Assessing stable isotope fractionations during differentiation through spatial sampling

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The development of techniques to measure stable isotope ratios of elements such as Si, Fe and Mg has brought new insights into magmatic differentiation processes. Systematic variations in these systems occur with changes in SiO_2, somewhat surprisingly given that equilibrium fractionation between phases scales at $1/T^2$. An alternative proposal is that this relationship results from differentiation occurring within a temperature gradient by thermal diffusion effects. Increases in δ^{56}Fe and δ^{30}Si with down temperature differentiation by thermal migration are consistent with this process.

Support for this hypothesis includes positive covariation of different isotope systems relative to spatial position in a given igneous body. Results for δ^{56}Fe and δ^{30}Si in sample sets that involve spatial control include a gabbro to plagiogranite transect in Troodos, interior to country rock transects within 2 silicic plutons (Torres del Paine, Chile and Aztec Wash, NV) and a combined layered mafic intrusion/granophyre body within the Duluth Complex (Sonju Lake/Finland intrusion). A compositionally zoned volcanic sequence from Cedar Butte volcano (representative of a pre-eruptive magma body) is also presented. We find: 1) A distinct increase in δ^{56}Fe and SiO_2 along the 700m transect within Troodos. 2) δ^{30}Si and δ^{56}Fe sequentially increase upward in a 70 m thick sill of the Finland zoned upward from diorite to leucogranite; a second zoned sill sequence although less clear shows increasing δ^{56}Fe upward; finally both the bottom and top of the Sonju Layered intrusion have δ^{56}Fe consistent with prediction of thermal diffusion. 3) Although individual transects within Torres del Paine show considerable scatter, the average δ^{56}Fe of granite samples from the pluton's interior is isotopically lighter than the average δ^{56}Fe of granites closer to the country rock; furthermore, the youngest out-of-sequence diorite sill of Leuthold *et al* (2013) has an anomalously light δ^{56}Fe. 4) Finally, the Cedar Butte volcanic sequence ranging from first erupted high-silica rhyolite down to last erupted basaltic trachyandesite shows systematic changes from heavy to light δ^{56}Fe and δ^{30}Si. While definitive conclusion about causes of stable isotope variation also requires assessment of equilibrium fractionation processes, these spatial observations provide evidence supporting a thermal diffusion effect.