Relationship between Plagioclase shape, size and density during the cooling of a basaltic andesite under various pre-treatment conditions

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Introduction

As mentioned by **Fokin et al. (1999)** and **Shea and Hammer (2013)**, the presence of seeds modifies the nucleation process in their direct vicinity (the courtyard effect). The seeds may be pre-existing crystals or various artifacts (crystals, fragments of country rocks, …) entrained by the magma during its ascent.

In order to test the role of seeds on the shape, the density and size of crystals, we performed isobaric multi-step cooling experiments without and with an isothermal dwell above the liquidus (pre-existing crystals or not, Fig. 1). We tested the crystallization of plagioclase in a natural basaltic andesite because this mineral is the main crystalline phase in most volcanic rocks.

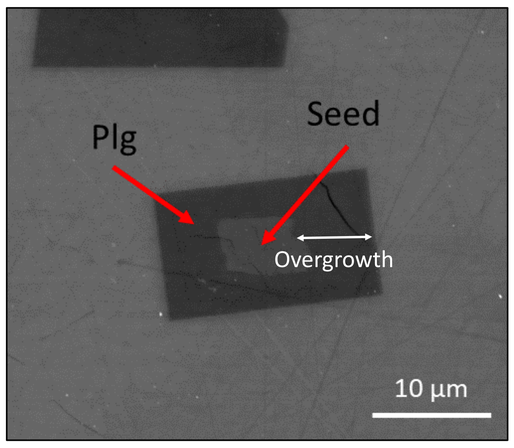


Figure 1 : BSE image of plagioclase with seed (An-rich content) heart. Contrast has been increased.

Experimental Method

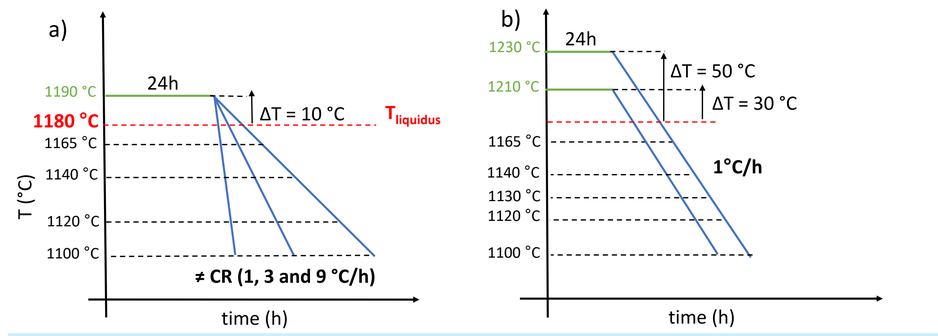


Figure 2: Sketch of the multi-step cooling experiments. All experiments were quenched at various temperatures down to a final temperature of 1100 °C. a) Dynamic crystallization with different cooling rates (CR) after an initial dwell at 10 °C above the liquidus temperature (**1180 °C**). The path with a cooling rate of 1°C/h was performed with and without initial crystals (pre-heated at 1450 °C). b) Dynamic crystallization experiments with an initial dwell at 30°C and 50°C above the liquidus temperature and then a cooling rate of 1 °C/h.

	OS36	1190 °C
	Basaltic andesite	Run
SiO_2	56,94	57,65
TiO_2	1,30	1,28
Al_2O_3	16,27	16,64
FeO	9,56	9,53
Cr_2O_3	0	0
MnO	0,18	0,19
MgO	2,79	3,13
NiO	0	0
CaO	6,39	6,63
Na_2O	4,32	4,14
K_2O	0,91	0,89
P_2O_5	0,26	0,3

Table 1 : Major element composition of the starting material (OS36) analysed with the X-ray fluorescence (whole-rock) (**Bechon et al., 2022**) and with the electron microprobe (experimental run held 10 °C above the liquidus for 24 hours). Platinum loops were pre-saturated in order to limit FeO loss.

