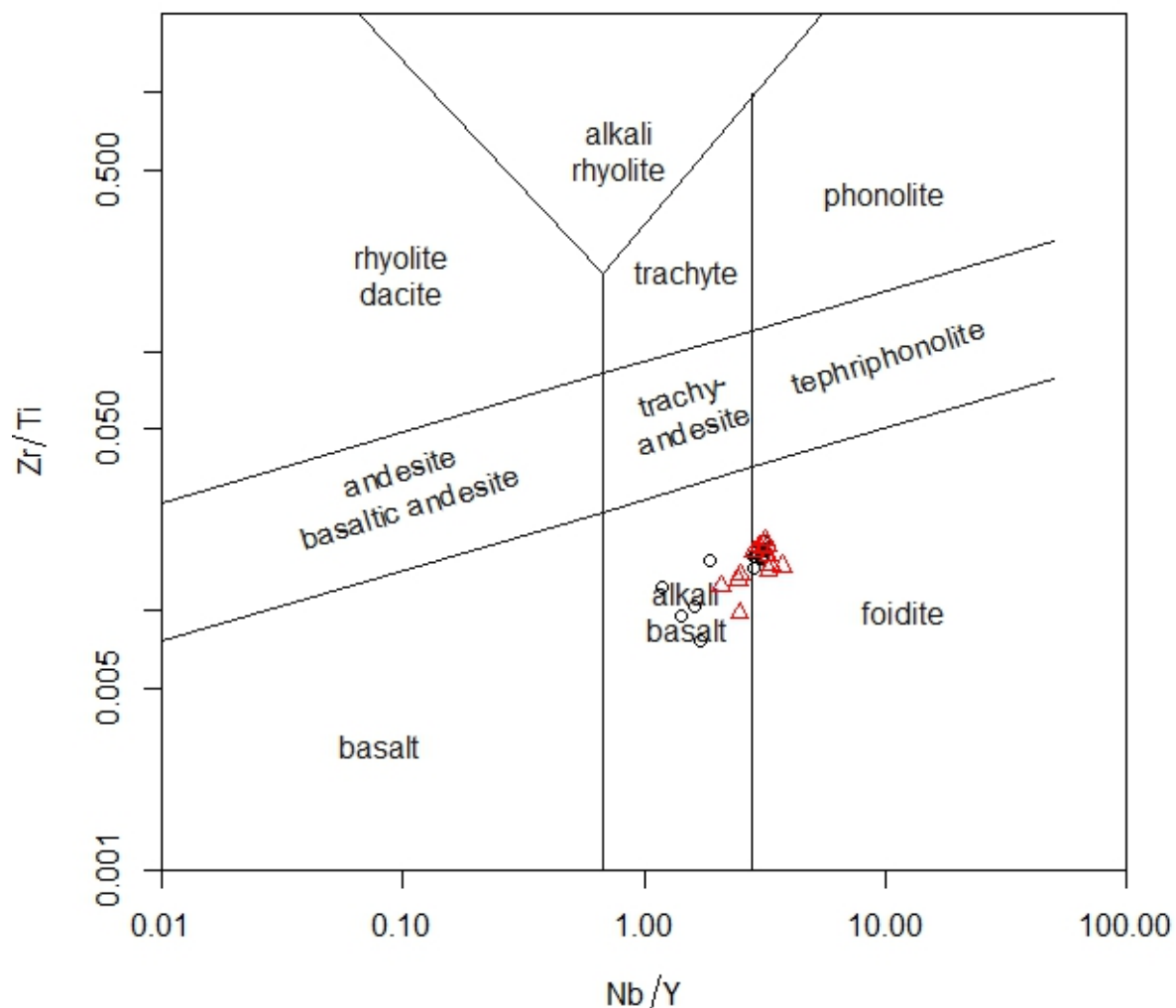


Figure 8. (Nb/Y versus Zr/Ti) after Pearce, (1996) for the Kerang Basaltic Rocks.

Major oxides of the basaltic rocks from Kerang volcanoes were correlated with silica (SiO_2). The following major oxides; Al_2O_3 , Fe_2O_3 , TiO_2 , P_2O_5 , MgO , CaO , and K_2O display marked decrease with increasing SiO_2 content thereby defining a negative slope (Fig. 9a, b, c, e, f, g & h) except Na_2O versus SiO_2 oxides which defines a positive correlation slope (Fig. 9d). In a similar plot of Mg# versus these oxides (SiO_2 , Al_2O_3 , Fe_2O_3 , MgO , CaO , K_2O , Na_2O , and MnO); a display of decrease with increasing Mg# was also observed

(Fig. 10b, c, e, f, h & i). However, the oxides of SiO_2 , MgO , and K_2O , exhibit a corresponding increase in their Mg# content thereby defining a positive correlation (Fig. 10a, d & g). This follows the fractionation/removal of ferromagnesian minerals (olivine and pyroxenes) pattern at the early stage of magma crystallization (Ebinger & Sleep, 1998; Deer & Zussman, 1979; Rollinson, 1993; Yucel et al., 2017; Smellie, 1987).

