PETROGRAPHIC AND GEOCHEMICAL CHARACTERISTICS OF THE KIEJO, RUNGWE AND NGOZI VOLCANIC ROCKS, SOUTHERN TANZANIA: IMPLICATION FOR TECTONIC ACTIVITIES AND MAGMATIC DIFFERENTIATION

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ABSTRACT

Rock samples were collected from the Kiejo, Rungwe and Ngozi volcanoes, southern Tanzania. Results show that, in the Ngozi and Rungwe volcanoes, magma cooled relatively fast. After large part of the magma had crystallized, nucleation of crystals at a relatively slow rate crystallized from interstitial fluids of the primary magma that had already crystallized fine grained minerals resulting into large grains of minerals. In the Kiejo volcano, both zoned and unzonned olivine crystals exist; unzoned crystals being primary and the zoned ones are secondary. Such observations also indicate that the magma responsible for these rocks had interstitial fluids that crystallized into olivine of different chemical and grain sizes.

The lack of olivine, and the presence of orthopyroxene, the high amount of SiO_2 wt% (~ 63) as well as (Na_2O + K_2O) wt% ~ 9.38 in the Ngozi volcano, indicate that the volcanic rocks in the Ngozi volcano are a result of a relatively silica saturated magma source. Otherwise, the magma could have originated from deeper in the crust such that it became contaminated with continental crust materials as it was erupting.

Based on the Alikali-Silica diagram of Le Bas et al. (1986), the Ngozi and Rungwe magma contents fall in the field of trachy-dacite, and those from the Kiejo volcano fall in the field of basaltic trachy-andesite and basaltic magma. Such a pattern highlights close genetical and ?structural relationship of the magma that formed the three volcanoes.

Key words: Kiejo, Rungwe, Ngozi, volcanic rocks, Southern Tanzania.

INTRODUCTION

The Ngozi, Rungwe and Kiejo volcanoes are within the Rungwe Volcanic Province (RVP). The RVP covers an area of about 3,000 km^2 and lies within latitudes 8.75°S – 9.60°S and longitudes 33.20°E – 34.00°E (Fig. 1). Based on the surface expression, the three volcanoes are separated by about 15 km from each other and are in a NW-SE structural trend (Fig. 2).

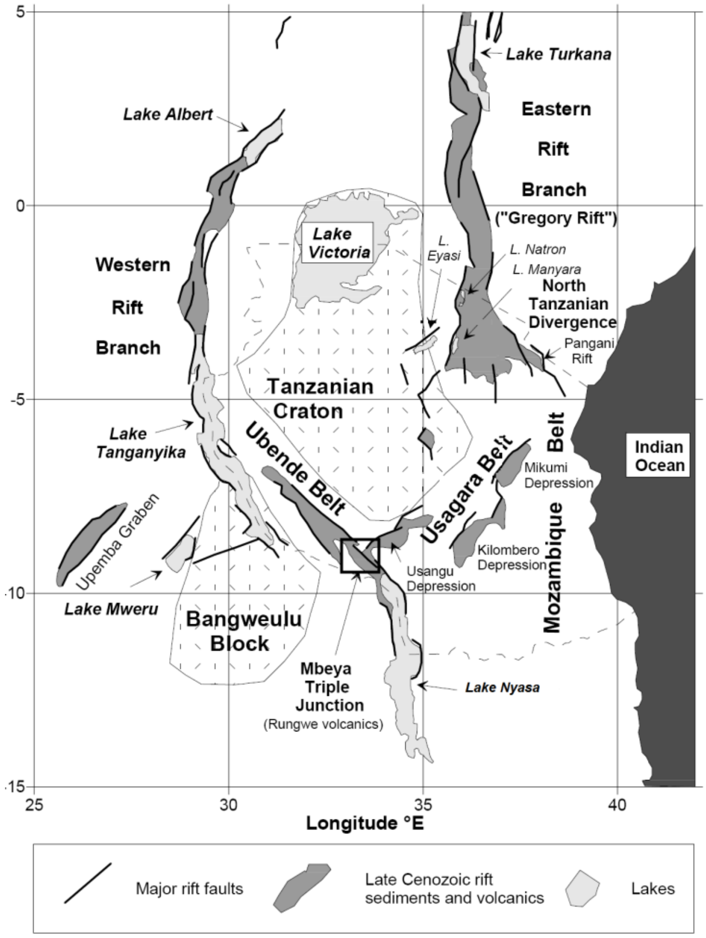


Figure 1a: The Geology map of Tanzania showing the Rungwe volcanic province (Part of the Mbeya Tripple Junction) of the East African Rift System (EARS), After Macheyeki et al (2008).

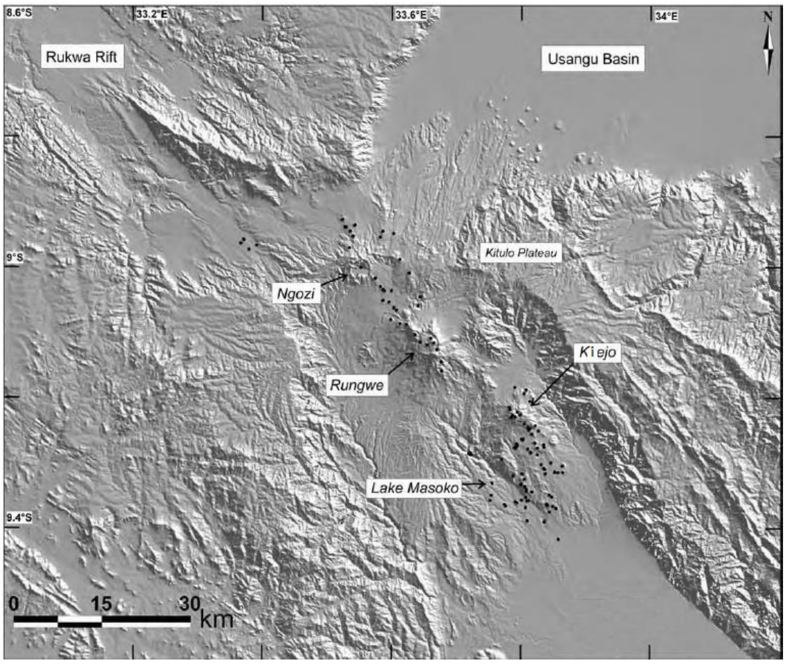


Figure 1b: SRTM shaded relief DEM at 90m resolution of the Rungwe volcanic province region (USGS, 2006), with its rift segments and main recent volcanic centers. Eruptive centers are indicated by a black dot (After Fontijn et al 2010).