- The starting composition is a powdered basaltic andesite (Osorno volcano, Chile: Table 1) mixed with water (mud) and then heated in a muffle furnace on platinum loops at 1000 or 1450 °C to remove volatiles and a certain number of initial crystals. At 1450 °C, all pre-existing crystals were removed.
- Different cooling rates were used (Fig. 2). BSE images acquired for each experimental run were treated with GIMP and FIJI.
- The 3D shape of plagioclases was estimated using **Mangler et al. (2022)** ShapeCalc and **Morgan and Jerram (2006)** CSDslice excel spreadsheets.

Textural observations

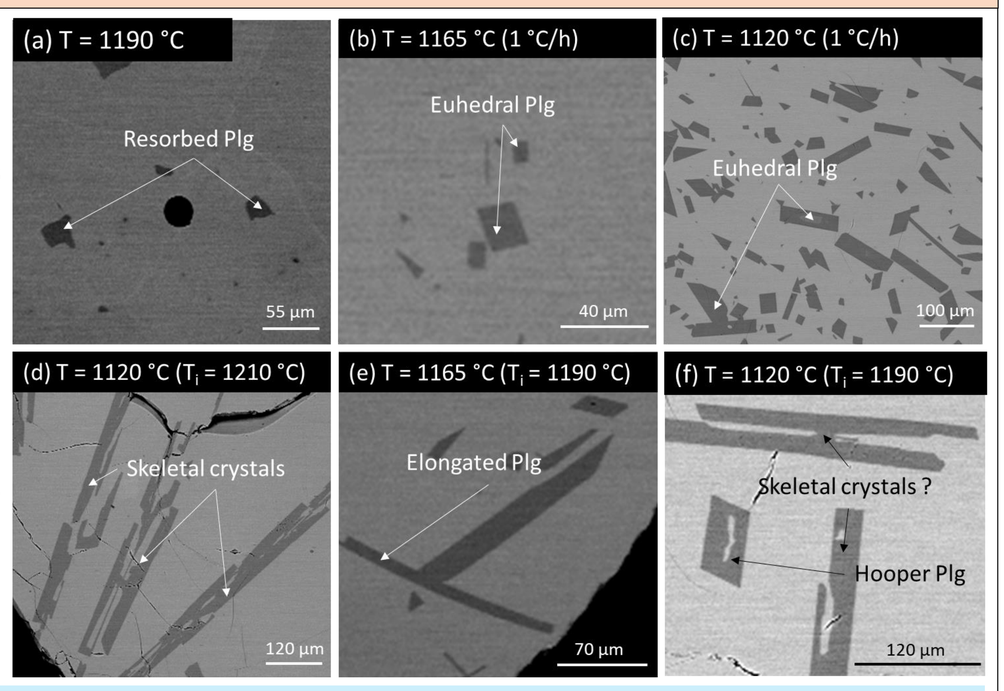


Figure 3 : BSE images of the 2D plagioclase textural evolution at various quench temperatures. Initial dwell at 10 °C above the liquidus for (a-c) (with seeds). (a) 10 °C above the liquidus (end of the initial step). (b - c) 15 °C and 60 °C below the liquidus.
Cooling experiments without seed (d-f). (d) initial superheating of 30 °C above the liquidus. (e – f) 15 °C and 60 °C below the liquidus in absence of pre-existing crystals.

- Experiments with seeds:
  - close to the liquidus temperature, the pre-existing plagioclase crystals display evidence of partial resorption (Fig. 3a)
  - growth of 2D euhedral and tabular crystals at lower temperatures (Fig. 3b and c).
- Experiment without seed:
  - With an initial dwell at 1210 °C (Fig. 2b), the crystallization of plagioclase is significantly delayed (liquidus at ≈1140 °C instead of 1180 °C) (not shown here).
  - Nucleation starts and evolves with large skeletal crystals with no visible seeds (diffusion controlled growth) (Fig. 3d).
  - On the contrary, if after an initial superheating step (1450 °C), a subsequent temperature dwell close to the liquidus temperature is used (1190 °C), the nucleation of plagioclase indeed occurs at 1180 °C.
  - At increasingly lower temperatures, tabular and elongated crystals (Fig. 3e) followed by hooper crystals crystallize (Fig. 3f).

