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The emplacement of class 1 kimberlites

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Abstract

Class 1 kimberlites are distinct from Class 2 and Class 3, in that they are characterized by three zones, namely; root, diatreme and crater. Class 2 and 3 kimberlites do not form diatreme zones filled with diatreme-facies rocks. Consequently these kimberlites probably form by different processes. Within the root zones of Class 1 kimberlites, subvolcanic contact breccias occur at particular horizons within the immediate wall rocks. These could be formed by hydraulic fracturing caused by crystallization-induced exsolution of juvenile volatiles within the cooling hypabyssal kimberlite. This exsolution may subsequently also lead to the formation of transitional-facies kimberlites in the uppermost parts of extended columns or plugs of hypabyssal kimberlite. From such settings, break through to surface and explosive eruption is thought to occur and pipes having characteristic diatremes slope angles of 82° and 500–700 m deep craters are formed. Through these processes these kimberlites undergo fundamental textural changes to produce a variety of rocks from hypabyssal-, through transitional-, to diatreme- and crater-facies kimberlites.

Keywords: kimberlite; emplacement; exsolution; juvenile volatiles

1. Introduction

The exsolution of juvenile volatiles initiated at great depth and continued to levels of around 3 km from surface essentially drives the emplacement of southern African type (Class 1) kimberlite pipes. This exsolution leads initially to the production of subvolcanic contact breccias (as defined by Clement, 1982) and subsequently to the explosive eruption of relatively large volumes of kimberlite in single powerful blasts. These blasts produce a vent or diatreme, initially flared from about 2.2 km all the way to surface at on average 82°. This exsolution also leads to the production of a unique suite of rocks that change from hypabyssal-, through transitional-to diatreme-and crater-facies rocks present in three zones, namely root, diatreme and crater zones (re. Clement, 1982; Clement and Reid, 1989). The specific geological features and kimberlite rock types are not evident in the Victor/Fort a la Corne type (Class 2) nor the Koala/Jwaneng type (Class 3) kimberlites. Consequently, it is likely that emplacement processes for Class 1 kimberlites are quite different from those of the other two classes.

The big-bang/bottom-up model presented here for Class 1 kimberlites is in contrast to the episodic/up-down model for the emplacement of all kimberlites as postulated by Sparks et al. (2006). This model is opposed to the phreatomagmatic models of Lorenz (many publications e.g. from Lorenz, 1975 to Kurszlaukis and Lorenz, 2006). Clement (1982) and Clement and Reid (1989) first presented ideas on this type of model, which Skinner and Marsh (2004) reinforced.

2. Kimberlite zones

Class 1 kimberlite pipes typically consist of three separate zones (Fig. 1). From the bottom up these include: (a) root zones, where the margins tend to be highly irregular, (b) diatreme zones, where the margins are smooth, consistently at a slope of about 82° and (c) crater zones, which in most cases consist of an upper, larger, flared part and a lower, smaller, narrower part.

2.1. Root zones

Many (>10) different intrusions of hypabyssal kimberlites (HK), mostly of macrocrystic, calcite–serpentine–phlogopite–monticellite kimberlites fill the root zones of single pipes

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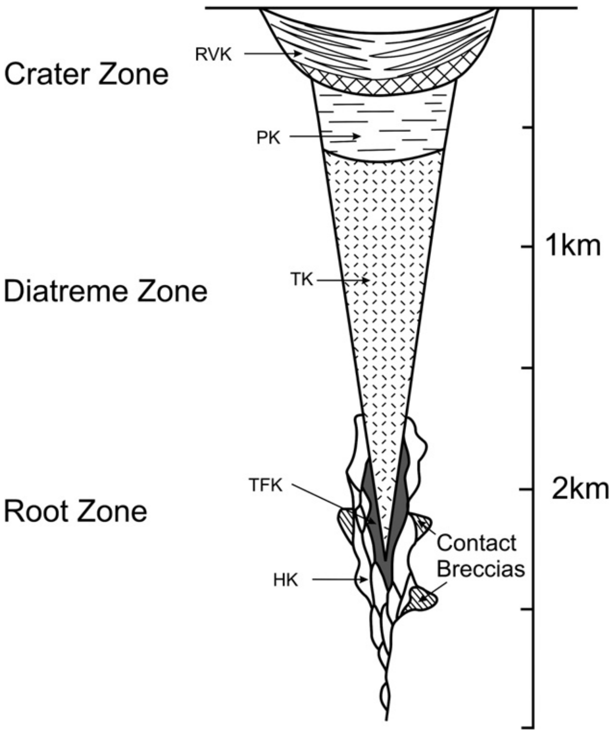

Fig. 1. Composite model of a (Class 1) kimberlite pipe (RVK = Resedimented volcaniclastic kimberlite, PK = Pyroclastic kimberlite, TK = Tuffisitic kimberlite, TFK = Transitional-facies kimberlite, HK = Hypabyssal kimberlite).

