DIPONEGORO UNIVERSITY

CHEMICAL AND PETROGRAPHY ANALYSIS
IN PETROGENESIS STUDY OF MURIA VOLCANO, CENTRAL JAVA

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Chemical and Petrography Analysis in Petrogenesis Study of Muria Volcano, Central Java

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ABSTRACT

Muria volcano is located in the north coast of Central Java, in a northward extending land known as Muria Peninsula. Muria volcano has long been known as an anomaly of volcanoes in Java due to its different features, most conspicuous viewed from its position, compared to the other volcanoes, which is not located in regular pattern of Java's volcanic arc.

Purposes of this research are identifying characteristic of Muria magma, finding out relationships between characteristic of Muria erupted lavas which is expressed in mineralogy and geochemical to its tectonic setting, the last is proposing petrogenesis of Muria volcano. Methods used in this research are survey method, descriptive method, and laboratory method. Extended by analytical method include petrography analysis and chemical analysis. K-Ware Magma software is used in helping these analyses.

Igneous rocks from Muria volcano have intermediate to ultrabasic character regarding to its silica abundances with molecule weight percentage of SiO_2 = 44.25 to 55.42. Respects to silica saturation, these rocks are ranged from silica saturated which consists only saturated minerals, to silica undersaturated which essentially contains minerals such as olivine and feldspathoids i.e.: leucite and nepheline. Magma series of Muria volcano fall into the alkaline magma series shown by molecule weight percentage of $Na_2O + K_2O$ = 9.24 to 10.1, then its subdivision is ranging from K-series to high-K series. Muria volcano is a typical of transitional volcanism between island arc and intra-continental plate environment regarding to its tectonic setting. Enrichment of lithophile elements (LILE) along with niobium anomaly in spiderdiagram marks an involvement of subduction zone fluid added to the mantle source of magma during partial melting. However, niobium anomaly still is not showing real depletion of niobium whereas it is truly has been slightly enriched from mid-ocean ridge basalt (MORB) value. Slight enrichment of the other high field strength elements (HFSE) marks the existence of magma source rich of incompatible elements i.e.: strontium, rubidium, barium, potassium, thorium, niobium and group of rare earth elements.

Keywords: *geochemistry, magma, muria, mineralogy, petrography, tectonic*

INTRODUCTION

Background

Muria volcano has long been known as an anomaly of volcanoes in Java due to its different features. Indeed, this unusual magma emanation feature should have certain characteristics such as expressed in many igneous provinces with certain tectonic patterns. However, studying a lot of characteristic related to this issue is impossible at one time. Nevertheless, some attempts to provide information regarding to igneous petrogenesis in such from mineralogy and geochemical data are now considered to be more petrogenesis-oriented by many igneous petrologist.

In order to make a more petrogenesis-oriented approach, this research is performed by two way identification which each other are closely related, petrography and chemical analysis. Petrography is preferable in identifying optical features from rock forming minerals and texture which strongly indicate crystallization processes within igneous rocks. Chemical analysis is also desirable as hint at mineral content even though it tells nothing about rock textures. These two way identification are intended to be combined in order to make a comprehensive igneous rock data within the Muria. This combination would really be a help to get the brighter answers in discussing the Muria magma, therefore to its petrogenesis.

Research Objectives

The objectives of the research are:

a. To identify characteristic of Muria magma using petrography and chemical analysis.
b. To find out relation between characteristic of Muria erupted lavas which is expressed in mineralogy and geochemical to its tectonic setting.
c. Proposing petrogenesis of Muria volcano.

Location

Muria volcano is located in the north coast of Central Java, in a northward extending land known as Muria Peninsula. It is approximately at latitude 6^{o} 37` south and longitude $110^{o}$ 53` east. It belongs to three different regional sectors including Kudus at south, Pati at east, and Jepara at north and west part of volcano. It takes about two hours to reach the southern flank or Rahtawu cauldron from Semarang using vehicle and about two hours more if willing to try for continuing to reach the northern flank or Tempur cauldron.

