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Petrology and Geochemistry of Basalts from Tonnge Area, Tigyaing Township, Sagaing Region, Myanmar

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Abstract

Tonnge basalt is a relatively small basaltic field situated in the Tigyaing Township, Sagaing Region, Myanmar. This basaltic field is considered as one of the occurrences of younger extrusive rocks along the major strike-slip fault of central Myanmar. The basaltic lava flows erupted and rested upon the Upper Miocene-Pliocene Irrawaddy Sandstone. Petrological and geochemical studies of the Tonnge basalts have not been carried out yet. This paper reports the results of petrological and geochemical investigation on the basalts from Tonnge area. These data have provided insight into the origin and petrogenetic processes during evolution. The petrographic characteristics of the basalts have been studied using polarizing microscope. The major- and trace-element compositions of basalt samples were analyzed using X-Ray Fluorescence. The Tonnge basalts are porphyritic, holocrystalline and consist of phenocrysts of olivine, plagioclase ± clinopyroxene which are set in the fine-grained intergranular groundmass of olivine, pyroxene, and opaque minerals. The basalts show typical characters of alkali olivine basalts. Trace element assemblage of the studied basalts plots on various discrimination diagrams as within-plate basalt erupted in the continental setting. A relatively small volume, monogenetic nature and unique geochemical characteristics of the basaltic lavas suggest that they are derived from a single, short-lived, discrete parental magma as a result of partial melting.

Keywords

Tonnge, Olivine Basalt, Within-Plate, Partial Melting

1. Introduction

Myanmar is located in the eastern marginal zone of India-Asia collision and marked by a prominent still-active dextral Sagaing Fault which connects the eastern Himalayan Syntaxis to the north and the Andaman Sea to the south [1] [2] [3]. This major strike-slip fault medially divides Myanmar into the eastern part (Shan-Thai Block) and the western part (West Burma Block) [4]. The former consists of the Shan Plateau, the Mogok Metamorphic Belt and the Shan Scarps, whereas the later comprises the Indo-Burma Range, the Wuntho-Popa magmatic arc and overlying Cretaceous-Paleogene sediments [3] [5] (**Figure 1(a)**).

Cenozoic magmatism is one of the prominent features in the geologic history of Myanmar. Magma generation processes are related to the India-Asia collision that was commenced during Early Eocene and associated regional plate reorganization, a transition from oblique subduction to dextral movement in Miocene, and subsequent "rollback" of the subducted Indian oceanic lithosphere in the Quaternary [3]. Based on geochronological data from the previous studies [3] [6] [7], the volcanic centers in the central Myanmar are mostly recognized as Quaternary in age.

Tonnge basalt is considered to be one of the occurrences of younger extrusive rocks along the dextral Sagaing Fault of central Myanmar. It is an intraplate
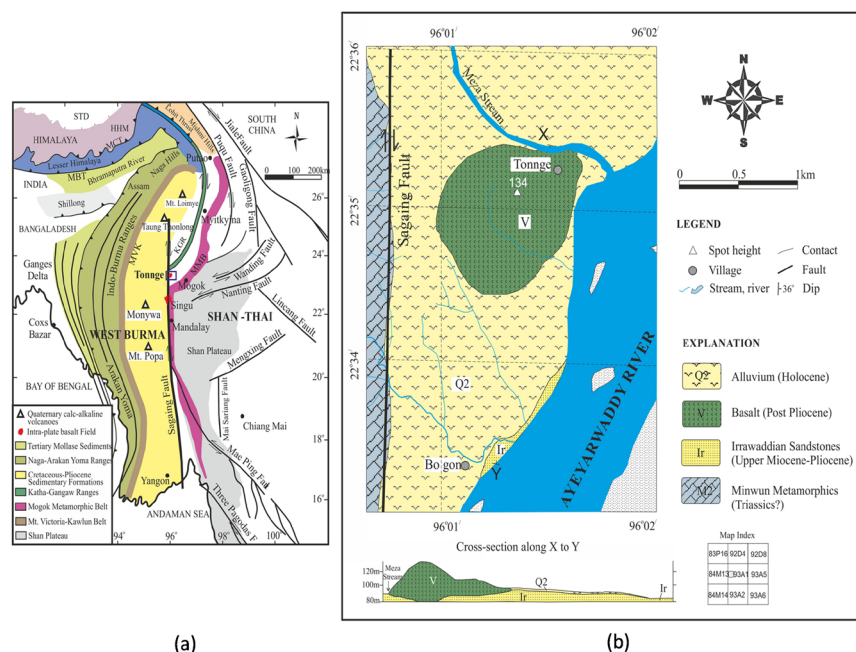

