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In-situ fractional crystallization as a major mechanism in differentiation of Karaj sill, northern Iran

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During the upper Eocene–Oligocene, the Karaj Dam basement sill (KDBS), located within the E–W-trending Alborz range in northern Iran, intruded the middle and upper tuff units of the Karaj Formation. The KDBS consists of a layered series between upper and lower chilled margins, with local fine-grained monzonitic dykes. The rocks of the chilled margins are gabbroic in composition and show porphyritic texture. The rocks show a continuous transition from porphyritic to equigranular texture toward the center of the sill. Most of the KDBS is medium to coarse grained, showing magmatic layering defined by modal variations in pyroxene and plagioclase, the main constituent minerals. The layered series, dominated by gabbro, diorite, and monzodiorite, formed almost upward from the lower to the upper chilled margin, with gradational transitions between rock types. The KDBS shows an S-shaped profile of MgO concentration from the base to the top of the sill. In situ crystallization is indicated by an approximately constant modal abundance of pyroxene and plagioclase, a narrow range of major element contents in the main lithologies (e.g., 49–54 wt% SiO2, 17–19 wt% Al2O3, and 2.7–5.2 wt% MgO), and variable trace element concentrations (e.g., 500–1150 ppm Ba, 45-130 ppm Rb, 150-720ppm Sr, and 50–160 ppm Zr). Disequilibrium crystallization, caused by Soret fractionation in the marginal series, is indicated by an unexpected overall enrichment trend in MgO concentration and Mg# of pyroxenes from the chilled margin (olivine-bearing gabbro) to marginal gabbro. Formation of chilled margins form an effective insulating layer between contacts and overlaying hot, turbulent magma causing magma cool considerably slowly and have sufficient time to produce different differentiated sequence by in-situ nucleation and growth from gabbro to diorite and monzodiorite. Following the formation of chilled margins, the parent magma composition was established on the Plg-Cpx cotectic line of the Ol-Plg-Cpx ternary system or in the Plg field of the Cpx-Ab-An phase system. In the latter system, Plg starts to crystallize in mushy layers and its composition changes from anorthite to albite until reaching the cotectic line, at which point Cpx starts to form. The presence of plagioclase laths as inclusions within large crystals of clinopyroxene indicates cotectic crystallization and the early crystallization of Plg during formation of the gabbroic unit. Subsequently, the liquid line of descent followed the cotectic line toward the Ab-Cpx eutectic point. During this process, gabbroic cumulate formed at the solidified margins of the magma chamber. After the formation of Plg-Cpx cumulate, the evolved interstitial liquid, which had undergone chemical fractionation, migrated out of the gabbroic cumulate pile within the main magma body, thereby changing the composition of the magma reservoir. Consequently, the melt composition would have been different from the initial melt, being more evolved. The subsequent evolution of the liquid line of descent of compositionally new melt followed the same path at every stage of the formation of new melt; the An% of plagioclase decreased and Ab% increased to approximately 40%. In addition, the Cpx content showed a gradual decrease. Eventually, the Plg accumulates as dioritic cumulate in solidified margins of the chamber. Subsequently, the composition of the main magma changed, approaching the eutectic point of the Or-Ab solid solution binary system. in time, at the eutectic point, Kf started to crystallize and formed monzodiorites downward from the roof of the magma chamber during the final stages of differentiation. Although gravitational crystal settling contributed to the evolution of these rocks, it is not considered to have been a major factor in the development of the observed layering.