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Modelling the magmatic history of the Boleng volcano, Indonesia

Introduction

Boleng is a stratovolcano in the south-eastern part of the island Adonara. Its eruptive behaviour is explosive, but so far all eruptions were small. Samples have been taken at the volcano which have been analysed for various oxides. The samples are referred to as BO and a number. In total there are 6 samples which will be used for the modelling exercise. The objective is to determine the relationships between these magmatic samples and whether fractional crystallisation of minerals occurred, magma mixing, or both. The samples can be analysed for the degree of evolution by looking at the SiO2 content or the relationship between MgO and FeO. See figure 1 and 2. Below the samples are shown in table 1 with corresponding mineral content.

Table 1

Sample	Mineral content				
BO1	Olivine	Clinopyroxene		Plagioclase	Magnetite
BO2		Clinopyroxene	Orthopyroxene	Plagioclase	Magnetite
BO5		Clinopyroxene	Orthopyroxene	Plagioclase	Magnetite
BO10		Clinopyroxene	Orthopyroxene	Plagioclase	Magnetite
BO11		Clinopyroxene	Orthopyroxene	Plagioclase	Magnetite
BO14	Olivine	Clinopyroxene		Plagioclase	Magnetite

The least evolved magma (or parent magma) is BO14 and BO1. The most evolved magma (or daughter magma) is BO11. These extremes are not necessarily the end-members if more evolved or less evolved magmas exist but have not been sampled.

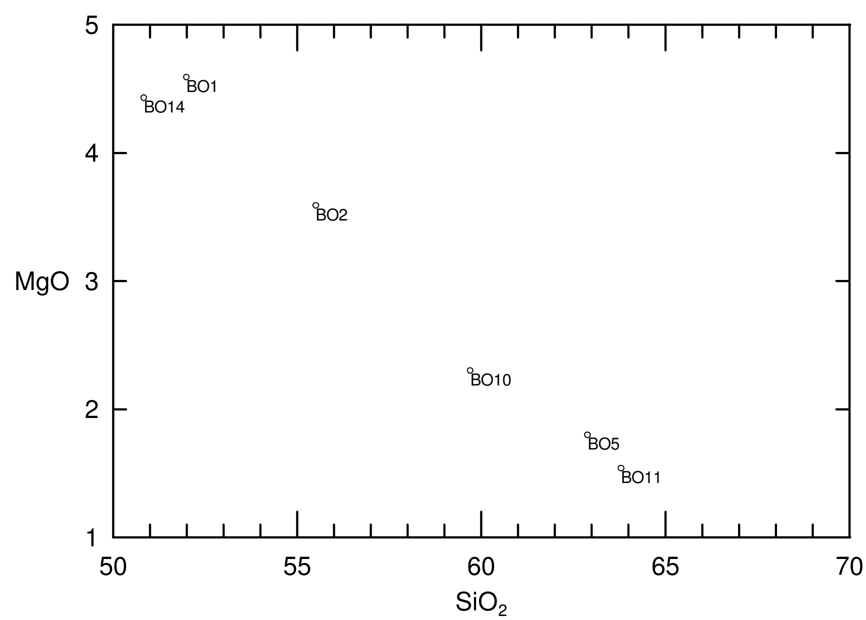

Figure 1 The relationship between MgO and SiO2. The least evolved magma is BO14 and BO1 shown in the upper left corner. The magma evolves to BO11, the most evoled magma.

