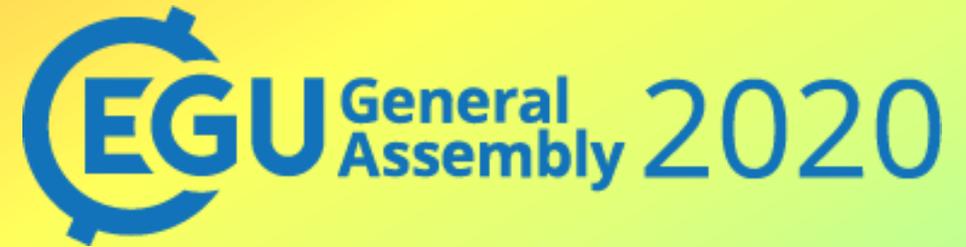




SAPIENZA
UNIVERSITÀ DI ROMA



**AMPHIBOLE GROWTH FROM A PRIMITIVE ALKALINE
BASALT AT 0.8 GPA: TIME DEPENDENT
COMPOSITIONAL EVOLUTION, GROWTH RATE AND
COMPETITION
WITH CLINOPYROXENE**

Barbara Bonechi*, Cristina Perinelli, Mario Gaeta, Vanni Tecchiato, Alessandro Fabrizio

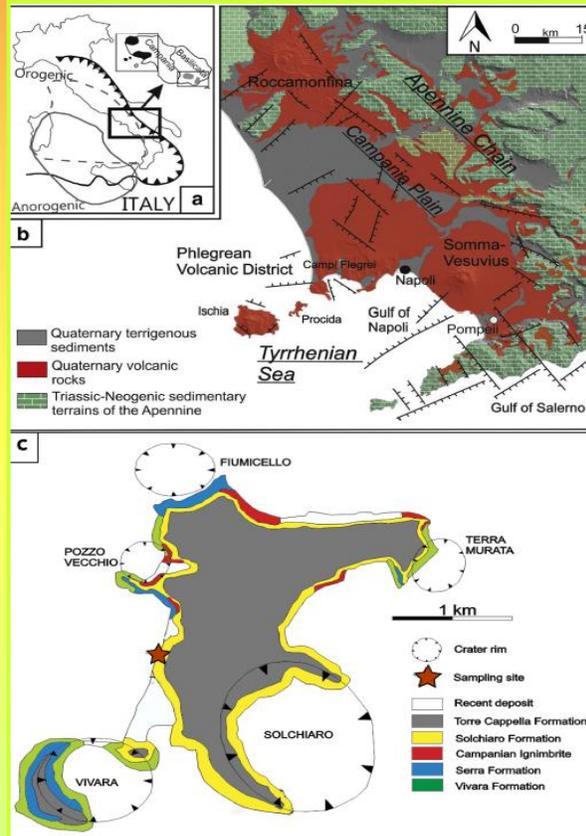
barbara.bonechi@uniroma1.it



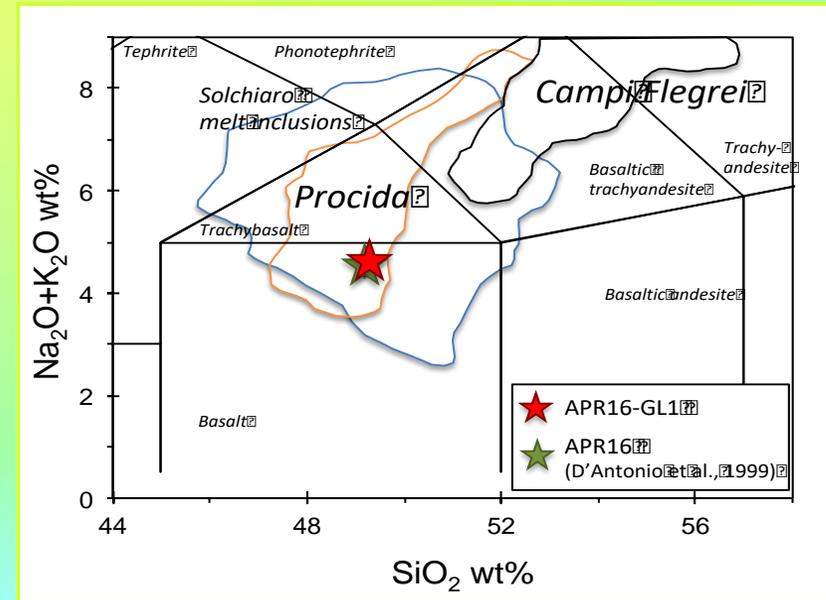
Starting material

An anhydrous glass (APR16GL) prepared by melting the APR16 natural powder at atmospheric pressure and 1400 °C using a gas mixing furnace ($fO_2 = NNO$)