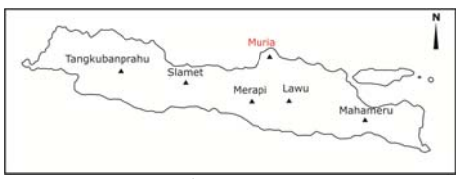

Fig. 1. Location map of Muria volcano.

Scope of Research

In attempt to avoid broadening of discussion about petrogenesis of Muria volcano, this research is focused into two geological interests which believed to be essential in providing information related to igneous petrology: mineralogy and geochemistry. Based on these two interrelated interests, steps to discuss the Muria petrogenesis are taken carefully.

Problems

The problems which need to be revealed in this research are:

a. What is characteristic of Muria magma regarding to its mineralogy and geochemistry?
b. What do those characteristics express to?
c. How is petrogenesis of Muria regarding to relationship between those characters and tectonic setting?

Hypotheses

Hypotheses related to this research are:

a. Igneous rocks of Muria volcano consist of silica deficient rocks regarding to its silica composition.
b. Igneous rocks of Muria volcano will probably show high alkalinity value, some minerals may present to express this value.
c. Muria volcano is suspected as an evidence of transitional volcanism from island arc (recent Java arc) to intra-plate (Sunda plate) volcanism.

METHODOLOGY

Research Methods

Methods used during this research can be divided into survey method, descriptive method, and laboratory method. The two main analysis techniques performed in this research are petrography and chemical analysis. Both of them are interrelated in study of rocks mineralogy, but chemical analysis itself is further useful in expressing geochemical features.

Petrography Analysis

Study of textural characteristic of igneous rocks beneath a microscope is preferred instead of megascopic identification. Rock sample should be prepared in thin section which has reliable thickness, commonly used in 0.03 mm thick for microscope identification. The primary instrument used in petrography is polarization microscope, which is exclusively designed for studying interaction of light and matter or, in this case, crystal of rock forming minerals respectively.

Interaction between light and certain crystal will show a distinct behavior known as optical properties. From this subject, each mineral can be determined one by one according to sequence in **Fig. 2**.

Igneous rock classification used generally refers to standardized rock classification by the IUGS Committee in Petrology proposed by Streckeisen (1967). If the mineral mode cannot be determined as is often the case for volcanic rocks, then a chemical classification of total alkalis versus silica is used. The sequence that should be followed is shown in **Fig. 3**.

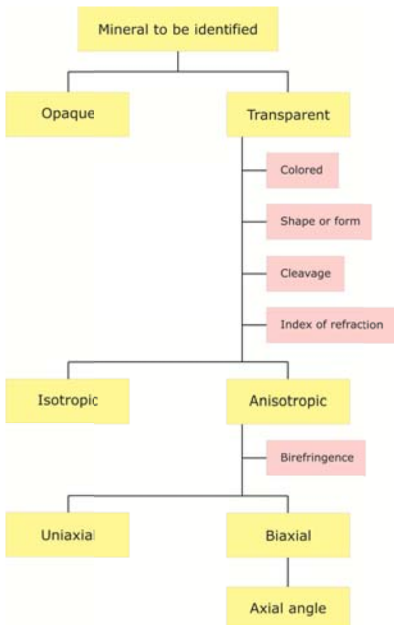

Fig. 2. Systematic identification of mineral regarding to its optical properties (Kerr, 1959).

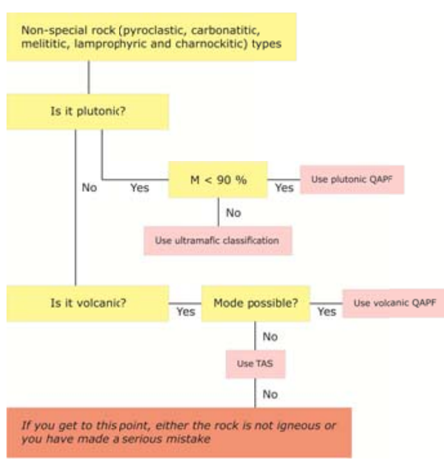

Fig. 3. Flow chart for the IUGS classification of igneous rocks usage (Le Maitre *et al*., 1989).

