Geophysical Research Abstracts
Vol. 16, EGU2014-7085, 2014
EGU General Assembly 2014

Spatial distribution analysis of igneous textures: Numerical modeling and interpretation of crystal accumulation in plutons

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Magma differentiation by fractionation of crystals from their parental liquids is central to igneous petrogenesis and it has been thoroughly documented by geochemical studies on the suites of cogenetic magmatic rocks. In spite of this, physical nature of the fractionation process remains poorly understood as are consequences of crystal-liquid separation for quantitative interpretation of igneous textures. We have developed a new Monte Carlo numerical model that simulates texture evolution during accumulation of crystals or extraction of melt from the crystal-liquid assembly. As the input parameters, the model utilizes three-dimensional configuration of crystal centers resulting from dynamic crystallization terminated at predefined crystallinity level. To simulate the melt extraction, the configuration is packed randomly into progressively decreasing volume and this process is repeated to obtain ensemble averages. To facilitate the interpretation of natural sections or outcrop patterns, predicted three-dimensional textures are cut by two-dimensional sections where we analyze the spatial distribution pattern of crystal centers using the clustering index and the radial distribution function. In contrast to the closed-system crystallization, progressive accumulation of crystals (or extraction of interstitial melt) induces increasing ordering, that is, anti-clustering of crystals. These effects result from finite sizes of individual crystals in the time of accumulation that thus cannot approach each other closer than is the sum of their respective sizes. To apply the new approach, we have measured spatial distribution patterns of alkali feldspar megacrysts in the Jizera granite of the Krkonoše-Jizera batholith in central Europe. The granite is porphyritic, biotite-rich, with ∼10 to 25 % of alkali feldspar megacrysts. The observed textural patterns suggest the extraction of ∼15 to 70 % melt from the original crystal mush prior to its solidification, reflecting a systematic and progressive decrease in melt extraction towards the pluton roof. The melt extraction has appeared at initial phenocryst crystallinities of ∼10 %. By contrast, olivine crystal patterns in the cumulate zone of komatiite flows record degree of melt extraction up to over 80 % (crystal accumulation by a factor of three). The modeling is consistent with the phenocrysts in porphyritic rocks being early crystals, possibly displaced from their original site, rather than the late-stage products coarsened during the period of subsolidus annealing. Our results provide an approach and constraining parameters to quantitatively assess the mechanical mobility and the role of crystal accumulation during the magma emplacement and pluton construction based on textural record.