(a)   (b)

Figure 1. (a) Simplified geological map showing structural elements, Tertiary volcanoes and basalt fields in Myanmar and related regions (modified from Searle *et al.* [1]; Lee *et al.* [3]). Inset refers to the principal terrane boundaries and Cenozoic tectonic extrusion in East Asia related with the India-Asia collision. HHM = High Himalayan Metamorphics. LHS = Lesser Himalayan Metasedimentary Series. STDS = South Tibet Detachment System. MCT = Main Central Thrust. MBT = Main Boundary Thrust; (b) Geological map of the Tonnge area, Tigyaing Township, Sagaing Region, Myanmar [8].

basaltic field situated 100 km north of Mandalay, in Tigyaing Township, Sagaing Region of Myanmar. This basaltic field is located to the north of Singu-Kabwet basaltic lava field that poured out from the fissure along the prominent dextral Sagaing Fault of Myanmar. The basaltic field of Tonnge area, however, contains relatively small volume, predominantly monogenetic lava flows compared to the Singu-Kabwet area. Detailed petrological and geochemical studies of the Tonnge basalts are still lacking till date to constrain the petrogenesis and evolution of the basaltic lava. This paper documents the petrography and geochemical data for the basaltic lavas in order to elucidate the characteristics of basalts, magmatic processes during their genesis and implications on their emplacement.

2. Geology of the Tonnge Basalt

The basaltic field in the Tonnge area displays a general circular outline (**Figure 1(b)**) and consists of basaltic lava flows with rare volcaniclastics which are likely to be erupted from a centralvent. The volcanic center is probably located in the northeastern part of the Tonge Hill where central vent eruptions of lava initiated and further spread out laterally to the south-southwest direction. The basaltic lavas rest upon the clastic sediments (sandstones) of Irrawaddy Formation (Upper Miocene-Pliocene) over an area of approximately 2 km^2. Therefore, the basaltic lava field is considered to be produced in post-Pliocene period. The geological map of Tonnge area is shown in **Figure 1(b)** [8].

The basaltic lava flows are generally less than 5 m thick (**Figure 2(a)**). The flows in the southern and southeastern parts of the Tonnge Hill are represented
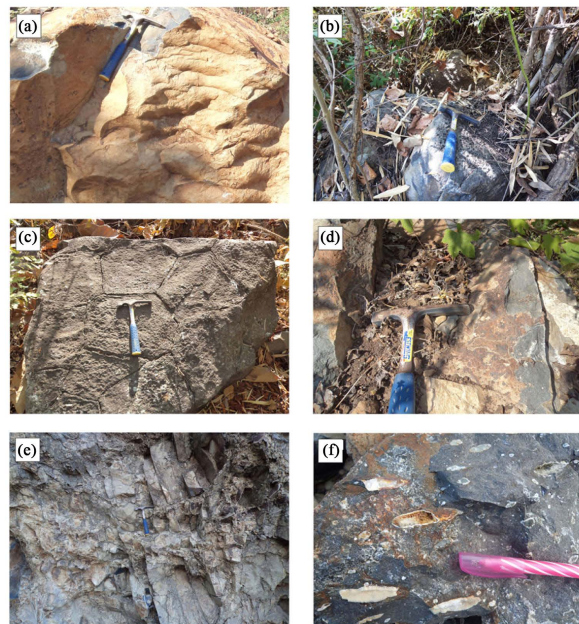

Figure 2. Field photographs of (a) basalt showing the flow nature; (b) vesicular basalt; (c) polygonal columnar jointing in the basalt; (d) iron oxides coating on the surface of basalt outcrop; (e) dyke-like intrusion of columnar basalt and (f) parallel elongated amygdales in the basalt filled by zeolites.

by bluish grey to dark grey vesicular lavas in the upper part (**Figure 2(b)**) with polygonal columnar joints (probably entablature) and dense masses in the lower part. Vertical columns are generally 4- to 6-sided and 0.3 to 0.5 m across (**Figure 2(c)**). The characteristic blocky and massive lavas are mostly confined to the remaining parts of the Tonnge area. Irregular blocky or prismatic jointing is also observed in these basaltic lavas. The fresh surface of the basalts is usually bluish to dark grey. The surfaces of the lava blocks are often coated by reddish brown iron oxides (**Figure 2(d)**).