After Mazzeo et al., 2014



The APR16 sample ($Mg\# = 0.66$) is a K-basalt scoria clast within the hydromagmatic tuff of the Solchiaro eruption (Procida Island, Phlegraean Volcanic District, South Italy).

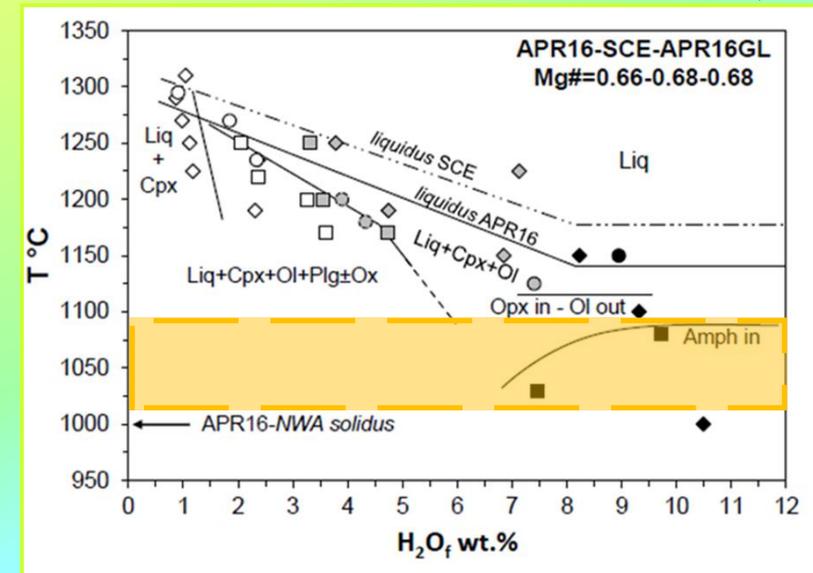


Experimental technique

- Piston cylinder apparatus at the HP-HT laboratory of the Earth Sciences Department, Sapienza University of Rome
- Static experiments
- Isobaric pressure (0.8 GPa)
- Hydrous conditions (4 wt.% H₂O_i; 1030-1080 °C)
- Dwell time of 0.25, 3, 6 and 9 hours