Chemical Analysis

Determination of an extensive range of major and trace elements is desirable within analysis of igneous rock. Instrumental method used in this research is only XRF, and this is provided by Geological Research and Development Center and National Atomic Energy Agency.

A variation diagram of wt. % Na_2O + K_2O versus wt. % SiO_2 or TAS provide a useful way of displaying the wide compositional range of terrestrial volcanic rocks and their nomenclature. This diagram was proposed by Subcommision on the Systematics of Igneous Rocks, Le Bas *et al*. (1986). This is also consistent with the QAPF classification, based on modal proportions of constituent minerals by Streckeisen (1967). Using this TAS, distinguishing the alkaline and subalkaline rocks will refer to alkali-silica discrimination diagram compiled by Rickwood (1989). Another version in distinguishing the alkaline and subalkaline rocks will refer to Cox *et al*. (1979). Further, rocks of the alkaline magma series may be subdivided into sodic (Na-series), potassic (K-series), and highly potassic (high-K series) in terms of a plot of K_2O versus Na_2O; this subdivision of alkaline magma series refers to Middlemost (1975).

During this research, the data source of spiderdiagram for abundance of trace element of igneous rocks of Muria volcano is adopted from Edwards *et al*. (1991) will be compared with typical island arc high-K calc-alkaline and tholeiitic basalts spiderdiagram from Pearce (1983).

Flow Diagram of Research

Systematically, steps conducted during this research might be seen in the diagram below.

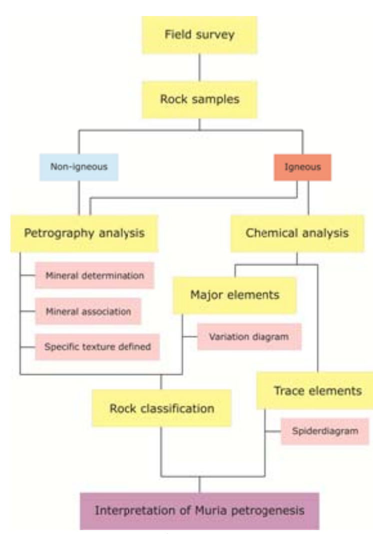

Fig. 4. Research's flow diagram.

RESULT AND DISCUSSION

Petrologic Features

For ease when giving interpretation of all igneous rock origins based on modal mineral, overall mineral abundances and plot of igneous rock samples in QAPF diagram is preferable as seen in Table 1 and **Fig. 5**. Note that, overall igneous rocks from Muria volcano are more likely fall into the middle to lower part of double triangle QAPF plot diagram. From this, it is can be further separated into two distinct groups of rocks. First is the silica saturated rocks group, lack in feldspathoid minerals, which plot falls near the border of line AP marked by blue dashed line circle. The other group is the silica undersaturated rocks group, considerably richer in feldspathoid and also ferromagnesian minerals, which plot falls near the line PF marked by green dashed line circle.

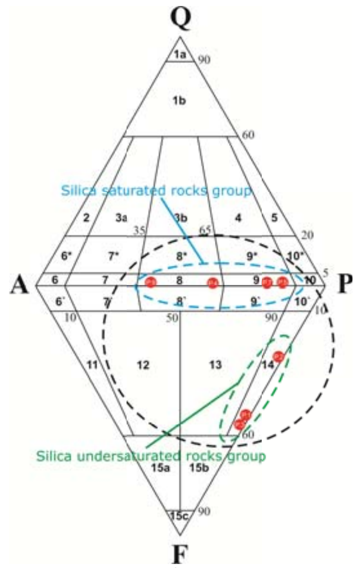

Fig. 5. QAPF plot of overall igneous rock samples.