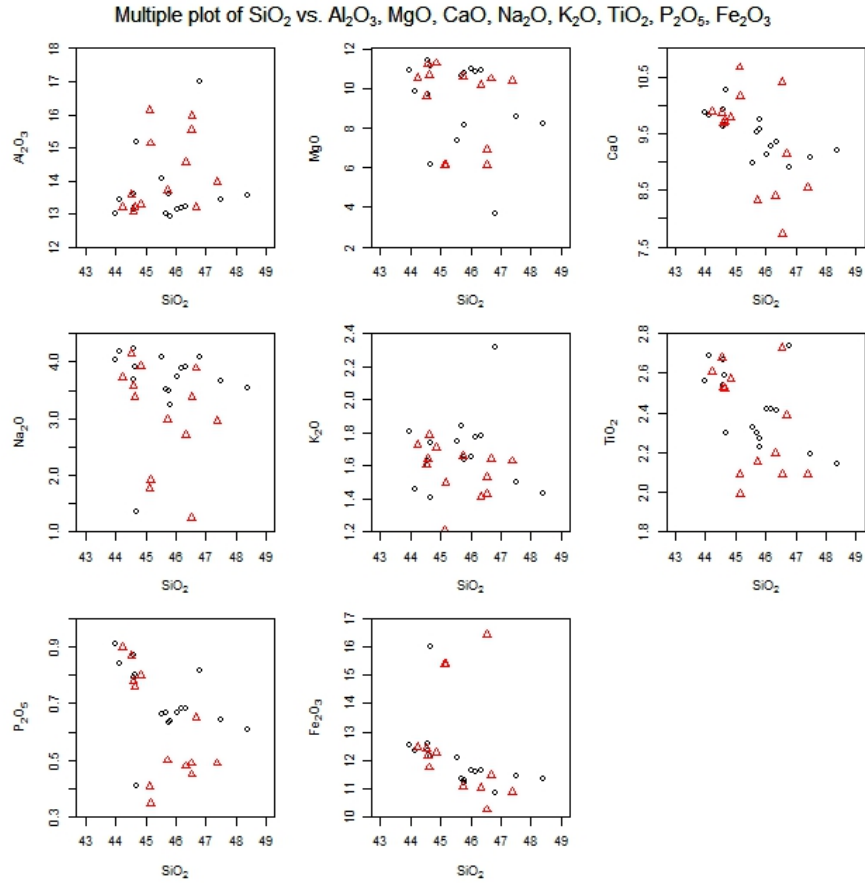


Figure 9 (a-h): SiO_2 versus Major Oxides for the Kerang Basaltic Rocks

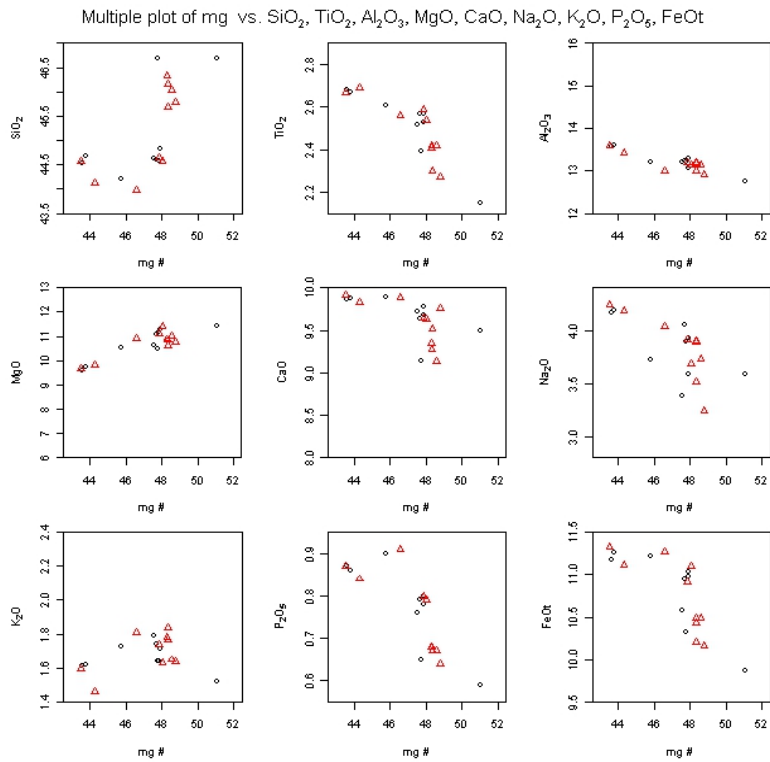


Figure 10 (a-i): Mg# versus Major Oxides for the Kerang Basaltic Rocks.

