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Trace Element Geochemistry and Tectonic Setting of the Kerang Twin Volcanoes Within the Panyam Volcanic Line, Jos Plateau, Nigeria

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ABSTRACT

This study presents the geochemical characteristics of basalts of Kerang twin volcanoes within the Panyam Volcanic Line with a focus on their evolution and tectonic setting. The Kerang twin volcanoes as the name implies, are made of 2 large volcanoes which are major landmarks in the southeastern portion of Jos Plateau Volcanic Province of central Nigeria. Like other volcanoes along the Panyam volcanic line, they are well-preserved volcanic cones built of product of eruptive lapilli, scoria, breccias, basalts and pyroclastic materials (ash, granitic, lava flow, etc.). The volcanic edifices extruded the Precambrian migmatite-gneiss and Pan African biotite granite. The traverse mapping method was used to map the area. A total of 30 fresh samples collected from the volcanic cones and surrounding areas were analyzed for trace elements using the Inductively Coupled Plasma Mass Spectrometry. The constituent composition of these basaltic rocks displayed clear enrichment in both their Large-Ion-Lithophile Elements ($\geq 100\times$ chondrite) and High Field Strength Elements ($>10-80\times$ chondrite) relative to chondrite. Similarly, their enrichment in incompatible element ratios Zr/Nb (3.20–3.47); Ba/La (10.24–12.85); La/Nb (0.76–0.85) and Ba/Nb (8.51–9.91), speaks for an Oceanic Island Basalt (OIB) source rather than Mid-Oceanic-Ridge Basalts (MORB). All of these mentioned geochemical features shown by the basaltic rocks of the Kerang twin volcanoes, imply that they were derived from a deep mantle source that is enriched in incompatible elements with partial melting playing a significant role in their evolution. Furthermore, their trace element compositions reveal that they are “within plate’s alkaline basalts” emplaced along major NNW–SSE lineament within the pre-existing basement complex rocks.

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Introduction

There are three major volcanic provinces in Nigeria viz., the Jos Plateau (a superficial area of 8600 km² and 500 m thick), the Biu Plateau (a superficial area of 5000 km² and 250 m thick), and Longuda Plateau (a superficial area of 250 km² 300 m thick) respectively (Dautria, et al., 1983; McCurry, 1989; Turner, 1978). Several hundreds of volcanic cones and plugs dot the entire volcanic provinces of Nigeria (Fig. 1).

Jos Plateau is situated in central Nigeria bounded by latitudes 9°00' and 10°00' N and longitudes 8°30' and 9°30' E. The basement complex rocks of the Lower Paleozoic to Precambrian ages underlie about half of its entire landmass (Fig. 2). These rocks comprise of gneiss-migmatites basement rocks, the Pan-African Granites (Older Granite), and the predominant Jurassic non-orogenic alkaline Younger Granites (McCurry and Wright, 1972; Turner, 1976; Lar et al., 2018). The entire volcanic province of the Jos Plateau is represented by several volcanic cones, plugs, and lava flows. They extruded the Precambrian basement

migmatite-gneisses complex and in some places the Pan-African Granites and the Younger Granites Complexes (McCurry, 1989; Turner, 1976; Wright, 1969). Their cones are composed of ash, lapilli, bombs, tuff agglomerates, basalts, and scoria. Most of them occur in the form of simple or composite cones with well-defined central craters 1 km across and built of basaltic scoria and pyroclastic materials. These volcanic hills are aligned in an NNW–SSE direction extending for several kilometers. The sizes of these plugs and cones vary between 200 m – 1000 m in diameter with heights ranging from 429 m – 1628 m above sea level (Macleod et al., 1971; Ugoduluwa and Shoeneich, 1994; Lar et al., 2007, Uriah, et al., 2020). The dormant volcanoes of the Jos Plateau are categorized into two different groups; the northwestern and southeastern groups (Bakari, 2007; Suleiman, 2007; Idi, 2012; Igwilo, 2012). The Panyam volcanic line belongs to the southeastern groups and is made up of seven members.

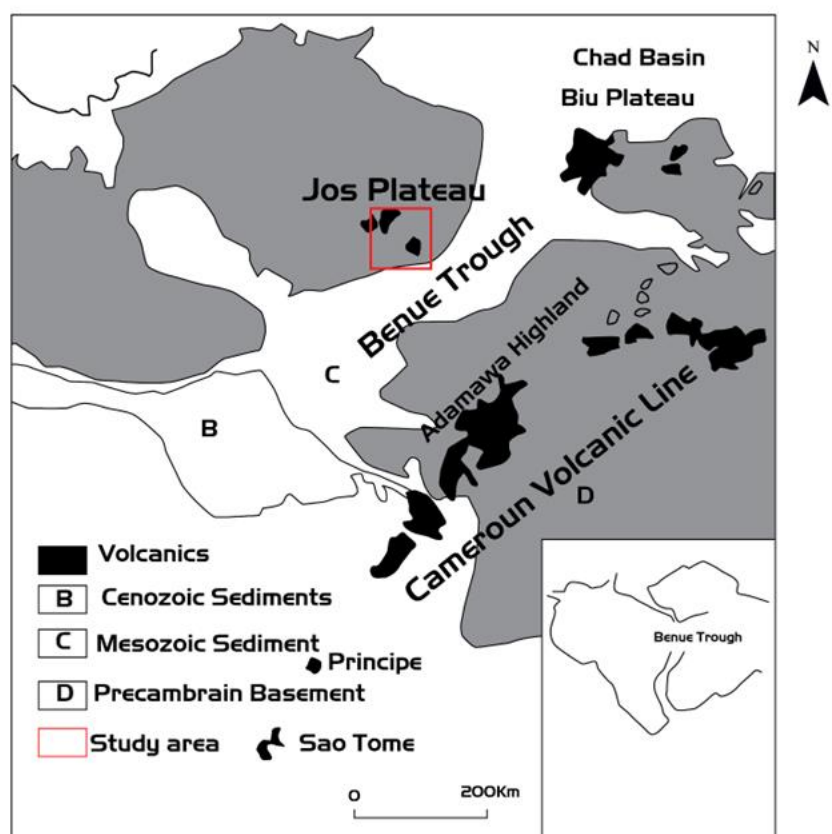


Figure 1. Location Map of Jos Plateau Volcanic Provinces in Nigeria (Modified after Wright, 1976)

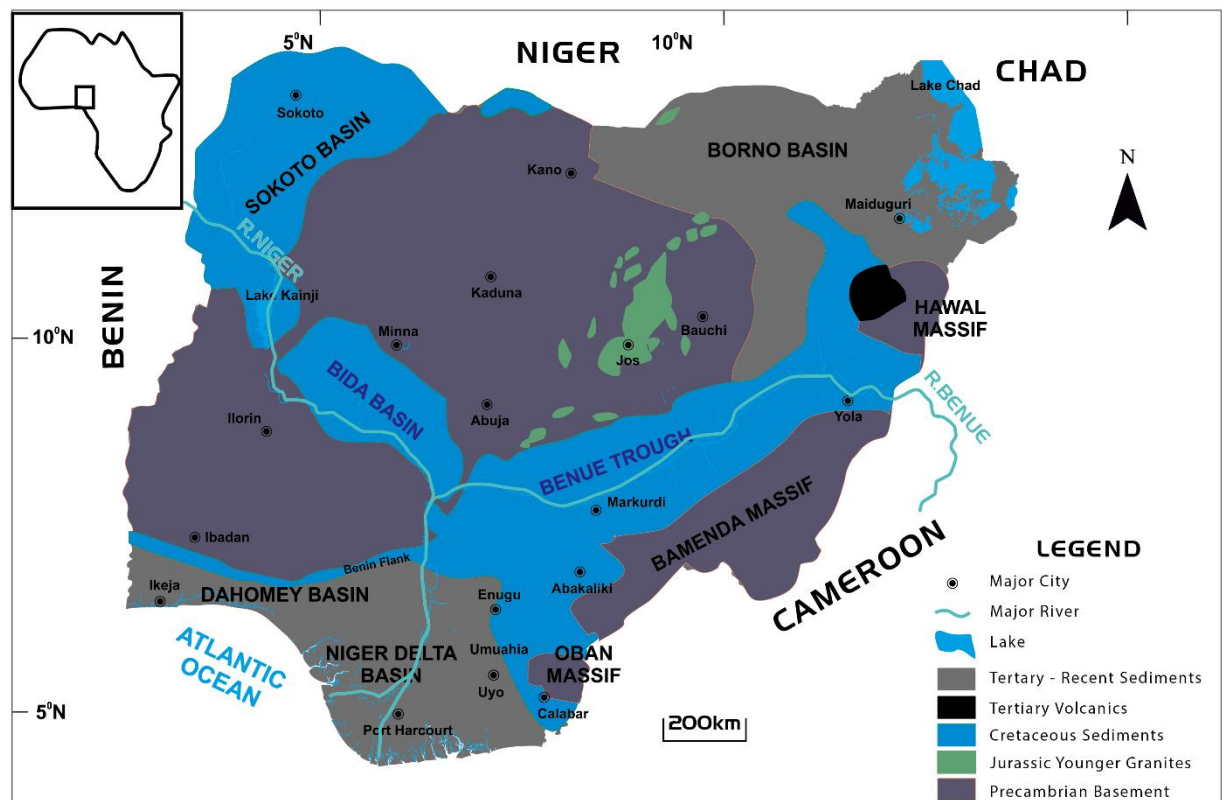


Figure 2. Simplified Geological Map of Nigeria (after Lar et al., 2018).