The Ngozi volcano is within the so called ‘older extrusives’ (Tuffs: trachyte - phonolite and phonolites)’ of most likely Plio-Pleistocene in age (Harkin 1960). The extrusives form part of the Poroto Mountains (Fig. 2). The Rungwe and the Kiejo volcanoes are considered as ‘younger volcanoes’, the Kiejo, being the youngest (Fontijn *et al.* 2010). The Rungwe volcano is characterized by agglomerates, phonolitic trachytes, tuffs, basalts, lava, pumice and ash. The Kiejo volcano is essentially made up of older basaltic lavas and younger basaltic lavas, some of the latter lava erupted in the 19^{th} century (Harkin 1960). The stratigraphic record shows that both the Rungwe (including the Kiejo) and Ngozi volcanoes experienced significant volcanic activity through the Holocene. The Ngozi volcano is characterized by a major, possibly caldera-forming eruption ca. 10–12 ka ago (Fontijn *et al.* 2010).

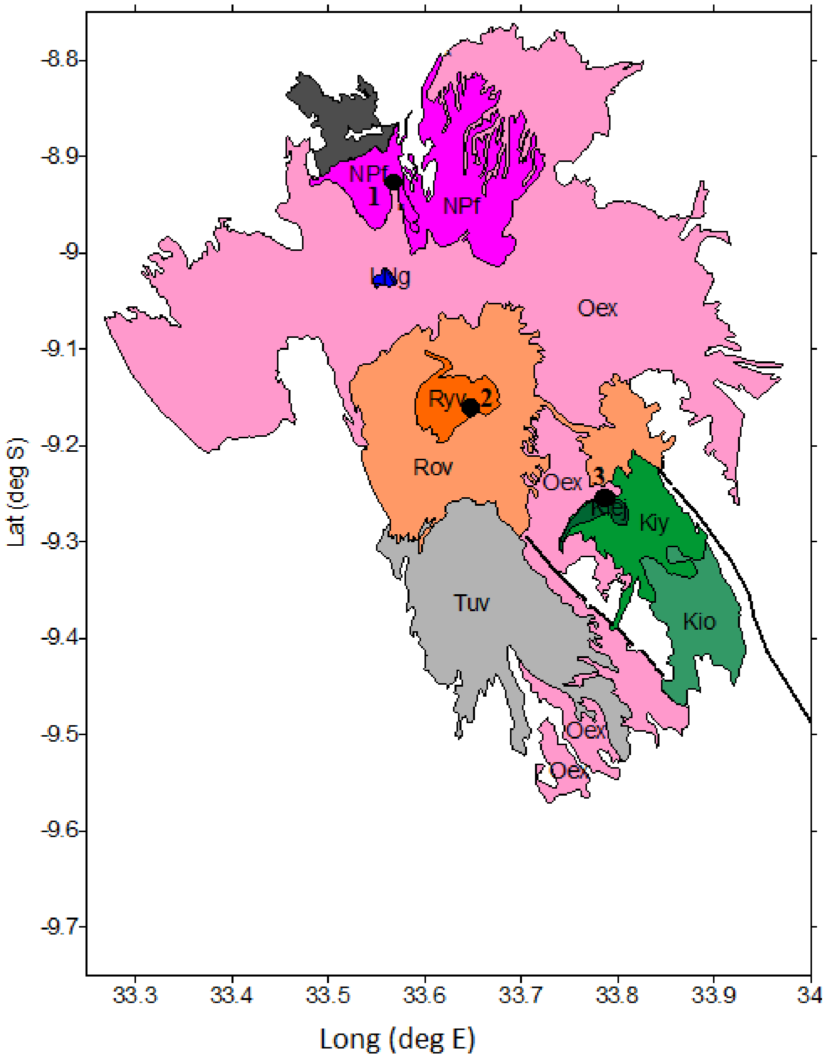


Figure 2: A Simplified map of the Rungwe Volcanic Province showing the Ngozi (LNg), Rungwe (Ryv, Rov), Kiejo (Kij, Kiy, Kio) volcanoes and other volcanic rocks: Npf = Northern Poroto old basalts, Oex = Old extrusives and Tuv = Tukuyu extrusives. Sample points (as filled thick points) and the associated structures are also shown. Note: LNg = Lake Ngozi, Ryv = Rungwe young volcanic rocks (lava, pumice and ash), Rov = Rungwe old volcanic rocks (basalt, tuff, trachytes and agglomerates). Three black filled circles (Nos 1, 2 and 3) represent three sample points (Map after Harkins, 1960).

The basement to the RVP is Precambrian in age (Paleoproterozoic Ubendian tectonic domain). The domain is characterized by high grade metamorphic rocks; older granulites (2100-2025 Ma) and amphibolites of 1950-1850 Ma (Theunissen *et al.* 1996, Boven *et al.*, 1999), each of which corresponds to a metamorphic event (Boven *et al.* 1999, Sklyarov *et al.* 1998).

This study that was carried out in November, 2009 intends to compare the petrographic and geochemical compositions of the three volcanoes: Ngozi, Rungwe and Kiejo volcanoes. The study further elucidates the interplay between petrography and geochemistry of the volcanoes versus Cenozoic tectonic activities in the area. Various reports such as Delvaux *et al.* (2001), Ebinger (1989), Le Gall (2004, 2008), Delvaux and Williamson (2008), Macheyeki *et al.* (2008), which are focused on active tectonics, reveal that the Cenozoic tectonics rely heavily on Precambrian structural setting.

The Ubendian tectonic domain has undergone a complex structural evolution and that the most obvious NW-SE trend, which has been used to structurally identify the belt, is a late deformational event associated with shearing (Nanyaro *et al.* 1983).

Structurally analysis along the western branch of the East African Rift System, especially along Lake Nyasa demonstrates a NW direction of regional extension that is related to Cenozoic NW-SE relative movement of continental blocks (Chorowiciz 1989). The principal direction of compression is along a horizontal plane and not in a vertical direction (Chorowiciz 1989). According to Chorowiciz (1989), NW-SE trending faults (also observed along Lake Nyasa) that are parallel to Cenozoic movement are readily reactivated as transform faults, even if they had been initially only small faults. To the contrary, NE-SW trending faults rework as pure normal faults.

Structural setting in the RVP shows that the Ngozi, Rungwe and Kiejo volcanoes are located along a NW-SE trending structures (high-angle faults) that re-activate older basement structures. Within the same fault system, strike slip movements occur (Delvaux and Williams 2008). Field observations have shown that two sets of sub vertical faults (NNE-SSW and ENE-WSW), are important in controlling the major and minor late Quaternary volcanic events and the discharge of thermal springs as well as carbon dioxide (CO_2) gas (Delvaux and Williams 2008, Fontijn *et al.*, 2010). Delvaux *et al.* (1992) and Fontijn *et al.* (2010) report that dated volcanic materials as well as sediments from the Rungwe volcano constrain ages for this RVP to be ca. 1.5 to 1.0 Ma.

