Ascent and emplacement controls of mafic magmas in the mid crust – evidence from 3D modelling of basic bodies of the Koperberg Suite, Namaqualand

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Abstract

The 3D modelling of basic bodies of the Koperberg Suite (1060 to 1030 Ma) and their wall rocks from Narrap Mine illustrates the distribution, geometries and, by implication, processes that determined the ascent and emplacement of the mantle-derived mafic magmas into the partially-molten, mid-crustal granite-gneiss sequence of the Okiep Copper District in Namaqualand. The lens-like, discontinuous geometry of basic bodies suggests the transfer of the mafic magmas as self-contained, buoyancy-driven hydrofractures. The presence of both shallowly-dipping, foliation-parallel sills and subvertical lenses in zones of steep foliation development, so-called steep structures, indicates an emplacement of the mafic magmas under low deviatoric stresses and irrespective of the regional stress field. Instead, the emplacement of the mafic magmas parallel to pre-existing anisotropies (tectonic fabrics or lithological contacts) highlights those differences in tensile strength and fracture toughness parallel to or across anisotropies determined the propagation of the magmas. This also accounts for the common occurrence of basic bodies in steep structures in which the vertical gneissosity promoted the buoyancy-driven ascent of the mafic magmas.

On a regional scale, the mechanical stratification of the subhorizontal, sheet-like granite gneisses and interlayered metasediments exerted important controls on the ascent of Koperberg Suite magmas. The preferential emplacement of basic bodies in schist and gneiss units suggests that the lower rigidity of the ductile wall rocks facilitated magma emplacement through a combination of viscous wall-rock deformation and fracture blunting that led to the arrest of the magma-filled hydrofractures. Multiple intrusive relationships of successively emplaced magma batches suggest that later magmas reutilised earlier established magma pathways, particularly in steep structures. High-rigidity lithologies, such as the massive Springbok Quartzite, in contrast, only allowed for smaller fracture apertures and limited dilation, resulting in the pinching of basic bodies and rather stringer-like geometries. It is conceivable that the higher fracture toughness of the quartzite may also have prevented propagation of the mafic magmas through the Springbok Quartzite and, instead, led to the ponding of basic bodies below the metasediments.

The geometry and structural and lithological controls of basic bodies at Narrap Mine are similar to Koperberg Suite intrusions documented from many of the other mine workings in the Okiep Copper District. This suggests similar underlying emplacement controls of the cupriferous rocks, which can be extrapolated on a regional scale and that may guide exploration.

Introduction

The processes of magma transfer through dykes and sills in the upper crust are reasonably well understood and documented from many volcanic provinces, continental rifts and interiors (e.g., Anderson, 1951; Rubin, 1995; Gudmundsson, 2002, 2009; Rivalta et al., 2005, 2015; Menand and Tait, 2002; Menand, 2011; Kavanagh, 2018; Galland et al., 2015; Magee et al., 2016). Magma