The Kerang twin volcanoes namely; Kerang I and Kerang II, comprise of two gigantic volcanic cones and are part of the series of the Panyam volcanic line. The volcanic edifices extruded the Precambrian basement migmatite-gneiss complex and the biotite granites (Older Granites) (Fig. 3). These volcanoes occur as vast, but isolated patches in the field. Their cones are mainly built of basaltic boulders, scoria, pumice, and pyroclastic, with their vesicles filled with a variety of inclusions (olivine, zeolites, calcite, etc.) and xenolith (lherzolite) (Buchanan et al., 1971; Macleod et al., 1971, Turner et al., 1971; Wright, 1979, Uriah et al., 2020). Most recently, geochemical studies on some volcanoes on the Jos Plateau, support their evolution from a common source, with the magma

originating from the upper mantle (Gusikit, 2010; Idi, 2012; Igwilo, 2012; Lar and Tsalha 2005; Lar et al., 2007; CGGT, 2014; Mohammed, 2014). The trace element geochemistry of the Kerang twin volcanos has not been studied in detail, apart from the preliminary attempts by some undergraduate and graduate students at the Department of Geology, University of Jos. Consequently, more information is required as to the chemical composition, source, tectonic setting, and the evolution process of these volcanoes. This research paper aims at studying the geochemical composition (trace elements), to understand their source, process of formation, and environment of emplacement (tectonic setting).

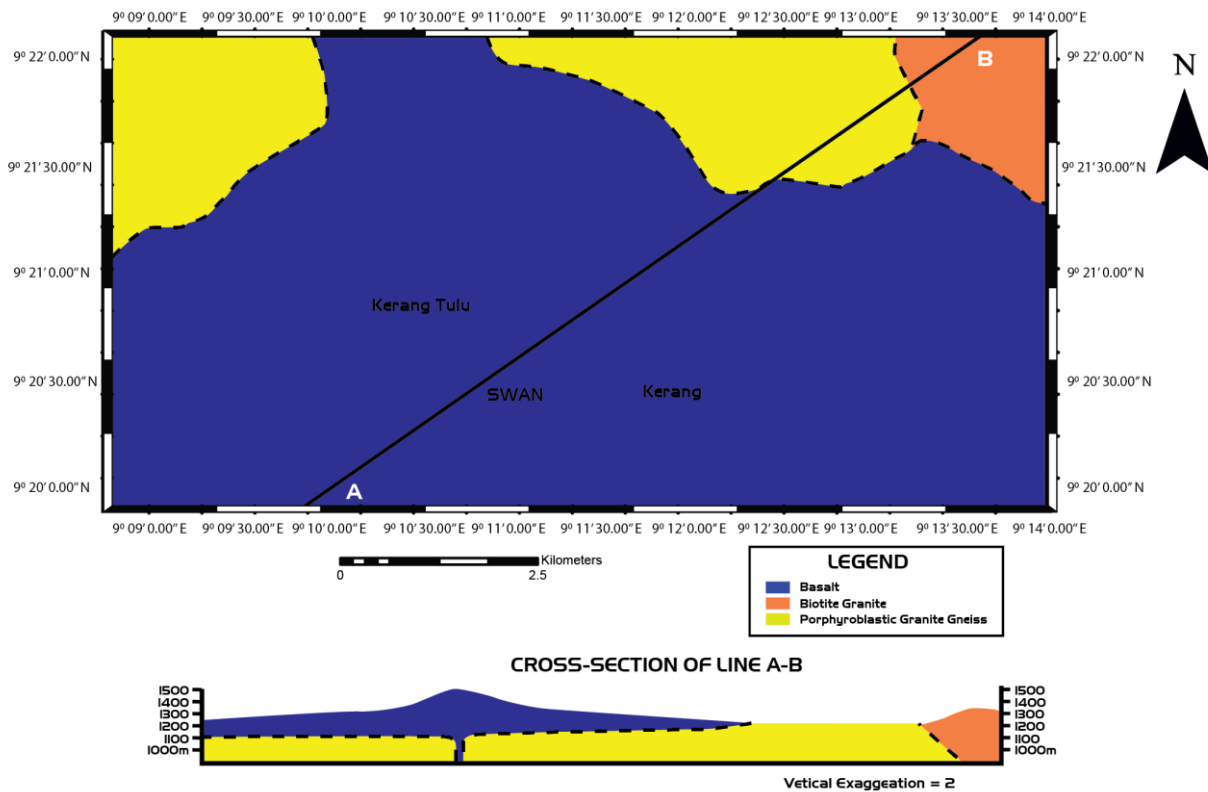


Figure 3. Geological Map of the Study Area.

2. Geologic setting of the Jos plateau volcanic province

The African plate contains a large number of volcanic centers believed to have erupted between Tertiary – Quaternary times and thought to be related to mantle plumes (Black and Giraud, 1970; William, 1985; Maluski et al., 1995; Burke, 1996; Pavoni, 1992). The alkaline volcanisms on the topographic swells and ocean island chains of Africa have been attributed to separate plumes which possibly stem from the African plate standstill relative to the mantle circulation some 35 million years ago (Burke, 2001; Guiraud et al., 1987; Wilson and Guiraud 1992). The continent has also experienced greater uplift during the Tertiary than has any other continent, and much of it now stands above 1 km e.g., Hoggar in Algeria (Black and Giraud, 1970; Dautria and Gui, 1991; Fitton, 1987; Nyako et al., 2006).

Field investigations across the continent, suggest that pre-existing basement fractures/lineaments have exerted fundamental control on the emplacement of volcanoes in Africa (Kervyn et al., 2017; Fitton, 1987; Kamgang et al., 2010). Based on decreasing volcanicity from the Miocene to the

Quaternary and the present low heat flow of the area, it suggested that the Quaternary basalts resulted from smaller degrees of partial melting from a greater depth. Also, the geochemistry of these basaltic rocks suggests that the rocks originated from a mantle source which was enriched in incompatible elements (Vincent, 1970; Wilson & Guiraud, 1992; Halliday et al., 1990). Volcanic activity has taken place intermittently from Tertiary to recent times in Nigeria (Buchanan et al., 1971; Kogbe, 1989; Wright, 1985). This volcanic activity which was basaltic and mainly alkaline relative to acidic in Nigeria, was the most widely spread. The most extensive outcrops are found in Benue Trough, Biu, Longuda, and Mambilla Plateaux occupying the northeastern portion of Nigeria and on the Jos Plateau (Black et al., 1985; Dautria et al., 1983).

The provinces are characterized by basement uplift just like most of the prominent volcanic provinces in Africa, such as the Bameda Highlands, the Mambila Plateau, the Adamawa Plateau, and numerous alkaline olivine basalts together with minor intrusive of trachytes and phonolites in the Benue Trough and Jos Plateau (Kogbe, 1989;

Njonfang et al., 2011; Nyako et al., 2006; Pavoni, 1992; Turner, 1983). The large volcanic provinces of Nigeria (Fig. 2), suggest that volcanic activity was intense on the Jos Plateau, the Benue trough and along the northeast to southwest Cameroon Volcanic line. In the relatively uplifted Jos Plateau region, volcanic rocks are represented by volcanic cones and calderas (Lar and Tsalha, 2005; Lar et al., 2020; MacLeod et al., 1971; Turner, 1978). The volcanic bodies occur as relics of volcanism in the form of scattered volcanic plugs, domes, lava flows and volcanic cones (Hossain et al., 1986; Wright, 1969 and 1985).

The relics of this volcanism on the Jos Plateau have been linked to the widespread Cenozoic volcanism that overlies directly the Pan-African Basement and in some places the Younger Granite bodies by several workers such as Burke 2001; Liegeois et al., 2005; Wilson and Guiraud, 1992; McCurry, 1989; Wright, 1976 and 1985. Similarly, the Jos Plateau volcanic provinces, like most of the other prominent volcanic provinces such as the Bameda Highlands, the Mambila Plateau and the Adamawa Plateau are characterized by basement uplift and relics of scattered volcanism (Uriah et al., 2020; Nyako et al., 2006; Turner, 1998). These basaltic rocks which are found to either directly overlie the pre-existing basement rocks and/or cross-cutting both the younger granitic rock bodies are categorized into two main types (i.e., older and newer basalts respectively) based on their age of emplacement and morphologies (Macleod et al., 1971; Turner, 1978; Wright, 1976; Wright, 1979; Lar et al., 2007). The Older basalts are believed to have been formed during the Tertiary times and the newer basalts during the Quaternary. Recent geochemical data support the evolution of these basaltic rocks on the Jos Plateau from a common source (CGGT, 2014; Mohammed, 2014; Uriah et al., 2020).