After Perinelli et al., 2019

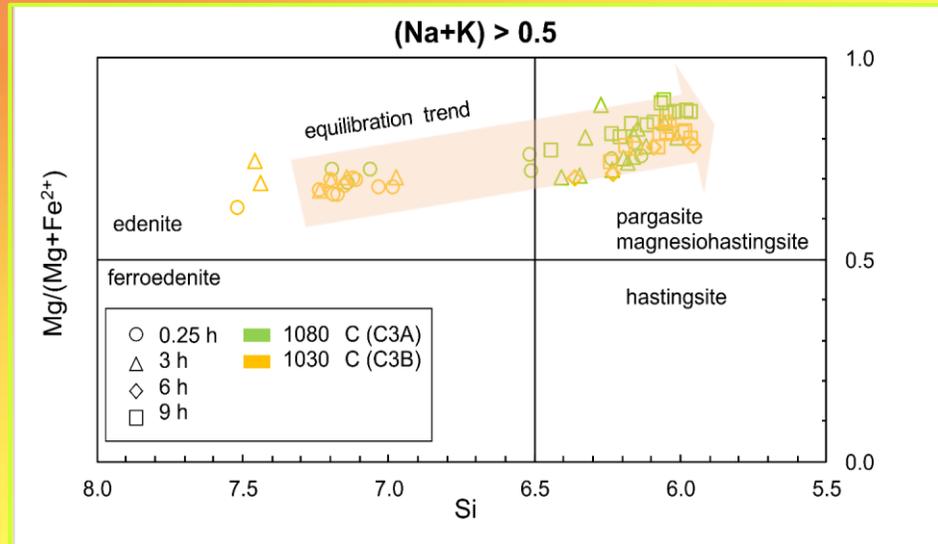


Amph: amphibole; Cpx: clinopyroxene; Liq: liquid; Ol: olivine; Opx: orthopyroxene; Ox: oxide; Plg: plagioclase;

Results

Amphibole composition

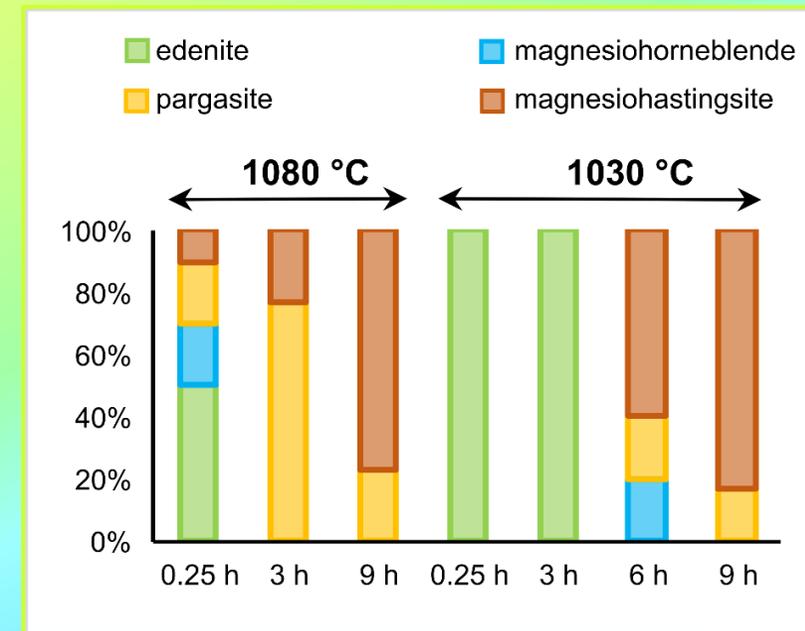
Bonechi et al., 2020a LITHOS



Synthetic Amph are all calcic type, their composition varies from magnesiohorneblende and edenite to pargasite and magnesiohastingsite.

Edenitic amphibole is the dominant term in short (≤ 3 h), low-temperature (1030 °C) runs, whereas the abundance of magnesiohastingsite type progressively increases shifting towards longer experimental duration and higher temperature.