Localized dyke-like intrusion (**Figure 2(e)**) is observed in the central-eastern part of the Tonnge Hill. In this part, basaltic lava exhibits vesiculation features containing abundant amygdaloidal infillings (**Figure 2(f)**). Vesicles are developed when dissolved gases are released during the ascent of lava due to pressure drop, forming gas bubbles (the cavities) in the upper part of the lava flow. The cavities in the basalts are perfect rounded or elliptical in shape and range from 1 - 10 cm in diameter. Those vesicles are filled with secondary minerals due to near-surface circulation of meteoric water. Common amygdale minerals are quartz, calcite, and zeolites.

3. Analytical Techniques

About fifty basalt samples (average size 12 cm × 10 cm × 8 cm) were collected from Tonnge area. Of these, 25 samples were prepared for thin-sections and studied under polarizing microscope in order to determine the mineralogical composition and textural characteristics. The major and trace elemental compositions of twelve basalt samples were analyzed by X-Ray Fluorescence (XRF) from pressed pellets using a RIGAKU RIX-3100 (Series VR 25006), with relative standard deviations < 5%. For quality control, the reference sample JA-3 was used as standard sample. The XRF analyses were performed at the Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University (Japan) and the X-ray machine is operated at 50 kV and 50 mA, scanning speed: automatic and 4°/min for the determination of major and trace elemental compositions. The loss on ignition (LOI) was measured for all samples by weight difference after ignition at 1000°C.

4. Result and Discussion

4.1. Petrography

The basalts from Tonnge area are porphyritic, holocrystalline and consist of phenocrysts of olivine, plagioclase ± clinopyroxene. Olivine is the dominant mineral phase in the studied basalt samples. Phenocrysts of olivine are usually subhedral to euhedral (**Figures 3(a)-(e)**), unzoned and are often characteristically marked by corroded and embayed margins (**Figure 3(a)**), due to resorption of the crystals by reaction with surrounding liquid. Some phenocrysts exhibit skeletal texture (**Figure 3(c)**). A cluster of olivine and plagioclase phenocrysts often develops distinct glomeroporphyritic texture (**Figure 3(b)**).
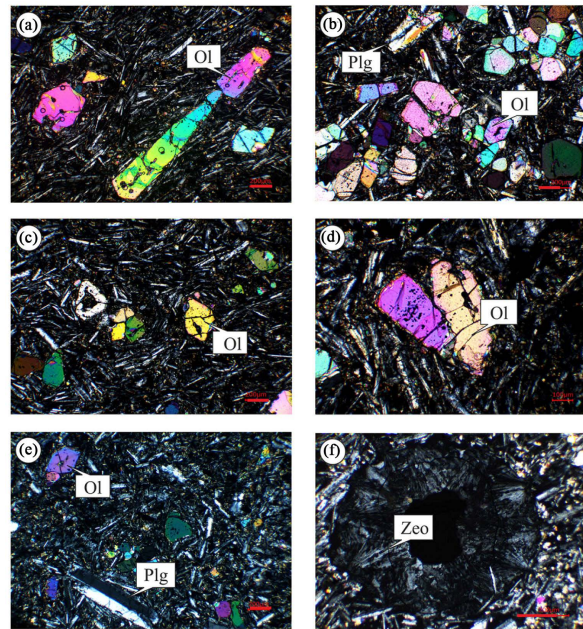
Figure 3. Photomicrographs showing common textures in the basalts (a) parallel-growth crystals of olivine (elongate) and embayed phenocryst (purple) aligned and embedded in the trachytic groundmass; (b) clustered olivine phenocrysts with minor plagioclase phenocrysts enclosed by intergranular groundmass of plagioclase, olivine and pyroxene developing glomeroporphyritic texture; (c) skeletal olivine phenocrysts in the sub-parallel plagioclase microlites; (d) Small opaque inclusions in two large olivine phenocrysts with corroded margins; (e) phenocrysts of plagioclase (labradorite) and micro-phenocrysts of olivine in different sizes set in fine-grained groundmass developing seriate texture; (f) zeolite filling in the amygdule of basalt.