3. Materials and methodology

3.1. Materials

Field vehicle, topographic/base map, satellite images, Brunton compass, hammer and chisel, measuring tape and hand lens, Global Positioning System (GPS), and camera are among the tools used during the field work.

3.2. Methodology

The traverse mapping technique was employed for this investigation. All seven of the Panyam line's volcanoes were given a reconnaissance tour to determine their exact coordinates and get a basic idea of their physical characteristics, occurrence patterns, types of outcrops, and sizes. The Kerang twin volcanoes were then delineated for further detailed geological and geochemical investigation. This was the initial phase. In the second phase, the Kerang twin volcanoes were meticulously, methodologically, and in great detail mapped out at a scale of 1:10,000. An N-S and E-W grid was used to find outcrops in the field and take traverses across the basaltic hills.

The types of volcanoes, their dimensions, and their morphologies and outcrop patterns were identified. Their crater diameters were measured in the field, and the field notebook was used to record all observations obtained in the field. In the field, samples were described megascopically, and observations were documented. Changes in soil color and rock types were used to infer mappable rock boundaries. Sixty-four (64) fresh representative samples of basaltic rocks were collected from the Kerang I & II volcanic cones and their lava flows in the study area along N-S and E-W traverses across the volcanoes. From these 64 samples, 30 were re-examined and selected for further petrographic and geochemical studies. The thirty (30) samples which were studied under the microscope were also grounded into powder/pulverized of 0.063 μ m size, using a Tungsten carbide spex mill at the Department of Geology, Ahmadu Bello University Zaria. Two grams of each of the pulverized rock samples were stored in small polythene bags and then mailed to Acme Laboratory in Canada for geochemical analysis.

3.2.1. Analytical techniques

The Inductively Coupled Plasma Mass Spectrometry (ICPMS) technique, was used to analyze the following trace elements: Be, Cr, Ni, Co, V, Cu, Pb, Zn, Bi, Cd, W, Mo, As, Nb, Hf, Zr, Ag, Au, Hg, Rb, Cs, Ba, Sr, Tl, Ga, Se, Sb, Ta, Y, Th and U. The ICPMS method has the advantage of analyzing multi-element capability. The instrument was calibrated using recommended international rock standards at each time. The precision and accuracy of the data were lower than 0.1 ppm for the trace elements.

4. Result

4.1. Geochemical data

The trace elements composition of basaltic rocks from the Kerang twin volcanoes are presented in Tables 1 and 2. The ratios of their incompatible elements are presented in Tables 3 and 4. The elements are expressed in parts per million (ppm).

Table1. Trace element compositions (in ppm) of the Kerang I basaltic rocks.

Analyte		Cs	Rb	Ba	Sr	Pb	Th	U	Zr	Hf	Ta
Unit		ppm	Ppm	ppm	Ppm	ppm	Ppm	ppm	Ppm	ppm	ppm
MDL		0.1	0.1	1	0.5	0.1	0.5	0.1	1	0.5	0.1
Sample ID	Coordinates										
LICD 1	N09°19'887"/E009°10'100"	<0.50	32	562	489	9.00	4.20	0.90	155	3.40	4.90
LICD 2	N09°19'997"/E009°1'009"	0.80	46	655	676	6.00	5.50	1.20	185	3.90	4.30
LICD 3	N09°20'587"/E009°11'109"	0.80	46.8	710	105 4.40	3.10	8.50	2.00	273.40	5.60	4.40
LICD 4	N09°20'795"/E009°11'998"	0.90	57.5	677	873	2.00	7.50	1.80	233.3	5.50	4.30
LICD 5	N09°20'370"/E009°11'655"	0.60	47.6	707	103 6.7	2.50	8.40	2.00	267.8	5.70	4.60
LICD 6	N09°21'511"/E009°11'856"	0.70	54.9	725	105 8.2	2.90	9.00	2.00	282.2	6.10	4.90
LICD 7	N09°20'805"/E009°11'910"	0.80	44.00	647	685	7.00	5.60	1.20	187	3.90	4.40
LICD 8	N09°20'905"/E009°11'955"	0.60	36.00	721	711	6.00	5.70	1.10	195	4.30	4.30
LICD 9	N09°21'468"/E009°11'605"	0.35	35.61	633.81	811. 16	3.49	6.49	1.81	162.96	3.43	4.00
LICD 12A	N09°20'940"/E009°12'010"	1.00	49.6	757	113 3	1.50	9.80	2.50	292.30	6.50	5.80
LICD 12B	N09°21'750"/E009°12'511"	0.80	44.9	629	102 8.5	3.20	7.70	1.80	253.60	5.50	4.60
LICD 13	N09°20'196"/E009°12'256"	0.35	35.61	633.81	811. 16	3.49	6.49	1.81	162.96	3.43	4.00
LICD 22	N09°21'850"/E009°13'810"	0.61	40.05	634.46	751.2 1	3.92	7.18	2.18	163.22	4.00	2.98
LICD 31	N09°21'880"/E009°10'980"	0.24	40.38	1234.40	947. 08	3.80	6.63	1.50	159.84	5.00	4.00

MDL=Minimum Detection Limit
Analysis by ICPMS

Table 1 contd: Trace element compositions (in ppm) of the Kerang I basaltic rocks.

Analyte		Y	Nb	Sc	Cr	Ni	Co	V	W	Ga	Zn	Cu
Unit		ppm	ppm	ppm	ppm	Ppm	Ppm	Ppm	ppm	ppm	ppm	ppm
MDL		0.5	0.1	1	0.1	0.1	0.2	8	0.5	0.5	1	0.5
Sample ID	Coord.											
LICD1	N09°19'887"/E009°10'100"	22.0 0	46.0 0	17.0 0	280. 00	150. 00	40.0 0	139. 00	1.00	20.0 0	100. 00	50.0 0
LICD2	N09°19'997"/E009°1'009"	19.0 0	62.0 0	18.0 0	390. 00	340. 00	52.0 0	149. 00	7.00	18.0 0	110. 00	60.0 0
LICD3	N09°20'587"/E009°11'109"	27.8	83.2 0	17.5 6	308. 00	223. 00	152. 40	197. 00	457.40	20.0 0	90.0 0	33.8 0
LICD4	N09°20'795"/E009°11'998"	21.7	70.8 0	18.6 0	328. 00	222. 00	83.8 0	189. 00	251.70	20.4 0	78.0 0	45.0 0
LICD5	N09°20'370"/E009°11'655"	24.8	80.4 0	17.6 0	335. 00	212. 00	74.2 0	195. 00	168.80	19.8 0	88.0 0	33.6 0
LICD6	N09°21'511"/E009°11'856"	27.3	84.6 0	17.4 0	212. 00	129. 00	82.9 0	196. 00	331.60	20.6 0	85.0 0	32.0 0
LICD7	N09°20'805"/E009°11'910"	18.0 0	60.0 0	18.0 0	390. 00	320. 00	51.0 0	150. 00	3.00	18.0 0	100. 00	60.0 0
LICD8	N09°20'905"/E009°11'955"	18.0 0	67.0 0	18.0 4	330. 00	320. 00	51.0 0	150. 00	3.00	19.0 0	110. 00	60.0 0
LICD9	N09°21'468"/E009°11'605"	25.9 4	63.7 2	17.4 6	772. 00	131. 00	461. 00	141. 05	<1.30	20.8 2	90.0 7	46.8 9
LICD12A	N09°20'940"/E009°12'010"	28.2	89	23.9 4	308. 00	171. 00	97.0 0	193. 00	530.20	20.5 0	69.0 0	14.5 0
LICD12B	N09°21'750"/E009°12'511"	25.8	73.1	21.4 6	294. 00	177. 00	94.3 0	178. 00	522.00	18.4 0	83.0 0	29.8 0
LICD13	N09°20'196"/E009°12'256"	25.9 4	63.7 2	17.4 6	772. 00	131. 00	461. 00	141. 05	<1.30	20.8 2	90.0 7	46.8 9
LICD22	N09°21'850"/E009°13'810"	26.8 7	67.5 4	22.0 9	987. 10	130. 00	443. 00	142. 14	<1.30	21.0 5	94.8 8	45.2 6
LICD31	N09°21'880"/E009°10'980"	25.9 2	64.4 5	18.3 9	863. 00	149. 00	455. 00	150. 40	<1.30	18.8 7	96.9 4	37.2 4

