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Geochemistry and Petrogenesis of Evolved Lavas from Wainama East (S. E. Mount Oku Flank, CVL)

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Abstract- The Wainama East lavas are an integral part of the Mount Oku, which belong to the continental domain of the Cameroon Volcanic Line (CVL). The Wainama East evolved lava includes; basanite, basalt, mugearite and rhyolite with fluidal and flow banding. The lavas are alkaline in nature corroborated by high ratios of $(Ce/Yb)_N$=4.341 and $(La/Yb)_N$=11.457. These lavas also present weak to strong positive anomalies in europium. The La/Nb ratios of the Wainama East lavas range from 0.69-0.94 which is closer to OIB with EM1 and EM2 signatures. The Wainama East lava originates from the partial melting of a garnet peridotite at a rate of 1-2% in a volcanic intraplate context. Discrimination diagrams indicate an intraplate volcanic setting of these lavas.

Keywords- *Wainama, Oku, CVL, Partial Melting, Evolved Lava*

I. INTRODUCTION

Active Volcanism in Cameroon occurs along the prominent Cameroon Volcanic Line (CVL). The CVL is a 1600 km Y-shaped chain dated tertiary to recent, consisting generally of alkaline volcanoes that extend more than 900 km across Cameroon from the Biu and Ngaoundere (Adamawa) plateaus to Mount Cameroon and Equatorial Guinea in the gulf of Guinea (Fitton, 1987; Déruelle et al., 1991, 2007; Nkouathio et al., 2002, 2008; Itiga et al., 2004; Fosso et al., 2005, Njome and DeWit., 2014). It continues further seaward about 700 km through the Atlantic island of Principe, Sao Tome and Pagalù (Emilo et al., 2004). The continental sector is made up of massifs amongst which are: Mount Cameroon, Mount Kupe, Mount Manengouba, Mount Bambouto, Mount Bamenda and Mount Oku (Figure 1)

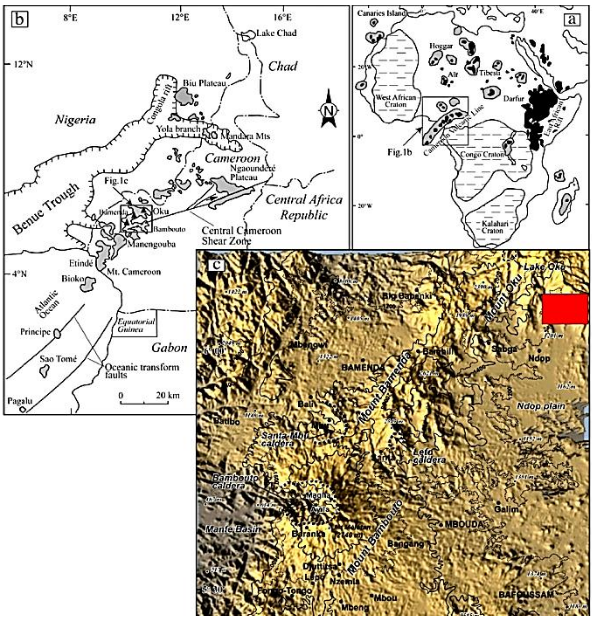

Figure 1. (a) Location map of the Cameroon Volcanic Line (CVL); the main geologic features of Africa are indicated. (b) The main volcanic centers of the Cameroon Volcanic Line. Central Cameroon Shear Zone according to Ngako et al. (2006); fracture zones following Lee et al. (1994) and Ballentine et al. (1997). (c) Digital elevation model (DEM) of the Cameroon Western Highlands (CWH) Modified from Gountie Dedzo et al. (2011). The red rectangle marks the study area.

(Fitton, 1987; Halliday et al., 1990; Marzoli et al., 1999, 2000; Ngounouno et al., 2000; Ngounouno et al., 2000). Lavas from Lake Oku have lower alkali, higher TiO2 and more depletion and enrichment in most incompatible trace elements.

This lava indicates the involvement of at least three mantle components: depleted mid-ocean ridge basalt mantle, high-μ and EM1 components in the magmatism of the Lake Oku lavas (Asaah et al., 2015).

Wainama East is situated at the SE flank of Mount Oku which is the highest Mountain on the Cameroon Western Highlands (CWH) (Figure 1). Most works have been centered on the central part of Mount Oku (Njilah, 1991; Njilah et al., 2007, 2008, 2013; Asaah, 2015). This paper focuses on: geochemical characterization, interpretation of petrogenetic processes and nature of the source and degree of melting in this area using geochemical data. This work will complement the already existing data on the Oku massif which shall further throw more light on the understanding of the volcanism along the CVL.

II. GEOLOGICAL SETTING

The Wainama East area (06°03′-06°05′N and 10°34′-10°35′E) lies at the South eastern flank of Mount Oku, which is one of the edifices of the Oku Volcanic Group (OVG). Mount Oku is a complex stratovolcano rising to a height of 3011m above sea level. About 2000m of lava pile have erupted here ranging from basalt through hawaite, mugearite to trachyte-rhyolites, high level intrusions and intercalated pyroclastics (Njilah, 1991; Njilah et al., 2007). Magmatic activity on this Mountain extends from 31My to present (Njilah, 1991). Ancient lava of Mount Oku forms a bipolar series with alkaline basalt on the one hand, trachyte and rhyolite on the other hand. Recent volcanism formed craters and partially scoria cones, comprising many lakes like the Nyos, and Oku (Nana, 1991; Asaah et al., 2015). According to Marzoli et al. (1999), the oldest (24.79±0.11My) felsic volcanism in the WCH occurred at Mount Oku. The enriched geochemical signatures (EM) of the Oku magmas do not result from crustal assimilation during magma ascent. Rather, they are thought to be derived from a sub-continental lithospheric mantle enriched in incompatible trace elements by ancient metasomatic processes (Njilah et al., 2013). Beneath the Mount Oku, there is the existence of more than one magma chamber proven by chemical analyses of morphological and chemically zoned clinopyroxene (Njilah et al., 2008).