Bonechi et al., 2020a LITHOS

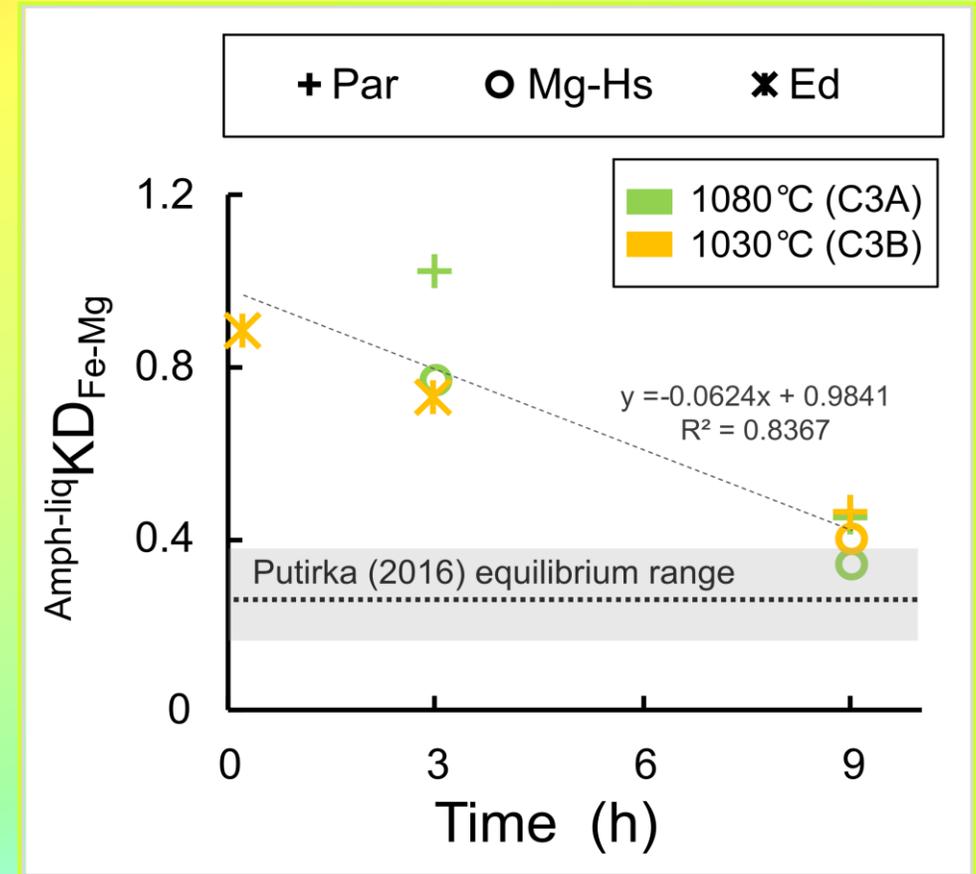


Amphibole approach to equilibrium

Amph-melt Fe-Mg exchange coefficient decreases from ~1 to ~0.3 increasing time indicating that only the magnesiohastingsite crystallized in the runs at 9 h attained the Amph-liquid equilibrium conditions (i.e. $\text{Amph-liq}KD_{\text{Fe-Mg}} = 0.28 \pm 0.11$; Putirka, 2016).

Conversely, on the basis of their $\text{Cpx-liq}KD_{\text{Fe-Mg}}$ values (0.41 - 0.43), clinopyroxenes crystallized with Amph are in disequilibrium with the coexisting melt (equilibrium $\text{Cpx-liq}KD_{\text{Fe-Mg}} = 0.28 \pm 0.08$; Putirka, 2008)