Analyte		Cs	Rb	Ba	Sr	Pb	Th	U	Zr	Hf	Ta
Unit		Ppm	ppm	Ppm	Ppm	ppm	Ppm	ppm	ppm	Ppm	ppm
MDL		0.1	0.1	1	0.5	0.1	0.5	0.1	1	0.5	0.1
Sample ID	Coord.										
LICK 2	N09°20'305"/E009°11'310"	0.8	47	673	1058.5	2.4	8.5	1.9	260.4	5.7	4.6
LICK 4	N09°20'401"/E009°11'210"	1	59.5	696	855	2.1	7.8	1.6	233.7	5.7	4.6
LICK 5	N09°20'640"/E009°11'360"	1.1	57.5	679	843.7	2.1	7.6	1.5	230.2	5.1	4.4
LICK 6	N09°20'451"/E009°11'300"	1.1	57.7	694	857.1	2.1	7.7	1.8	235.8	5.3	4.6
LICK 8	N09°20'430"/E009°12'420"	1	53.7	702	876.5	3.7	7.9	1.9	231.3	5.4	4.6
LICK 9	N09°20'805"/E009°12'910"	0.31	37.57	506.59	737.03	4.55	6.23	1.81	206.51	3.74	2.72
LICK 10	N09°20'950"/E009°13'810"	0.9	3.1	801.1	987.7	3.7	4.2	1.9	168.7	3.4	4.9
LICK 12	N09°21'205"/E009°13'980"	0.33	34.7	497.3	697.8	4.38	6.11	1.74	122.02	2.64	2.36
LICK 14	N09°21550"/E009°13'510"	0.9	46.4	689	1012.5	3	9	2.1	271.8	6.2	5.1
LICK 17	N09°21'350"/E009°10'303"	1	50.8	637	896.6	3.1	7.4	1.7	219.6	4.4	4.2
LICK 19	N09°20'610"/E009°11'651"	1	62.98	741.03	1005.83	5.01	8.44	2.57	237.59	4.51	3.66
LICK 27	N09°19'065"/E009°11'451"	1.1	50.1	769	1131.7	3.7	9.9	2.2	281.4	6.3	5.3
LICK 28	N09°19'015"/E009°10'351"	1.1	53.5	734	1033.3	2.7	9.6	2	274.3	6.1	5.5
LICK 30	N09°20'650"/E009°14'413"	0.8	43.5	651	992.6	2.5	7.9	1.9	246.7	5.6	4.3
LICK 32	N09°20'059"/E009°09'040"	0.65	39.61	459.83	733.57	4.22	6.09	1.76	106.57	2.39	2.58
LICK 36	N09°20'650"/E009°10'670"	0.42	35.3	464.3	724.3	3.99	7.09	1.79	136.83	3.06	2.5

Analysis by ICPMS

[illegible]

LICK 2	N09°20'305" / E009°11'310"	27	77.5	0	328. 1	222. 2	80	189	252. 9	20.1	89	37.2
LICK 4	N09°20'401" / E009°11'210"	23	70.4	0	349. 2	236. 2	85.5	176	403. 7	18.6	80	61.6
LICK 5	N09°20'640" / E009°11'360"	22.8	69.9	0	363. 1	235. 8	69.6	184	201	18.6	87	47.9
LICK 6	N09°20'451" / E009°11'300"	22.9	71.6	0	335. 3	224. 7	83.4	187	307. 1	19	84	47.9
LICK 8	N09°20'430" / E009°12'420"	23.7	68.6	0	363. 2	231. 6	110	180	634. 1	18	87	49
LICK 9	N09°20'805" / E009°12'910"	24.25	45.48	17.5	141. 5	128. 5	42.9	166.7	5	18.5	126. 3	49.4
LICK 10	N09°20'950" / E009°13'810"	26.9	31.6	10.5	822. 1	171. 3	457	154.1	6	25.4	87.9	34.1
LICK 12	N09°21'205" / E009°13'980"	25.9	36.98	17.1	176. 6	154. 3	39.3	168.3	3.45	17.5	100. 3	51.9
LICK 14	N09°21'550" / E009°13'510"	25.8	81.3	0	219. 21	143. 7	81.5	185	344	18.3	100	34.4
LICK 17	N09°21'350" / E009°10'303"	22.5	65.4	0	397. 1	239. 9	85.1	182	322. 5	17.8	83	58.6
LICK 19	N09°20'610" / E009°11'651"	27.32	77.45	10	19.5	3.4	28.8	181.4	6.13	24.1	113. 2	43.2
LICK 27	N09°19'065" / E009°11'451"	28.3	88.3	0	274. 4	192. 5	87	184	307. 9	19.2	91	30.7
LICK 28	N09°19'015" / E009°10'351"	26.4	82.6	0	205	132. 1	82.6	190	298. 3	19.8	88	32.9
LICK 30	N09°20'650" / E009°14'413"	25.9	73.8	0	322. 2	230. 2	77.8	187	309. 6	17.8	92	35
LICK 32	N09°20'059" / E009°09'040"	25.47	43.82	17.5	229. 1	183. 9	41.4	162.7	2.99	18.7	94.8	40.8
LICK 36	N09°20'650" / E009°10'670"	25.2	40.59	17.9	199. 4	421. 2	39.9	159.6	5.13	17.8	116. 4	46.4

MDL = Minimum Detection Limit
Analysis by ICPMS

Table3. Incompatible elements ratios of Kerang I basaltic rocks.

RATIO	Coordinates	La/Y b	La/Nb	Ba/La	Ba/N b	Nb/Y b	Th/Yb	Nb/Y	Zr/Ti	Zr/TiO 2
LICD1	N09°19'887"/E009°10' 100"	0.70	3.37	17.45	12.2 2	2.09	0.01	0.01	30.67	2.80
LICD2	N09°19'997"/E009°1'0 09"	0.65	2.98	16.33	10.5 6	3.26	0.01	0.01	47.69	4.23
LICD3	N09°20'587"/E009°11' 109"	0.82	3.29	10.36	8.53	2.99	0.01	0.02	46.48	4.75
LICD4	N09°20'795"/E009°11' 998"	0.78	3.30	12.26	9.56	3.26	0.01	0.02	48.49	5.14
LICD5	N09°20'370"/E009°11' 655"	0.81	3.33	10.88	8.79	3.24	0.01	0.02	45.42	4.75
LICD6	N09°21'511"/E009°11' 856"	0.81	3.34	10.60	8.57	3.10	0.01	0.02	47.00	5.00
LICD7	N09°20'805"/E009°11' 910"	0.66	3.12	16.42	10.7 8	3.33	0.01	0.01	46.15	4.31
LICD8	N09°20'905"/E009°11' 955"	0.63	2.91	17.21	10.7 6	3.72	0.01	0.01	47.86	4.07
LICD9	N09°21'468"/E009°11' 605"	0.74	2.56	13.47	9.95	2.46	0.01	0.01	42.48	4.32
LICD12 A	N09°20'940"/E009°12' 010"	0.83	3.28	10.24	8.51	3.16	0.01	0.02	50.57	5.57
LICD12 B	N09°21'750"/E009°12' 511"	0.76	3.47	11.37	8.60	2.83	0.01	0.02	40.61	4.28
LICD13	N09°20'196"/E009°12' 256"	0.74	2.56	13.47	9.95	2.46	0.01	0.01	42.48	4.32
LICD22	N09°21'850"/E009°13' 810"	0.73	2.42	12.83	9.39	2.51	0.01	0.01	51.95	5.52
LICD31	N09°21'880"/E009°10' 980"	0.71	2.48	26.93	19.1 5	2.49	0.01	0.01	32.23	3.31

Table 4. Incompatible elements ratios of Kerang II basaltic rocks.

Sample ID	Coord.	La/Yb	La/Nb	Ba/La	Ba/Nb	Nb/Yb	Th/Yb	Nb/Y	Zr/Ti
LICK 2	N 09° 20' 305" / E 009° 11' 310"	36.57	0.80	10.89	8.68	45.86	5.03	2.87	0.02
LICK 4	N 09° 20' 401" / E 009° 11' 210"	41.74	0.78	12.63	9.89	53.33	5.91	3.06	0.02
LICK 5	N 09° 20' 640" / E 009° 11' 360"	40.22	0.78	12.41	9.71	51.40	5.59	3.07	0.02
LICK 6	N 09° 20' 451" / E 009° 11' 300"	40.00	0.78	12.48	9.69	51.51	5.54	3.13	0.02
LICK 8	N 09° 20' 430" / E 009° 12' 420"	37.67	0.82	12.42	10.23	45.73	5.27	2.89	0.02
LICK 9	N 09° 20' 805" / E 009° 12' 910"	29.04	1.04	10.69	11.14	27.86	3.82	1.88	0.02
LICK 10	N 09° 20' 950" / E 009° 13' 810"	28.51	1.39	18.25	25.35	20.52	2.73	1.17	0.01
LICK 12	N 09° 21' 205" / E 009° 13' 980"	29.40	1.29	10.43	13.45	22.81	3.77	1.43	0.01
LICK 14	N 09° 21' 550" / E 009° 13' 510"	37.63	0.80	10.58	8.47	46.99	5.20	3.15	0.02
LICK 17	N 09° 21' 350" / E 009° 10' 303"	38.71	0.83	11.75	9.74	46.71	5.29	2.91	0.02
LICK 19	N 09° 20' 610" / E 009° 11' 651"	33.71	0.78	12.29	9.57	43.31	4.72	2.84	0.01
LICK 27	N 09° 19' 065" / E 009° 11' 451"	42.78	0.85	10.21	8.71	50.17	5.63	3.12	0.02
LICK 28	N 09° 19' 015" / E 009° 10' 351"	43.81	0.82	10.81	8.89	53.29	6.19	3.13	0.02
LICK 30	N 09° 20' 650" / E 009° 14' 413"	39.87	0.82	10.74	8.82	48.55	5.20	2.85	0.02
LICK 32	N 09° 20' 059" / E 009° 09' 040"	28.58	1.04	10.06	10.49	27.39	3.81	1.72	0.01
LICK 36	N 09° 20' 650" / E 009° 10' 670"	29.88	1.15	9.96	11.44	26.01	4.54	1.61	0.01