III. ANALYTICAL TECHNIQUE

Ten and twenty one representative rock samples selected from the study area were sent to the Geotech Lab Canada for thin section and to the ACME analytical laboratories Ltd., Vancouver (Canada) (www.acmelab.com) for geochemical analysis respectively. For geochemical analysis, samples were pulverized to obtain homogenous samples. After crushing and milling, samples were split and 50-60 g of samples was obtained for the analyses. Whole rock analyses for major and trace elements were done by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). 0.2g of rock powder was fused with 1.5g $LiBO_2$ and then dissolved in 100 mm 35% HNO_3. The REE contents were determined by ICP-AES from pulps after 0.25 g rock-powder was dissolved with 4 acid digestions. Analytical uncertainties vary from 0.1% to 0.04% for major elements; from 0.1% to 0.5% for trace elements; and from 0.01 to 0.5ppm for rare earth elements. Loss on ignition (LOI) was determined by weight difference after ignition at 1000˚C. Petrographic analysis was carried on thin sections using the petrographic light microscope at the Geology Laboratory HTTC of the University of Bamenda

IV. RESULTS AND DISCUSSIONS

A. Petrography

Basanite; it displays a porphyritic microlitic texture. The constituent minerals in this rock are: Plagioclase (60 vol.%); they exist as laths and are haphazardly distributed in the rock; some occur as isolated crystals, while some occur in cluster. They are euhedral and show a polysynthetic twinning (Figure 2C). Pyroxene (20 vol.%); occur both as phenocrysts and microcrysts in the groundmass, crystals are subhedral to euhedral while others are anhedral in shape. The phenocrysts are randomly distributed on the rock. They mostly occur as isolated crystals and some show zoning. Olivine (15 vol.%); it presents a high relief, enclosing some minor opaque minerals. It is sometimes associated with pyroxene crystals. They exist both as phenocrysts (Figure 2D) and microcrysts in the groundmass. Opaque minerals (3 vol.%); they are mostly rounded in shape and occur as inclusions in some phenocrysts and in the groundmass. Glass (2 vol.%) is well represented in the rock.

Basalt; shows a porphyritic microlitic texture with phenocrysts of Plagioclase and pyroxene. This rock is made up of the following minerals: Plagioclase (60 vol.%); they exist both as phenocrysts and microlites in the groundmass (Figures2G & H). Some large crystals are seen to enclose a portion of the groundmass. The larger phenocrysts occur sometimes in clusters. They show polysynthetic twinning with a porphyritic texture. Olivine (20 vol.%); some phenocrysts are surrounded by plagioclase microlites in a groundmass. They are mostly subhedral in shape and display irregular cracks. Some are almost entirely altered (forming a reaction ring) to Iddingsite (Figure 2G). Pyroxene (15 vol.%); they occur mostly in groundmass. They show simple twinning with some having inclusions of plagioclases. Opaque minerals (4 vol.%); they occur mostly in the groundmass and as inclusions in plagioclases. They have irregular shapes; some are rounded while some are elongated. They are haphazardly distributed within the entire rock. Glass (1 vol. %) is poorly represented.

Mugearite; it presents a doleritic texture, the constituent minerals in this rock are: Plagioclases (65 vol.%); they are preferentially oriented indicating direction of lava flow. Pyroxenes (15 vol. %); they are randomly distributed with some occurring in clusters. Olivine (10 vol.%); it is mostly anhedral in shape and randomly distributed in the groundmass. Opaque minerals (4 vol.%); they are randomly distributed in the rock mass and also occur as inclusions in pyroxene phenocrysts (Figure 2L). Amphibole (2vol. %); occur in the groundmass as microcryst. Glass represents about 3 vol. % of volume of the rock.

Rhyolite; It has a microlitic texture with some porphyries of sanidine. The principal minerals in the rock are: Sanidine (60 vol.%); are subhedral and euhedral in shape with some showing Carlsbad twinning (Figure 2P). Quartz (20 vol. %); they are mostly anhedral in shape and exist as phenocrysts. Plagioclase (10 vol. %); they are elongated and show simple twinning. Opaque mineral (8 vol. %); they occur in ground mass having irregular shapes. Glass constitutes about 2 vol. % of the rock volume.

Figure 2. Photographs and photomicrographs of rocks from the Wainama East area; (A-D) basanite, (E-H) basalt, (I-L) mugearite and (M-P) rhyolite

The different rock formations in the Wainama East area are illustrated on the geologic map (Figure 3)

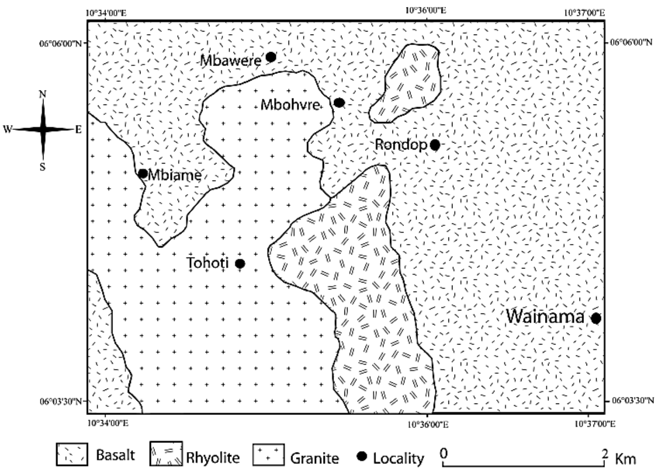

Figure 3. Geologic map of the Wainama East

B. Geochemistry

According to the total alkali-silica (TAS) classification of Le Bas et al. (1986) (Figure 4) the volcanic rocks of the Wainama East area belong to basanite, basalt and mugearite showing a range in the SiO_2 contents from 43 to 51 wt.%. They are under saturated (0.63 to 4.04 wt. % normative nepheline for basalt and mugearite; 0.58 to 1.03 wt.% normative hypersthene for basanite) and alkaline sodic (Na_2O/K_2O=2.14-2.36). The Mg-number values (Mg#=100∗MgO/ (MgO+FeO), atomic ratio, assuming that Fe_2O_3/FeO=0.15) lie between 30.54 and 54.18, and mostly correlate with major element (Table 1).