Small inclusions of opaque minerals (probably Ti-Fe oxides) are occasionally observed in the phenocrysts of olivine (**Figure 3(d)**). Partial or complete replacements of iddingsite are observed around the edges and along the cracks of some olivine phenocrysts. They are secondary constituents resulted from the hydrous alteration of the primary mafic minerals. Phenocrysts of plagioclase (principally labradorite) are euhedral to subhedral (**Figure 3(e)**). The groundmass is intergranular and consists predominantly of microlites of plagioclase with subordinate olivine, clinopyroxene, and opaque minerals such as titanomagnetite and ilmenite (**Figures 3(a)-(d)**). Parallel and sub-parallel orientation (trachytic) of plagioclase microlites is commonly observed (**Figure 3(a)**, **Figure 3(c)**, **Figure 3(d)**) in the basalt samples. The amygdales in amygdaloidal basalts are often filled with secondary minerals such as quartz, calcite, and zeolite minerals (**Figure 3(f)**).

4.2. Whole Rock Geochemistry

Major and trace elemental compositions of the basalt samples from the Tonnge area are shown in **Table 1**. The studied samples show silica content ranging from 49.01 to 50.87 wt%, low to moderate MgO and CaO (4.39 to 5.33 wt% and 7.96 to 8.47 wt% respectively). Al_2O_3 contents of the samples show a narrow

Table 1. Whole-rock major- and trace-element compositions for basalts of Tonnge area.

Sample ID	Tn-01	Tn-02	Tn-03	Tn-04	Tn-05	Tn-06	Tn-07	Tn-08	Tn-09	Tn-am	Tn-am1	TN-am3
SiO_2	50.74	50.56	50.42	50.62	50.56	50.69	50.87	50.55	50.34	49.63	50.36	49.01
TiO_2	2.01	2.00	2.03	2.01	1.99	2.03	2.02	2.03	2.07	1.99	2.04	2.01
Al_2O_3	17.71	17.65	16.92	17.51	17.61	17.38	17.86	17.63	17.50	17.19	17.33	16.61
FeO	8.94	8.92	8.95	8.89	8.81	9.03	9.15	9.03	9.19	8.80	9.15	8.84
MnO	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
MgO	4.46	4.46	5.33	4.63	4.39	4.83	4.56	4.55	4.60	4.80	5.04	5.03
CaO	8.02	8.07	7.96	8.20	8.01	8.42	8.11	8.28	8.16	8.04	8.47	8.00
Na_2O	3.36	3.34	2.82	2.98	3.33	2.62	3.41	2.88	3.11	2.64	2.24	2.24
K_2O	2.36	2.32	2.27	2.47	2.31	2.45	2.32	2.44	2.38	2.52	2.71	2.69
P_2O_5	0.61	0.58	0.59	0.60	0.60	0.64	0.59	0.60	0.60	0.58	0.59	0.55
L.O.I	1.36	1.69	2.30	1.66	1.97	1.46	0.68	1.56	1.60	3.35	1.62	4.54
V	208	208	211	211	209	218	220	207	231	215	219	209
Cr	173	170	175	173	173	174	177	185	181	192	178	177
Co	58	47	56	59	60	52	120	61	60	52	85	81
Ni	60	59	63	61	59	61	63	62	63	62	65	67
Sb	28	17	17	24	21	15	20	23	22	25	18	22
Sn	23	19	14	25	20	20	19	25	26	20	24	15
W	34	0	18	30	19	0	260	18	13	9	17	9
Mo	8	6	7	8	7	8	9	10	7	10	8	12
Rb	59	59	62	57	57	59	58	57	57	64	73	75
Sr	816	818	849	869	818	867	969	966	926	1092	900	1287
Ba	727	701	699	705	713	710	677	725	712	723	718	737
Y	28	26	27	26	26	27	26	27	30	27	29	28
Zr	186	181	184	182	181	187	187	187	192	181	190	181
Nb	53	51	53	53	52	54	53	54	55	53	53	55
Th	9	8	9	8	9	9	9	12	11	9	8	11
$Mg^{\#}$	47	47	52	48	47	49	47	47	47	49	50	50
$Na_2O + K_2O$	5.72	5.66	5.09	5.45	5.64	5.07	5.73	5.32	5.49	5.16	4.96	4.93
K_2O/P_2O_5	3.85	3.99	3.86	4.11	3.87	3.82	3.93	4.03	3.98	4.34	4.62	4.85
Normative minerals												
Or	13.95	13.71	13.41	14.6	13.65	14.48	13.71	14.42	14.06	14.89	16.01	15.9
Ab	28.43	28.26	23.86	25.22	28.18	22.17	28.85	24.37	26.32	22.34	18.95	18.95
An	26.27	26.32	26.81	27.11	26.28	28.43	26.57	27.97	26.76	27.61	29.23	27.32
Di	7.94	8.27	7.31	8.03	7.94	7.61	8.17	7.65	8.16	7.04	7.42	7.27
Hy	5.21	5	14.7	9.65	6.28	15.87	3.73	11.26	7.1	12.91	17.4	16.33
Ol	11.34	11.36	6.13	8.27	10.27	4.36	12.82	7.24	10.39	6.43	3.83	4.28
Il	3.82	3.8	3.86	3.82	3.78	3.86	3.84	3.86	3.93	3.78	3.87	3.82
Ap	1.41	1.34	1.37	1.39	1.39	1.48	1.37	1.39	1.39	1.34	1.37	1.27
Pr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Note: L.O.I—Loss on ignition.

