Using machine learning techniques to determine pressure and temperature of magma storage below volcanoes

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Introduction

Determining the structure of magmatic plumbing systems is an integral part of understanding the processes preceding volcanic eruptions. Thermobarometry estimates the pressure and temperature of crystallisation of minerals using their chemical composition. These minerals are erupted to the surface in magma during eruptions (melt plus crystals). This can provide quantitative information on the depth and temperature of magma storage before eruption. Clinopyroxene, a common crystal found in volcanic rocks, has been shown to be a reliable mineral for thermobarometry. Machine learning offers a approach to thermobarometry.

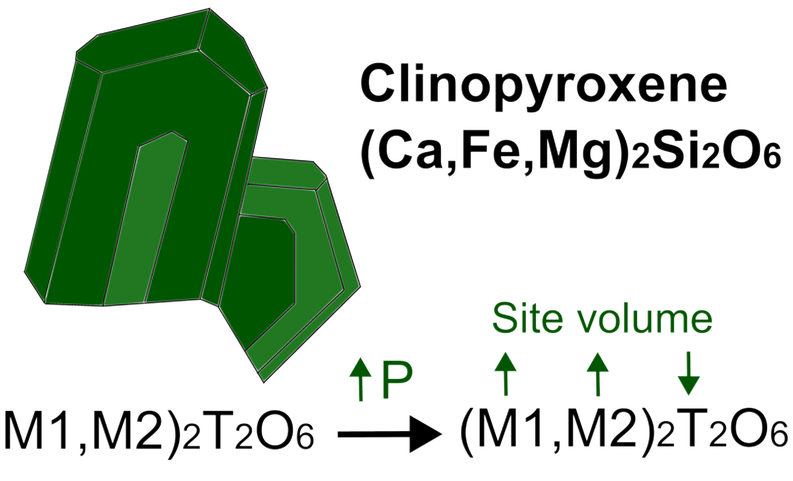

Figure 1. *Clinopyroxene has a set mineral structure, where the element sites change volume with different pressure and temperature. Thus different elements are preferentially incorporated.*

How does Random Forest Machine learning work?

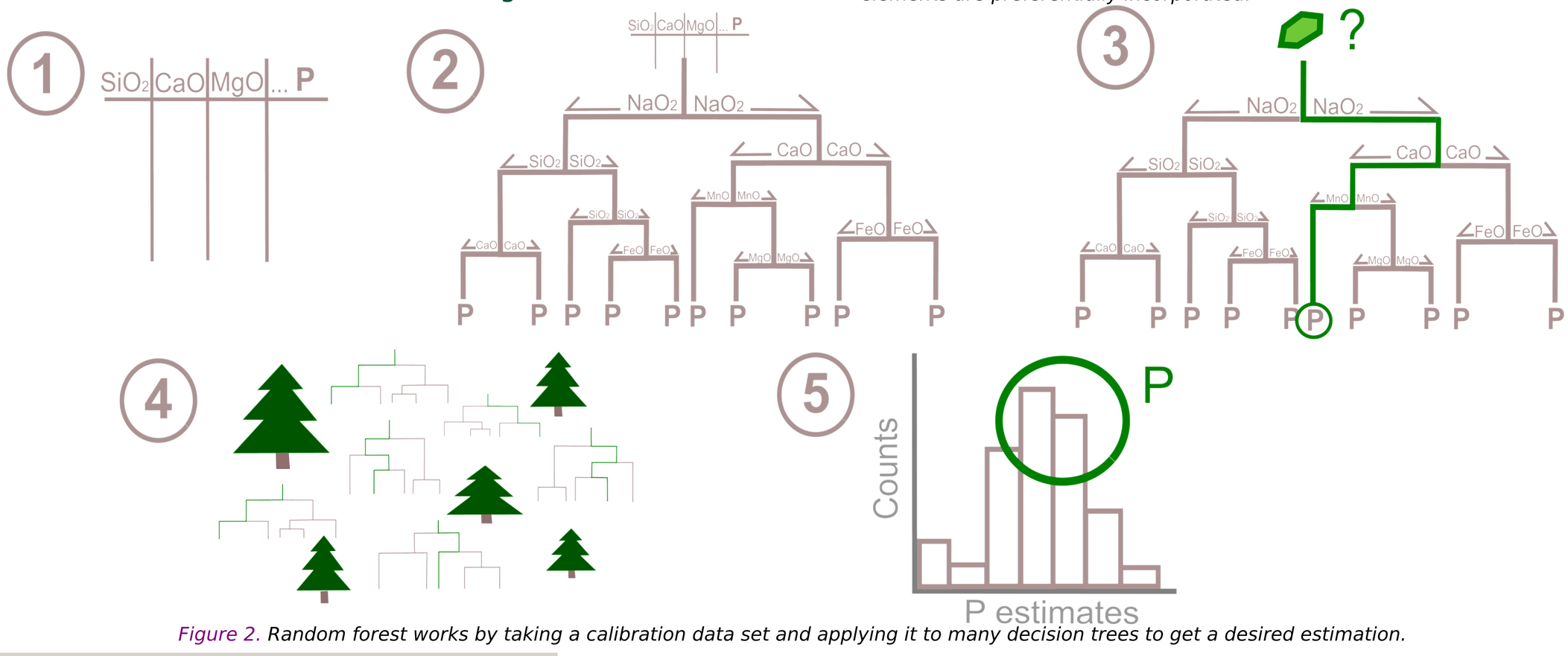

Figure 2. *Random forest works by taking a calibration data set and applying it to many decision trees to get a desired estimation.*

