DIATREMES AND KIMBERLITES 1: DEFINITION, GEOLOGICAL CHARACTERISTICS AND ASSOCIATIONS

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INTRODUCTION

Diatremes and kimberlites are unusual and enigmatic features and rock types. Their characteristics have been approached from a variety of disciplines and perspectives as evidenced by definitions and discussions in the recent *Encyclopedia of Volcanolgy* [Sigurdsson, 2000]. From a geophysical standpoint, Jeanloz [2000] defines kimberlite as "An explosively emplaced volcanic rock that is originally a fluid-rich ultramafic in overall composition and typically contains many xenoliths." According to Jeanloz, kimberlites represent explosive eruptions that extract xenoliths very rapidly and at least in some cases erupt from great depths. The presence of diamond in some kimberlites indicates a source at pressures of at least 4-5 GPa, the pressure at which diamond is stable relative to graphite at mantle temperatures; this corresponds to depths of ~100-150 km. From a petrological standpoint, Rutherford and Gardner [2000] define kimberlite as "A very low silica igneous rock rich in volatiles that erupts explosively from sources in the upper mantle. Commonly contains mantle xenoliths, occasionally contains diamonds." From a mineral deposit standpoint, White and Herrington [2000] define kimberlite as "A porphyritic alkalic peridotite containing abundant phenocrysts of olivine (commonly altered to serpentine or carbonate minerals) and phlogopite in a fine-grained groundmass of calcite, olivine, and phlogopite with accessory minerals. Kimberlite is the main host rock for diamonds." Finally, Vesperman and Schmincke [2000] define diatremes as: "Funnel-shaped breccia pipes that reach as much as 2500 m in depth. Diatremes are thought to form by hydrovolcanic fragmentation and wall rock collapse. Diatremes may underlie maars and grade at depth into dikes." This range of definitions illustrates the unusual properties of diatremes and kimberlites. We here summarize the characteristics of these features to provide the basis for developing models for the ascent and eruption of kimberlites and the formation of diatremes and associated features [Wilson and Head, 2000].

BACKGROUND

Early studies of kimberlites [Mitchell, 1986] showed that they occur both as 1) carrot-shaped vertical intrusions (pipes or diatremes) and 2) as tabular dikes known as fissure kimberlites, but their connections were not fully appreciated until the classic analyses of Dawson [1971] and Hawthorne [1975] who established the basic principles of kimberlite magmatism by recognizing [Mitchell, 1986]: "1) the existence of hot mobile kimberlite magmas, 2) that such magmas could undergo differentiation, 3) the occurrence of pyroclastic and epiclastic kimberlites, 4) that diatremes with increasing depth are gradational into nonbrecciated hypabyssal kimberlites, 5) the existence of kimberlitic sills." From this time on, kimberlites were recognized as "volatile-rich ultrabasic magmas whose evolution and emplacement can be described in terms of standard differentiation, intrusion and extrusion processes"..."and diatremes are only a particular manifestation of a more general magmatic style..." [Mitchell, 1986]. The relationships between the major components of a kimberlite magmatic system (Fig. 1) include effusive rocks and crater, diatreme, and hypabyssal rocks [Clement and Reid, 1986]. These three components also have three textural genetic groups of rocks, each associated with a particular style of magmatic activity.

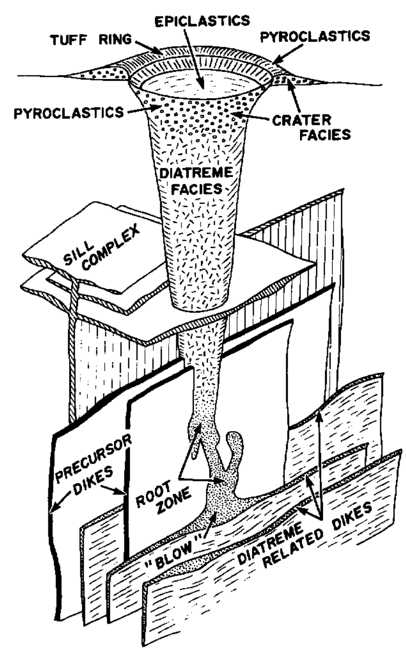

Fig. 1. Model of an idealized kimberlite magmatic system illustrating the relationships between crater, diatreme, and hyabyssal zones and facies rocks. Not to scale. From Mitchell [1986].

CRATER FACIES KIMBERLITES

These include lavas, pyroclasitic rocks and epiclastic rocks. Kimberlitic magmas rarely produce lava flows but typically form pyroclastics, which, where studied in detail [Mannard, 1968], display four types of deposits (oldest, lowest, to youngest): 1) basal breccias, 2) poorly stratified coarse pyroclastics (these tuffs and tuff breccias contain fragments of kimberlite, country rock, and mantle-derived xenoliths cemented by pyroclastic material like overlying tuffs), 3) well-stratified tuffs (alternating layers of coarse lapilli-sized tuffs and laminae of finer ash-sized tuffs), and 4) epiclastic lacustrine deposits. Graded beds and depositional features seem to be absent leading to the interpretation that the tuffs are primarily airfall [Mannard, 1968]. Fluviatile reworking of tuffs in crater lakes produces epiclastic kimberlites. Volumes of pyroclastics are small and they are typically confined to craters and to thinly bedded tuff-rings; magmatic upwelling and magma-filled conduits do not follow pyroclastic eruptions. Erosion quickly follows, but marginal downfaulting may preserve rim facies. Similarities of this model to hydrovolcanic tuff ring formation models [Wohletz and Sheridan, 1983] exist.