Rock samples were collected from the Kiejo, Rungwe and Ngozi volcanoes, southern Tanzania. The aim of the study was to compare the petrographic and geochemical compositions of the volcanoes and relate it with active tectonic activities in the areas.

Samples were analyzed petrographically and geochemically at the Laboratories of the Geological Survey of Tanzania.

MATERIALS AND METHODS

As the aim of this study was to ascertain the relationship between mineralogy and geochemistry of the volcanoes of the Rungwe volcanic province and later on be able to link the two with tectonic activities; two main laboratory procedures were performed; (i) petrography and (ii) geochemical analyses of the rock samples collected from Kiejo, Rungwe and Ngozi volcanoes. Prior to petrography and geochemical analyses, samples were respectively prepared according to procedures detailed below:

Five rock samples were collected from the Kiejo volcano namely RUN01, RUN02, RUN03, RUN04 and RUN08. RUN04 and RUN08 are from the southern part of the volcano (Fig. 2). RUN01, RUN02 and RUN03 are from the northern part. The location coordinates of the samples are shown in Table 1.

Table 1: Coordinates (in UTM 36, Arc 1960) of the samples from the RVP. ELV = Elevation.

Sample No.	UTME	UTMN	ELV_m
RUN01	585792	8981260	1836
RUN02	585924	8981114	1886
RUN03	585935	8980782	1964
RUN04	586058	8980782	2075
RUN05	573343	8990473	2961
RUN08	586054	8980784	2075
RUN09	561628	9003726	2255

One sample (RUN05) was taken from the pick of the Rungwe volcano and RUN09 was taken on the rim of the Ngozi caldera, making a total of seven samples.

Samples from both the Ngozi and Rungwe volcanoes were sampled under the assumption that they were taken from the latest eruptions on either volcano. Samples from the Kiejo were not necessarily from the last eruptive events but at least from the youngest possible volcanic flows. This assumption was necessary as multiple volcanic events on either volcano have been reported. (e.g. Newhall and Self, 1982).

All the samples were cleaned, dried and cut into two halves: one for petrographic and geochemical analyses while another one remained as reference material. RUN01 and RUN02 from Kiejo volcano were relatively weathered thus no thin sections were made from both samples.

Petrographic Analysis

Five samples from the Kiejo, Rungwe and Ngozi volcanoes were analyzed for both in hand specimen and under the plane-polarized microscope at the Geological Survey of Tanzania.

Geochemical Analysis

Samples were analyzed at the Geological Survey of Tanzania laboratories. Prior to analyses, samples were dried in an open air for two hours using Infra-Red lamps. After that they were ground to particle size ≤ 177µm (80 mesh) using swing mill pulverizer. The powdered samples were pressed into XRF sample cups mounts with PANalytical B.V X-Ray film polyesterpetp. Multi-element determinations for samples were undertaken using PANalytical, Minipal 4 Energy Dispersive X-Ray Fluorescence Spectrometer; (ED-XRF) Model PW4030/45B.

RESULTS

Results from both hand specimen petrography and plane polarized microscopic studies are hereby summarized under the order, Ngozi, Rungwe and Kiejo:

The Ngozi Volcano:

Hand specimen results:

The sample looks slightly weathered, and less dense. It is fine grained with about 0.5 x 5 mm lenticular minerals in the ground mass (Fig. 3).

Microscope results

The Ngozi volcano (Fig. 1, 4) is characterized by over 90% fine grained lenticular minerals and the remaining 10% is occupied by large prismatic minerals (Fig. 5). The fine grained minerals occur as interlocking star-like crystals. When they occur with pyroxene (orthopyroxene), the orthopyroxene is sub rounded by these fined grained minerals (Fig. 5). The fine grained minerals are interpreted as sanidine. The sanidine occupy about > 95 modal% whereas orthopyroxene occupy about 2 modal%. Opaque minerals, most likely iron oxides and titanium oxides occupy about ≤ 2 modal%

a b

Figure 3: Sample (RUN09) taken from the Ngozi volcano. 'a' and 'b' represent same sample.

The large minerals observed in thin section from the Ngozi volcano are interpreted to be sanidine as well. The above observation shows that the magma that resulted into the Ngozi volcano was not rich in olivine as no olivine crystals were observed in the samples under the microscope. Furthermore, the textures of the crystallized minerals indicate that large part of the magma cooled relatively fast. After large part of the magma had crystallized, nucleation of crystals at a relatively slow rate crystallized from interstitial fluids of the primary magma that had already allowed crystallization of fine grained minerals (e.g. sanidine) resulting into large crystals of sanidine (i.e. secondary crystallization).

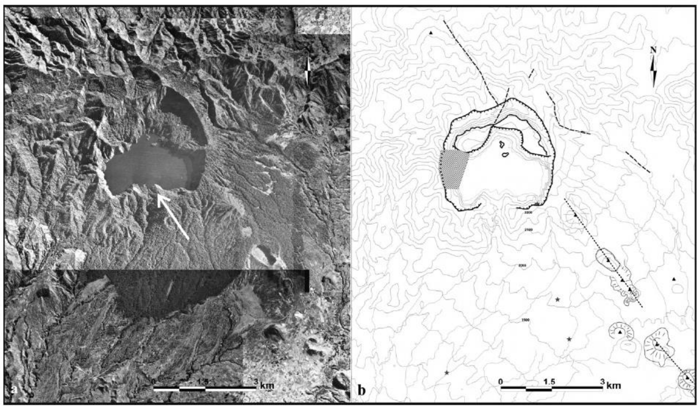


Figure 4: (**a**) - Air photo view of Ngozi caldera. Arrow indicates breach in Southern caldera wall. (**b**) Schematic structural interpretation of Ngozi caldera with major lineament possibly corresponding to a fault cross-cutting the caldera floor. Stars indicate locations of pyroclastic flow deposits. Contour lines based on SRTM DEM; 50 m interval (From Fontijn *et al*, 2010)

The Rungwe Volcano

Hand specimen results

A sample from the Rungwe volcano is relatively denser than that from the Ngozi volcano. It is also light colored (grey) but with relatively high proportion of dark minerals (Fig. 6). Lenticular minerals (~ 4 x 10 mm size) are relatively few as compared to those from the Ngozi volcano. The lenticular minerals have a fairly metallic luster and have a habit similar to that of feldspar but with much less hardness as they can be easily scratched by a finger nail.