Density and Size Evolutions

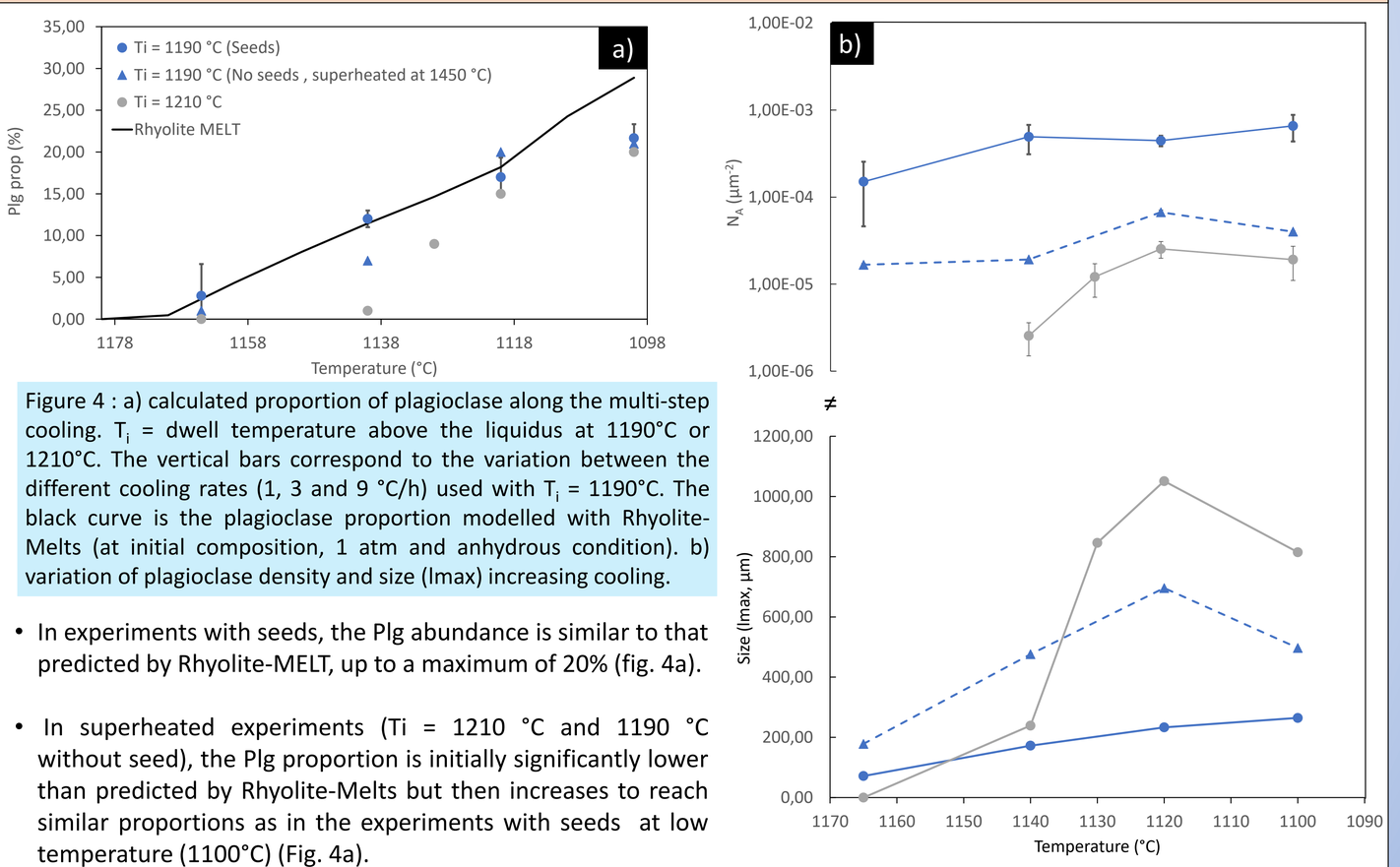
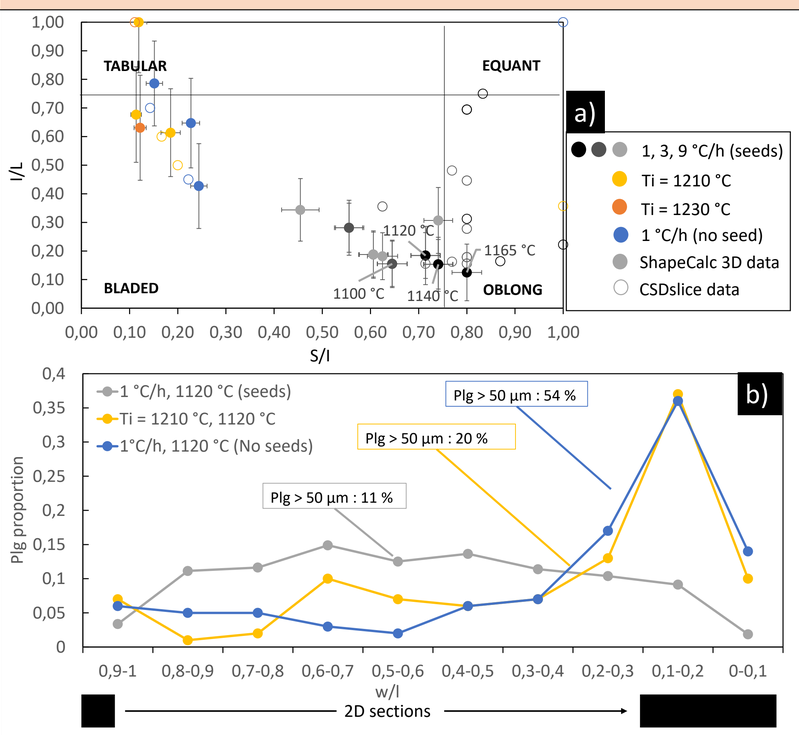


