# Fine-scale rhythmic magmatic layering by a double diffusion process: the example of the mid-crustal Punta Falcone mafic intrusion (Sardinia, Italy)

The granite-hosted mid-crustal mafic intrusion of Punta Falcone has a pervasive vertical structure defined by the injection of at least 6 distinct pulses forming 10 to 60 m wide individual cooling units. The injection of new pulses occurred in the centre of the system, leading to a symmetrical intrusion. Contacts between the units are well-defined and present slight chilled margins speaking against a continuous magma flux, which would have had a marked thermal impact on the adjacent units. The complex is similar to a sheeted dyke complex with an elliptical cross-section.

The presence of $An_{80-90}$ plagioclase as liquidus phase in all units and radiogenic isotope compositions indicate a common magma source for all injection units. Differences in the magmatic evolution occur after plagioclase crystallization. In the early units, it is followed by sub-/euhedral amphibole of mm-size with a wide range of compositions dominated by the edenite-type substitution, evidencing relatively fast, isobaric cooling at emplacement level. The later units accumulated high-An plagioclase before ascent as indicated by whole-rock chemistry. After emplacement and due to the thermal maturation of the system, they isobarically crystallized cm-sized oikocrysts of pyroxene enclosing high-An plagioclase, closely followed by amphibole with the same texture. This led to a sudden decrease in An-content in the subsequently crystallizing plagioclase rims ($An_{50}$), which are absent in the mafic phases. The change in amphibole composition from the early to the late units indicates a decreased contamination by the granitic host over time. Extraction of residual liquid lead to the cumulative chemical signature of the gabbros. The amount of expelled liquid is difficult to evaluate, but is likely to be higher in the late units.

The formation of rhythmic magmatic layering occurring in one of the late pulses was addressed by field work, textural and chemical investigation. Layering occurs parallel to the border of the pulse, has a constant spacing of ca. 3 cm and decreases in amplitude from the border inwards. Dark layers are formed by poikilitic pyroxene and amphibole including high-An plagioclase grains, and white layers are formed by rimmed plagioclase with interstitial quartz. Our observations allowed to exclude a gravitational or mechanical origin for layer formation, as well as an Ostwald ripening process leading to recrystallization of the rock in layers. We propose layer formation by a double diffusion process leading to rhythmic nucleation inhibition in a depleted boundary layer after each layer formation. This process is triggered by a thermal gradient, and perpetuated because of out of equilibrium crystallization due to overstepping of the crystallization temperature. The physical conditions under which this layering can occur were investigated by a numerical model.

Different cooling scenarios derived from numerical modelling using the geometry, size, number of pulses and emplacement chronology of the complex were combined with a nucleation-growth model for the layer forming mafic minerals. Our parameter space investigation showed that the proposed model can lead to rhythmic magmatic layering with the characteristics observed in the Punta Falcone for a small range of cooling rates of several tenths to several °C/year. Chemical diffusion values have to be high (around $10^{-10}$ $m^2/s$) to allow development of layering with important amplitude, that is with important modal contrast between the dark and white layers.