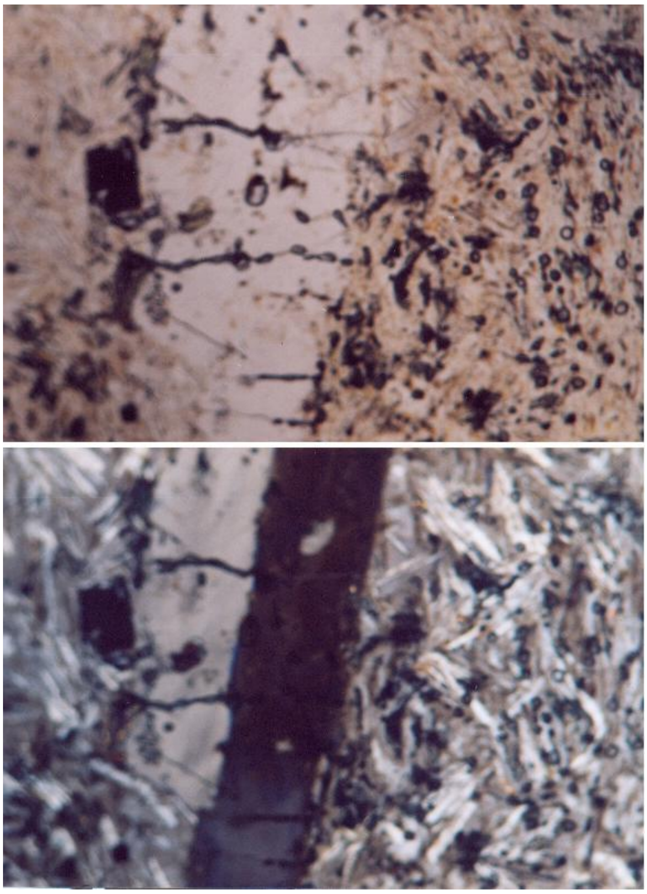


Figure 5: Large sanidine crystal within fine grained interlocking sanidine crystals. (upper photograph, uncrossed polars; lower photograph, crossed polars). Field of View x 5.

The Microscope results

Like the Ngozi volcano, the Rungwe volcano is also characterized by fine grained minerals (essentially sanidine) with a few large crystals. However there are basic differences; first: the fine grained minerals from the Rungwe volcano show a pattern that imply preferred orientation during development, two: the fine grained minerals are less than 50 modal%. In addition, the large sanidine crystals sometimes show twinning. The twinned mineral is interpreted to be anorthoclase (Fig. 7) because it shows compositional changes which are reflected by alternating bands as the microscope stage is rotated. Secondary and accessory minerals interpreted as biotite associated with the anorthoclase are also common.

The twinning and the compositional changes within the twinned minerals indicate that these large crystals, crystallized slowly from interstitial fluids of the primary magma that had already crystallized fine grained minerals. The large crystals slowly continued to grow as anorthoclase, a Na-rich silicate [(Na, K) $AlSi_3O_8$] as compared to sanidine, a K-rich silicate [(K, Na) $AlSi_3O_8$].

Figure 6: Sample from the Rungwe volcano

The Kiejo Volcano

Hand specimen results

Samples from the Kiejo volcano are generally dark colored, fine grained, relatively denser, fresh looking and characterized by 1-5 mm wide vesicles (Fig. 8). Some vesicles are filled in by foreign country rocks. There are two types of vesicles; rounded to sub-rounded and elongated vesicles. The former are likely to have been formed when the magma was in little or no motion whereas the latter were formed most likely at the time when the magma was in motion. Brownish 1-2 mm size stubby minerals (most likely pyroxenes) are seen on the rock ground mass.

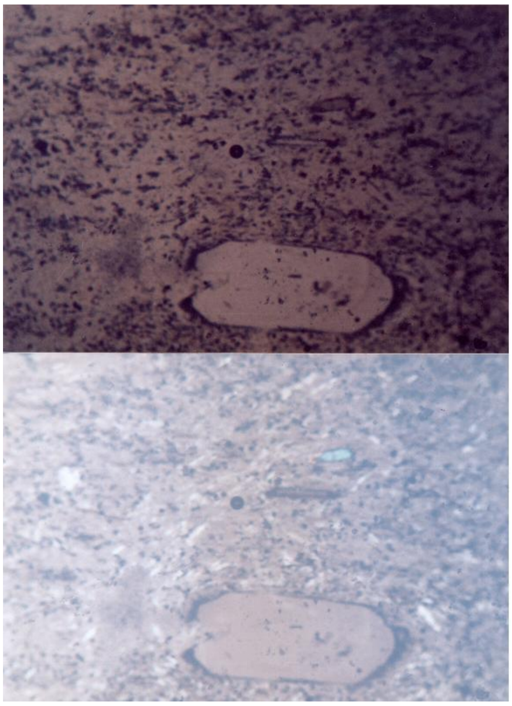


Figure 7: Large Sanidine or anorthoclase within a fine ground mass of sanidine crystals. (upper photograph, uncrossed polars; lower photograph, crossed polars). Field of View x5

The Microscope results

The Kiejo volcano differs from both the Ngozi and the Rungwe volcanoes in many aspects: firstly, it has a remarkable amount of voids implying that the eruption responsible for the particular magma was effusive i.e. associated with a significant amount of pressurized gasses. In terms of grain sizes, the minerals in the Kiejo volcano are much larger compared to those from Ngozi and Rungwe. The common minerals in this volcano are pyroxene and olivine. Most of the olivine minerals are zoned.

Figure 8: One of the samples (basalt) from the Kiejo volcano showing open and filled vesicles. White materials are thought to be country rocks.

The zoned olivines are generally isolated, unaltered, and the zoning is by average 3 rings per mineral (Fig. 9). The zoned olivine crystals are generally smaller than the unzoned ones. Plagioclase crystals are common. The presence of both zoned and unzoned olivine crystals suggest that the unzoned olivine crystals are primary and the zoned ones, secondary. It also explains that the magma responsible for this rock had interstitial fluids that crystallized into olivine of different chemical proportions (resulting into zoning) and grain sizes (Fig. 9). Olivine-olivine solid solution (most likely Fe-Mg solid solution; i.e. $MgSiO_4$ to $FeSiO_4$) is evident from Fig. 9.

Unzoned olivines changing into other silicate minerals (mainly pyroxenes), are not uncommon (Fig. 10). Furthermore, some pyroxenes seem to have had enough time to change compositionally into different pyroxenes (?solid-solution, Fig. 10).