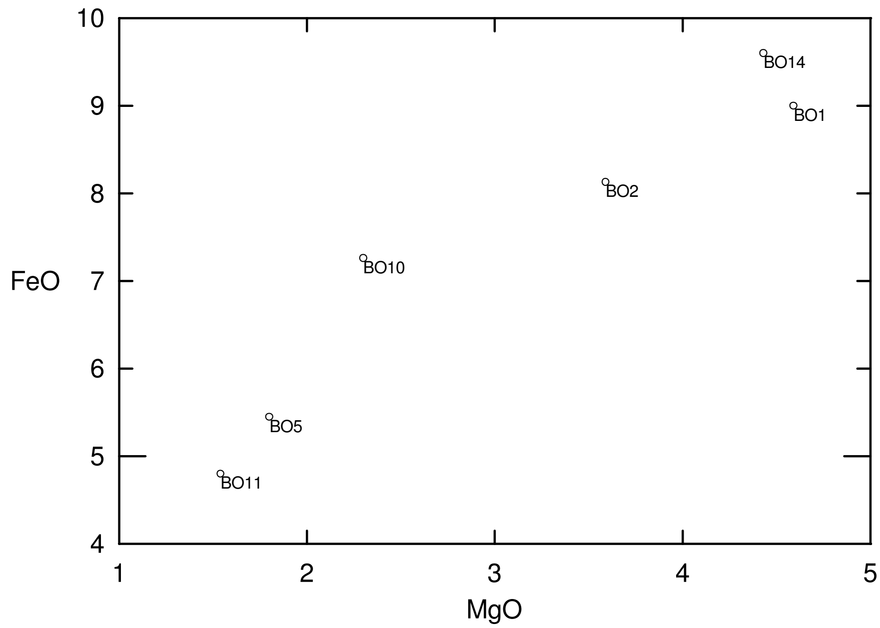

Figure 2 The relationship between FeO and MgO. As the magma evolves, through the out-crystallisation of minerals, the magnesium and iron oxides concentration decreases.
(Figures 1 and 2 are from the programme Igpet)

Method

The first step is to load the files *.pcs, *.mwt and *.min and *.roc into the mixing programme. All files are excel files, where the pcs file contains the trace element concentrations, the mwt file contains information to the degree each oxide must be weighted. The min file contains the list of minerals and the faction of oxides each mineral has. The roc file contains data on the oxides content in each of the BO# samples including the trace elements.

Then one can try out various combinations for fractional crystallisation and the minerals that form. This is done choosing a parent magma and a daughter magma and then choosing 4 or less relevant minerals that could crystallise out. So for example we take for the parent magma BO14 and for the daughter BO11. Then we can crystallise Olivine, Clinopyroxene, Plagioclase, and Magnetite, but not Orthopyroxene. The output displays coefficients for these minerals, the percentage of each crystallised out, and the sum of squares of residuals, which is an indicator how close the calculated concentrations of oxides compare to the observed oxides. If it is less than 1, the combination of minerals selected, which are crystallised out for a parent to a daughter magma, are possible. Negative values are impossible unless they are very close to zero, because they tell us that instead of crystallising out these oxides and minerals, they are added.

After trying out various sensible combinations of parent and daughter magmas for fractional crystallisation, you go on the try magma mixing between a parent and daughter magma with a hybrid magma. The hybrid magma should ideally lie on a straight line between the parent and daughter magma, see figure 2. From the sum of squares of residuals you can see if magma mixing is more or less sensible than fractional crystallisation.

The last model that can be run is for both processes. That is, fractional crystallisation and magma mixing happen at the same instant. Again from the sum of squares of residuals you can see if this process is more likely or less likely to have occurred between various combinations of parent and daughter magmas.

Results; see excel sheet print out, appendix A, B and C.

