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Construction of Layered Mafic Intrusions by Repeated Emplacement of Crystal Mushes

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A widely accepted physical model for the origin of Proterozoic massif type anorthosites (e.g. Nain, Rogaland, Adirondacks) involves emplacement of plagioclase-rich mushes that ascended to shallow crustal emplacement sites from deep (∼Moho) staging chambers in which ∼An50 crystals floated due to density relations at high pressure. Supporting evidence includes large (up to ∼1 m) grain size, compositional homogeneity of plagioclase with variable Mg# (caused by trapped liquid effects), and protoclastic textures. Isotopic disequilibrium (Sr, Nd, Pb) between cumulus plagioclase and post-cumulus pyroxene result from progressive contamination with continental components. This is dramatically demonstrated at Nain (Labrador), where the anorthositic crystal mushes (∼1.3 Ga) were emplaced into early Archean (∼3.8 Ga) country rocks. High-Al, high-pressure orthopyroxene megacrysts are commonly dragged upward in feldspathic mushes to shallow emplacement sites, where they exsolved plagioclase lamellae. Can a similar model be applied to layered mafic intrusions (LMI)? Many LMI (e.g. Bushveld, Stillwater, Dufek, Duluth) contain thick horizons of anorthosite with compositionally uniform plagioclase, in some cases throughout >1000 m of stratigraphy. This is best interpreted as representing repeated emplacement of plagioclase-rich mushes from one or more deeper crystallizing magma chambers, although the depths of these sub-chambers in the lithosphere are as yet uncertain. In the Bushveld Complex (South Africa), where deep drill cores have allowed near-continuous measurements of mineral compositions and geophysical properties, the results reveal a subtle cyclicity, invisible in outcrops, over scales of 50 – 100 m, commonly associated with broad reversals in mineral compositional trends. Each of these can be interpreted as a blending zone involving a new addition of crystal-laden magma. Much of Bushveld stratigraphy, and that of other LMI contains plagioclase : pyroxene demonstrably higher than cotectic proportions, supporting overall construction by plagioclase-rich magmas. Dramatic isotopic disequilibrium effects have been detected in Bushveld cumulates, most notably in the Merensky Reef (Prevec et al., 2005, CMP 149, 306), and lend further support to mush emplacement models; more subtle isotopic disequilibrium between coexisting minerals is present over wide stratigraphic sections of the Main Zone (Roelofse & Ashwal, 2012, J. Petrology 53, 1449). Large LMI were probably constructed by repeated emplacement of dozens of individual magmatic entities with variable crystal : melt ratios. Even the properties of very small (∼30 km2) LMI like that at Doros, Namibia (Owen-Smith & Ashwal, Fall AGU, 2012) show clear indications of multiple mush interaction. Evidence for emplacement as crystal-laden mushes is abundant therefore, in a wide variety of mafic magma systems (i.e. products of broadly basaltic magmatism), including Proterozoic and Archean anorthosite complexes, layered mafic intrusions and an assortment of sills and dikes.