range between 16.61 and 17.86 wt%. The K_2O contents in the samples range from 2.27 to 2.71 wt%. They have high FeO content (8.8 to 9.19 wt%). It is observed that two samples (namely Tn-Am and Tn-Am3) have high LOI values (3.35 and 4.54 wt% respectively). The TiO_2 contents range from 1.99 to 2.07 wt%. The basaltic rocks having $TiO_2 \geq 2$ wt% are recognized as high-Ti basalts and they are considered to be the plume-related basalts erupted in both continental and oceanic environments [9] [10] [11]. Tonnge basalts are classified as high Ti-basalts ($TiO_2 \geq 2$ wt%) because most samples have TiO_2 greater than 2.

Contents of compatible elements (Ni and Cr) range from 59 - 67 ppm and 170 - 192 ppm, respectively. These values are relatively lower than that of primary mantle melt (*i.e.* Ni > 200 ppm, Cr > 400 ppm). There is a positive correlation between decreasing Ni and Cr with MgO (Table 1). High ratios of K_2O/P_2O_5 ($K_2O/P_2O_5 > 2$) are observed. Basalts have relatively higher contents of Rb (57 - 75 ppm) Ba (677 - 737 ppm) and Sr (816 - 1092 ppm) as compared to those of Oceanic Island Basalts (OIB) (Rb-31 ppm; Ba-350 ppm: Sr-660 ppm). Nb contents (51 - 55 ppm) are fairly higher if compared to that of OIB (Nb: 48 ppm).

The Mg-numbers of the basalt samples range from 47 to 52. CIPW normative compositions of the basalts are calculated and presented in Table 1. Normative compositions of the basalts are marked by the presences of diopside (7.04 to 8.27 wt%), olivine (3.83 to 12.82 wt%), and hypersthene (3.73 to 17.4 wt%). The silica-undersaturated character of the basalts can be inferred from normative mineralogy.