5. Discussion

5.1 Magma series and classification of the Basalts

The basaltic rocks from the Kerang twin volcanoes are composed predominantly of phenocrysts of clinopyroxenes, titan augites, olivines, orthopyroxenes, labradorites, and opaque minerals (Fe-Ti oxides) set in a fine groundmass. This mineral composition is consistent with basalts which are known to be composed of essentially calcic plagioclases and ferromagnesian minerals which usually include clinopyroxenes and magnetites as minor constituents (Le Maître, 2012) relative to rocks like granites. Based on the geochemical features of the basaltic rocks from the Kerang volcanoes, they are alkaline rocks (Figs. 7 & 8). This is further supported by the TAS classification diagrams of Cox et al., (1979) and Le Bas et al., (1986) with few displaying basanites to trachy basalt-tephrite compositions (Figs. 4, 5 & 6). Their silica contents show that they are silica undersaturated (43.52–48.39 wt.%). This is consistent with SiO₂ content for basaltic magma types – indicating that the magma that gave rise to the Kerang volcanoes was alkaline. The geochemical features displayed by the Kerang volcanoes suggest that they belong to the basaltic (alkaline in nature) magma series in contrast to the andesitic or rhyolitic magma series which have higher silica contents (Irvine and Baragar, 1971; Kushiro, 1996; Thompson, 1974; Thompson et al., 1982; Wood et al., 1979; Yan, 2008; Smellie 1987).

5.2. Petrogenesis (origin/evolution) of the Kerang Basaltic rocks

The plots of SiO₂ content versus major oxides often shed some light on the geological processes related to the evolution of basaltic magma. The SiO₂ contents versus major oxides (Al₂O₃, Fe₂O₃, MgO, CaO, P₂O₅, and K₂O) of the basaltic rocks of the Kerang volcanoes display a progressive decrease relative to SiO₂. There is, however, a negative correlation in SiO₂ versus Na₂O (Fig. 9). Similarly, the plot of Mg# versus these oxides (Al₂O₃, Fe₂O₃, TiO₂, CaO, P₂O₅, and Na₂O) also displayed progressive decreases with increasing Mg#, except for the oxides of SiO₂, MgO, and K₂O where a corresponding increase in their content increases with Mg# (Fig. 10). Such major element correlation follows the common trends of olivine

and olivine+clinopyroxenes fractional crystallization and/or phenocryst accumulation of minerals in a mafic melt (Deer et al., 1979; Wood, 1980; Rollinson, 1993; Yan et al., 2008; Burrell, 2017). The Mg# versus major oxides variations displayed by the basaltic rocks of the Kerang volcanoes indicate that a low degree of partial melting of the upper mantle has exerted significant control in their evolution process. From the petrographic study of the basalts of the Kerang volcanoes, nodules or phenocrysts of olivine and pyroxenes are seen in hand specimens. Similarly, their microscopic analyses revealed large phenocrysts of olivine, zoned clinopyroxenes and titanomagnetites, and phenocrysts of plagioclases in their mineral compositions. Also, reaction rims with the inclusion of xenocrysts were observed in the basaltic rocks of the Kerang volcanoes. This signifies earlier accumulation of these minerals at the first stage of magma crystallization at a higher pressure – deep mantle source (Abdel-Fattah and Kumara, (1999); Hart, 1970; Kerr et al., 2019; Wood, 1980; Wright, 1984; Yan et al., 2008).

6. CONCLUSION

The Kerang volcanoes are principally basalts which extruded the Precambrian basement gneiss and Pan African granites (older granites). They are classified as alkaline basalts and belong to the alkaline magma series. Their geochemical signatures revealed that they evolved through the process of partial melting of materials from a deep mantle source. Additionally, their geochemical results did not display any distinction between the basaltic rocks earlier referred to as newer and older. This has been confirmed by the recent radiometric dating of some of these basalts revealing that they represent multiple episodes of eruptions spanning the period from Pleistocene – Recent.

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