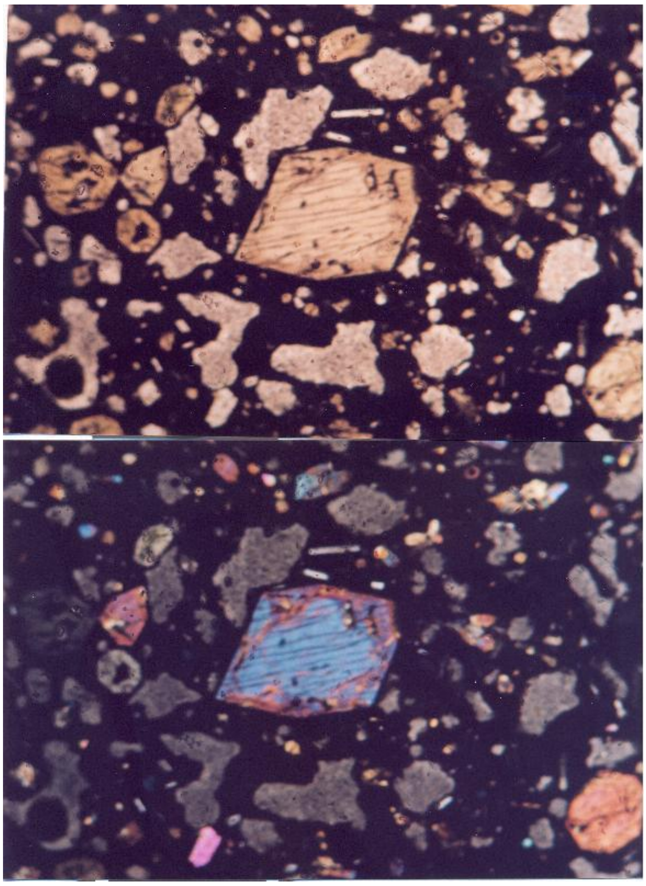


Figure 9: Zoned olivine crystals (the largest crystals). They show an average of 3 rings upon rotation of microscope stage. (upper photograph, uncrossed polars; lower photograph, crossed polars). Field of View x 5.

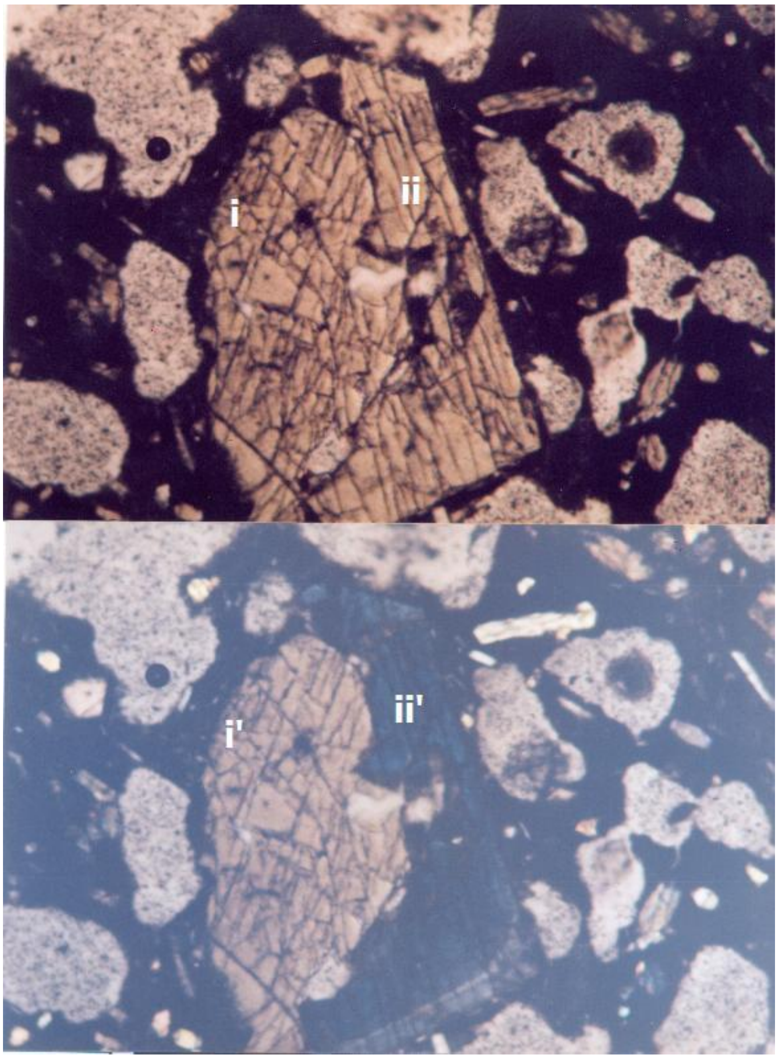


Figure 10: Possible solid-solution occurring among orthopyroxenes. i = i', ii = ii': (upper photograph, uncrossed polars; lower photograph, crossed polars). Field of View x 5.

Alteration on the rims of unzonned olivine is also common. Olivine alteration rims have grown to about ≥ 10% by volume. Under the microscope, these alteration zones seem to be opaque which means that such zones could be the Fe-oxide formed as a result of olivine alteration. In some places, orthopyroxene tend to subround olivines (Fig. 11). Orthopyroxenes are anhedral to subhedral. They are also fractured and within the fractures, occasionally fluids of reflective index similar to that of fluids surrounding rims of olivine in contact with orthopyroxene are visible. These fluids could be representing alteration products of olivine (serpentine?), Fig. 11.

Other than olivine, pyroxene, Fe-oxides, lenticular minerals (labradorites?) are present in significant quantities within the Kiejo volcano and they form large part of the ground mass. Small bluish minerals within orthopyroxene are interpreted to be haūyne (Fig. 11).