In the total alkali ($Na_2O + K_2O$) vs. silica (SiO_2) diagrams (Figure 4(a)) [12], the basaltic samples fall within the field of trachy-basalt and show an alkaline composition. In the K_2O vs. SiO_2 diagram (Figure 4(b)) [13], magmatic affinity of the basalts shows absorakite (shoshonitic). In Harker' variation diagram (Figure 5), the basalts are characterized by increasing Al_2O_3, and Na_2O with decreasing SiO_2. In contrast, K_2O and MgO contents show negative correlation
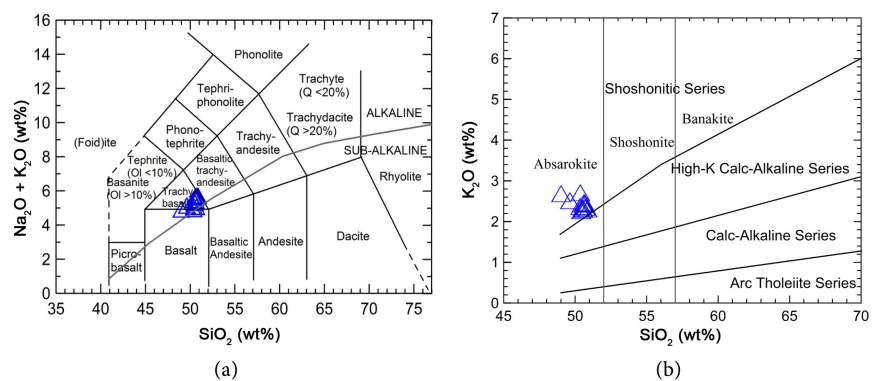

(a)   (b)

Figure 4. (a) Total alkali ($Na_2O + K_2O$) vs. silica (SiO_2) diagram [12] showing the basalt samples from Tonnge area in the field of trachy basalt. The line separating the sub-alkaline and alkaline subdivisions was after Irvine and Baragar [14]; (b) K_2O vs. SiO_2 variation diagram [13] showing the alkaline composition of Tonnge basalts. The classification for K_2O–SiO_2 contents and shoshonitic series was after Gill [15], and Peccerillo and Taylor [13], respectively.
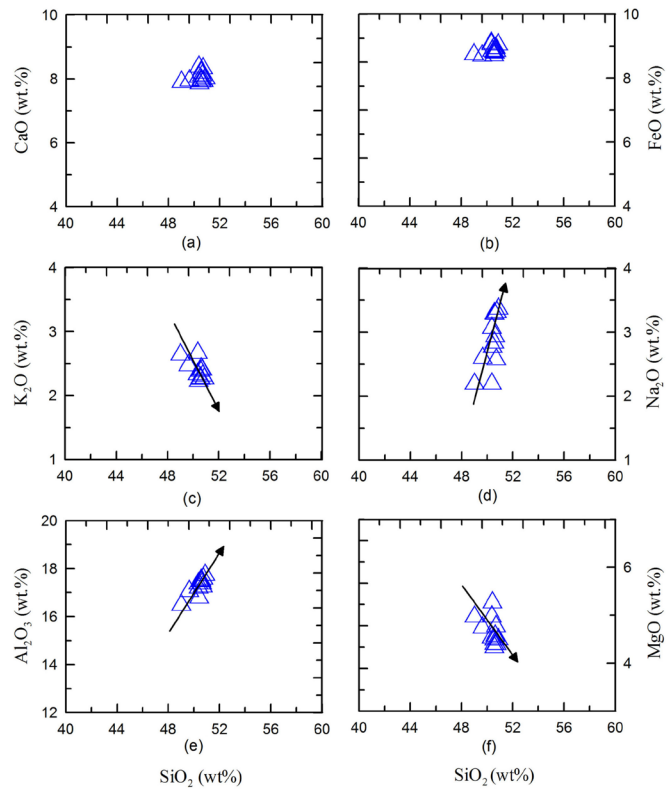
Figure 5. Plots of major elements vs. SiO$_2$ (Harker diagram) for Tonnge basalt samples.
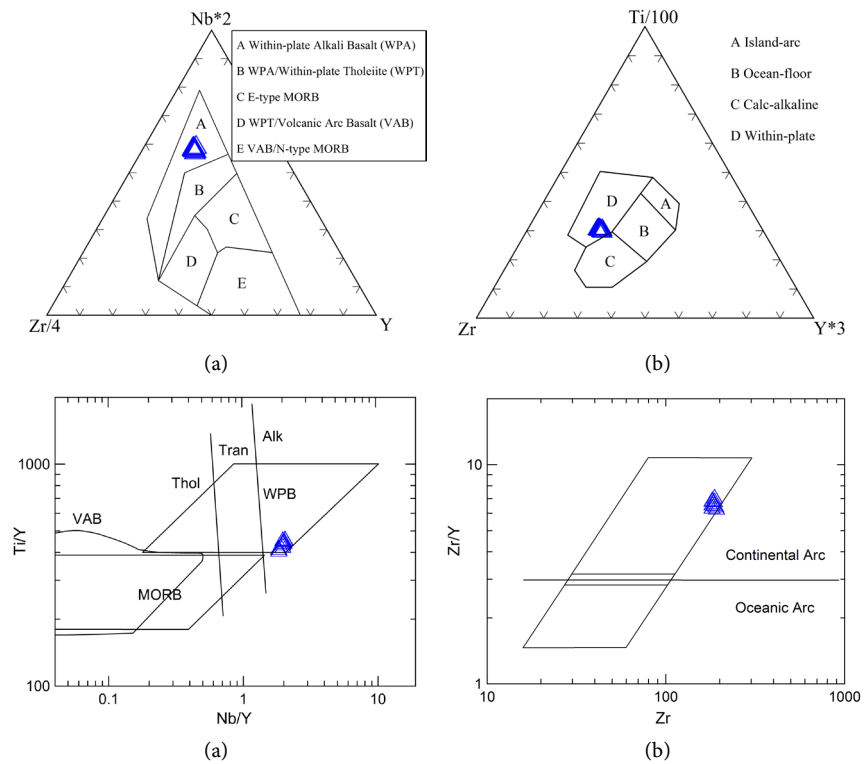