DIATREME FACIES KIMBERLITES

Underlying crater facies kimberlites are carrot-shaped bodies with circular to elliptical cross-sectional areas that have vertical axes and steeply dipping margins that converge and terminate at depth in a root zone, where the diatreme expands, contracts, or splits up into an irregularly shaped multiphase intrusion of hypabyssal kimberlite [Mitchell, 1986]. The commonest rocks in the diatreme facies are tuffisitic kimberlite breccias, containing abundant angular to rounded country rock inclusions (mostly a few cm down to microscopic), and discrete and fractured grains of olivine, garnet and ilmenite mega- and macrocrysts, set in a fine-grained matrix of microcrystalline diopside and serpentine. The matrix quickly undergoes alteration and replacement by clays and secondary calcite [Mitchell, 1986]. Typically, one to three texturally distinctive varieties of tuffistic kimberlite breccias are seen in diatreme zones.

HYBABYSSAL FACIES KIMBERLITE

These are rocks formed by the crystallization of volatile-rich kimberlitic magma and they exhibit igneous textures and effects of magmatic differentiation; often they contain sufficient country rock xenoliths to be called kimberlitic breccias. These occur as dikes and sills and form the root zones of diatremes (Fig. 1). Kimberlitic dikes are typically vertically dipping with 1-3 m widths, but can be up to 10 m [Mitchell, 1986], and commonly form swarms of parallel features. Most dikes are single intrusions and pinch out toward the surface, thickening with depth; many show evidence of flow differentiation, glassy selvages are absent, and contact metamorphic effects are slight. Some dikes are observed to expand along strike into lenticular features 10-20 times the dike width and up to 100 m in length; these are termed "blows" and may represent the lowermost portions of root zone intrusions [Mitchell, 1986]. Erosion and mining have enabled unprecedented studies of the three-dimensional and temporal relations of dikes to be made. *Antecedent or precursor dikes* form swarms similar to regional swarms, and are concentrated in the vicinity of pipes, extending to levels well above the level that subsequent diatremes expand upwards, but not to their uppermost levels or to the land surface [Mitchell, 1986]. *Contemporaneous dikes* occur as offshoots from the main pipe into the adjacent country rock, are usually short (~1 m) and occur along joints or fractures; such dikes are very rare and do not occur in most diatremes. *Internal dikes* are common in most diatremes and root zones, but are small, rootless, sinuous and pinch out laterally and vertically, cross-cutting intrusions within the pipes but not extending into the surrounding country rock. Most have no preferred orientation and may be localized at the dike-wall rock contact or at the contact between discrete intra-diatreme intrusions. Although some internal dikes occur in only one phase of the pipe, several periods of dike formation are suggested by the petrology: 1) unevolved macrocrystal hypabyssal kimberlite, 2) aphanitic kimberlites, 3) mica-rich varieties, or 4) calcite-rich late differentiates [6]. Subsequent, or cross-cutting dikes are extremely rare, suggesting that the diatreme-forming event is the closing stage of kimberlitic magmatism. Kimberlitic sills are relatively rare and appear to be controlled by local structure and rock types. Plutonic kimberlitic complexes are unknown [Mitchell, 1986].

SUMMARY

This discussion summarizes the definitions and characteristics of kimberlites and diatremes and provides an assessment of the major factors that need to be explained in any model for the formation of these features [e.g., Mitchell, 1986; Clement and Reid, 1986]. These include:

1. Lack of extensive extrusive deposits.
2. Lack of exposed plutonic complexes.
3. Kimberlitic composition and mineralogy.
4. Tripartite division into crater, diatreme and hypabyssal regions and the distinctive facies associated with each of these.
5. The volatile-rich nature, dominantly carbon dioxide.
6. The implied low temperatures of their emplacement.
7. The nature and distribution of country rock inclusions.
8. The nature and distribution of mantle xenoliths.
9. The presence of diamonds.
10. The presence of wide parts of the dikes.
11. The presence of "blows".

12. The configuration of contemporaneous and internal dikes.
13. The general lack of subsequent dikes.
14. Their apparently rapid emplacement.
15. The presence of olivine-cored pelletal lapilli with surrounding usually altered quenched kimberlitic melt or glass.
16. The paucity of thermal metamorphism.
17. The carrot-shaped nature of the diatreme.
18. Country-rock clasts typically devoid of a kimberlitic mantle.
19. Vesicles and composite lapilli commonly absent.
20. Presence of glass and rapid quenching.
Pronounced sphericity of lapilli and 1-10 mm size.
22. Angular xenoliths from local rocks and smaller amounts of more rounded lower crustal and mantle material.
23. Country rock xenoliths from uppermost part of stratigraphic section exposed deeper within diatreme.

In a separate contribution, we develop our integrated model of the formation of kimberlites and diatremes, using these observations as constraints [Wilson and Head, 2003].

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