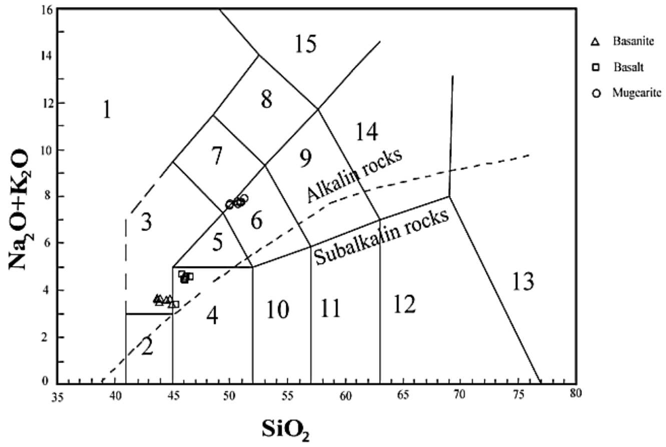

Figure 4. Nomenclature of the lavas of Wainama East in the diagram of TAS (Le Bas et al., 1986). The curve with the broken lines is the limit of Irvine and Baragar, (1971) separating the alkaline series from the subalkaline series. The different domains are: 1=Nephelinite or melilitite; 2=Picrobasalt; 3=Basanite if Ol>10% and Tephrite if Ol<10%; 4=basalt; 5=hawaite; 6=mugearite; 7=Phonotephrite; 8=Tephriphonolite; 9=Benmorite; 10=Andesitic Basalt; 11=Andesite; 12=Dacite; 13=Rhyolite; 14=Trachyte; 15=Phonolite.

1) Major elements

The major elements variation versus MgO present two tendencies: a progressive reduction from basanite to mugearite in CaO (4.76 to 10.7 wt.%), Fe_2O_3 (11.50 to 13.40 wt.%) and TiO_2 (1.96 to 3.32 wt.%). This global evolution can be explained by the incorporation of CaO during the fractionation of clinopyroxenes and Fe_2O_3 in the olivines. The decreasing TiO_2 in basalt and mugearite indicates fractionation of Ti-bearing oxide content, correlated with an increase concentration of Al_2O_3 (13.15 to 16.35 wt.%), Na_2O (2.29 to 5.52 wt.%), K_2O (1.06 to 2.38 wt.%), P_2O_5 (0.45 to 1.18 wt.%) and SiO_2 (44.3 to 51.10 wt.%) of lavas (figure 5). Again, the quick decrease of Al_2O_3 in mugearite points to plagioclase fractionation.

TABLE I. MAJOR ELEMENTS DATA AND THE CIPW NORM FOR LAVAS FROM WAINAMA EAST AREA

	Basanite							Basalt							Mugearite						
Sample	JP071	JP072	JP073	JP074	JP075	JP076	JP077	JP031	JP032	JP033	JP034	JP035	JP036	JP037	JP021	JP022	JP023	JP024	JP025	JP026	JP027
SiO_2	43.90	44.70	44.30	45.20	43.80	43.70	44.90	46.30	46.40	46.10	46.30	46.00	46.40	46.10	50.70	50.60	50.60	50.80	50.00	49.90	51.10
TiO_2	3.23	3.25	3.24	3.32	3.23	3.29	3.28	2.80	2.83	2.81	2.82	2.79	2.81	2.80	1.99	2.00	1.99	2.00	1.97	1.96	1.99
Al_2O_3	13.45	13.15	13.25	13.45	13.15	13.65	13.45	15.60	15.65	15.60	15.60	15.50	15.55	15.50	16.35	16.25	16.30	16.35	16.20	16.05	16.35
Fe_2O_3	1.72	1.67	1.75	1.77	1.74	1.74	1.76	1.62	1.63	1.60	1.62	1.61	1.63	1.61	1.53	1.55	1.54	1.54	1.55	1.52	1.58
FeO	11.45	11.15	11.67	11.81	11.59	11.59	11.72	10.79	10.88	10.66	10.79	10.71	10.84	10.71	10.22	10.35	10.26	10.26	10.31	10.13	10.53
Fe_2O_3t	14.45	14.06	14.73	14.89	14.61	14.61	14.78	13.61	13.73	13.45	13.61	13.50	13.67	13.50	12.89	13.06	12.95	12.95	13.00	12.78	13.28
FeOt	13.00	12.65	13.25	13.40	13.15	13.15	13.30	12.25	12.35	12.10	12.25	12.15	12.30	12.15	11.60	11.75	11.65	11.65	11.70	11.50	11.95
MnO	0.18	0.18	0.18	0.18	0.17	0.19	0.18	0.18	0.19	0.18	0.19	0.18	0.18	0.18	0.21	0.22	0.21	0.21	0.20	0.21	0.21
MgO	8.50	8.60	8.81	9.41	8.84	8.51	9.25	5.81	5.85	5.83	5.87	5.78	5.82	5.80	3.14	3.13	3.15	3.16	3.12	3.08	3.12
CaO	10.00	9.94	10.15	10.15	10.10	10.70	10.10	8.56	8.66	8.60	8.62	8.56	8.60	8.60	4.85	4.81	4.92	4.85	4.79	4.76	4.76
Na_2O	2.50	2.51	2.48	2.29	2.42	2.46	2.31	3.17	3.14	3.12	3.15	3.12	3.16	3.14	5.43	5.42	5.34	5.45	5.38	5.33	5.52
K_2O	1.08	1.08	1.07	1.07	1.06	1.13	1.07	1.41	1.41	1.40	1.40	1.39	1.41	1.39	2.32	2.32	2.37	2.31	2.30	2.28	2.38
P_2O_5	0.46	0.47	0.45	0.45	0.44	0.46	0.45	0.78	0.77	0.75	0.76	0.76	0.77	0.77	1.12	1.15	1.14	1.13	1.12	1.12	1.18
LOI	1.57	1.48	1.57	1.39	1.77	1.77	1.47	1.63	1.78	1.76	1.82	1.62	1.58	1.66	1.81	1.77	1.79	1.89	1.96	1.82	1.93
TOTAL	99.3	99.4	100.2	101.8	99.6	100.5	101.2	99.9	100.4	99.6	100.1	99.2	99.9	99.4	100.8	100.7	100.8	101.1	100.0	99.3	101.8
CIPW Norm																					
Orthose	6.62	6.60	6.50	6.38	6.49	6.86	6.42	8.59	8.55	8.56	8.52	8.52	8.58	8.50	14.01	14.02	14.32	13.92	14.02	13.99	14.25
Albite	17.53	19.85	17.26	18.38	16.78	13.91	18.26	27.65	27.28	27.32	27.44	27.39	27.52	27.51	41.82	41.91	41.34	41.96	41.24	42.00	41.96
Anorthite	23.10	22.16	22.46	23.47	22.67	23.47	23.53	24.91	25.09	25.27	25.01	25.09	24.78	24.94	13.68	13.45	13.81	13.59	13.68	13.63	12.97
Nepheline	2.38	1.15	2.33	0.63	2.40	4.04	0.86	-	-	-	-	-	-	-	2.78	2.70	2.63	2.75	3.10	2.61	2.90
Diopside	20.60	20.95	21.45	19.88	21.44	22.84	19.88	11.25	11.45	11.40	11.49	11.42	11.53	11.59	2.90	2.76	2.98	2.89	2.78	2.77	2.66
Hypersthene	-	-	-	-	-	-	-	0.73	0.75	0.78	0.58	1.03	0.97	0.79	-	-	-	-	-	-	-
Olivine	19.72	19.29	20.02	21.25	20.19	18.79	21.07	17.12	17.11	16.95	17.21	16.81	16.87	16.90	16.03	16.26	16.08	16.08	16.33	16.16	16.35
Magnetite	2.58	2.51	2.61	2.59	2.61	2.59	2.59	2.42	2.43	2.40	2.42	2.42	2.43	2.41	2.27	2.30	2.28	2.28	2.31	2.29	2.32
Ilmenite	6.36	6.38	6.32	6.36	6.35	6.41	6.33	5.48	5.52	5.52	5.51	5.50	5.49	5.51	3.86	3.88	3.86	3.87	3.86	3.86	3.83
Apatite	1.10	1.13	1.07	1.05	1.06	1.09	1.06	1.86	1.83	1.80	1.81	1.83	1.84	1.85	2.65	2.72	2.70	2.67	2.68	2.69	2.77
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Norm Pl	51.80	50.45	51.51	54.70	52.18	53.21	54.44	47.40	47.92	48.06	47.68	47.81	47.38	47.56	22.75	22.47	23.19	22.60	22.77	22.73	21.70
DI	26.53	27.60	26.08	25.40	25.67	24.81	25.54	36.24	35.83	35.88	35.96	35.91	36.10	36.01	58.61	58.63	58.28	58.62	58.36	58.59	59.11
Mg#	52.40	53.37	52.82	54.18	53.09	52.15	53.94	44.40	44.37	44.79	44.65	44.48	44.34	44.56	31.31	30.96	31.28	31.35	30.99	31.08	30.54