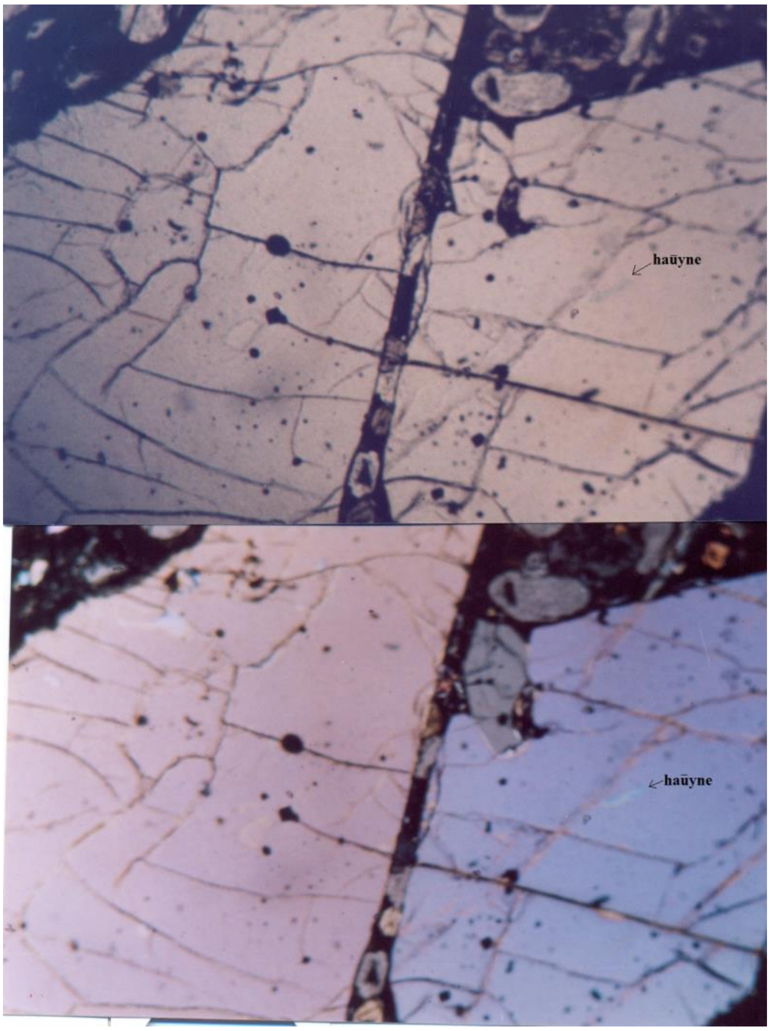


Figure 11: – Anhedral to subhedral orthopyroxene subrounding olivine. They are also fractured and within the fractures serpentine grows. Note also the fluids having light reflection similar to that of orthopyroxene. Note also a green mineral haūyne. (upper photograph, uncrossed polars; lower photograph, crossed polars). Field of View x 5.

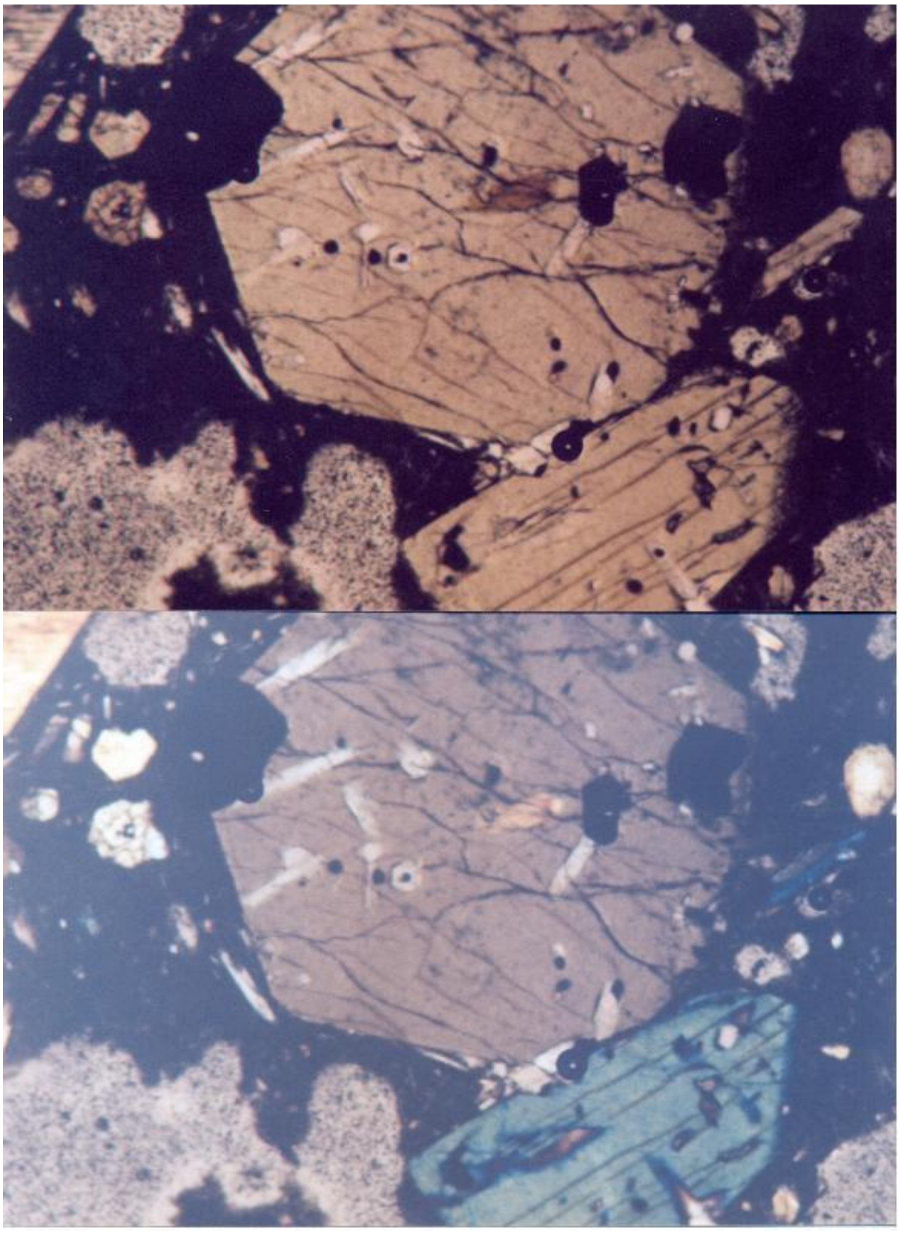


Figure 12: Olivine minerals subrounded by pyroxenes (largest crystals) and some pyroxenes (orthopyroxenes) surround plagioclase (laths) completely. (upper photograph, uncrossed polars; lower photograph, crossed polars). Field of View x 10.

Interesting textures do exist between olivine, plagioclase (most likely labradorites) and pyroxene where the olivine minerals are subrounded by pyroxenes while some pyroxenes (orthopyroxenes) surround plagioclase partially and some completely

(Fig. 12). Presence of such large crystals could imply that favorable conditions for growth of orthopyroxene did exist to the magma prior to eruption.

Major elements results

Major elements analysis was conducted for 7 samples from Ngozi (RUN09), Rungwe (RUN05) and Kiejo (RUN01-4, RUN08) volcanoes as stated earlier. Fig. 13 shows that Al_2O_3 wt% contents are minimum at the Kiejo volcano and maximum at the Ngozi volcano. Another element that is behaving as Al_2O_3 is K_2O.

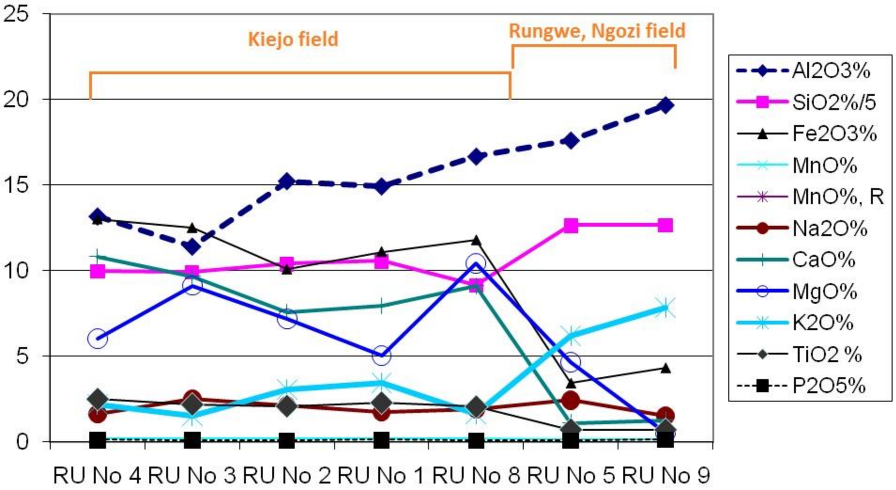


Figure 13: The plot of Major elements (wt %) on the y-axis versus locations on the x-axis. Note sample numbers are arranged from west to east. In this case the westernmost sample is RUN09 and the easternmost, RUN04. RUN09 is from Ngozi volcano, RUN05 is from the Rungwe volcano and the other samples are from the Kiejo volcano. Note also that Fe2O3 represent total Fe-oxide and the values for SiO2 have been divided by 5 for clarity purposes. RU No=RUN0.