4.1.1. Trace elements data for basalts of the Kerang twin volcanoes

The transition metals (Ni, Cr, and V) for the Kerang twin basaltic rocks are plotted against Mg# values (Fig. 4a-c). These transition metals display a progressive increase in their content with Mg# (Fig. 4b & c) except for Cr, which shows an inverse relationship (Fig. 4a). This is consistent with the fractionation/removal of ferromagnesian minerals (olivine and pyroxenes) in a mafic melt that is controlled by partial melting at great depth yielding silica-undersaturated basaltic rocks (Halliday et al., 1990; Pandey et al., 2013; Rollinson, 1993; Oyan et al., 2017; Wang and Xiu, 2001). In a generalized spider graph plot of incompatible elements (Ba, Rb, Th, K, Nb, Ta, La, Ce, Sr, Nd, P, Zr, Hf, Ti, Tb, Y, Tm, and Yb) of the Kerang twin volcanoes normalized to chondrites after Sun et al., (1980); the following incompatible elements: (Rb, Ba, Th, U, Nb, Ta, K, La, and Ce) are highly enriched ($\geq 100\times$ chondrites) relatively to chondrite (Fig. 5). So also, the spider graph plot after Thompson, (1982) present

relatively same higher values (Fig. 6) to that of Sun et al. (1980). There is however a conspicuous negative anomaly in Nb and K (Figs. 5 & 6). There is also a clear enrichment in their Large-Ion Lithophile Elements (LILE) (Ta, La, Ba, Th, and U) relative to their High Strength Field Elements (HSFE) (Nb, K, Sr, and Zr). Another characteristic of the spectra displayed is the positive anomalies in Ta, La & Ba displaying a 'domed' shape (Fig. 7), which is a typical characteristic of alkaline basalt (Abdel-Fattah and Kumara, 1999; Burrell, 2017; Halliday et al., 1995; Wood et al., 1979). Further spider graph plot of their incompatible elements normalized to Mid-Ocean Ridge Basalt (MORB) (after Pearce, (1983), display very clear enrichment of their elements ($>1\times$ to $50\times$) relative to MORB (Fig. 7). The positive anomalies in K, Rb, Ba, Th, Ta, Nb, and Ce displaying a 'humped' shape pattern which is a characteristic pattern of alkaline basalts (Burrell, 2017; Wood et al., 1979; Yan et al., 2008; Yucel, et al., 2017).

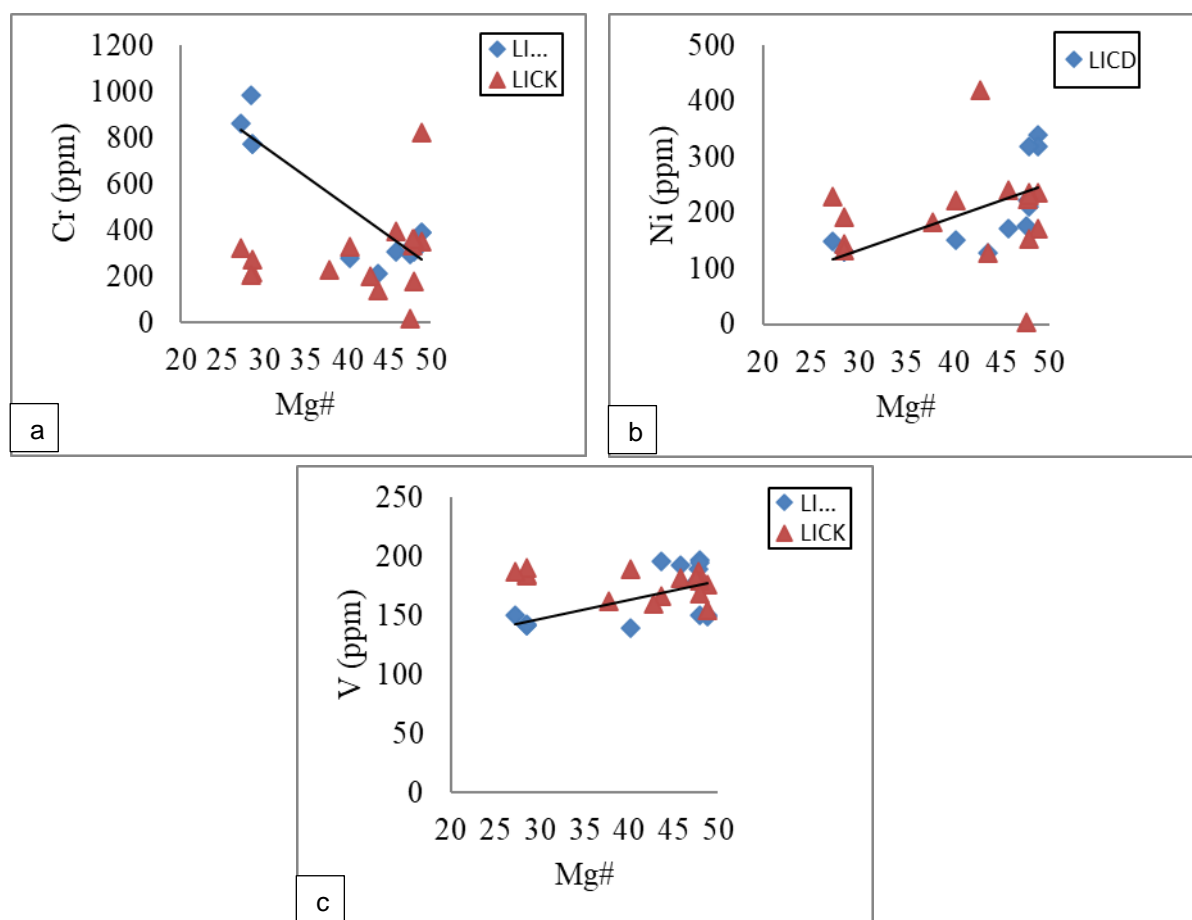


Figure 4 (a-c): Mg# versus Compatible elements (ppm) for the Kerang twin basaltic rocks.

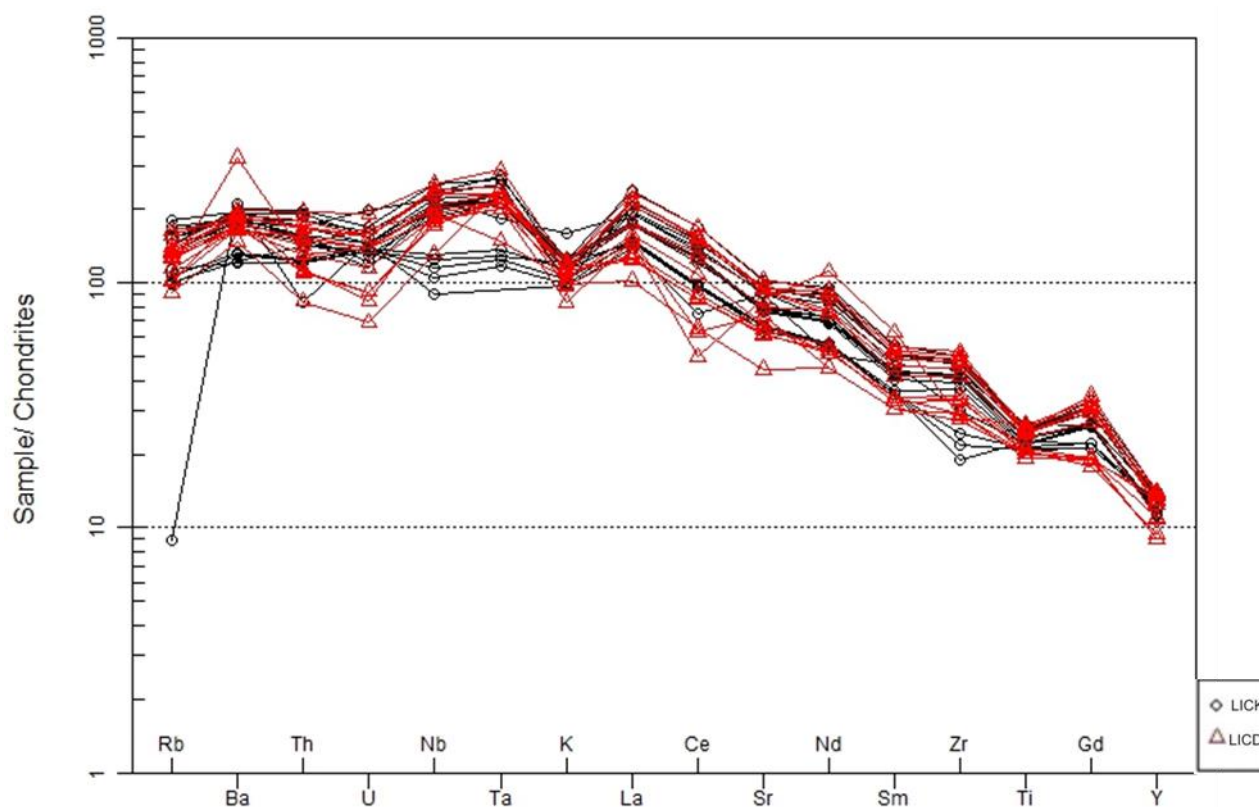


Figure 5. Generalized Spider graph of Incompatible element compositions of basaltic rocks from Kerang twin volcanoes normalized to chondrites (after Sun et al., 1980).