Mg#=100∗(MgO/40.31)/(MgO/40.31)+Fe_2O_3∗0.8998/(71.85∗(1–0.15), assuming $Fe_2O_3/(Fe_2O_3+FeO)=0.15$. Recalculated to 100% anhydrous; Total iron is expressed as Fe_2O_3; LOI: Loss on ignition

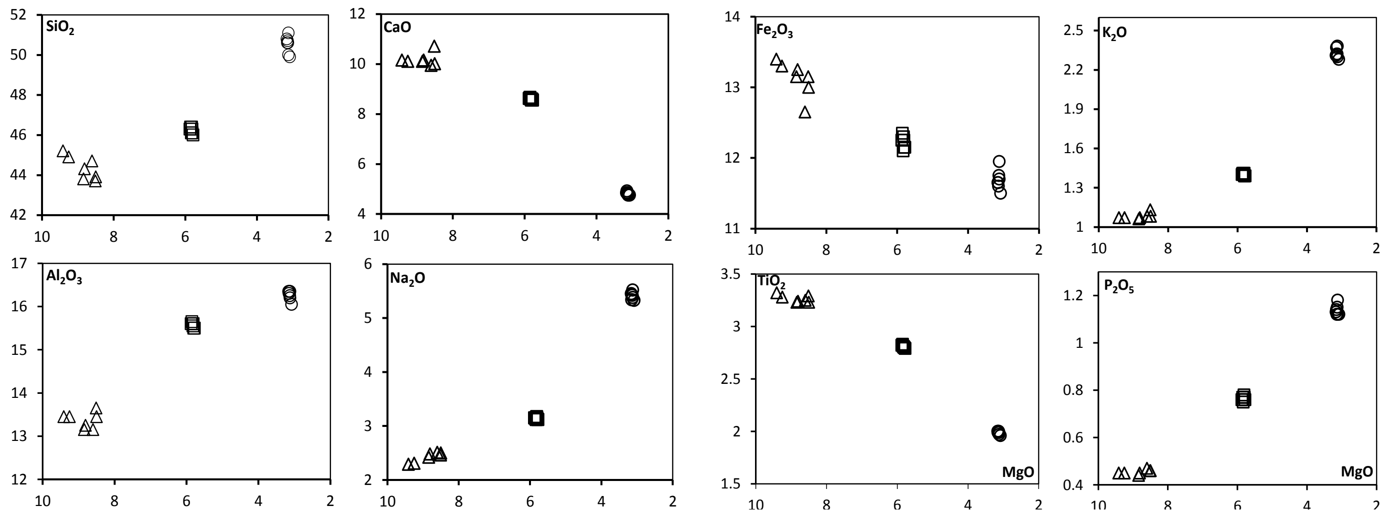

Figure 5. Major element variation diagram for the lavas of Wainama East area

The alkaline series of the intraplate is characterized by their TiO_2, K_2O and P_2O_5 contents which are high (Zayane et al., 2002), the basic and intermediate lavas of Wainama East have TiO_2, K_2O and P_2O_5 contents which are high. A comparative study of the incompatible elements, alkaline and potassium oxide was realized between the transitional lavas and the alkaline lavas of Kerguelen (Giret et al., 2003). The comparison of these results with those of Wainama East suggests that the later are alkaline. The curve with the broken lines of Irvine et Baragar (1971) that separates the alkaline series from the sub alkaline series confirms this affinity (Fig. 4). These lavas are of nepheline normative, mugearite (0.63<ne<4.04) and basalt (2.61<ne<3.10) except in Basanite where nepheline is absent. Meanwhile, basanite are characterized by weak hypersthene content (0.58-1.03), contrary to the other lavas.

In the minor element (Table 2), variation diagrams (Fig. 6), the sudden decrease of Cr in basanite points to Mg-Fe phase fractionation. Vanadium decreases in basalt and mugearite, like titanium, indicating an oxide fractionation. Strontium exhibits a narrow range of contents betraying the homogeneity of the Wainama East lavas.

