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Two types of differentiation mechanisms in a sheet-like intrusion: Constraints from the Aosawa dolerite sill

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Homogeneous differentiation involving crystal nucleation, growth and separation from melt, and boundary layer differentiation involving separation of fractionated interstitial melt from crystal-dominant boundary layer have been advocated as two major differentiation mechanisms in a crustal magma chamber (Jaupart and Tait, 1995; Marsh, 1996). We studied one of dolerite sills in the Aosawa area, Yamagata prefecture in order to constrain the roles of the two differentiation mechanisms in a sheet-like magma body. The intrusion is approximately 100m in thickness and is more than 5km in lateral extension. It is concordantly intruded into late Miocene black mudstone. The dolerite is composed of plagioclase, augite, pigeonite, olivine, magnetite, and interstitial glass with quench crystals (or groundmass). The chilled margins contain olivine (5.3 vol %) and plagioclase (1.9 vol %) as phenocrysts, but no clinopyroxene phenocryst is present. Olivine and plagioclase show bimodal size distribution even inside the intrusion. The whole-rock composition of the upper and lower chilled margins and the average composition of the intrusion are essentially the same, indicating that the intrusion was formed by a single injection of a homogeneous magma laden with phenocrysts of olivine and plagioclase. There are systematic correlations among abundances of TiO2 and other trace elements (Cr, Ni, Co, Sr, Zr, and Rb). The variation trends require addition or subtraction of not only olivine and plagioclase but also clinopyroxene that was absent in the intruded magma, suggesting fractionation due to separation of crystals grown in situ from residual melt. The mode and size of clinopyroxene increase downward from the upper contact reaching maxima near the bottom with rapid decrease towards the lower contact. The number density of clinopyroxene is scattered in the internal part but tends to be high near the bottom with notable increase towards the both contacts. Pigeonite only occurs in the lower part (2-6m) of the intrusion in Aosawa dolerite, which suggests enhanced fractionation of interstitial melt probably aided by slower cooling there. The size of matrix plagioclase steadily increases and its aspect ratio decreases downward. These observations strongly suggest that the lower part of the intrusion underwent slower cooling than the upper part. The clinopyroxene crystals with Cr-rich core are more abundant at 5-15m above the lower contact. Such Cr-rich core contains rounded melt inclusions and small euhedral plagioclase and shows notable sector zoning. These textural features suggestive of rapid growth of the core indicate that clinopyroxene nucleated and grown near the upper boundary layer, where large supersaturation was realized as confirmed from the above textural information, and settled to concentrate near the bottom. The zone of high concentration of Cr-rich clinopyroxene is high in compatible elements but low in incompatible elements, from the horizon of which the compatible elements decrease and the incompatible elements increase upward to the height of 15-40m from the bottom. These observations suggest that growth on the settled clinopyroxene produced fractionated melt, which was transported upwards. It is concluded that sill-scale magmatic differentiation in Aosawa dolerite took place through crystal settling from the unstable roof boundary layer followed by upward transportation of fractionated melt from the bottom boundary layer. During the fractionation, the dolerite may have stayed stagnant to have cooled mostly via thermal conduction.

Keywords: differentiation mechanisms, transportation of melt and crystal, homogeneous differentiation, boundary layer differentiation, Aosawa dolerite sill