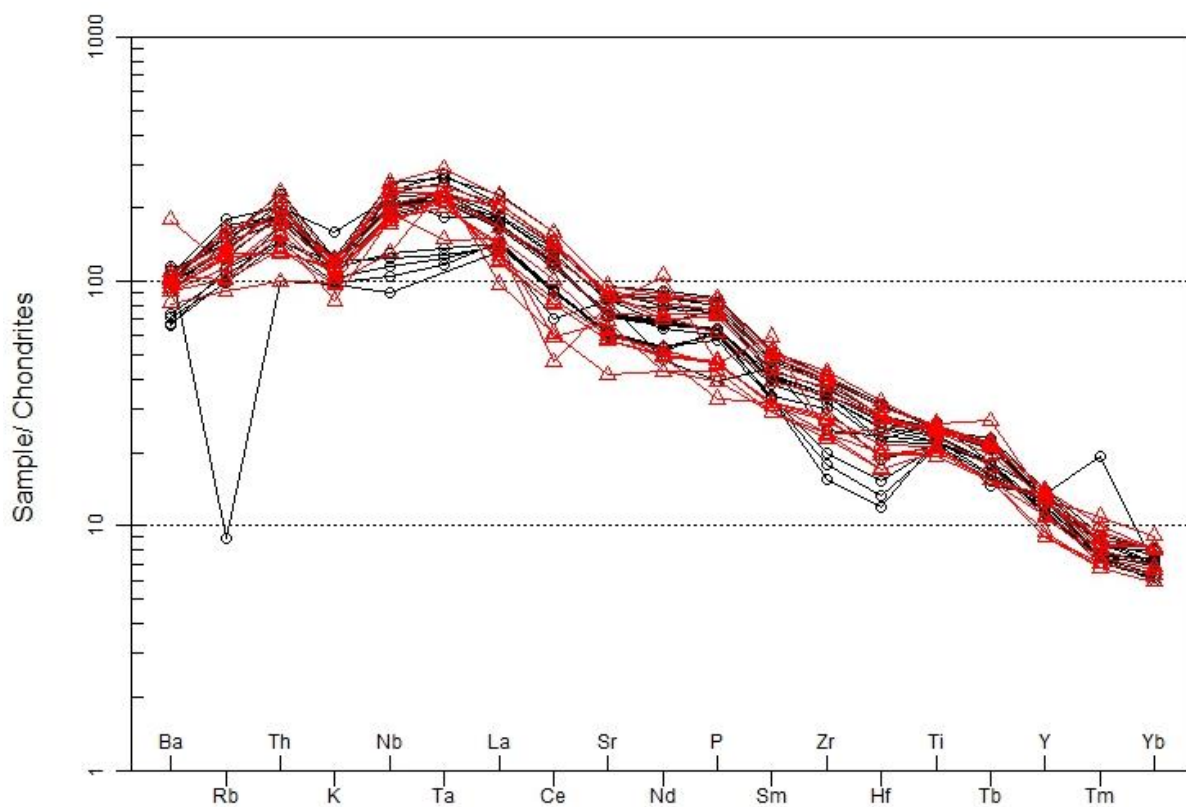


Figure 6: Spider graph of Incompatible element compositions of basaltic rocks from Kerang twin volcanoes normalized to chondrites (after Thompson, 1982).

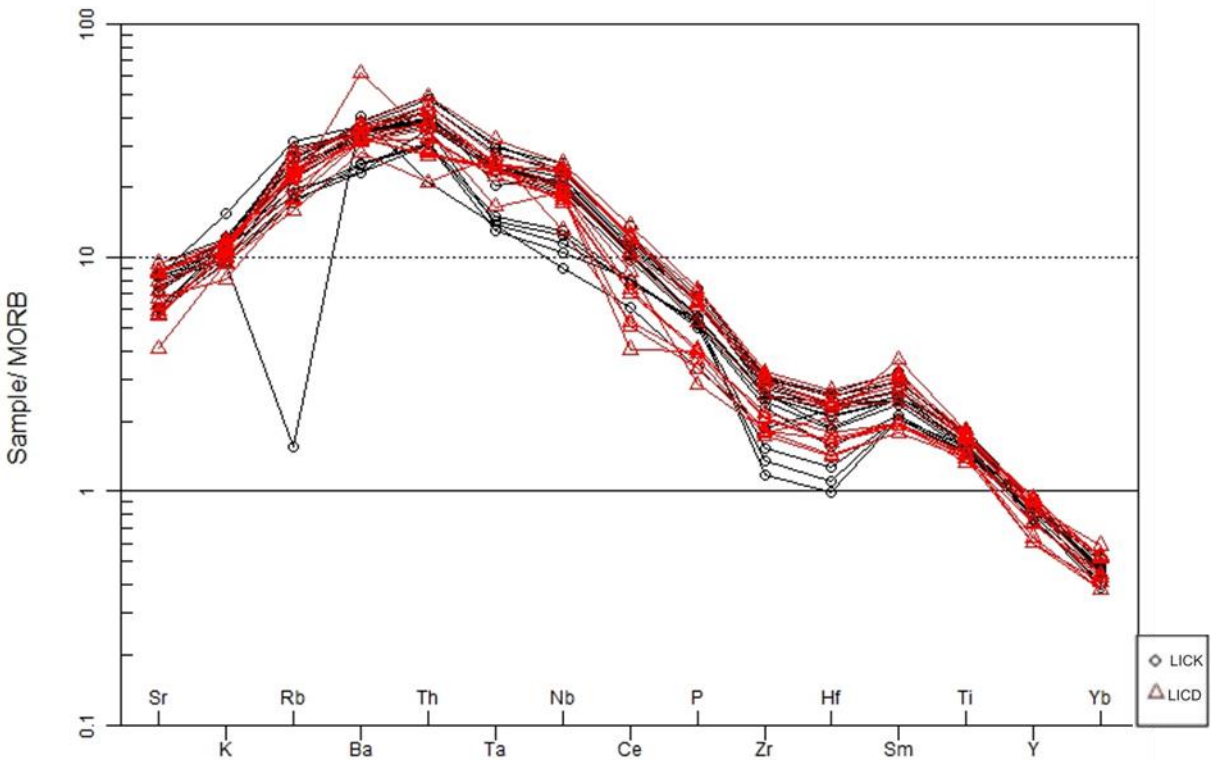


Figure 7. Spider graph of Incompatible element compositions of basaltic rocks from Kerang twin volcanoes normalized to MORB. Normalizing data from Pearce, (1983).