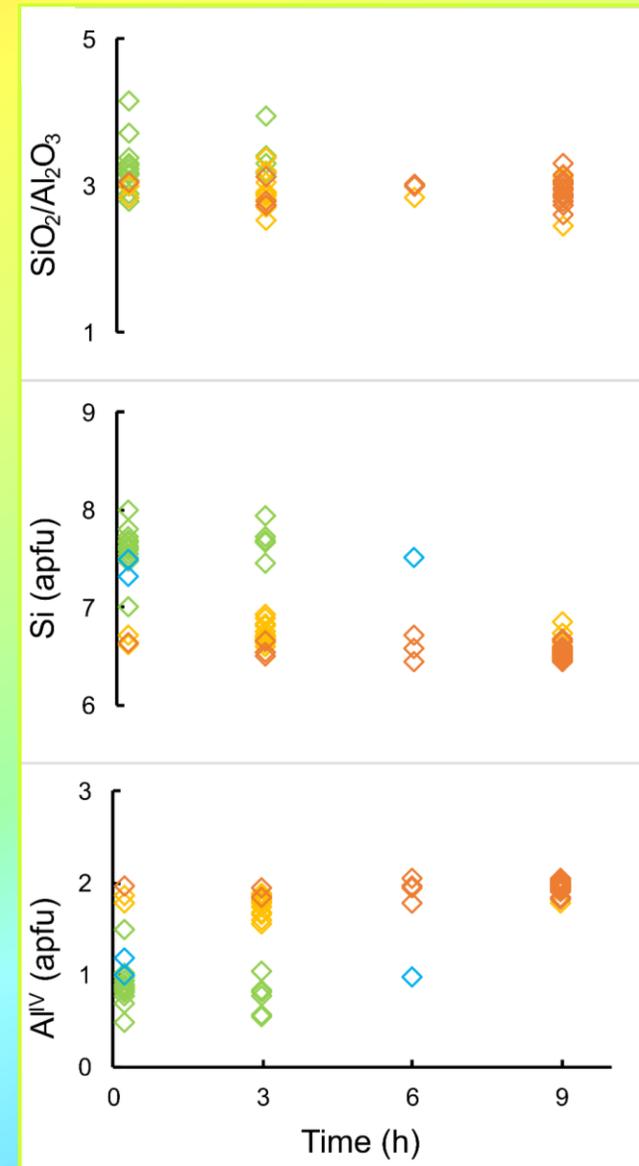
Bonechi et al., 2020a LITHOS



Chemical evolution of amphibole with time

The variation of Si and Al^{IV} in the tetrahedral site with time depicts the overall tendency of amphibole to preferably incorporate Al rather than Si in four-fold coordination, mirroring the time-dependent chemical evolution from more siliceous (i.e. edenite) to more aluminous (i.e. magnesiohastingsite) species. By exemplifying the edenite and magnesiohastingsite activity as a function of the exchange reaction $(\text{Na}_A\text{Si}_T) = ((\text{Ca},\text{Mg})_{A-M} \text{Al}_T)$ where the subscripts indicate the A, M and T sites of amphibole structure, it can qualitatively be concluded that the absence of plagioclase and the minor abundance of clinopyroxene in the 6-9 h experiments drive the reaction to the right, stabilizing magnesiohastingsite.

