Temporal change of Barujari Volcano magmatic process: Inferred from petrological study of erupted products since AD 1944

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Abstract - Barujari volcano is an active volcano located in Lombok Island Indonesia. The volcano is a part of post caldera stage of Rinjani volcano. The volcano shows strombolian to vulcanian type eruption and produces mainly lava with basaltic-andesitic composition (54-56 wt% SiO₂). The volcano actively erupts several times during past 70 years. However, temporal change of its petrological characteristic has not been discussed. This paper discusses petrological changes in Barujari volcano erupted material through time from AD 1944 to 2015. Total 31 samples erupted from AD 1944, 1966, 1994, 2004, 2009, and 2015 are observed and analyzed with XRF method. Our study shows that most of samples can be classified into basaltic trachy-andesite with 53-56 wt% SiO₂. All samples show nearly linear trend in harker diagram and shows no systematic change through time. However, AD 1966 shows curved trend and more silicic composition compared to other samples. We suggest that magma mixing with repeated injection of more mafic magma play an important role in producing most of basaltic-andesitic Barujari lava as suggested by linear trend of harker diagram and appearance of heterogeneity in groundmass. AD 1966 samples also contain evidence of magma mixing but curved trend does not suggest simple mixing processes. Appearance of olivine-poor samples in SiO₂ rich AD 1966 samples might suggest more close system differentiation process that mixed with common Barujari products.

1. Introduction
Barujari is an active volcano located in Lombok Island (figure 1). The volcano is a part of Rinjani Volcano Complex and grows inside huge Rinjani Caldera. The volcano is a part of post-caldera stage of Samalas (Old-Rinjani) Volcano [1]. It shows strombolian to vulcanian eruption style and produced mainly lava flows, scoria, and pyroclastic ash fall with basaltic-andesitic composition[1]. Since its first recorded eruption in 1847, Barujari has erupted at least 19 times with various rates but good record of its eruption detail begun from AD 1944 eruption.
During AD 1944 to AD 2015, Barujari has erupted 6 times that produced lava flows [2]. Study on this lava flows shows that Barujari compositional variation is relatively constant within 54 to 56 wt% SiO₂ range [3]. However, temporal change of its eruption activity has not been discussed in detail. Therefore, this research will discuss temporal changes that occurred in Barujari Volcano from AD 1944 to AD 2015 using combination of petrographic observation and whole-rocks geochemical analysis. The study focused on lava that produced during AD 1944 to AD 2015 period.
2. Data and Methods
The study focused on lava flow produced in 6 eruption periods, A.D. 1944, 1966, 1994, 2004, 2009, and 2015 (figure 2). Total of 30 samples were collected that composed of 6 samples for each eruption period, except for 2004 (1 sample) and 2015 (5 samples). All samples were observed under polarization microscope. Modal mineral composition was determined with point counting method for 3000 points for each sample. Whole-rocks geochemistry were obtained with X-Ray Fluorescence method using Spectric MagiX PRO systems in Hokkaido University.

3. Results and Discussion
Barujari lava showed porphyritic texture with phenocryst volume ranged from 25 to 40% (figure 3a). Plagioclase was dominant phenocryst phase followed by clinopyroxene, olivine, and orthopyroxene. Mineral clots are abundant. Plagioclase showed complex multi-texture within single grain (fig.3c). The textures found were mostly sieve texture and zoning. Clear plagioclase rarely found. Clinopyroxene was second most-abundant phenocryst phase, mostly euhedral, no zoning or very weak zoning, and few crystals showed oscillatory zoning or simple zoning (figure 3d). Olivine was small in term of size and volume percentage but found scattered throughout thin section (figure 3f). Olivine with reaction rim were found. High SiO$_2$ samples from AD 1966 were found poor in olivine. The groundmass is composed of plagioclase microlith, pyroxene, and glass.