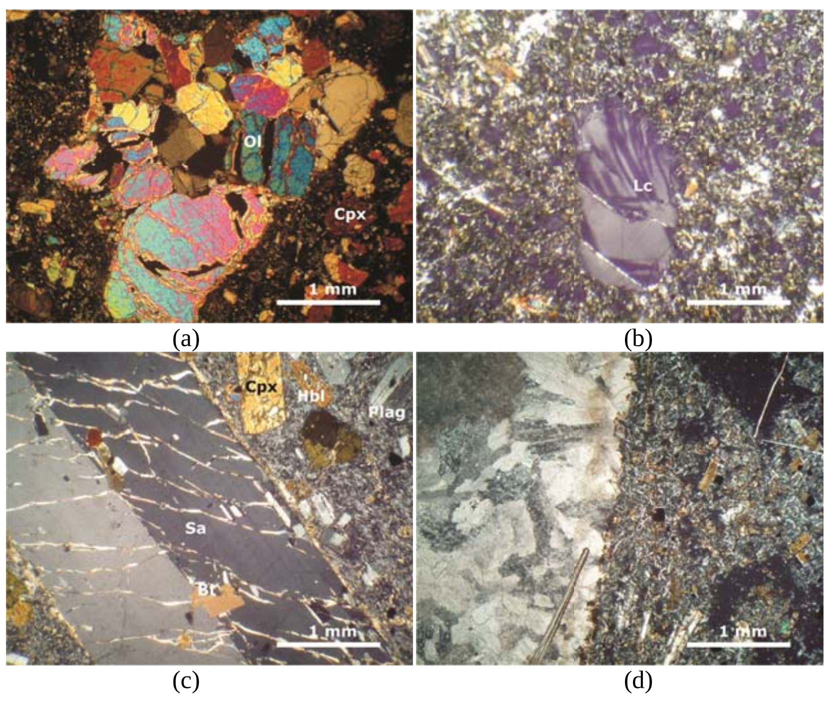

Fig. 6. (a) Cluster of olivine in olivine tephrite (40x, crossed polar). (b) Phenocryst of leucite in leucite tephrite, note that rounded smaller leucite crystals scattered the entire groundmass (40x, crossed polar). (c) Very large crystal of sanidine in trachyandesite (40x, crossed polar). (d) Bordering line in the center of picture is dividing fossiliferous calcite in the left side and fine crystal within lava in the right side (x40, crossed polar).

Table 1: Mineral abundances of all samples for designation of QAPF diagram.

		Thin section sample						
		P.1	P.2	P.3	P.4	P.5	P.7	P.9
Abundance Percentage	Q	0	0	0	0	0	0	0
	A	0	0	0	27	10	11	51
	P	27	47	29	49	70	71	29
	F	23	23	37	0	0	0	0
	M	50	30	34	24	20	18	20

Q = Quartz A = Alkali Feldspars P = Plagioclase F = Feldspathoids M = Mafic minerals

It can be summarized; there are two different mineral-based rock groups which have been produced in such a single magmatic activity during genesis of Muria volcano. Differentiation like this can be explained using Bowen's reaction series which is responsible in changing of magma composition. The first unmodified magma erupted will more likely to be basaltic, rich in Fe, Mg, and Ca content, low silica content expressed by many of mafic minerals; this may refer to undersaturated condition i.e.: olivine tephrite and leucite tephrite. While repeated fractional crystallization occurs, erupted magma will become progressively more silica-rich; this is referring to silica saturated condition i.e.: andesite and trachyandesite, see **Fig. 6**. The involvement of magma assimilation with country rock will also makes further changing of magma composition. The signature of magma assimilation with sedimentary bed by xenolith found at the eroded cauldron in south flank of Muria volcano gives a strong proof that this process has been occurred. Many calcareous parts from fossil form has been strongly recrystallized due to thermal metamorphism during remelting by magma which gone uncompleted. The other part may still showing fossil form in good condition. This reaction is occurred as one of important process which modifies magma composition.