Bonechi et al., 2020a LITHOS

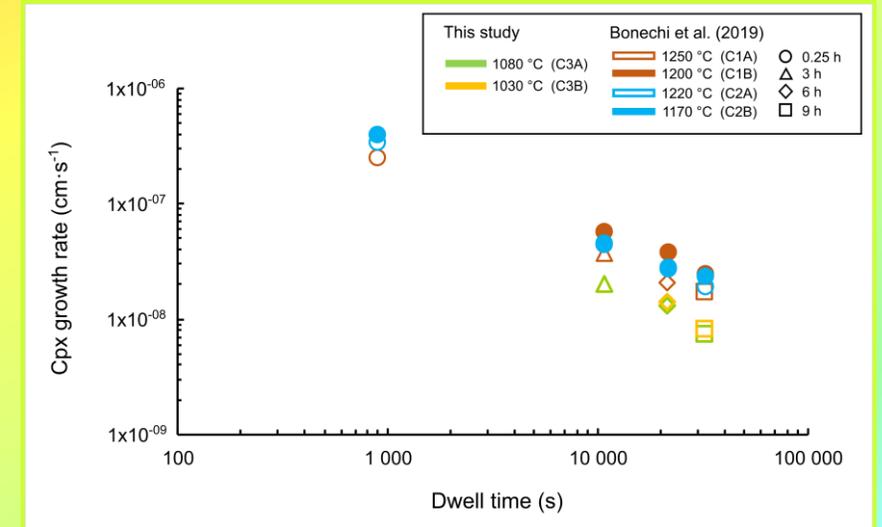


Antagonism with clinopyroxene

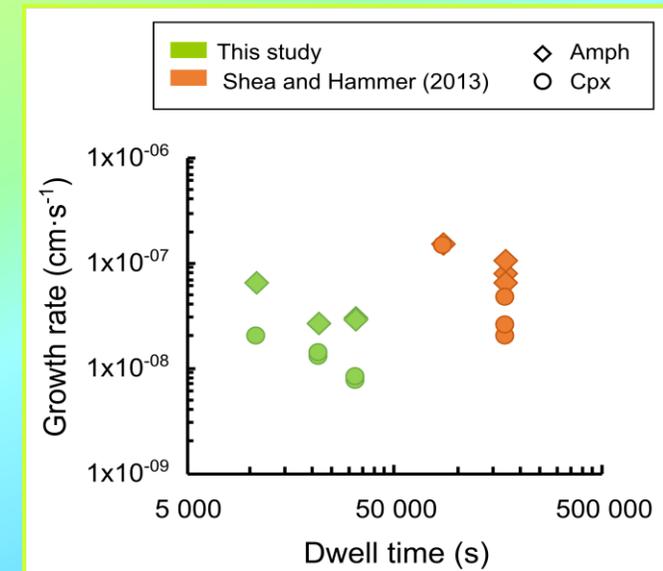
Cpx growth rate decrease from $2.0 \cdot 10^{-8}$ to $8.2 \cdot 10^{-9}$ cm s^{-1} with increasing time paralleling the trend described by data of Bonechi et al. (2020b) for synthetic Cpx crystallized at $T = 1170$ - 1250 °C and $\text{H}_2\text{O}_f \leq 5$ wt%.

The small differences in $\text{Cpx-}G_L$ values can be explained by the contemporary amphibole clinopyroxene crystallization in our experiments and by the strikingly evidences of the faster growth of amphibole relatively to clinopyroxene. Such phenomenon is explained by the chemical and structural similarities of these minerals that compete for Mg, Fe, Ca and to a lesser extent Al and Na. The occurrence of amphibole at high water content, therefore, not only reduces the abundance of clinopyroxene, but also the rates of clinopyroxene nucleation and growth.

Bonechi et al., 2020a LITHOS



Bonechi et al., 2020a LITHOS

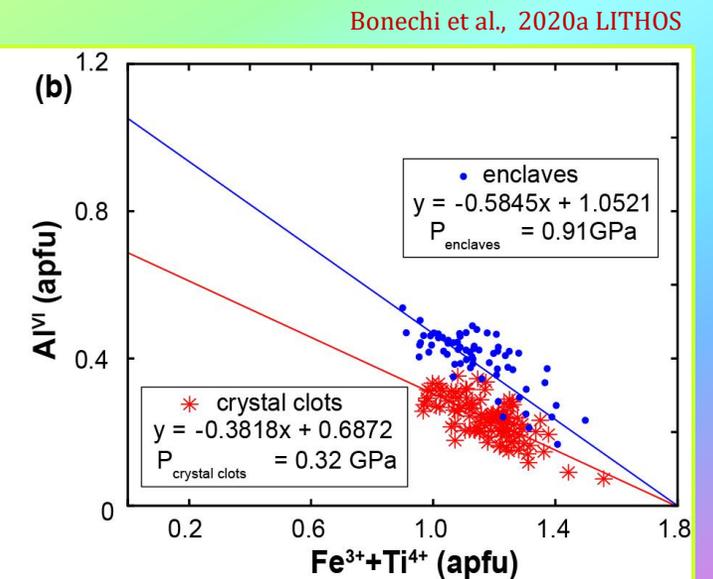
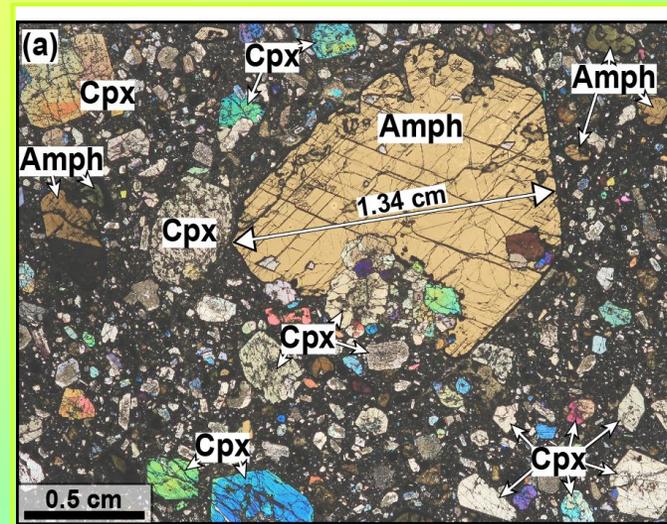


