Structural overview of selected Group II kimberlite dyke arrays in South Africa: implications for kimberlite emplacement mechanisms

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ABSTRACT

Group II kimberlite dykes occur in small, dominantly en-echelon dyke-fracture arrays, with individual dyke-fractures showing small angular variations from their array trends (5° to 15°). The analysed dyke systems are characterized by closely matching opposing dyke contacts, "*in-situ*" breccia, multiple kimberlite stringers within a dilated dyke-parallel fracture cleavage, wedge-shaped apophyses in bent bridges at dyke-fracture offsets/overlaps, kimberlite-free offset/overlap areas and calcite vein fibres orthogonal to dyke contacts. Commonly found microscopic structures include syn-emplacement/syn-crystallization calcite veinlets, containing high aspect ratio stretched fibrous calcite, and elongate phlogopite phenocrysts and serpentinized olivine phenocrysts growing across the width of these veins. Both macro- and microscopic structures support a model of orthogonal host rock dilation during kimberlite emplacement. Terminations of dyke-fracture segments show minimal curvature or overlap, suggesting that remote horizontal stresses dominated during their emplacement ("passive" intrusion), as opposed to magma overpressured systems wherein dyke or dyke-fracture overlaps curve strongly towards each other ("active" intrusion). The application of Mohr diagrams suggests that low differential stresses, with no or only a very minor shear component, prevailed at the time of emplacement. The dominance of remote horizontal forces, imparting small differential stresses to the brittle portions of the crust, a closely-spaced, dilating dyke-parallel fracture cleavage ahead of the dyke tip (imparting a local suction) and the low-volume, low-viscosity, highly volatile nature of kimberlitic magmas may explain their empirically-constrained high emplacement velocities. This, in turn, explains the means by which such magmas may entrain significant volumes of high specific-gravity mantle material. Mobile hydrofracturing in the fringe zones around dilated craton-scale jointing is proposed to be a viable mechanism for kimberlite emplacement.

Introduction

Three textural-genetic facies of kimberlite are recognized, each attributable to a specific mode of emplacement. Hypabyssal facies dykes and sills typically underlie the diatreme facies, which is in turn overlain by crater facies kimberlite (Hawthorne, 1975; Clement, 1982; Mitchell, 1986; Field and Scott-Smith, 1999). Kimberlite diatremes, typified by those in the Kimberley area of South Africa, currently command greater attention in exploration and mining efforts than their associated, underlying dykes, due to their surface areas and volumes (Field and Scott-Smith, 1999). Diatremes, consisting of tuffisitic kimberlite and/or tuffisitic kimberlite breccia, have provided much of the data used to infer the mechanisms of kimberlite emplacement and the nature of the transition from dykes, via a feeder zone, to the base of the diatreme itself (Clement, 1982). The structural development of kimberlite dykes has yet to be addressed to the same extent as dykes of other magma systems (McKenzie, 1985; Maløe, 1987, 1998; Rickwood, 1990; Lister and Kerr, 1991; Takada, 1999; Watanabe *et al*., 1999). Models of plume-related carbonatite, lamproite and kimberlite intrusion (Crough *et al*., 1980) rely on the spatial distribution of intrusion ages, *e.g.* across South Africa (le Roex, 1986; Skinner *et al*., 1992) and eastern North America (Heaman and Kjarsgaard, 2000). McCandless (1999) attributed phases of kimberlite magmatism to vector changes in oceanic crust being subducted to great depths. Alkaline magmatism has also been attributed to post-tectonic or post-break-up events (Sykes, 1978). However, none of these models accurately describes the structural control on kimberlites in the near-surface environment.

Mid-Cretaceous kimberlites in southern Africa have been divided on geochemical and mineralogical grounds into two groups, which also show a temporal clustering: Group I kimberlites (95 to 80 Ma) are predominantly ilmenite-bearing, with ϵ_{Nd} values ranging from –0.5 to +6.0, $^{87}Sr/^{86}Sr$ ratios of 0.703 to 0.705 and Pb isotope ratios that give negative or future ages relative to the intrusion age. In contrast, Group II kimberlites (145 to 115 Ma) are highly-micaceous and ilmenite-poor, with ϵ_{Nd} values of -7 to -12, relatively high $^{87}Sr/^{86}Sr$ ratios of 0.707 to 0.712 and low radiogenic Pb levels (Smith, 1983; Smith *et al*., 1985). Group II kimberlite dykes that are currently exploited in South Africa include Bellsbank/Bobbejaan, Ardo, Roberts Victor, Star, Klipspringer and Helam (Figure 1).

The dykes in these systems are typically thin (maximum 1.3m wide), limited in strike extent (maximum of ~4km for an individual dyke) and have been proven by drilling and geophysics to have a down-dip extent of up to 830m below surface (Bellsbank/Bobbejaan, personal communications