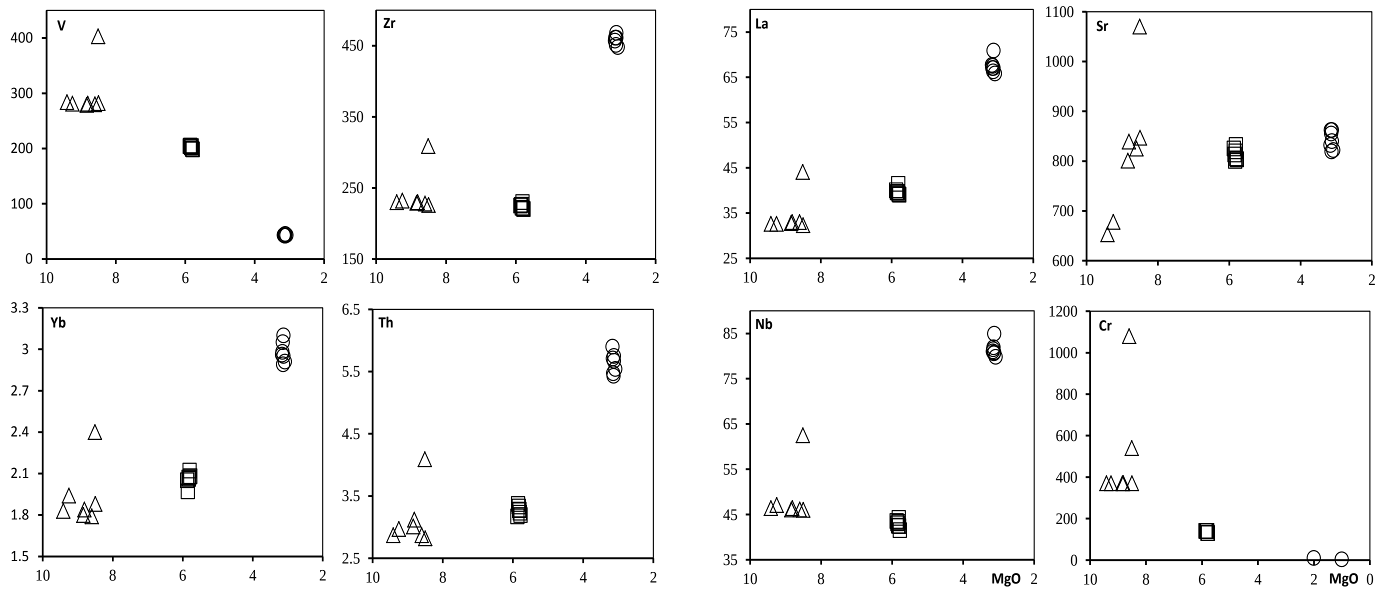

Figure 6. Trace element variation diagrams of Wainama East lavas plotted against MgO

TABLE II. TRACE ELEMENTS DATA FOR LAVAS FROM WAINAMA EAST AREA

	Basanite							Basalt							Mugearite						
Samples	JP071	JP072	JP073	JP074	JP075	JP076	JP077	JP031	JP032	JP033	JP034	JP035	JP036	JP037	JP021	JP022	JP023	JP024	JP025	JP026	JP027
Ba	446	384	384	304	316	703	309	1230	1200	1185	1200	1175	1200	1190	667	674	657	656	664	685	739
Ce	71.6	70.8	71.9	71.2	71	95.9	72.2	87.6	86.1	84.2	86.8	83.8	85.9	84.6	142	141.5	142.5	142	140.5	139	148
Cr	370	1080	370	370	370	540	370	140	140	140	140	130	140	130	10	<10	<10	<10	10	<10	10
Cs	0.16	0.13	0.15	0.23	0.19	0.24	0.29	0.46	0.44	0.47	0.47	0.37	0.36	0.4	3.41	4.32	3.33	3.69	3.52	3.72	4.59
Dy	4.95	5.02	4.78	4.94	4.94	6.67	5.03	5.82	5.76	5.76	5.75	5.79	5.72	5.63	8.17	7.85	8.45	8.4	8.32	8.41	8.29
Er	2.31	2.32	2.33	2.18	2.19	2.85	2.11	2.84	2.6	2.88	2.7	2.67	2.75	2.66	3.83	3.64	3.83	3.72	3.63	3.63	4.11
Eu	2.42	2.59	2.41	2.5	2.55	3.31	2.56	4.21	4.23	4.09	4.07	4.1	4.08	4.16	4.00	3.77	4.08	4.03	4.1	3.97	4.4
Ga	20.5	20.3	18	17.9	18.5	24.8	18.9	23.3	23	22.3	22.4	21.9	22.8	22.3	23	22.9	23.6	22.9	23.2	22.9	24.3
Gd	6.61	6.58	6.79	6.8	7.07	9.22	7.19	8.06	8.08	7.8	8.01	7.58	7.96	7.5	11.35	11.35	11.25	11.65	11.1	11.4	11.8
Hf	5.4	5.4	5.7	5.7	5.5	7.5	5.5	5.3	5.3	5.2	5.1	5.2	5	5	10	9.4	9.6	10	9.7	9.4	10
Ho	0.9	0.89	0.92	0.97	0.89	1.22	0.92	1.12	1.06	1.02	1.01	1.01	1.07	1.02	1.46	1.45	1.46	1.51	1.48	1.5	1.45
La	32.3	33	33	32.6	32.8	44.1	32.6	41.4	39.6	39.5	40	39	39.6	39.2	67.5	66.3	67	67.7	67	65.8	70.9
Lu	0.25	0.26	0.27	0.28	0.25	0.33	0.26	0.31	0.31	0.28	0.31	0.28	0.3	0.29	0.42	0.45	0.44	0.41	0.42	0.44	0.45
Nb	46	46.1	46.4	46.4	46.1	62.5	47.1	44.2	43	42.5	43.5	41.5	43.3	42.4	81.9	80.6	81.5	81	80.8	79.8	84.9
Nd	36.8	36.8	37.6	37	37.5	51.3	38.3	47	46.7	46	46.2	44.8	45.7	44.7	71.4	70.7	72.2	70.9	70.3	70.6	73.3
Pr	8.89	8.9	9.03	8.93	8.93	12.15	9.09	11.15	10.8	10.9	10.85	10.55	10.75	10.75	17.3	17.15	17.35	17.3	17.25	16.9	17.95
Rb	21.3	21.5	21.2	21.6	21.2	29.5	22	24.8	24.5	24.6	25.6	23.9	24.7	24.7	57.1	63.4	61.1	56.5	58	57	67.5
Sm	7.7	7.86	7.97	7.68	7.57	10.55	7.98	9.56	10	9.7	9.64	9.61	10	9.39	13.9	13.95	13.85	14.35	14.05	13.9	14.45
Sr	847	825	839	653	801	1070	678	832	813	800	825	803	819	805	855	819	862	832	840	822	862
Ta	2.7	2.8	2.8	2.7	2.8	3.7	2.8	2.7	2.6	2.6	2.6	2.5	2.5	2.5	4.7	4.6	4.8	4.7	4.7	4.6	5
Tb	1.01	0.96	1.01	0.97	0.99	1.31	0.96	1.15	1.13	1.13	1.12	1.13	1.15	1.11	1.67	1.56	1.58	1.71	1.61	1.61	1.63
Th	2.82	2.87	3.12	2.87	3.01	4.09	2.97	3.28	3.37	3.33	3.17	3.19	3.27	3.23	5.47	5.43	5.71	5.9	5.67	5.54	5.75
Tm	0.31	0.28	0.27	0.31	0.32	0.39	0.29	0.36	0.37	0.35	0.35	0.34	0.35	0.36	0.48	0.48	0.48	0.52	0.52	0.49	0.53
U	0.8	0.87	0.88	0.86	0.81	1.19	0.86	0.95	0.99	0.83	0.89	0.9	0.92	0.92	1.61	1.58	1.61	1.65	1.62	1.56	1.57
V	282	280	281	284	279	403	281	204	205	202	204	198	202	199	43	42	43	43	42	43	45
Y	23	22.4	22.4	22.2	22.4	30.5	22.7	27	26.1	25.9	26.3	25.4	25.9	25.9	37.2	36.9	37.4	37.4	37.1	36.7	38.7
Yb	1.88	1.79	1.84	1.83	1.8	2.4	1.94	2.07	1.97	2.07	2.05	2.08	2.06	2.12	3.05	2.89	2.98	2.96	2.95	2.91	3.1
Zr	226	228	230	230	229	309	232	230	226	222	225	220	226	221	461	451	461	457	461	448	468
Eu*/Eu	1.07	1.14	1.04	1.09	1.1	1.06	1.07	1.52	1.49	1.49	1.46	1.52	1.45	1.57	1.01	0.95	1.03	0.99	1.00	1.07	1.04
ΣREEs	177.9	178.1	180.1	178.2	178.8	241.7	181.4	222.7	218.7	215.7	218.9	212.7	217.4	213.5	347	343	347	347	343.2	340.6	360