Figure 6. Tectonic discrimination diagrams for basalts from Tonnge area (a) Nb-Zr-Y diagram [16]; (b) Ti-Zr-Y diagram [17]; (c) Nb/Y-Ti/Y diagram [18] and (d) Zr vs. Zr/Y diagram [19].

with SiO_2 contents. It indicates that possible fractionation of early formed mafic minerals such as olivine occurs during evolution of magma and no apparent fractional crystallization involved during the ascent of the basaltic magma.

Incompatible trace element abundances and HFSE ratios are considered as suitable parameters in order to discriminate the tectonic environment for the eruption of basaltic magmas. The basalt samples are plotted on the various tectonic discrimination diagrams such as Nb-Zr-Y, Ti-Zr-Y, Nb/Y-Ti/Y and Zr vs. Zr/Y (**Figures 6(a)-(d)**). In the plot of Nb-Zr-Y diagram (**Figure 6(a)**) [16], all basalt samples are plotted in the field of the within-plate alkali basalt (WPA). The plots of these samples also cluster in the field of within plate basalts on the Ti-Zr-Y (**Figure 6(b)**) [17] and Nb/Y-Ti/Y diagrams (**Figure 6(c)**) [18]. On Zr-Zr/Y diagram, it is possible to discriminate the basalts of Tonnge area as continental basalt (**Figure 6(d)**) [19].

5. Conclusions

Petrographical studies of basalts from the Tonnge area indicated that they were composed primarily of olivine, plagioclase and pyroxene. They were classified as olivine basalt as olivine was considered to be the most common essential mineral phase, followed by other minerals such as plagioclase, pyroxene, and Fe-Ti oxides. Absence of quartz and presence of fairly abundant olivine (as both phenocrysts and groundmass) in the studied samples indicated that they were typical alkali olivine basalts [20].

Geochemical and tectonic discrimination diagrams indicated that the basaltic lavas were formed by the eruption from central vent in the continental intraplate setting. The unique geochemical characteristics of basalts indicated that they were derived from the discrete magma batch as a result of partial melting of continental lithospheric mantle source and evolved independently by variable degrees of fractional crystallization. The abundance of olivine phenocrysts in the basalts suggested that the melt has ascended from its source and subsequently detained in the magma chamber and phenocrysts were settled down during subsequent ascent. A positive correlation between decreasing Ni and Cr with respect to decreasing MgO suggested that fractionation of olivine and clinopyroxene occurred during the evolution of the basaltic magma. The higher ratios of K_2O/P_2O_5 in the basalts pointed to the fact that assimilation of magma with the silicic crystal component or with wall rocks occurred during their emplacement and/or ascent as within-plate basalt in the continental setting.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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