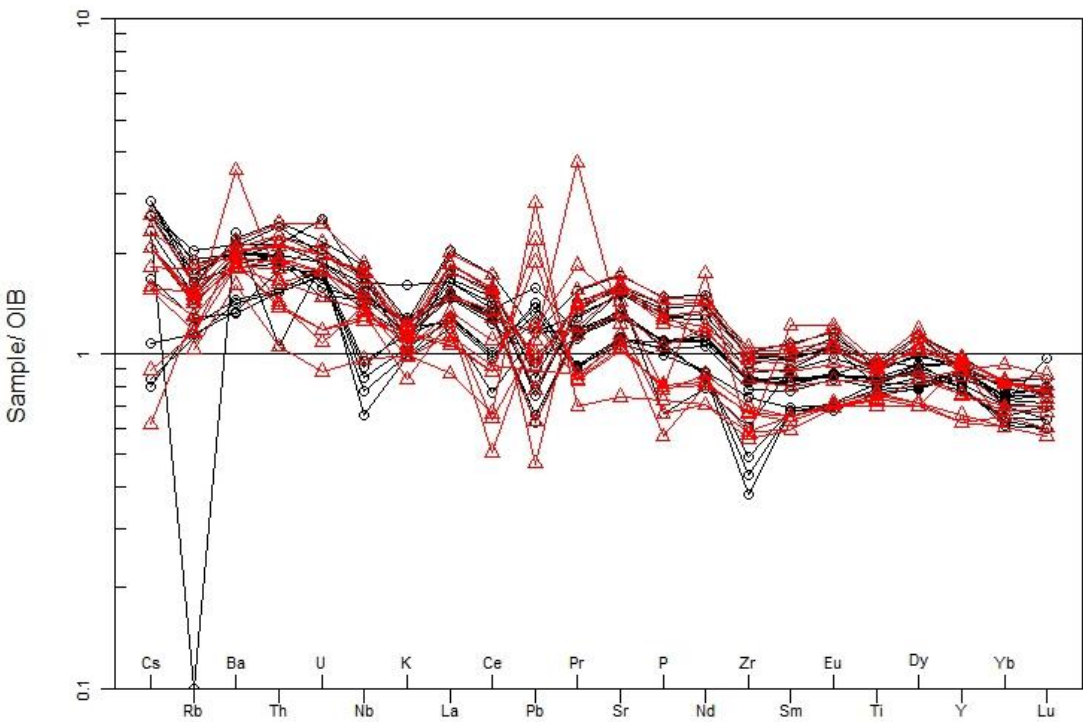


Figure 8. Spider graph plot of incompatible element compositions of basaltic rocks from the Kerang twin volcanoes normalized to OIB. Normalizing data from Sun and McDonough, (1989).

The Kerang twin basaltic rocks are enriched in these elements: Sr, K, Rb, Ba, Th, U, Ta, and Ce, relative to MORB (1–50X). Y and Yb (<1X) are depleted relative to MORB. They display similar spectra relative to OIB with slight enrichment of Cs, Rb, Ba, Th, U, K, La, Ce, and Sr with marked negative anomalies in Nb, Pb, and Zr (Fig. 7). Thorium seems to be excessively high (up to 60X MORB). They show subparallel patterns when normalized to Ocean Island Basalt (OIB), suggesting a similar origin with OIB (Fig. 8).

The ratios of highly incompatible elements such as: La/Nb; Zr/Nb; Ba/La; Ba/Nb are often used to characterize the petrological affinities and tectonic settings of volcanic rocks based on their relatively

immobile nature (Coulon et al., 1996; Eby, 1990, 1992; Hart, 1970; Meschede, 1986; Pearce and Cann, 1973; Pearce and Norry, 1979; Thompson, 1974; Winchester and Floyd, 1979). The basaltic rocks from the Kerang twin volcanoes present incompatible element ratios of Zr/Nb, Ba/La, Ba/Nb, and La/Nb varying from 3.19–12.35; 10.21–26.93; 8.47–10.23; 0.76–0.85 respectively (Tables 3 & 4). These ratios are comparable to those from Normal-Mid Oceanic Ridge Basalt, continental basalts, alkaline magmatism, tholeiitic magmatism, and HIMU (Table 5), suggesting the derivation of the Kerang twin basaltic rocks from a common source that was highly enriched in these incompatible elements relative to MORB.

Table 5. Comparison of incompatible element ratios of basaltic rocks from Kerang twin volcanoes and N-MORB, continental basalts, alkaline magmatism (of upper and lower Benue Trough), basalts of the Cameroun volcanic line, Liberia and OIB (modified from Baundin, 1991)

	La/Nb	Zr/Nb	Ba/La	Ba/Nb
N-MORB	1,07	30,0	4,0	4,3
CONTINENTAL BASALT	2,20	16,2	25,0	54
ALKALINE MAGMATISM (BENUE)	(0,67)(0,72)	5,4	(12,0)	(8,0)
Alkaline U. Benue(11)		6,2	9,9	7,4
Alkaline L. Benue(8)	(0,60)	(4,4)	14,8	8,8
Jos Plateau (Kerang)	0.76-0.83	3.20–3.47	10.24–12.85	8.51-9.91
THOLEIITIC MAGMATISM (BENUE)				
Transitional tholeiitic U. Benue (3)	0,89 0,94	8,8 9,1	18,7 16,2	16,6 15,3
Tholeiitic L. Benue(6)	0,87	8,7	20,2	17,3
Cameroun (15)	(0,64-1)	(2,9-6,7)	(6,7-14,2)	(5,5-15,6)
LIBERIA Continental Tholeiites (10)	1,42-2,40		(13,4-18,7)	20-45
HIMUOIB				
StHelene	(0,69)	4,5	8,7	5,9
Tubuall	(0,72)	(3,2)	6,9	4,9
Raivava	0,66	4,2	8,3	5,4

EMIOIB				
Walvis Ridge (H.525A)	1,90	11,4	14,9	17,7
Walvis Ridge (H.530A)	(0,64)	5,9	8,8	5,6
Gough	0,97	6,8	16,6	16,1
Tristande Cunha	0,86	4,2	13,2	11,4
EMIIIOIB				
Samoa, Tutuiia	0,89	7,3	8,3	7,3
Samoa, Upolu	1,09	4,5	(10,4)	11,0
Tahaa, Societe	0,97	6,5	(11,3)	10,9

4.1.2 Tectonic setting of Kerang Volcanoes

To be able to decipher the tectonic setting in which the Kerang twin volcanoes were emplaced, the Zr, and Y composition of the rocks were plotted in discrimination diagrams of Pearce and Norry, (1979). The rocks fall in the ‘within plates’ domain, indicating that the basalts are emplaced within the

continental tectonic setting (Fig. 9). The same was obtained in the ternary diagram plot of Meschede, (1986) using Zr – Nb – Y composition of the rocks (Fig. 10). All the basaltic rocks from the Kerang volcanoes, plotted in ‘within plates’ alkaline basalts field with one sample showing tholeiitic affinity.

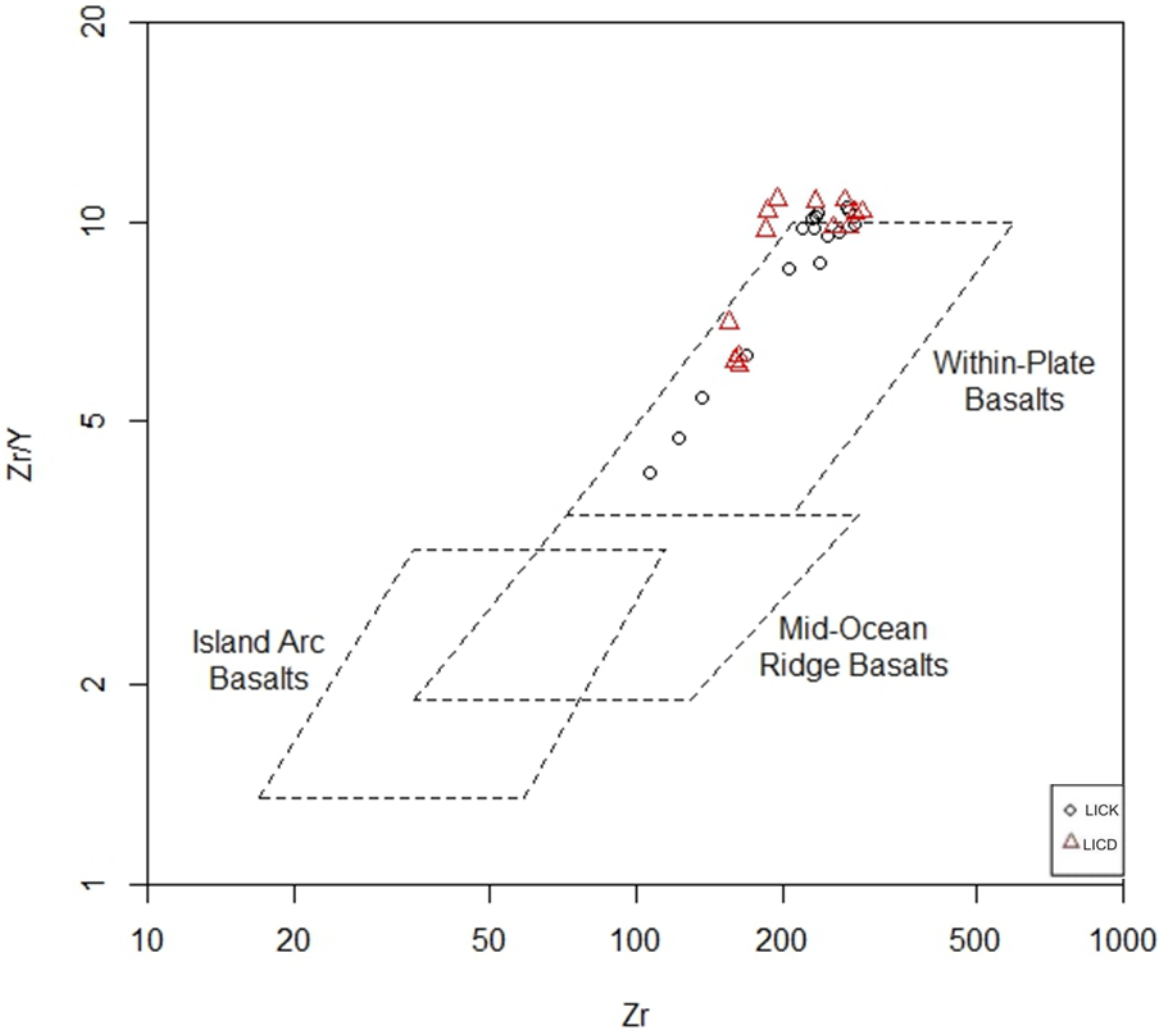


Figure 9. The plot of Zr (ppm) versus Zr/Y (ppm) discrimination diagram for the Kerang basaltic rocks (After Pearce and Norry,1979).

