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Post-emplacement melt flow in saucer-shaped sills: a mechanism for the generation of S-, D-, and I-shaped compositional profiles

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Basic-ultrabasic sills are recognized as features whose study can provide important insight into processes that lead to the differentiation of natural silicate magmas. The detailed geochemical study of the Golden Valley Sill Complex (GVSC) shows a wide range of compositions and typical fractional crystallization trends. Vertical compositional variations in Mg-number in the GVSC reveal I-, S-, and D-shaped profiles plus one example of C-shape. Such profile patterns are typically observed in tholeiitic sills, and we show here that different patterns may develop in different parts of a single saucer-shaped sill. Furthermore, systematic lateral variation of compositional profiles along two conjugate continuous limbs of a single saucer-shaped sill is observed. The profiles are I-shaped at the limb tips and S- and D-shaped at their center.

The central part of the D-shaped profiles exhibits two distinct textural domains. One domain is characterized by circular ophitic clinopyroxene. This clinopyroxene-rich domain is characterized by more Mg-rich mineral compositions that reflect hotter crystallization conditions. This domain is surrounded by more plagioclase-rich textural domains that indicate lower equilibration temperatures and more iron-rich minerals.

Based on geochemical/petrological data and numerical modeling we propose that D-shaped profiles result from post-emplacement flow of remaining melt in the sill. The driving force for this flow is the development of thermal stress during the cooling of the sills. Numerical thermo-mechanical simulation on cooling sills show that large under-pressure will develop in the region that remains porous for the longest period of time. That is reflected by the Mg-rich mineral chemistry found in the central region of D-shaped profiles. Residual melt in the central region of the sill will tend to flow towards the regions of under-pressure and leave behind more Mg-rich minerals. This melt will transport incompatible elements from the central to the distal parts of the sill. The various compositional profiles found in nature probably represent snapshots at different stages of melt migrations within cooling sills. Thus, we proposed here that an advection process driven by thermal stress is an efficient process for segregation of melts in sills during cooling. This mechanism is likely to be responsible for the differentiation trends recognized in igneous sills.