Application to Colli Albani

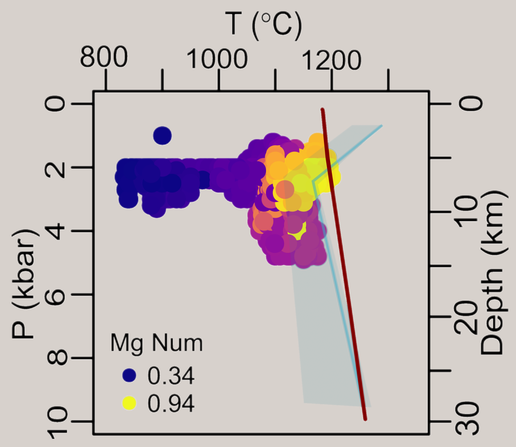

Figure 3. *Results from the random forest thermobarometer applied to Colli Albani clinopyroxene. Points are colour coded for Mg#, an indicator of mantle material. SEE is 3.2 kbar and 71.9 °C*

Colli Albani is a volcano in central Italy which has low viscosity (mafic and alkaline) magma which should erupt effusively but instead it erupts explosively! The unique chemistry means it cannot be used with classical thermobarometers. Thus we turn to the random forest thermobarometer! We applied the RFTB to Colli Albani's cpx and found an exciting PT story! The pressures indicate relatively shallow crystallization which is opposite of what the mineral chemistry indicates. This tells us that there is a deep magma which resided in the shallow crust for a very short period of time before eruption! Additionally the wide range of temperatures tells us that the assembly of the shallow magma chamber happened through a series of pulses of magma which crystallized at progressively hotter temperatures as the crust got thermally primed.

Hyper parameter tuning

- Hyperparamters in random forest effect the performance thus we have endeavoured to optimized these.
- The optimal number of tree is 200
- the optimal mtry (which increase the randomness of the model) is equivalent to 2/3 the variables

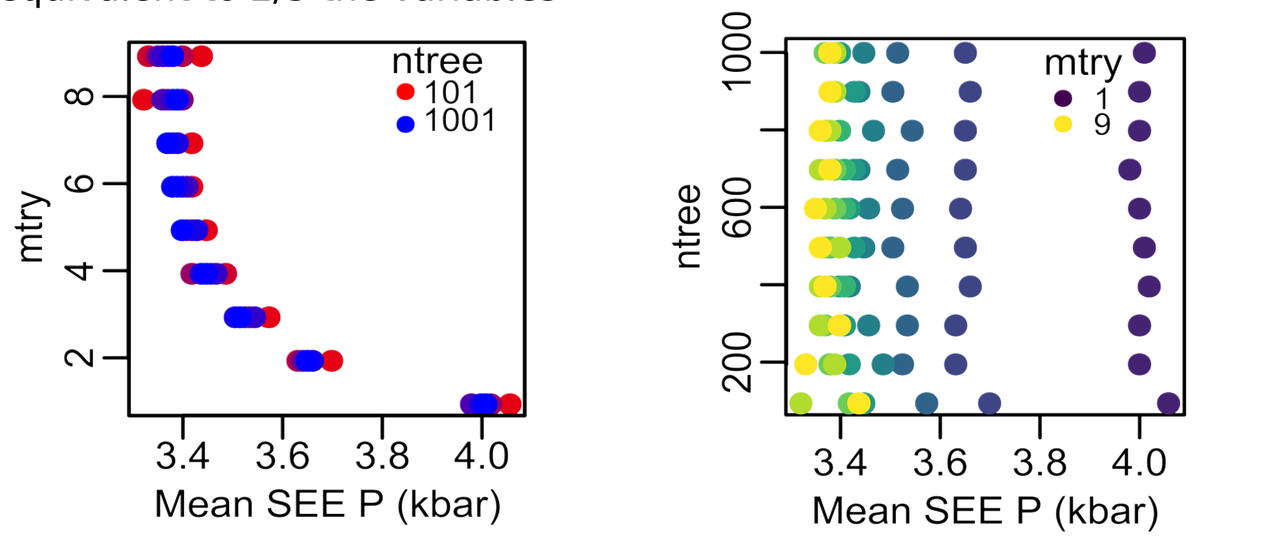

Figure 4. *SEE performance of mtry (left) and ntree (right)*

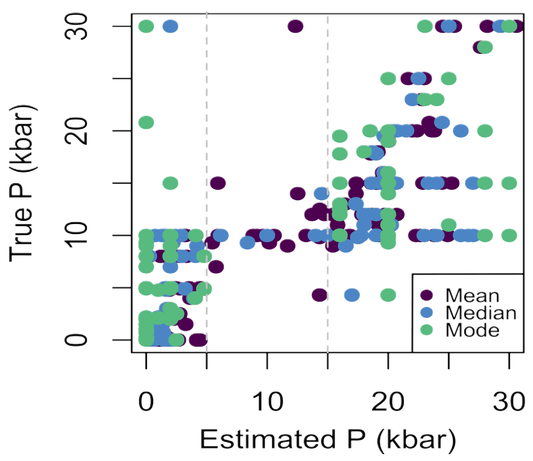

Figure 5. *Mode performs poorly with a gap is forced into the training dataset*

- Using the average estimate from all the decision trees results in poor estimates as the mean is strongly influenced by bad estimates
- Can utilize the mode but it cannot interpolate
- Median is the happy median!

[1] Leo Breiman. Manual on setting up, using, and understanding random foest v3.1. *Statistics Department University of California Berkeley, CA, USA*, 1, 2002.

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[3] C. Jorgenson, O. Higgins, M. Petrelli, F. Bégué, and L. Caricchi. A machine learning-based approach to clinopyroxene thermobarometry: Model optimization and distribution for use in earth sciences. *Journal of Geophysical Research: Solid Earth*, 127, 4 2022.