On the other hand, Na_2O and MgO decrease from the Kiejo volcano to the Ngozi volcano through the Rungwe volcano. Although Fe_2O_{3T} and CaO decrease from Kiejo to Rungwe as do Na_2O and MgO, the former slightly show elevated values in the Ngozi volcano. The trends of other elements, TiO_2, MnO, and P_2O_5 are not so clear.

High Field Strength Elements results

The group of large cations with high charges Zr, Hf, Ta, Nb, Th and U all which tend to be rejected by the common igneous minerals are strongly concentrated in residual liquids. From Figure 14, Nb and Th are concentrated in RUN04 (Kiejo) whereas Zr, U, Nb and Th are concentrated in RUN5 (Rungwe). Surprisingly, although RUN08 is essentially from the same position (Kiejo), all elements have minimum values. However, all of these elements show increasing trends towards RUN09 (Ngozi).

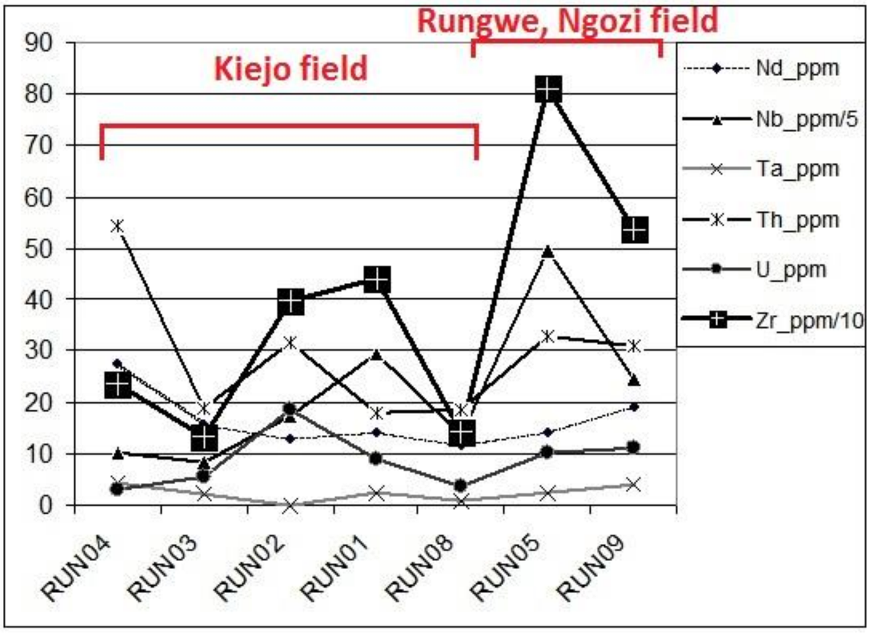


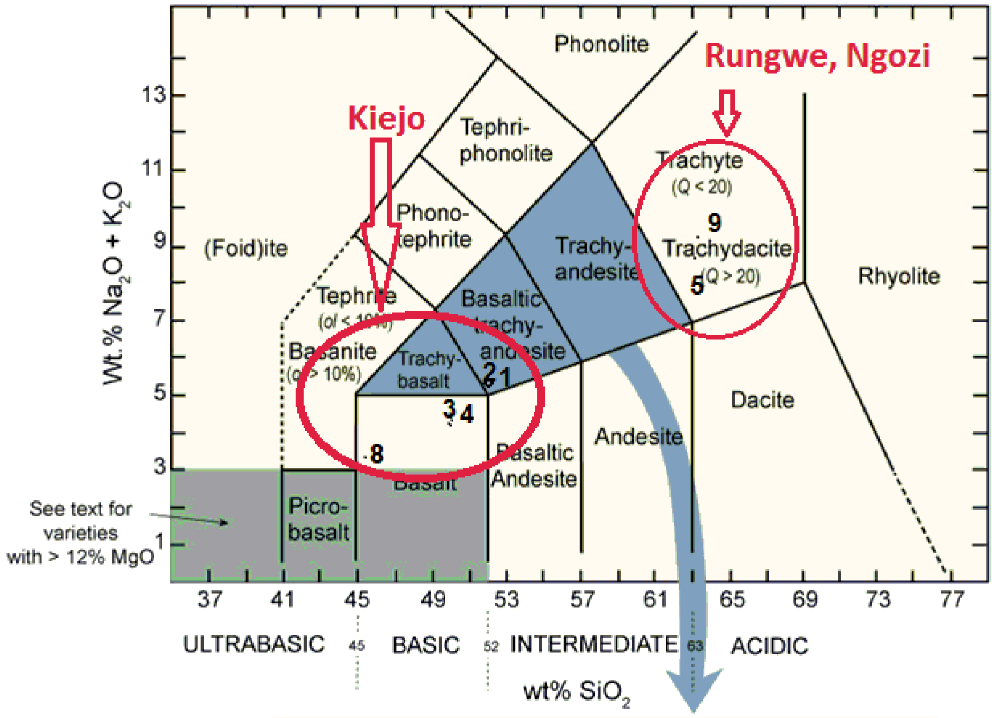
Figure 14: The plot of HFS elements

DISCUSSION

Based on the petrography results, it can be observed that there is lack of olivine and presence of orthopyroxene, the high amount of SiO_2 wt% (~ 63) as well as (Na_2O + K_2O) wt% ~ 9.38 in the in the Ngozi volcano. This indicate that the volcanic rocks in the Ngozi volcano are a result of a relatively silica saturated magma source. Otherwise, the magma could have originated from deeper in the crust such that it became contaminated with continental crust materials as it was erupting.

The eruption that resulted into the Ngozi volcano was most likely explosive due to the fact that, today, there is a relatively large crater (~ 3 km diameter) observed there that is now a lake (Lake Ngozi), Fig. 4.