Interpretation + discussion

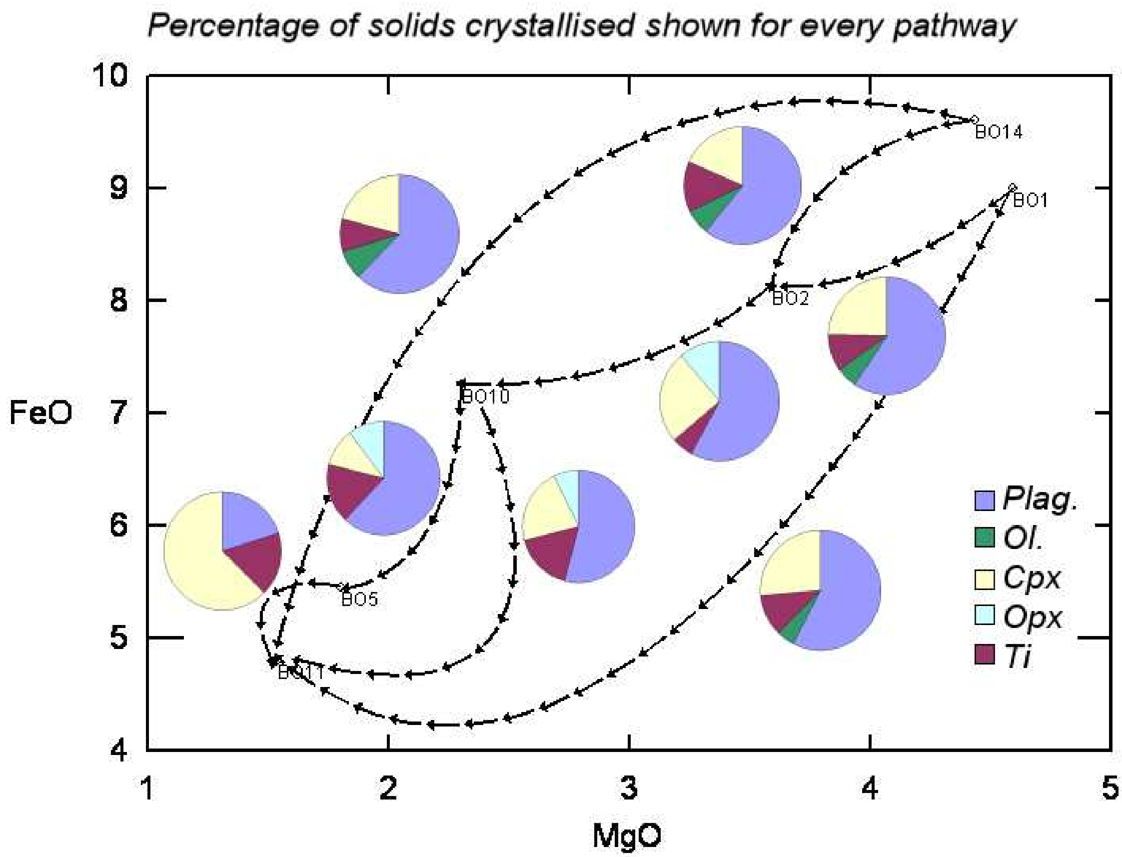

Figure 3 - The percentage of solids crystallised for various pathways from parent magma to daughter magma

Figure 3 shows various pathways of fractional crystallisation from a parent magma to a daughter magma with the corresponding amounts of solids that are crystallised out according to the programme. Note that in the figure there is made no distinction between the different plagioclases or clinopyroxenes, etc. Also these results are based on the best 'sum of squares of residuals' obtainable. From the diagram it is readily apparent that from BO1 or BO14, olivine is formed. And that interestingly from BO5 to BO11 no orthopyroxene is crystallised. Overall, plagioclase forms a major component of the bulk material formed. Only from BO5 to BO11, clinopyroxene is the more abundant phase. Further orthopyroxene and olivine do not co-exist. The percentage amount of Titanium from magnetite varies a lot. From BO2 to BO10 it is little, but from BO10 to BO11 it is quite a lot.