Table 2: Major element analysis data from Muria Volcano.

Oxides (%)	Sample C.1	Sample C.2	Sample C.3
SiO_2	44.25	54.05	55.42
TiO_2	0.927	0.439	0.487
Al_2O_3	18.28	19.07	19.85
Fe_2O_3	8.3	4.71	5.57
MnO	0.161	0.149	0.154
MgO	6.02	0.892	1.2
CaO	11.23	4.56	3.98
Na_2O	3.96	4.49	3.5
K_2O	5.28	5.61	5.98
P_2O_5	1.13	0.311	0.403
NiO	0.0112	0.0072	0.0112
ZrO_2	0.033	0.0467	0.0021
CuO	0.0094	0.0022	0.0014
SrO	0.118	0.154	0.0499
V_2O_5	0.0436	0.0184	0.0031
Cr_2O_3	0.0519	0.0021	0.189

Major Element Characteristics

In order to review the overall alkali-silica characteristics of rocks, the results are plotted together into TAS diagram as seen in **Fig. 7**. Note that the entire plot fall above the dividing line into the alkaline suite field marked by red dashed line circle. Further subdivision of alkaline magma series, it falls into the K-series to high-K series as seen in **Fig. 8**. Silica composition is ranged from intermediate to basic-ultrabasic. If it is correlated to analysis of modal mineral using petrography results, intermediate rocks here are similar to silica saturated rocks group, and basic-ultrabasic rock group here is similar to silica undersaturated rocks group. As suspected from petrographic identification, major elements characteristic express the existing optically observed minerals. Igneous rocks from Muria volcano are surely to be alkaline magma origin. Respect to this alkaline affinity, key minerals which appear known to be sodium-potassium elements bearing include orthoclase or sanidine, Na-plagioclase or albite, nepheline, and leucite; and also such an essential common accessory mineral associated with includes biotite. These minerals are present in expressing the alkaline affinity of Muria's magma.

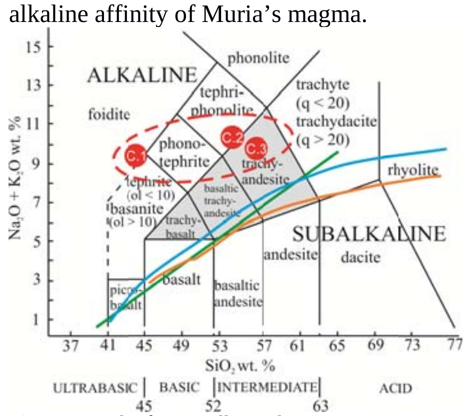

Fig. 7. TAS plot for overall samples.

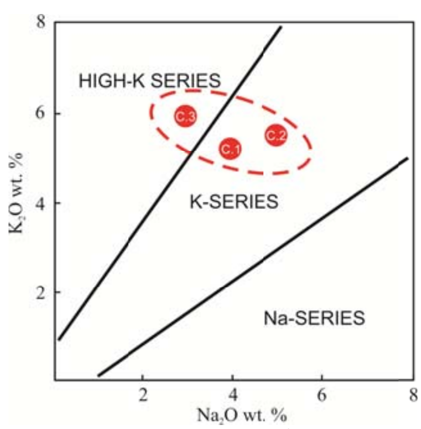

Fig. 8. Alkaline magma subseries for overall samples.

As previously written in summary of petrologic features section, chemical data has supporting the petrological data which also showing two different mineral-based rock groups have been produced a single magmatic activity during genesis of Muria volcano. Fractional crystallization and magma assimilation are responsible processes taking on here. However, chemical data are able for further explaining about alkaline affinity of Muria's magma. The element K and Na; and of course Si too, are signature of further step of magma evolution due to fractional crystallization, and these elements are tend to be highly concentrated in the crust. The contamination of magma by assimilation with crustal rocks will also further modify the magma composition.