The higher silica content observed could be explained by at least two factors even if the magma could have originally been basic in composition prior to emplacement to the surface: (1). Magma contaminating with continental crust materials and (2). Nature of eruption, i.e. when there is long interval of repose of the eruption, mature volcanoes evolve felsic magmas in the uppermost level of the reservoirs and the longer the interval between eruptions, the greater the volume and explosivity of the first liquid to be discharged (McBirney 1993).



Further subdivisions of shaded fields	Trachybasalt	Basaltic Trachyandesite	Trachyandesite
$Na_2O - 2.0 \geq K_2O$	Hawaiite	Mugearite	Benmoreite
$Na_2O - 2.0 \geq K_2O$	Potassic Trachybasalt	Shoshonite	Latite

Figure 15: The total Alikali-Silica diagram after Le Bas et al (1986) for volcanic rocks from Kiejo, Rungwe and Ngozi volcanoes. Note the numbers 1-5, and 8-9, refer to RUN01-5 and RUN08-9 respectively.

Based on Fig. 15, the plots of SiO_2 (wt%) versus (Na_2O + K_2O) wt% for all samples from Ngozi, Rungwe and Kiejo fall in the field of trachy-dacite, basaltic trachy-andesite and basalt respectively. Such a pattern highlights close genetical relationship of the magma that formed the three volcanoes; more especially the Ngozi and Rungwe volcanic magmas.

The above relationship shows that the Kiejo lava is basic in nature and falls within the basaltic to basaltic trachy-andesite (RUN01-04 and RUN08) whereas the Rungwe (RUN05) and Ngozi volcanoes (RUN09) are intermediate to felsic in composition. Zooming in the Kiejo volcano, the northern and southern parts of the volcano portray compositional variations, both petrographically and in terms of mineralogy. Petrographically, the northern part is characterized by more magmatic affinity as can be seen from relatively highly altered and zoned olivine crystals.

Anhedral and subhedral orthopyroxenes are characteristic in this part of the volcano. The development of anhedral to subhedral orthopyroxenes indicates that the magma responsible for the emplacement of the northern part of the volcano is undergoing significant magmatic differentiation.

Not much of the rocks in the southern part of the Kiejo volcano show zoning of olivine but rather replacement of the olivine by pyroxene and other silicate minerals as well as twining of the newly formed minerals from replacement of olivine (e.g. Fig. 12), synonymous to discontinuous branch of the Bowen reaction series.

Such a petrographical approach reveal that the Rungwe and Ngozi volcanoes are not as magmatically evolved as the Kiejo volcano. Comparing the former two, the Ngozi volcano is even less evolved than the Rungwe volcano.

Table 2: Major elements as analyzed by XRF at the Geological Survey of Tanzania (LOI data not included).

Element (wt)	RUN01	RUN02	RUN03	RUN04	RUN05	RUN08	RUN09
Al_2O_3	16.54	17.28	13.05	3.36	19.17	14.55	19.83
SiO_2	42.22	44.12	47.14	66.21	59.45	42.75	57.2
Fe_2O_{3T}	8.13	6.56	6.63	6.86	1.36	9.21	1.94
MnO	0.21	0.22	0.19	0.18	0.19	0.22	0.19
Na_2O	7.51	8.56	4.18	4.73	2.87	8.27	1.33
CaO	7.24	7.25	9.49	3.83	0.88	7.83	1.35
MgO	3.44	2.71	4.47	4.18	0.55	5.31	0
K_2O	2.43	2.27	1.21	0.42	5.06	1.15	6.27
TiO_2	1.78	1.66	1.67	0.74	0.55	1.43	0.27
P_2O_5	0	0.12	0.18	3.26	0.08	0.34	0
Total	89.5	90.75	88.21	93.77	90.16	91.06	88.38

Based on geochemical data (Table 2), the Ngozi volcano is relatively more felsic (silica saturated) as compared to the Rungwe volcano. The latter volcano is relatively more felsic compared to the Kiejo volcano. Again, as with the petrographic data, the geochemical data e.g. Major elements: SiO_2 (wt%) versus (Na_2O + K_2O) wt% of the samples from Kiejo volcano show two significant clusters: those related to the northern part of the volcano (RUN01-3) and those related to the southern part (RUN04, 08). Similar geochemical approaches for all samples from either volcano clearly indicate that there is a relationship between age of eruption and chemical composition of the volcanoes

Tectonic and Magmatic Differentiation Implications

The entire RVP is confined within the Triple Junction: The area thought to be the structural node defined by both the Eastern and Western branches of the Eastern African Rift and the Nyasa rift. The volcanoes studied here portray a NW-SE trend: the oldest (Ngozi) to the northwestern end, and the Kiejo to the southeastern end. According to Delvaux and Williams (2008), two sets of sub vertical faults that trend NNE-SSW and ENE-WSW control both major and minor late Quaternary volcanic vents and the discharge of thermal springs as well as CO_2 gas.

Based on these information (geochemical and structural), a model can be proposed: (1) a magma from the upper mantle found its way out through deep seated fissures that are a function of both the Precambrian fabric and selective reactivation of the structures (shear zones and faults) in tune with the tectonic stress field at the present time associated or not with far field stress, (2) the rate and intensity of the magma eruption being a function of pressure of the magma, amount of magma and volatile components, size of the magma through a given fissure, the total number and size of faults reactivated and their orientation in relation to stress field, and (3) the magnitude of stress field with time, the presence and size of the regional structural node (s) – the Triple Junction played a great role.

Assuming a single magmatic chamber source within the continental crust, one would imagine of an inclined magmatic body in relation to positions of the three volcanoes; Kienjo being basic in composition and close to the root/ base of magma and Ngozi relatively far away from the base of the magma owing to its felsic composition nature.

The spatial relationship among tectonic rifting lineaments, larger volcanoes and numerous smaller vents in the RVP has been analyzed by Fontijn *et al.* (2010). The detailed Holocene eruptive history of Rungwe was recently studied by Fontijn *et al.* (2010; 2011), and showed that Rungwe has had at least 8 moderate- to large-scale explosive eruptions in the last ~4,000 years. The most voluminous one was the ca. 4-ka Plinian-style Rungwe Pumice eruption. The volcanic materials on the Rungwe volcano (summit) having trachytic composition. In this work, it is shown that the summit volcanic rocks have similar composition (but with geochemical trends towards dacitic; i.e. trachydacitic).

CONCLUSION

Geochemical data show that most recent eruptions in the Kiejo volcano are more basaltic to basaltic trachy-andesite and those from the Rungwe and Ngozi, are trachy-dacite. These data also show that the last eruptions related to the Rungwe volcano (summit) and the last eruption of the Ngozi volcano (related to the Ngozi rims) are close related in terms of geochemical composition. This may imply that the ages for last eruptions from both Ngozi and Rungwe are also close related. The data also show that the three volcanoes are most likely from a single magmatic source that came to the surface through structures such as deep seated faults.

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