Application

Crystallization timing for Capo Marargiu Oligo-Miocene igneous products

Experimental growth rates have been applied to investigate the crystallization time of natural amphiboles and clinopyroxenes from the Oligo-Miocene products of north-western Sardinia (i.e. Capo Marargiu Volcanic District; CMVD). According to Tecchiato et al. (2018), these minerals crystallize at $P = 0.2\text{-}0.7$ GPa, $T = 960\text{-}1140$ °C and $H_2O = 5\text{-}6$ wt%. Based on Simakin and Shaposhnikova (2017), the bimodal distribution of amphibole from enclaves and crystal clots in the $Fe^{3+} + Ti^{4+}$ vs. Al^{VI} diagram implies the calculation of different regression equations.

The intercepts of these lines with the y-axis provide two Al^{VI} max parameters, that testifies to crystallization pressures of 0.91 ± 0.12 GPa and 0.32 ± 0.09 GPa, respectively, confirming the polybaric nature of these minerals and providing a slightly higher crystallization pressure for enclave crystals.



Crystallization timing for Capo Marargiu Oligo-Miocene igneous products

The G_L calculated in this work ($2.9 \cdot 10^{-8} \text{ cm s}^{-1}$) is in the order of the effective dimension of the five biggest amphibole crystals (1.34-2.85 cm), translating to crystallization times of 1.5-3.1 yr. In turn, clinopyroxene measurements yield maximum dimension of 1.37 cm for Type 1, and 0.38 cm for Type 2 crystals. Crystallization time for Type 1 clinopyroxene (i.e. 2.18 yr) is comparable to that from enclave amphibole (1.46-2.03 yr) only when the $2.0 \cdot 10^{-8} \text{ cm s}^{-1}$ growth rate from amphibole-free experiments of Bonechi et al. (2020b) is adopted. In contrast, the lowest growth rate of $7.4 \cdot 10^{-9} \text{ cm s}^{-1}$ from amphibole-bearing runs is necessary to retrieve a consistent Type 2 crystallization time (i.e. 1.62 yr). In conclusion, these results suggest that at the lower crustal pressures primitive Type 1 population crystals grow faster than the smaller more evolved Type 2 clinopyroxene crystals, reflecting the coupled effect of amphibole crystallization and temperature on clinopyroxene growth rate.