Trace Element Characteristics

Using incompatible trace element data adopted from Edwards et al. (1991), the spiderdiagram is created to understand the pattern of trace element abundances from igneous rock of Muria volcano. This spiderdiagram is already rearranged from its original version in order to adapt the comparing patterns for typical island arc high-K calc-alkaline and tholeiitic basalts from Pearce (1983). Designation for tectonic environment of Muria volcano is shown in **Fig. 9**.

Relatively less mobile or heavy trace elements (HFSE) Th, Nb, Zr, Ti, Dy, Y, Yb, and Lu are not much displaced and relatively close to MORB composition which reflecting pre-subduction characteristic. Group of these heavy elements are slightly displaced upward or enriched at Nb, Zr, and Ti. This elements enrichment, along with enrichment pattern of some LILE; especially light REE from La to Eu, makes overall pattern of 'humped' or rather convex shape. This pattern is usually appearing in ocean island basalt (OIB) composition which becomes signature the existence of incompatible element rich magma source, one kind of intra-plate volcanic important signature.

The spiderdiagram have distinctive trough at Nb which often called as niobium anomaly, this is considered to be related to petrogenesis of island arc setting where subduction occurs. It is need an attention to be paid whereas trough at Nb is not really means real depletion in Nb because Nb concentration is truly still close to that of MORB. The surrounding element plots are far more enriched except Nb itself that makes Nb appears as trough. But when it is looked carefully, Nb itself is has considerably enriched for about two or three times from MORB value although the surrounding trace element abundances are higher or have far more richer and still make a trough-look at Nb. But this trough is not as strong as that displayed by purely subduction-related magma.

Wilson (1989) on her book wrote distinguishing feature when reading spiderdiagram patterns of different magma sources:

"Compared to the relatively smooth shapes of the MORB and OIB spiderdiagrams, that of the subduction-related basalt is strongly spiked. …, the positive spikes are mostly a consequence of components added to the mantle source of basalts by subduction zone fluids [p. 21]."

Spiderdiagram pattern is not only rather spiked but also convex. The causes of spiked-convex feature are due to incompatible trace element addition which has been explained above. This transitional pattern indeed marks transitional tectonic environment of Muria volcano from island arc to intra-plate environment; or to OIB according to statement of Wilson (1989). Take a look on real geological setting of Muria volcano, the island arc respects to recent Java Arc, and then the intra-plate environment respects to Sunda plate or southeast part of the great Eurasian plate. The matching of spiderdiagram pattern for Muria volcano to standard pattern used by Pearce (1983) and its designation of tectonic environment might be seen in Figure 4.37 which is placed in the next page.