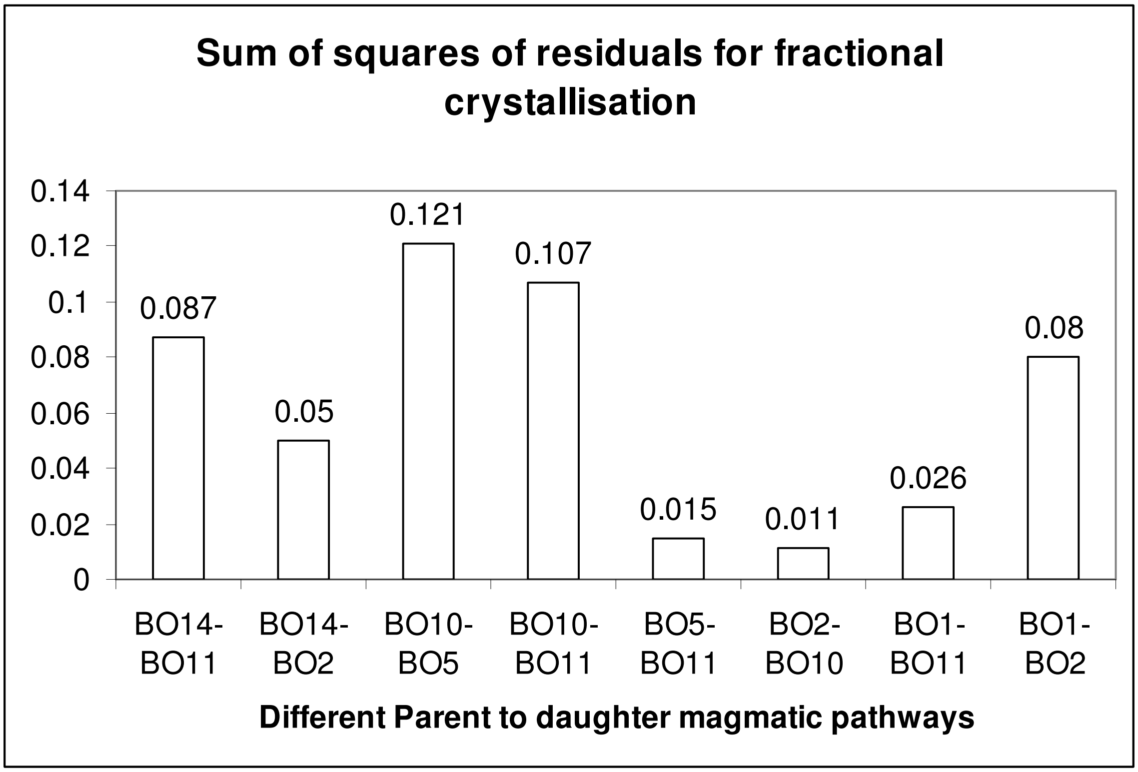

Figure 4 - The sum of squares of residuals for fractional crystallisation from parent to daughter magma for each pathway

Figure 4 shows the corresponding 'sum of squares of residuals (or R)' for all the pathways for fractional crystallisation. Clearly some combinations of minerals yield a very small R value, whereas from e.g. BO10 to BO5, the value is as much as 0.121. Still this is very good considering that the limit is at roughly 1. If above 1, then the selection of minerals that one chooses to crystallise from one parent magma to a daughter magma is unlikely. The closer the parent magma composition lies to the daughter magma composition, the smaller the R value can be provided that one chooses the correct minerals to crystallise.

