Crystal size distribution (CSD) of plagioclase phenocryst-microphenocryst and the calculation of crystal resident times in the continuous central eruption sequences of Mount Lasem, Central Java, Indonesia

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Abstract. Mount Lasem is an extinct volcano in Central Java. Based on field work, five continuous central lava eruption sequences were identified. The rocks sampled from those lava units were classified as andesite which exhibit sign of magma mixing based on textural features from optical microscopy observation. With consideration of the importance of plagioclase in magma cooling reconstruction, a quantitative approach using crystal size distribution (CSD) of plagioclase phenocryst (long axis $\geq$0.5 mm) and microphenocryst (long axis 0.1 – <0.5 mm) from five lava units was conducted. This method, which has never been applied to the eruption products of this volcano, revealed variation of magma resident time during the continuous central eruption phase of Mount Lasem. By using $G=10$-10 mm/s (growth rate) for plagioclase phenocryst and microphenocryst, residence times of the magma for both populations were predicted at 63 – 120 years and 8 – 18 years respectively. This results show that there are different time and mechanism constrains in the crystallization of the two populations prior to eruption events.

1. Introduction

Mt. Lasem is located east to Mt. Muria in the northern part of Central Java (Figure 1a). These two volcanoes lay on top of approximately 30 km continental crust [1] which may be part of the Southwest Borneo block [2]. There are two major structures bounding the region where Mt. Lasem located, namely Muria-Progo Lineament and Kendeng Thrust (Figure 1a). Previously, Disando and Abdurrachman [3] suggested that Mt. Lasem shows high-K calc-alkali andesite magma affinity.

This paper aimed to unravel processes that happened during magma ascension from magma chamber to the upper part of volcanic pipe of Mt. Lasem through combination of petrographic and crystal size distribution (CSD) approaches. In addition, approximation of the plagioclase crystal residence time was also conducted in order to give the temporal context to the analysis.
2. Data and method

Five hand samples were obtained from five lava units from Mt. Lasem’s central eruption sequence (Figure 1b). Thin sections were made from each sample to be analyzed microscopically under transmitted polarized light microscope. This analysis included recognition of textural features.

Quantitative crystal size distribution (CSD) analysis on approximately 4 mm² area were conducted on each sample using imageJ software [5] following the features recognition. The data acquired from CSD analysis [6] were corrected using CSDslice5 spreadsheet before plotting and calculation in CSDCorrections v.1.55 program [7]. The data were classified into phenocryst (long axis >=0.5 mm), microphenocryst (long axis 0.1 – <0.5 m). For each sample, slopes for those crystal populations were calculated and the values were used to calculate crystal residence time using the following formula:

\[
Tr = \left( \frac{-1}{G \times m^2} \right) / 31536000
\]

Where:
- \(Tr\) = calculated residence time (year)
- \(G\) = crystal growth rate (mm/s)
- \(m\) = crystal population trend line slope

In those formula, \(G\) is chosen based on proposed value by [8] for basaltic magma with cooling time of 3 – 300 years (\(G = 10^{-10}\) mm/s) while 31536000 is the conversion coefficient from seconds to years. In this paper, the following assumptions were employed to interpret mechanism of the crystallization:
- phenocryst crystals were formed when magma ascended to and resided in the magma chamber;
- microphenocryst crystals were formed in upper part of the volcanic pipe.

3. Result and discussion

Based on textural analysis, plagioclase phenocryst of the thin sections exhibited oscillatory zoning and sieve texture (Figure 2) with anorthite (An) content acquired from visual observation using Carlsbad-Albite method ranging from 24-54%. These textural features as well as the increasing An content to the
youngest magma unit suggest that there might be multiple introduction of more basaltic magma to the magma chamber which could also be responsible to the magma eruption due to vesiculation of the more silicic magma [9,10].

From CSD analysis, the distribution of pre-correction measured crystal long axis can be observed in Figure 4. It is also obtained that phenocryst and microphenocryst have different slopes in the CSD graph (Figure 5) which may be caused by magma mixing [11]. This interpretation is not only coherent with the textural and compositional features of plagioclase mentioned in previous paragraph but also raises possibility that the magma chamber received continuous supply of magma [12]. Furthermore, from slope changes of each crystal population, there are processes namely fractionation, accumulation, and changes in undercooling. In case of undercooling changes, the contributing factor might be heating from newly mixed magma [9,10] or cooling due and interaction with cooler wall rocks [13]. The latter mechanism may also lead to crystal fractionation [13].

Figure 2. Sieve and oscillatory zoning texture in plagioclase phenocryst of LN15 lava unit indicating magma mixing.

Figure 3. Anorthite content of the analyzed lava units showing increasing trend as the lava get younger and indicating magma mixing [9,10].

The calculation of residence time, yielded residence time of the plagioclase crystals are 63 – 120 years for phenocryst and 8 – 18 years for microphenocryst-groundmass (Table 1). The higher slope of the microphenocryst population compared to the phenocryst population shows that the microphenocryst population underwent higher undercooling [14] which might happen in higher crustal elevation and also shorter period of time (Figure 6a). This paper suggests that balance of nucleation and growth occurred in microphenocryst formation, while phenocryst crystalization may be dominated only by growth Figure 6c). However, a note about this research should be taken as higher resolution observation using electron microscope was not conducted, detailed distinctive features of the microphenocryst and groundmass crystals were not recorded.

Table 1. Calculation of residence time for analyzed lava units; the lava list is younger downward; abbreviations are: Ph – Phenocryst; Mph – Microphenocryst.

| Lava Unit | Slope of trend line | y-axis intercept | Residence time (years) |
|-----------|---------------------|------------------|------------------------|
| LN11      | -3.993              | -26.531          | 4.440                  | 11.091 | 79.40 | 11.95 |
| LN12      | -4.979              | -7.2444          | 5.982                  | 7.279  | 63.68 | 43.78 |
| LN13      | -2.626              | -38.099          | 2.982                  | 11.937 | 120.73| 8.32  |
| LN14      | -4.654              | -17.397          | 3.679                  | 7      | 68.12 | 18.23 |
| LN15      | -4.798              | -24.352          | 5.671                  | 10.260 | 66.09 | 13.02 |
Figure 4. Histogram of the pre-correction measured plagioclase crystals length showing domination of groundmass and microphenocryst populations.
Figure 5. (a) Composite graph of plagioclase crystals CSD analysis result from the five lava units; (b) composite graph of trend lines of phenocryst and microphenocryst population for the five lava units; (c-g) individual plot of CSD analysis and trend lines for individual lava unit.
4. Conclusions
Processes of magma mixing and wall rock interaction may affect the processes occurred during crystallization of plagioclase phenocryst population. Meanwhile, microphenocryst crystals were formed in higher undercooling condition relative to the phenocryst population. The calculation of residence time based on CSD analysis resulted in residence time of the plagioclase crystals are 63 – 120 years for phenocryst and 8 – 18 years for microphenocryst. These calculated results may also reflect the difference in location or relative crustal elevation during crystallization.

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