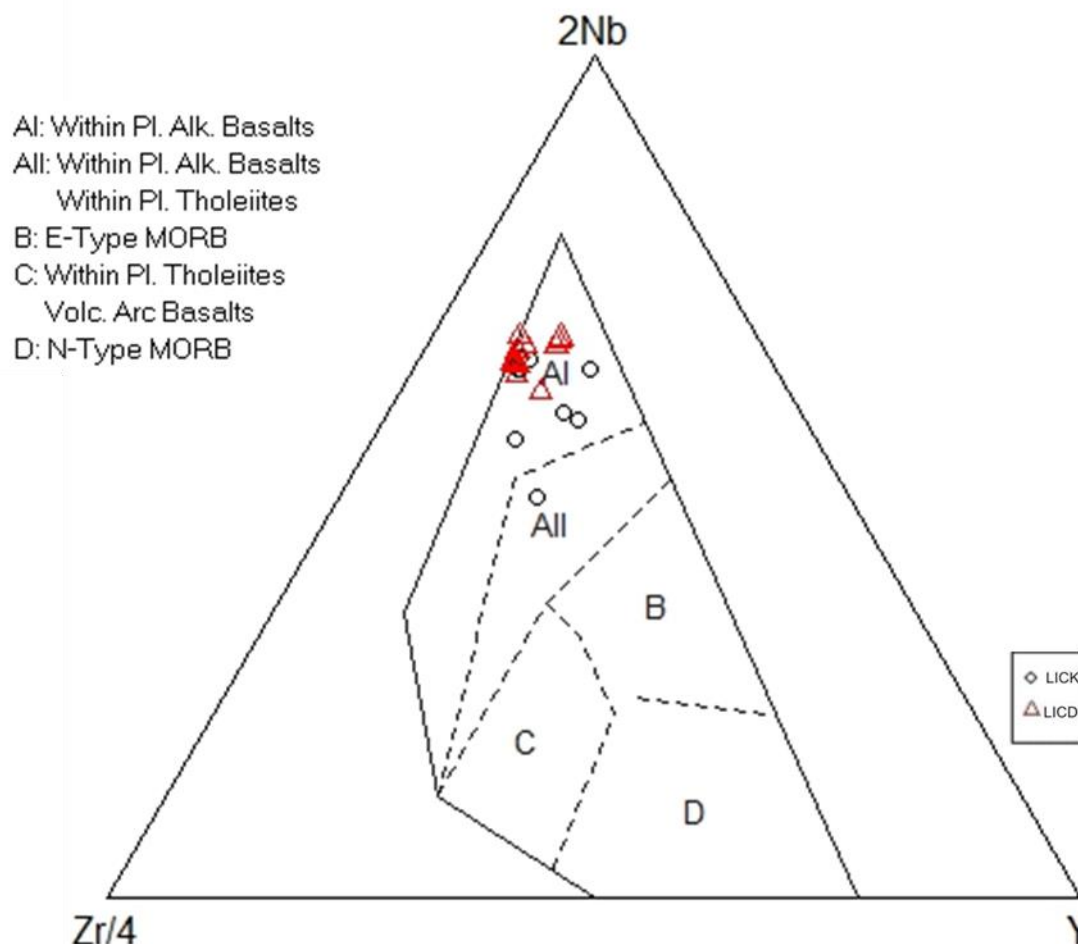


Figure 10. Plots of 2X Nb (ppm) – Zr/4 (ppm) – Y (ppm) Ternary Diagrams after Meschede, (1986) for the Kerang Basaltic Rocks.

5. DISCUSSION

5.1. Process of formation of the Kerang twin volcanoes

The concentrations of the incompatible trace elements; Cr, V, and Ni, of the Kerang volcanoes, show a progressive increase with a decrease in Mg#. This variation is controlled by partial melting at great depth yielding silica undersaturated basaltic rocks. On the spidergraph chondrite normalized incompatible elements plots of the Kerang twin volcanoes (Figs. 6–8), all the basaltic rocks of the Kerang twin volcanoes show similar patterns with clear enrichment in their LILE, such as Nb, Ta, Ti, Rb, Ba ($\geq 100\times$ chondrite), and HFSE, such as Sr, Ta, Zr, Hf, Y, Yb ($\geq 10\times$ chondrites) relative to chondrites respectively. The heat-producing elements (U and Th) are also highly enriched ($>10\text{--}80\times$ chondrite) relative to chondrites. These characteristic features are typical of most alkaline-rich basaltic suites formed from a deeper mantle source that has been influenced by partial melting similar to OIB (Irving

and Price, 1981; Kerr et al., 2019; Pearce, 1983; Thompson, 1982; Sun et al., 1980) as opposed to MORB that is depleted.

Similarly, the spidergraph plot of incompatible element compositions of the basalts of the Kerang volcanoes was normalized to MORB and OIB (normalizing data after Pearce, 1983 and Sun & McDonough 1989). The rocks display similar enrichment patterns in their LILE (10–50X MORB; Figs. 7 & 8) relative to HSFE (2–8X MORB) which are usually depleted in incompatible elements. The ‘humped’ shape pattern displayed by the Kerang twin volcanoes are typical pattern within plate alkaline basalts from either a continental or oceanic setting (Kerr et al., 2019; Wood et al., 1979; Wood, 1980; Yan et al., 2008; Rollinson, 1993; Pearce, 1983; Sun & McDonough 1989). High concentrations of incompatible elements have been suggested to result from a deeper mantle source that has undergone a small degree of melting (Hanson, 1980; Langmuir and Hanson,

1980; Rollinson, 1993; Smellie, 1987; Yan et al., 2008). All of these mentioned geochemical features exhibited by the basaltic rocks of Kerang twin volcanoes imply that they were derived from a deep mantle source which is enriched in incompatible elements with partial melting playing an important role in their evolution.

5.2 Tectonic setting of the Kerang twin volcanoes

Major and trace element geochemistry of basalts from different tectonic environments have been examined by many researchers and a diverse collection of discriminant diagrams has evolved. Most of these are based on relatively immobile trace elements such as Ti, Zr, Nb, Y, Ta, and Th (Meschede, 1986; Pearce and Cann, 1973; Pearce and Norry, 1979; Winchester and Floyd, 1979; Wood, 1980). These highly immobile elements are often preserved and considered not to be affected by changes in the magma chamber or during weathering. As such, they are used to characterize petrological affinities and tectonic settings of volcanic rocks (Eby, 1990, 1992; Hart, 1970; Pearce and Cann, 1973; Meschede, 1986; Thompson, 1974; Wang et al., 2001; Wood, 1980). Standard tectonic discrimination diagrams were used to deduce the tectonic setting of the basalts from the Kerang twin volcanoes. Using the discrimination diagram plots of Pearce and Norry, 1979 and Meschede, (1986); the basalts of the Kerang twin volcanoes display characteristic features of within-plate alkaline basalts. This is similar to the basalts of the Upper Benue Trough and Jos Plateau volcanoes (Adekeye and Ntekim, 2007; Ebinger and Sleep, 1998; Eby, 1990 & 1992; Lar and Tsalha, 2005).

In the diagram designed to discriminate between A I & A II groups of anorogenic magmas, the basalts of the Kerang volcanoes plotted in the A I group (Fig. 10) which is typical of A-type “within-plate alkaline basalts” of undeformed volcanic suites (Eby, 1992; Middlemost, 1986; McKenzie and Onions, 1991; Smellie, 1987; Whalen et al., 1987). Furthermore, the display of ‘humped’/‘domed’ shaped patterns (Figs. 6 & 7) by the Kerang twin volcanoes, are typical characteristics of intra-plate alkaline basalts (Thompson, 1982; Sun et al., 1980; Wood, 1980). The implication of the displayed features by the Kerang basaltic rocks is that they are emplaced within a continental environment/tectonic setting.

6. Conclusion

The Kerang twin volcanoes are basalts which extruded the Precambrian basement migmatite-gneiss and Pan-African biotite granites. They belong to the alkaline magma series. Their geochemical signatures revealed that they must have been formed through the partial melting of materials from a deep mantle source enriched in incompatible elements akin to MORB but comparable to OIB. Also, trace element compositions of these basaltic rocks suggest that they were emplaced within the continental crust along major NW–SE lineament within the pre-existing basement complex rocks.

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