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New insights into petrogenesis of basaltic magma conduits from chemical zonation of small dolerite dykes

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Basaltic magmas are delivered towards the Earth's surface to erupt as lavas or to stall as plutonic bodies via magma conduits that crystallize into a plexus of interconnected mafic dykes and sills. A recent geochemical study of dolerite dykes from many regions of the world has revealed a notable gap in our knowledge about petrogenetic processes operating in magma conduits (Chistyakova & Latypov, 2009a, b; 2010a, b, c). Contrary to common expectations, small dolerite dykes, ranging in size from about a meter down to several centimetres thick and looking macro- and microscopically quite homogeneous, are turned out to be remarkably zoned. In addition, the internal zonation proved to be anomalous in composition. It is not consistent with predictions of fractional crystallization of basaltic magma since compatible components are strikingly decoupled from incompatible ones. In particular, in most dolerite dykes both compatible (e.g. MgO, Ni, Cr) and incompatible (e.g. P2O5, TiO2, Zr, REE) components show a systematic decrease from margins inwards. Some dykes reveal prominent crossover points at which one inward tendency in a distribution of compatible/incompatible components or parameters (e.g. MgO, Mg#, TiO2) changes to the opposite one. Even more perplexing appears to be a decoupling between individual components of the same geochemical group. For instance, in the same profile some incompatible components can either increase (P2O5) or decrease (Zr) inwards or even initially increase at the margins and then decrease (TiO2) in the centre. Here we put forward a novel concept interpreting the anomalous compositional trends in small dolerite dykes as a result of a competitive operation of two petrogenetic processes with opposite effects on dyke rock composition. These are (a) the filling of dykes with magmas that become more evolved with time in response to the increasing extent of fractionation in deep parts of magma conduits and (b) in situ cumulate growth of inflowing magmas against dyke sidewalls that gives rise to an inward increase in the proportion of cumulus minerals. A key idea is that the nature of compositional profiles of dykes (normal, reverse or anomalous) is primarily controlled by a "winner" in this competition. Normal compositional trends will arise when quenching of inflowing magmas will control a distribution of all components whereas reverse compositional trends will emerge when in situ cumulate growth will govern a distribution of all components. Finally, anomalous compositional trends can be expected when one of these processes will control a distribution of one group of components (e.g. compatible) whereas another process will govern a distribution of another group (e.g. incompatible). Geochemical modelling reproduces all the observed patterns of decoupling between compatible and incompatible elements by variations in the relative contribution of these two competing processes. A major strength of a novel concept is that it does not only explain all the known compositional profiles but also predicts the new ones to be found in the future.

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