TABLE III. THE PRINCIPAL CHARACTERISTICS BETWEEN THE BASALT OF WAINAMA EAST AREA AND THE DATAS FROM KERGUELEN (GIRET ET AL., 2003) ARE INDICATED FOR COMPARISON.

	Incompatible elements (Th, Ta, Zr, Hf, Rb, LREEs)	Na2O+K2O (wt.%)	K2O (wt.%)
Transitional tholeiitic Basalt	Averagely enriched	2.5 to 5	<1
Alkali Basalt	Highly enriched	2.5 to 8	>1
Lavas of Wainama west	Highly enriched	3.36-7.9	1.06-2.28

2) Trace and Rare earth elements

On the pattern of REE normalized to Chondrite (Figure 7), there is an enrichment of the LREE (La, Ce, Nd, Sm) compared to the HREE (Gd, Tb, Dy, Ho, Er, Yb, La) with a positive anomaly in Eu. The spectra diagrams of multi-elements of the lavas of Wainama East normalized by the primitive mantle (McDonough, 2003) (Figure 8) are parallel to the spectra diagrams of OIB of Sun and McDonough. (1989). The spectra indicates a negative anomaly in K, Sm, Ti, Sr and a positive anomaly in Ba, Nb, Ta, Zr, Hf, Eu but mugearite presents a positive anomaly in Th and K and a negative anomaly for the rest.

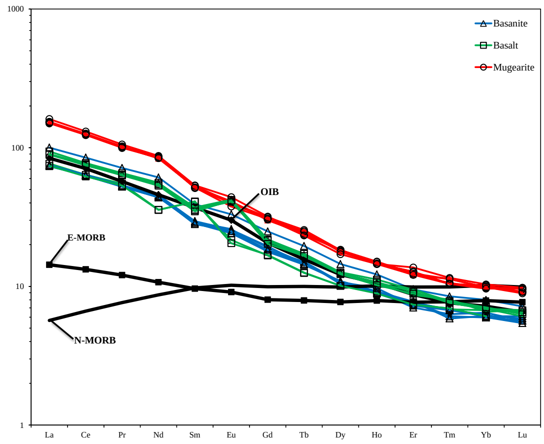

Figure 7. Chondrite normalized rare earth element patterns of basanite, basalt and mugearite of Wainama East (McDonough, 2003). N-MORB, E-MORB and OIB values from Sun and McDonough (1989) for comparison

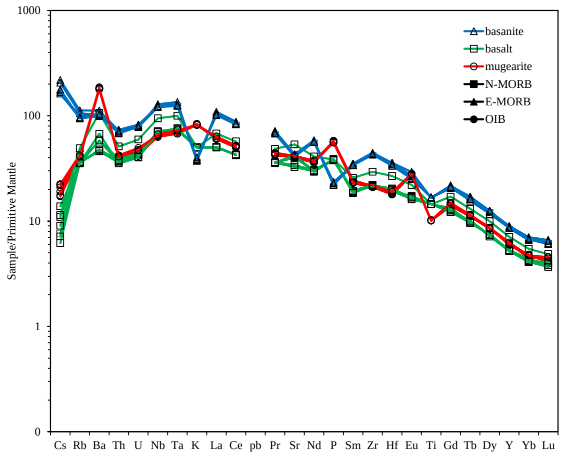

Figure 8. Multi-elements spider diagrams of Basanite, Basalt, and Mugearite of Wainama East normalized with primitive mantle (McDonough, 2003). The data of N-MORB, E-MORB, and OIB are of Sun and McDonough (1989)

The incompatible element signatures are illustrated with the Chondrite-normalized diagrams (Figure 7). The Wainama East lavas display light rare earth element (LREE) enrichment relative to heavy (HREE) with $(La/Yb)_N$ (where the subscript N means Chondrite-normalized) ratios ranging from 11.46 to 15.64 and 178 to 360 rare earth amounts. These variations of the Wainama east lava indicate homogeneity of the primary magma.