Conclusions

At the investigated P - T - H_2O conditions, amphibole growth rate decreases from $1.5 \cdot 10^{-7}$ to $2.9 \cdot 10^{-8}$ cm s^{-1} with increasing time (from 0.25 to 9 h), temperature (from 1030 to 1080 °C) and water content in the melt (from 8.3 to 10.2 wt%), reflecting time-dependent equilibration, melt depolymerization, viscosity reduction, and element diffusivity increase. Comparison between amphibole and clinopyroxene growth rates provide evidence for the faster growth of amphibole with respect to clinopyroxene; this can be due to chemical and structural similarities between these minerals that cause a “kinetic competition”. Applying the obtained growth rates to amphiboles and clinopyroxenes phenocrysts of the Oligo-Miocene products of Capo Marargiu Volcanic District (Sardinia, Italy) results that the biggest, more primitive Type 1 population of clinopyroxenes grow over a longer period of time (2.2 yr) than the smaller, more evolved Type 2 clinopyroxene (1.6 yr) associated to amphibole (1.5-3.1 yr) at colder conditions, reflecting the coupled effect of amphibole crystallization and temperature on clinopyroxene growth rate.

For further information see:

<https://doi.org/10.1016/j.lithos.2019.105272>

<https://doi.org/10.1007/s00445-019-1342-5>

*Thanks for your
attention!*



Rferences

- Bonechi B., Perinelli C., Gaeta M., Tecchiato V., Fabbrizio A. 2020a. Amphibole growth from a primitive alkaline basalt at 0.8 GPa: time-dependent compositional evolution, growth rate and competition with clinopyroxene. *Lithos*, 354-355, 105272. <https://doi.org/10.1016/j.lithos.2019.105272>
- Bonechi B., Perinelli C., Gaeta M. 2020b. Clinopyroxene growth rates at high pressure: constraints on magma recharge of the deep reservoir of the Campi Flegrei Volcanic District (south Italy). *Bulletin of Volcanology*, 82, 5. <https://doi.org/10.1007/s00445-019-1342-5>
- D'Antonio, M., Civetta, L., Di Girolamo, P., 1999. Mantle source heterogeneity in the Campanian Region (South Italy) as inferred from geochemical and isotopic features of mafic volcanic rocks with shoshonitic affinity. *Mineral. Petrol.* 67, 163-192. <https://doi.org/10.1007/BF01161520>
- Mazzeo, F. C., D'Antonio, M., Arienzo, I., Aulinas, M., Di Renzo, V., & Gimeno, D. (2014). Subduction-related enrichment of the Neapolitan volcanoes (Southern Italy) mantle source: new constraints on the characteristics of the slab-derived components. *Chemical Geology*, 386, 165-183. <https://doi.org/10.1016/j.chemgeo.2014.08.014>
- Perinelli, C., Gaeta, M., Bonechi, B., Granati, S.F., Freda, C., D'Antonio, M., Stagno, V., Sicola, S., Romano, C., 2019. Effect of water on the phase relations of primitive K-basalts: implications for high-pressure differentiation in the Phlegraean Volcanic District magmatic system. *Lithos* 342 (343), 530-541. <https://doi.org/10.1016/j.lithos.2019.05.032>
- Putirka, K.D., 2016. Amphibole thermometers and barometers for igneous systems and some implications for eruption mechanisms of felsic magmas at arc volcanoes. *Am. Mineral.* 101, 841-858.
- Putirka, K.D., 2008. Thermometers and barometers for volcanic systems. In: Putirka, K.D., Tepley III, F.J. (Eds.), *Minerals, Inclusions and Volcanic Processes. Reviews in Mineralogy and Geochemistry*, pp. 61-120. <https://doi.org/10.2138/rmg.2008.69.3>
- Simakin, A.G., Shaposhnikova, O.Y., 2017. Novel amphibole geobarometer for high-magnesium andesite and basalt magmas. *Petrology* 25 (2), 226-240. <https://doi.org/10.1134/S0869591117020047>
- Tecchiato, V., Gaeta, M., Mollo, S., Scarlato, P., Bachmann, O., Perinelli, C., 2018. Petrological constraints on the high-Mg basalts from Capo Marargiu (Sardinia, Italy): evidence of cryptic amphibole fractionation in polybaric environments. *J. Volcanol. Geotherm. Res.* 349, 31-46. <https://doi.org/10.1016/j.jvolgeores.2017.09.007>