(Clement, 1982). Emplacement occurs essentially through magmatic stoping and wall rock contacts are irregular. The kimberlite incorporates a limited amount of country rock material, which becomes highly altered. The root zones extend from about 3 km from the original surface (maximum depth of exposure on Class 1 kimberlite mines) up to at least 1.65 km from surface. In their model of kimberlite emplacement, Clement and Reid (1989) infer an upward migration of intermittent embryonic columns of HK to within 500 m of the surface. But in no cases do Class 1 HKs reach the surface, and Class 1 kimberlite lavas have not been found.

The absence of Class 1 kimberlite lavas (re. Mitchell, 2006) is important because this means that Class 1 HKs crystallize and degas before they reach the surface. This may be explained by the possibility that water-rich, kimberlite magmas behave in a similar fashion to water-rich peridotite. Wyllie (1987) shows that the solidus of water-rich peridotite is deflected towards lower temperatures at low pressure, while that of CO_2-rich peridotite (like dry basalt) is deflected to higher temperatures at low pressure (Fig. 2). The implications of this are that the intrusion path of a relatively water-rich kimberlite may cross the solidus at pressures around 330 bars; 1 km below the surface, whereas the intrusion path of a CO_2-rich kimberlite may not. Calcite-rich, Class 2 kimberlites clearly survive up to the surface as hot magmas, whereas relatively water-rich, Class 1 kimberlites do not.

Also, present within the root zones are what Clement and Reid (1989) refer to as “explosion and fluidization” breccias (here referred to as contact breccias, Fig. 3). The former consist mostly of in situ, angular, country rock clasts whereas the latter consist mostly of little-displaced but well-rounded and partly rotated country rock clasts. In both cases, these breccias are clast-supported and are essentially kimberlite free. Their monolithic character, their location under undisturbed country rock overhangs, their interlocking nature and the outward graduation from highly fragmented material to undisturbed wall rock are indications of in situ brecciation. The fragments in these breccias are in most cases closely packed and as such have the appearance of country rock, which has been intensely shattered. In other cases, the packing is less dense and cavities up to 10 cm may occur. In most cases, the cavities are empty although calcite and other minerals have crystallized on cavity surfaces. However, some (>20%) of these contact breccias have cavities partly to completely impregnated by hypabyssal kimberlite. In no cases are these filled or partly filled with tuffisitic kimberlite, even in cases where such breccias are cut by later tuffisitic kimberlite. As most are essentially free of kimberlite, it is reasonable to conclude that the brecciation occurs in association with a free gas phase that forms during crystallization-induced, exsolution. A state of over-pressure between the intrusive column of hypabyssal kimberlite and the wall rock generates fracturing (Burnham, 1985). These breccias are considered to form entirely subvolcanically, prior to explosive eruption of tuffisitic kimberlite, because they are never impregnated with tuffisitic kimberlite.

Lower parts of the pipe (towards the base of the diatreme zone and towards the top of the root zone) may also have contact zones of transitional kimberlites here referred to as transitional-facies kimberlites (TFK), or transitional hypabyssal and transitional tuffisitic kimberlites (HKt or TKtB, Hetman et al., 2004). However, extended columns of TFKs into the diatreme zone without associated HKs and TKs also exist (e.g as is the case in the Dark Piebald kimberlite at Premier Mine; Bartlett, 1998; Skinner and Marsh, 2004).

2.2. Diatreme zones

Diatreme zones are filled mainly with relatively few (<4) different varieties of tuffisitic kimberlite, that are restricted to

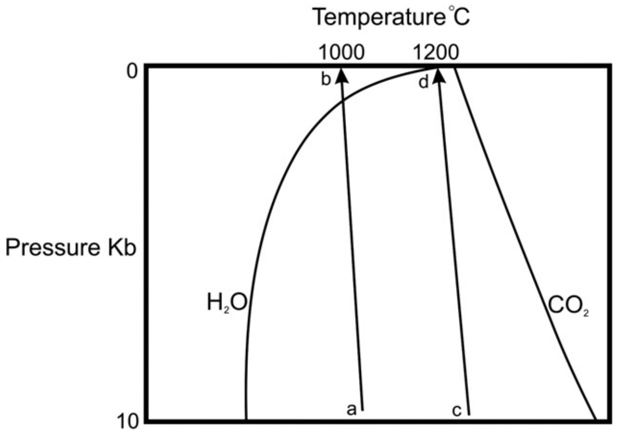

Fig. 2. A schematic illustration of the differences between possible water-saturated and CO_2-saturated kimberlite solidi (after peridotite solidi, Wyllie, 1987). Arrow ab shows an adiabatic trajectory within water-rich magma whereas arrow cd is within a magma richer in CO_2.