Distinct incompatible trace element characteristics of the Wainama lavas include: large variation of total rare earth element (ΣREE) contents (178-360 ppm) and trace element ratios such as Nb/La (1.08-1.44) and Ba/Nb (6.55-28.31). Several other key parameters are: Ba/Nb=6.55-28.31, Nb/U=46.07-57.50, Th/La=0.08-0.09and Zr/Nb=4.91-5.71. All the analyzed samples except JP022 and JP024 show positive europium anomalies (Eu/Eu*=1.00-1.57), In the absence of any cumulus textures and positive correlation between Al_2O_3 and Eu anomaly, we argue that the positive Eu anomalies in these lavas are an original geochemical feature of the melts rather than a result of plagioclase accumulation..

Chondrite-normalized Tb/Yb values (2.30-2.48) are roughly constant among the Wainama East lavas, and overlap values for Mount Cameroon (Yokoyama et al., 2007), Ngaoundéré volcanism (Nkouandou et al., 2008), alkali lavas of Nyos (Aka et al., 2004) and Bamenda mafic lavas (Kamgang et al., 2013). This ratio is a good indicator of residual garnet in the mantle source of the basalts, thus suggesting that Wainama East primary magmas have been formed by melting in the presence of garnet. REE patterns of N-MORB, E-MORB and OIB (Sun and McDonough, 1989) are also illustrated in Figures 7 and 8. All Wainama East samples are above those of N-MORB and E-MORB and strongly similar to that of OIB.

The uni-alignment of the lavas of Wainama East is materialized by a linear correlation and positive of the rocks in the binary diagram, notably Nb/Ta (Figure 9). The representative points are lined up following the same curve of the same slope in the representative diagram of each edifice or the diagram that regroups the three volcanic rocks. This permits us to suggest that the primary magma of Wainama East originate from the partial fusion of a mantellic source, having the same characteristics.

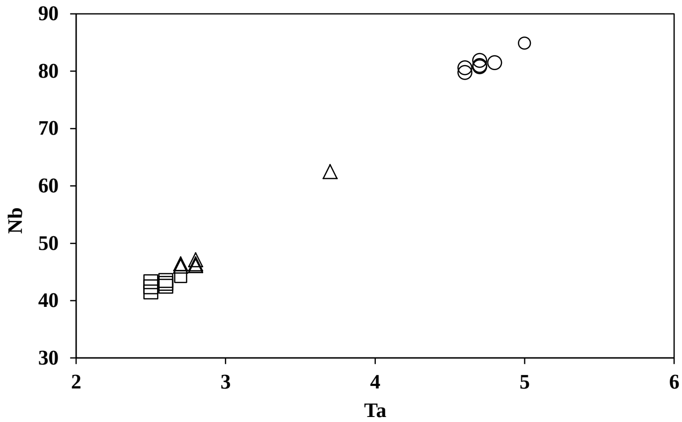

Figure 9. Diagram permitting the identification of the same magmatic alignment

C. Geotectonic context

The lavas of Wainama East are plotted on a series of discriminant diagrams using immobile trace elements to interpret the tectonic setting in which they are formed. Because intraplate ocean island basalt has Ti/Y and Zr/Y ratios, they can be distinguished from MORB and island-arc basalt on the basis of Pearce and Cann (1973), (Figure 10A. On the 2*Nb-Zr/4-Y (Meschede, 1986) triangular diagram (Figure 10B), these discriminate diagrams suggest an intraplate volcanism.

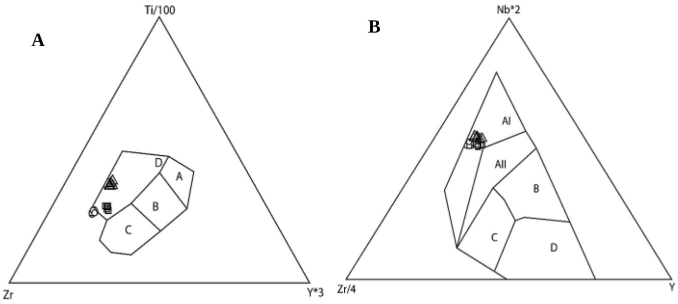

Figure 10. A and B: Discrimination diagrams.(A)Ti/100-Zr-Y*3 Discrimination diagram (Pearce and Cann, 1973). A, Calco-alkali basalt: B, MORB + island – arc Tholeiite + Calco-alkali basalt; C, island-arc Tholeiite; D, within-plate basalt; (B) Nb*2-Zr/4-Y variation diagram (Meschede, 1986). AI, within-plate alkali basalt; AII, within-plate alkali basalt and within-plate Tholeiites; B, E-type MORB; C, within-plate Tholeiites and volcanic-arc basalt; D, N-MORB and volcanic-arc basalt

D. Characterization of the mantle source

The relations of certain trace elements such as Zr/Nb, La/Nb, Ba/Nb, Ba/Th, Rb/Nb, K/Nb, Th/Nb, Th/La, and Ba/La, have distinctive values corresponding to different mantellic sources.These relations provide necessary clues on the components of the mantle source (Weaver, 1991). In this case, the relations of the lavas of Wainama East are listed on table 4 and are in conformity with those of EM1, and EM2, poles of OIB, suggesting that the parent magma of the lavas of Wainama East originates from an enriched mantle source (EM1 and EM2). When comparing the lavas of Wainama East with a few lavas of the CVL, we observe that those of Wainama East have relations that are similar to the lavas of Tombel plain, Mount Bamenda, Mount Manengouba, Mount Bambouto and Mount Oku but it should be noted that the relations Ba/Nb and Ba/Th of Wainama East lavas are higher.