Figure 3. Representative thin section of Barujari Lava a) porphyritic texture b) groundmass heterogeneity c) complex texture in plagioclase that composed of clear, sieve, and oscillatory zoning d) euhedral clinopyroxene with resorbed and zoned rim e) crystal clot composed of pl, cpx, & ol e) isolated olivine
All Barujari lava analysed could be classified as basaltic trachy-andesite. SiO$_2$ ranged from 53 to 56.3 wt% and high in aluminum (more than 17 wt% Al$_2$O$_3$) (figure 4). All samples also showed high-K Calc-alkaline series. All samples showed relatively linear trend in Harker diagram, except AD 1966 samples that show curved trend (figure 4). Geochemical compositions were constant and showed no systematic change through time but increasing trend was observed in AD 1966 (figure 5).

Figure 4. Representative Harker diagram of Barujari Volcano lava.

3.1. Evidences of Magma Mixing/Mingling
We suggested that magma mixing or mingling play an important role in producing Barujari lava. This statement could be supported by several evidences. First, there was heterogeneity observed both in hand specimen and thin section. The most obvious evidence of magma mingling could be found in hand specimen where two different color mixed in one rock sample. The sample showed darker color lava mingled with lighter color lava. In thin section, two different ground mass could be observed (figure 3b). Secondly, disequilibrium features, such as sieve texture, were abundant in plagioclase and occasionally found in clinopyroxene. Sieved plagioclase could be formed by interaction of plagioclase with more mafic or hotter melt[4][5]. Third, despite not ideal, the trend for each eruption period showed relatively linear trend in Harker diagram (figure 4). This is consistent with previous study about mixing process in Barujari lava that are the result of mixing between basalt and andesitic magma [6].
3.2. Possible scenario for constant variation

Barujari lava products showed constant variation both in petrographic textures and geochemical composition. Constant geochemical variation is also observed in Arenal Volcano in Costa Rica [7]. This constant variation is caused by constant mixing-dominated process and repeated injection of mantle-derived basaltic magma that buffering the final products [7]. This scenario might explain constant variation in Barujari lava products. This statement could be supported by obvious mixing/mingling evidences that can be found in Barujari products. Multiple injection of basaltic magma might buffer andesitic magma in main chamber and affected the final products to become basaltic-andesite. Abundant plagioclase with multiple sieved-zoning texture supported repeated injection scenario in Barujari system [8].

![Figure 5](image.png)

**Figure 5.** diagram showing correlation between time and some oxide from Barujari lava. The trend showed no systematic changes through time and relatively constant but increasing trend were observed in AD 1966 products.

3.3. Anomaly and non-linear trend in AD 1966

The AD 1966 samples contained similar evidence for magma mixing/mingling, e.g. sieved plagioclase, groundmass heterogeneity but the samples show curved trend. The AD 1966 products also show increasing geochemical range (figure 5). The high SiO$_2$ samples from AD 1966 were poor in olivine. This might suggest AD 1966 products underwent different magmatic process compared to samples from other eruption period.

We suggested that different magma path might lead to change in AD 1966 products. AD 1944 eruption is considered as flank eruption because its eruption was produced from northwest crater (900 m from central crater) (figure 2). Magma path in AD 1944 might not affect central magmatic chamber. This condition could provide longer residence time for magma to differentiate and produce olivine-poor basaltic-andesite that erupted in AD 1966 from central crater.
4. Conclusion
Magma mixing is important process that occurred in all eruption periods of Barujari Volcano. The mixing process involved injection of more mafic and less mafic magma. The injection of more mafic magma may buffer final erupted products to become constant in composition. Even though Barujari shows small magmatic changes, but anomaly in AD 1966 is considered as significant change in the evolution of Barujari magmatic processes. This change might be caused by different magma path between AD 1944 and AD 1966 that lead to longer magma residence time process prior to AD 1966 eruption. More detail research for mineral texture and composition is needed in order to confirm the processes and dynamic in magma plumbing system.

Acknowledgments
The authors thank Lembaga Pengelola Dana Pendidikan (LPDP/Indonesia Endowment Fund), Ministry of Finance, for sponsoring first author’s master degree program in Hokkaido University. Author would also thank Haryo Edi Wibowo, Kanai Chizuko, & Taniuchi Hajime for discussion and preparation of the samples.

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