Petrogenetic Model of Muria Volcano

Muria magma has already passed such a complex processes in its genesis involving subduction-modified magma sources at mantle depth and contamination of crustal rocks in the upper level. Explanation for overall petrogenetic of Muria volcano is written below, while the visualization model might be seen in **Fig. 10**. Assimilation due to contamination of magma by sedimentary rocks is strongly proven by the evidence of remained large xenoliths consist of sedimentary origin rock in Rahtawu cauldron. Igneous rocks from Muria volcano are product of the alkaline magmatism with emphasis on potassic character. The magma series ranged from K-series to high-K series. Mineralogy data has proven alkaline related minerals association within igneous rocks such as leucite, alkali feldspar, plagioclase, olivine, clinopyroxene, hornblende, and biotite. These minerals association express the alkaline magma affinity with some of them are potash-bearing minerals e.g.: feldspathoids, alkali feldspars, and biotite. As the element of K, Na, and Si which is relatively concentrated in the more evolved magma, it also can be related to their behavior of tendency being concentrated in the crustal rocks. These elements are termed lithophile in geochemistry because of their tendency for being concentrated in silicate phase. Crustal rocks which in case of petrogenesis of Muria volcano are the sedimentary rocks which induced assimilation of Muria magma, and now remained as xenoliths. Looking at the position from the main island arc of Java, Muria volcano occurred in the back arc setting where sediments tend to be deposited in large amount. This position of occurrence may explain why Muria magma suffered high contamination and resulting in the alkaline affinity magma. Igneous rocks from Muria volcano also having a set of silica spectrum ranging from ultrabasic to intermediate, which also to be a proof of differentiated magma product. Modification of magma composition results might be explained using Bowen's reaction series where the last minerals formed in the series proving the more differentiated or evolved magma product. The more differentiated magma is relatively younger than undifferentiated one within period of volcanic activity of Muria volcano. However, to ensure the source of Muria magma origin, this research also focused its concern on trace element. The trace element analysis has resulting in a transitional pattern of magma sources between two different tectonic settings. First is the involvement a subduction-zone in the south of Java which responsible in producing LILE concentrated fluid from remelting of oceanic crust of oceanic plate of Indian plate and subducted sediments from both reworked continental rocks of Sunda plate and oceanic sediments. In reality, oceanic crust in general has trace element composition similar to MORB because it is actually rocks which were generated at the spreading centers of mid-oceanic ridges, and then it was moved by plate motion in passed times until arrived to continental margins. LILE is strongly concentrated in the crustal rocks whereas can be moved into magma by subduction mechanism along the destructive plate margins. The next is the involvement of magma generation from subcontinental lithosphere at intra-plate setting beneath the Sunda plate. An intra-plate volcanism usually shows enrichment of most incompatible elements, both in LILE and HFSE. And these components must have been included into the magma. The mantle convection above the subducted oceanic plate slab must have been mixed these two different magma generations into a subduction-modified magma source which generate Muria magma.