TABLE IV. AVERAGE RATIOS OF INCOMPATIBLE TRACE ELEMENTS OF THE LAVAS OF WAINAMA EAST TO THOSE OF MANENGOUBA, BAMBOUTO AND BAMENDA MOUNTAINS WITH MANTELLIC POLES (OIB, PRIMITIVE MANTLE, E MORB, N MORB, EMI, EMII, AND HIMU). (SUN AND MCDONOUGH, 1989; WEAVER, 1991; KAMGANG, 2003; N`NI, 2004)

Domains	Zr/Nb	La/Nb	Ba/Nb	Ba/Th	Rb/Nb	K/Nb	Th/Nb	Th/La	Ba/La
Chondrite	15.7	0.96	9.8	83	9.4	2215	0.117	0.122	10.16
Primitive Mantle	14.8	0.94	9	77	0.91	323	0.117	0.125	9.6
N MORB	30	1.07	4.3	60	0.36	296	0.071	0.067	4
E MORB	8.8	0.76	6.87	95	0.61	253	0.07	0.1	9.05
CC	16.2	2.2	54	124	4.7	1341	0.44	0.204	25
OIB Average	5.8	0.77	7.3	88	0.64	250	0.083	0.108	9.4
HIMU	3.2-5	0.66-0.77	4.9-6.5	49-77	0.35-0.38	77-179	0.078-0.101	0.107-0.133	6.9-8.7
EMI	4.2-11.4	0.64-1.19	11.4-17.7	103-154	0.88-1.17	204-432	0.105-0.122	0.107-0.128	13.2-16.9
EMII	4.5-7.3	0.89-1.09	7.3-11	67-84	0.59-0.85	248-378	0.111-0.157	0.122-0.163	8.3-11.3
Manengouba	3.48-5.58	0.58-0.89	6.25-8.77	68-164	0.43-0.76	171-237	0.04-0.10	0.07-0.12	………
Bamenda	2.85-4.52	0.66-0.88		84-201	0.46-0.75	124-242	0.06-0.09	0.08-0.12	………
Tombel plain	4-5.3	0.68-0.90	6.2-9.3	68-151	0.34-0.58	145-221	0.056-0.092	0.079-0.125	8.5-12
Mont Bambouto	3.1-5	0.71-0.94	5.2-14.7	77-271	0.42-0.88	95-275	0.066-0.097	0.07-0.119	6.61-19.37
Mount Oku	4.39-4.50	0.72-0.75	6.76-9.32	74.51-116.39	0.48-0.52	185.67-197.49	0.08-0.09	0.10-0.13	9.33-12.07
Wainama East area	4.91-5.71	0.69-0.94	6.55-28.31	104.04-378.55	0.46-0.80	154.01-288.34	0.06-0.08	0.08-0.09	9.33-30.36

E. Condition of the mantle melting

The magmas of the continental basalt are considered as products of the Asthenospheric fusion and adiabatic decompression of anhydrate peridotite of the mantle and formation in relation with the ascending mantle plume (Garfunkel, 2008; Song et al., 2008). The composition of trace elements can be used to determine the nature of fusion of the mantle (Lassiter et al., 1995; Reichow et al., 2005). The samples of the lavas of Wainama East in the diagram of Tb/Yb in function of La/Yb (Figure 11) are close to the fusion curve of garnet peridotite and seem to have been formed by the fusion of the mantle less than 2%. Chatterjee and Bhattacharji (2008) estimated the condition of fusion of the mantle for the Deccan basalt using the variation of the relations Ba/Zr, Rb/Y, and Nb/Y and suggested low to average degrees for fusions between 1 to 20%. Therefore, the lavas of Wainama East have a fusion rate <2%, suggesting a low fusion rate. It should be noted that majority of the samples of mugearite have fusion rates less than 1%. Consequently, lavas of Wainama East originate from the partial fusion of a garnet peridotite (2%-4%) in the mantle at a fusion rate < 2%.

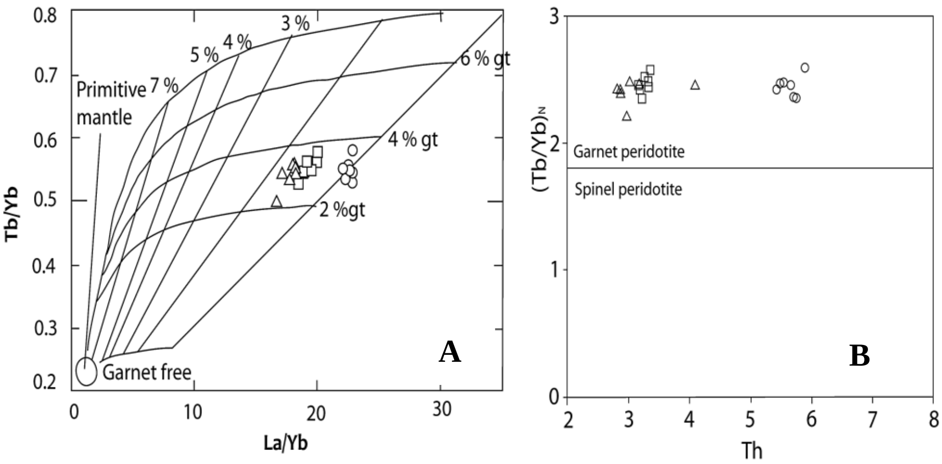

Figure 11. A and B: Variation diagrams.(A)Variation of La/Yb and Tb/Yb of the Wainama East compared with a fractional melting grid using primitive mantle ratios as the source (shown as a large white circle; Sun and McDonough (1989).(B)Primitive mantle normalized $(Tb/Yb)_N$ vs. Th for the Wainama East volcanic rocks (Wang et al., 2002).

V. CONCLUSION

The lavas of Wainama East are; basanite, basalt, mugearite and rhyolite. The mineralogy of the rocks is essentially made up of: plagioclase, olivine, clinopyroxene, amphibole, sanidine, quartz, glass, and opaque minerals. The principal texture of these lavas is porphyritic, with a microlitic, fluidal and flow banding. The geochemistry of these lavas in particular basanite, basalt and mugearite shows that they are alkaline in nature following the comparison with those of Kerguelen (Giret et al., 2003) and are confirmed by the high ratios of $(Ce/Yb)_N$=4.341 and $(La/Yb)_N$=11.457. These lavas are of nepheline normative, mugearite and basalt except in Basanite where nepheline is absent and are characterized by weak hypersthene content. All Wainama East samples are above those of N-MORB and E-MORB and strongly similar to that of OIB

Concerning the origin of the lavas of Wainama East, the conditions of fusion of mantle source indicate that these lavas originate from the partial fusion of garnet peridotite at an average rate of 1-2% and so the primary magma of Wainama East originate from the partial fusion of a mantellic source, having the same characteristics. With regards to the geotectonic context, the discrimination diagrams indicate an intraplate volcanic setting.

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