Replenishment, fractionation, and magma mixing in the Tottabetsu plutonic complex, north Japan

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An exposed cross section of the Tottabetsu plutonic complex, which constitutes part of the Hidaka metamorphic belt, north Japan, reveals critical information about the gravity-controlled processes such as replenishment, stratification, fractionation, and mixing in an evolving magma chamber. The pluton is compositionally stratified, and is divided into zones I to III on the basis of dominant lithology of each stratigraphic unit. Zone I (~7 km thick) is predominantly composed of mafic rocks and resides at the middle to lower part of the complex. It is overlain by zone II (1-1.5 km thick), which consists of wide variety of intermediate rocks. Zone III (1-1.5 km thick) constitutes the felsic cap at the top of the complex. Field relations and petrographical and geochemical data suggest that zones I and II sequentially formed at the aggrading floor of a single open-system magma chamber, at which repeated injections and ponding of less evolved magma into a crystallizing magma chamber were recorded.

In zone I, injections and ponding of less evolved magmas into a crystallizing magma chamber are represented by fine-grained gabbroic sheets (0.2 to more than 5m thick) interlayered with medium-grained gabbroic and leucodioritic cumulates. Individual gabbroic sheets are variably chilled against the neighboring cumulate layers. Attitudes of pegmatitic pipes penetrating the sheets indicate that the sheets were subhorizontal when they were formed. The fine-grained gabbros range from 50 to 53 wt% SiO2, indicating that the injected liquids were mostly basaltic in composition. Geochemical characteristics of the leucodioritic cumulates strongly suggest that they were formed from highly differentiated felsic liquids with liquidus zircon. Such a highly evolved liquid presumably existed in the magma chamber during the development of zone I.

The lower two thirds of zone II lack leucodioritic cumulates and consists predominantly of medium-grained mesodiorites, which are relatively homogeneous at the outcrop scale except for local presence of pods of fine-grained mesodiorites. Those medium-grained mesodiorites range in SiO2 content from 57 to 63 wt%, and become more felsic from bottom upward, consistent with cumulate stratigraphic record of progressive differentiation of a single magma batch. It is suggested that those medium-grained mesodiorites are cumulates formed from a large intermediate magma batch injected at the beginning of the development of zone II. The injected intermediate magma presumably ponded on the chamber floor, and displaced the resident felsic liquid upward.

In the upper one third of zone II, fine-grained mesodioritic sheets (0.6-3m thick) with chilled margins are interlayered with thin layers of medium-grained leucodioritic cumulates. The fine-grained mesodiorites are mostly andesitic (61-64 wt% SiO2), possibly approximating composition of the parental liquid to the mesodioritic cumulates in the lower two thirds of zone II. The leucodiorites in the upper one third of zone II are chemically similar to those in zone I, suggesting that the felsic liquid was again crystallizing at the floor of the magma chamber.

The granites in zone III mostly have compositions of rhyolite, ranging between 71 and 75wt% SiO2. Geochemical variations suggest that the granites formed by mixing between the two distinct felsic liquids complementary to the leucodioritic and mesodioritic cumulates, respectively. Buoyant liquid produced by fractional crystallization of the recharged intermediate magma presumably mixed with the resident felsic liquid as it diapirically ascended through the latter.