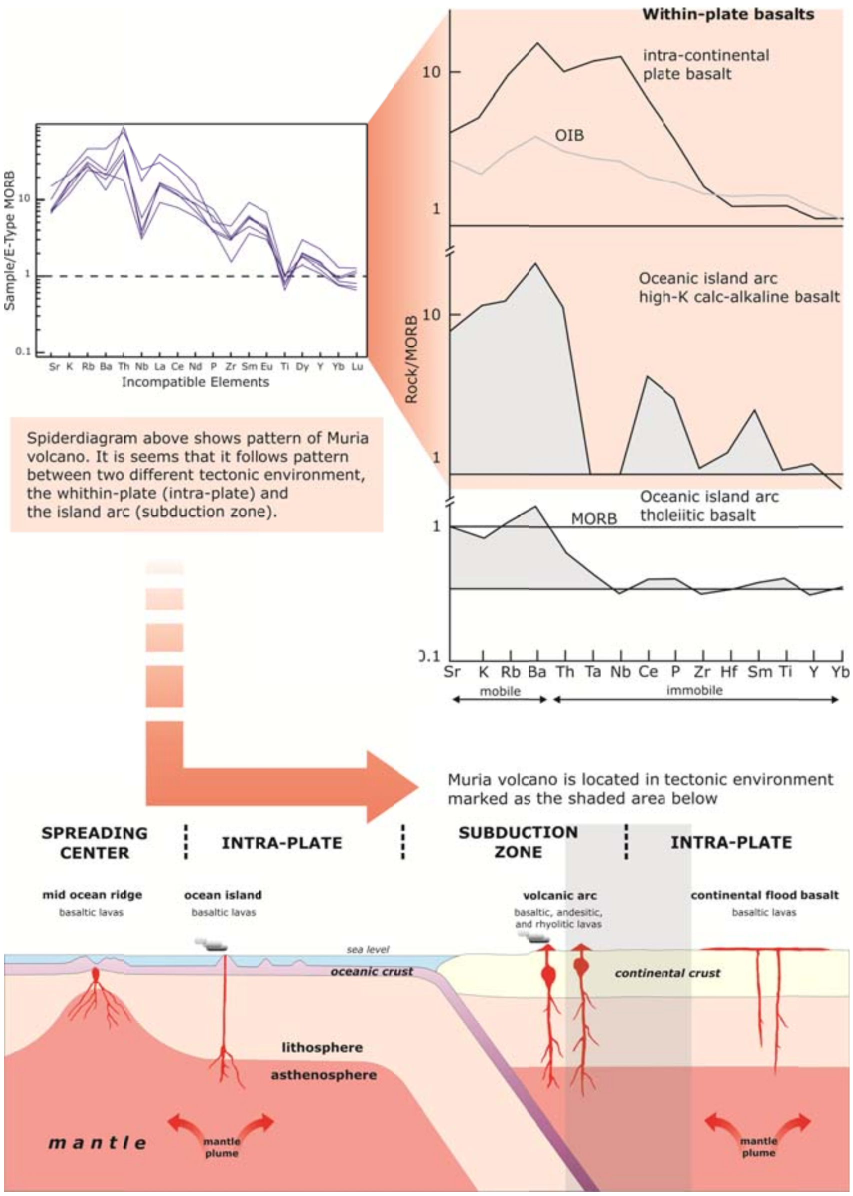

Fig. 9. Designation of spiderdiagram pattern of Muria volcano to its tectonic environment.

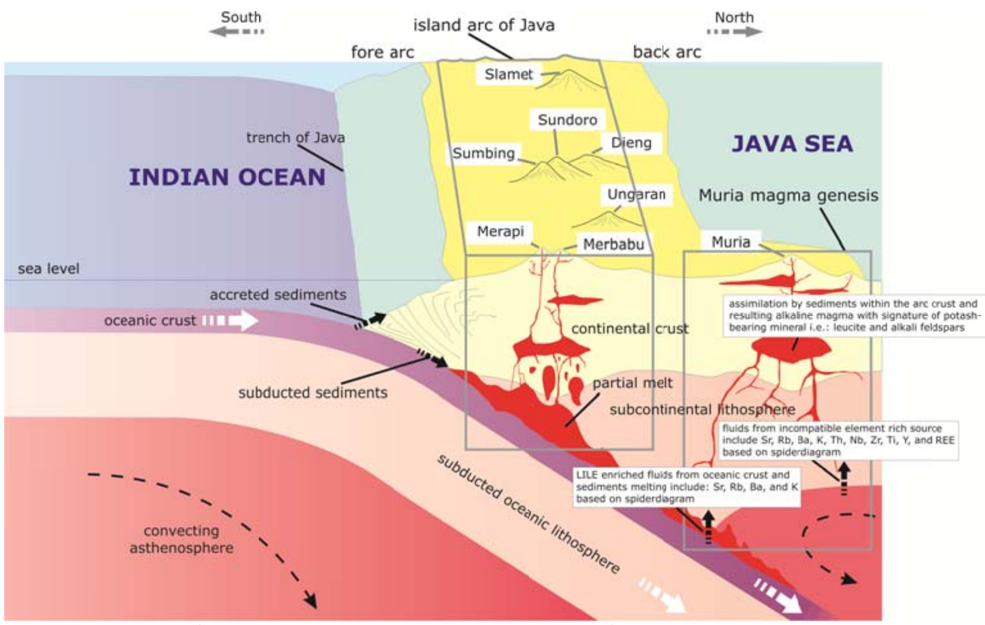

Fig. 10. Visualization of summarized process involved during generation of Muria magma.

CONCLUSION

Igneous rocks from Muria volcano have intermediate to ultrabasic character regarding to its silica abundances with molecule weight percentage of SiO_2 = 44.25 to 55.42 in wt.%. Magma series of Muria volcano fall into the alkaline magma series due to its high alkalinity value with molecule weight percentage of $Na_2O + K_2O$ = 9.24 to 10.1 in wt.%, then its subdivision ranging from K-series to high-K series. Key minerals which present to express this high alkalinity value are alkali feldspar and leucite. Muria volcano is a typical of transitional volcanism between island arc and intra-continental plate environment regarding to its tectonic setting.

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APPENDIX