Figure 4 : a) calculated proportion of plagioclase along the multi-step cooling. T_i = dwell temperature above the liquidus at 1190°C or 1210°C. The vertical bars correspond to the variation between the different cooling rates (1, 3 and 9 °C/h) used with T_i = 1190°C. The black curve is the plagioclase proportion modelled with Rhyolite-Melts (at initial composition, 1 atm and anhydrous condition). b) variation of plagioclase density and size (lmax) increasing cooling.

- In experiments with seeds, the Plg abundance is similar to that predicted by Rhyolite-MELT, up to a maximum of 20% (fig. 4a).
- In superheated experiments (Ti = 1210 °C and 1190 °C without seed), the Plg proportion is initially significantly lower than predicted by Rhyolite-Melts but then increases to reach similar proportions as in the experiments with seeds at low temperature (1100°C) (Fig. 4a).
- Experimental runs with an initial superheating step (without seeds) display few crystals but with the biggest sizes (Fig. 4b).

Shape evolution



- Experiments performed at different cooling rates display plagioclase with similar 3D shapes (Fig. 5 a). Moreover, there is no significant variation of the 3D shape during cooling.
- Crystals display significantly different shapes in experiments with (oblong crystals) and without seeds (tabular crystals) (Fig. 5a).
- Because of the absence of a real w/l mode (Fig. 5a), results between CSDslice and ShapeCalc are different.
- In the absence of seeds, the proportion of large crystals (> 50 mm) is higher and have an elongated shape (w/l = 0.1-0.2) (Fig. 5b).

Figure 5 : A) Zing diagram showing the Plg 3D shape evolution. S, I, and L corresponding to the minor, medium and maximum 3D axis.
B) Evolution of the w/l 2D shape factor during the cooling. w and l representing the 2D minor and major axis of each crystal.

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