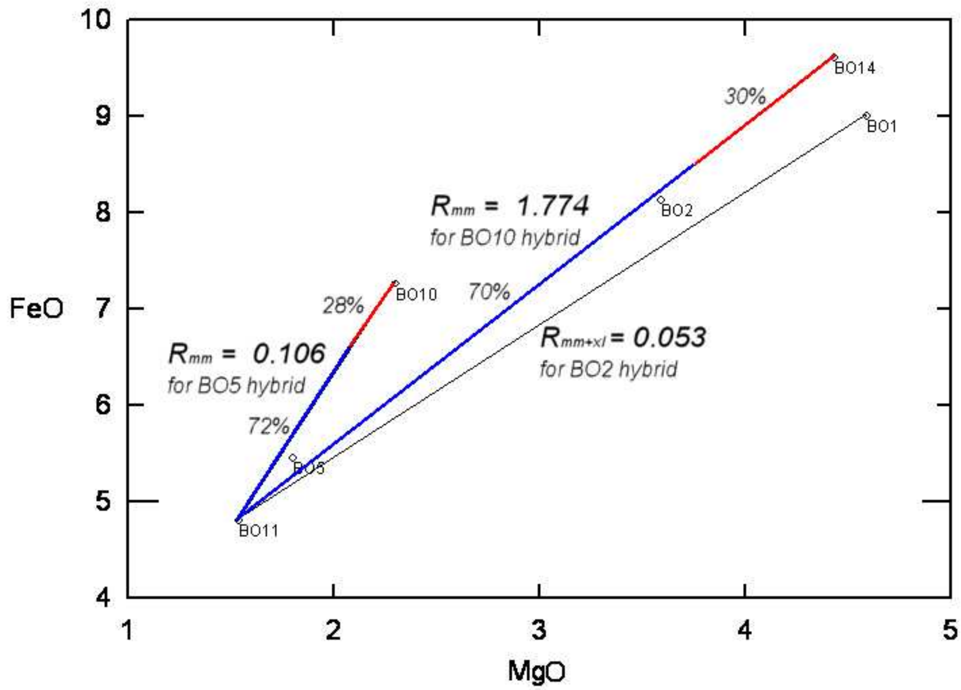

Figure 5 - Plot showing the sum of squares of residuals for magma mixing and fractional crystallisation (R_{mm+xl}) and magma mixing only (R_{mm}). The magma mixing lines show amount daughter added in blue and amount parent added in red to produce hybrid.

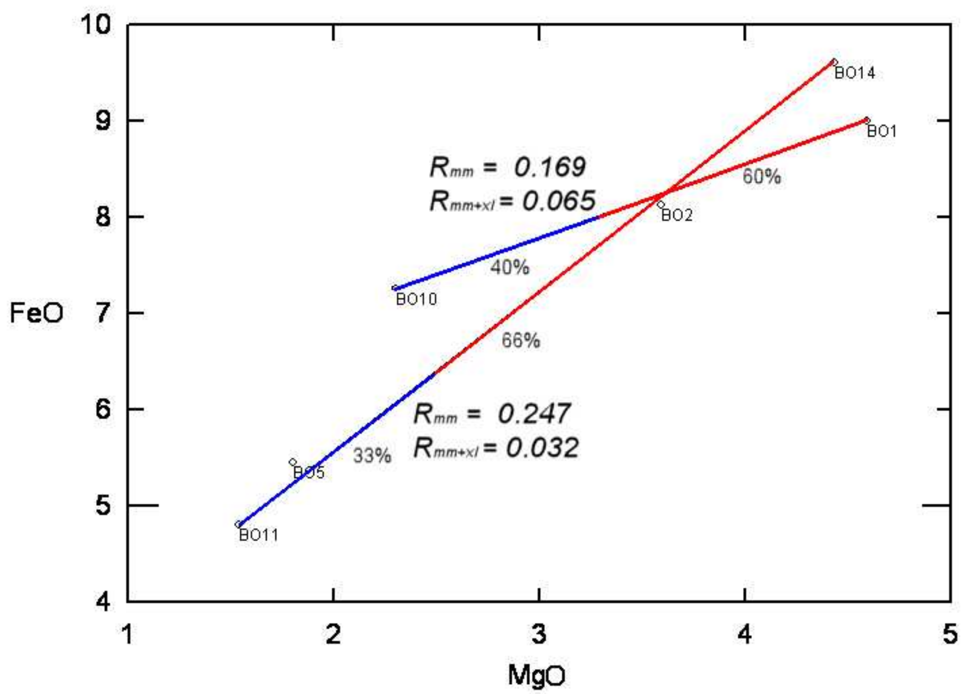

Figure 6 - Plot showing the sum of squares of residuals for magma mixing and fractional crystallisation (R_{mm+xl}) and magma mixing only (R_{mm}). The magma mixing lines show amount daughter added in blue and amount parent added in red to produce hybrid. Both have BO2 magma as hybrid.

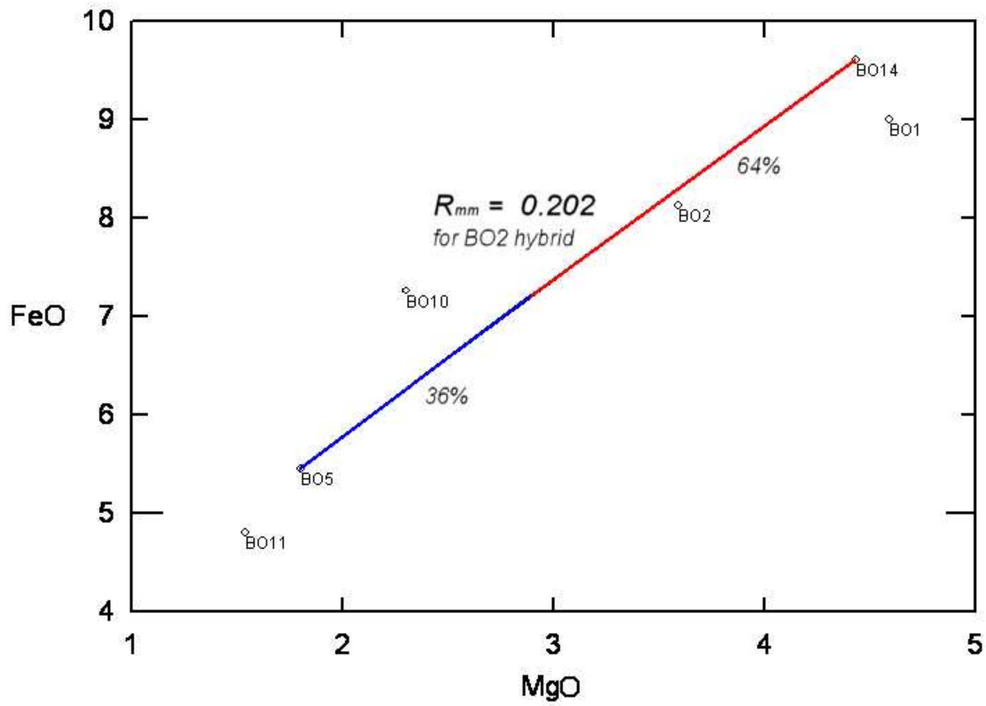

Figure 7 - Plot showing the sum of squares of residuals for magma mixing only (R_{mm}). The magma mixing lines show amount daughter added in blue and amount parent added in red to produce hybrid.

Figures 5, 6, and 7 show what would happen if only magma mixing were to occur and how likely that would happen, and also show if both processes, magma mixing and fractional crystallisation occurred at once, and how likely that would happen. The lower the R_{mm} or the R_{mm+xl} value, the better and the more likely the process would have happened. For example, in figure 5 the R_{mm} value is 1.774. This is way too high and therefore magma mixing between parent magma BO14 and daughter magma BO11 producing BO10 as hybrid is unlikely. On the other hand, figure 6 shows that for the BO2 hybrid, R values are much lower and even the distinction can be made that magma mixing and fractional crystallisation occurring at the same time is even more likely to happen than magma mixing occurring alone with an amazing $R_{mm+xl} = 0.032$ versus $R_{mm} = 0.247$. In addition, for magma mixing only, the percentage parent magma and the percentage daughter magma is calculated using the programme. From the same example, 66% BO14 mixed with 33% BO11 produces the hybrid BO2.

Data on the trace elements show the coefficients for each trace element from a daughter to parent magma, which basically means that the closer difference of the coefficient is to zero, the better. In some cases this amounts to 241 or other cases as low as -16. Although, this isn't wishful, it does not make the combination of minerals selected for fractional crystallisation erroneous, since we are dealing, after all, with trace elements. See appendix C for results.

Conclusion

Overall, it is apparent that R_{mm} is never below 0.100, whereas R_{mm+xl} does get smaller, which means that magma mixing and fractional crystallisation occurring at once is more likely to have happened at the Boleng volcano than magma mixing alone. However, looking back at figure 4, for fractional crystallisation only, some very small R values have also been obtained. At one occasion fractional crystallisation from BO2 to BO10 gives R = 0.011! In other words, it cannot be ruled out that fractional crystallisation plays a very important role during the evolution of magma in the Boleng volcano, but that together with magma mixing, with R values varying from 0.032 to 0.065, the both processes are equally likely to occur. However, for certain pathways, the programme reported inconsistencies with fractional crystallisation and magma mixing (see results BO14 to BO11 with hybrid BO5 and BO1 to BO11 with hybrid BO5). This is also true for magma mixing alone however these results were not noted down. Nevertheless, fractional crystallisation always works going from a parent magma to a daughter magma, provided that one selects the appropriate minerals to crystallise out. Regarding the fact that most R values, except on one occasion were way below 1, the Boleng volcano is very dynamic and the results from the programme do not rule out any process, be it fractional crystallisation, magma mixing, or both.